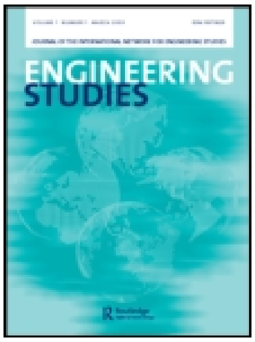


Engineering Studies

ISSN: 1937-8629 (Print) 1940-8374 (Online) Journal homepage: https://www.tandfonline.com/loi/test20

Becoming an engineer in industrialising Great Britain *circa* 1760–1820

Peter M. Jones

Engineering Studies
Vol. 3, No. 3, December 2011, 215–232

Routledge
Taylor & Francis Group

Becoming an engineer in industrialising Great Britain *circa* 1760–1820

Peter M. Jones*

History, University of Birmingham, Edgbaston, Birmingham, B13 9SE, England, UK

(*Received 18 May 2010; final version received 8 June 2011*)

This article explores the history of the engineer in Great Britain at a time when the transformation in the infrastructure of the country being brought about by the Industrial Revolution turned the practice of engineering from a trade into a profession. In pursuing the theme of technology transfer, it also sheds light on the trans-national context in which the early engineers acquired their experience and conducted their business. This article draws on research into the Archives of Soho (the Boulton & Watt steam engine partnership) and the technological travel literature of the 'industrial enlightenment'.

Keywords: engineer; military engineer; mechanic; science; secrecy; technology transfer; professionalisation; Society of Civil Engineers; Soho Manufactory; Matthew Boulton; James Watt

Introduction

This article is based on the correspondence files of the Archives of Soho,[1] probably the largest British business archive to survive for the eighteenth and early nineteenth centuries and a unique source for students of the history of engineering. In 1774, the English entrepreneur Matthew Boulton (1728–1809) and the Scottish engineer James Watt (1736–1819) formed a partnership to develop and market an improved version of the Newcomen steam engine. Much of the research and development for the new engine took place in or close to the Soho Manufactory which was situated on the outskirts of Birmingham in the rural parish of Handsworth (see Figure 1).

The workshops and courtyards of this manufactory started to attract sightseers even before the building work was completed in 1766. Over the next four decades, several thousand visitors flowed through the gates and up and down the stairways of the main building where they were able to view at close quarters a wide range of metal goods being manufactured on principles of advanced labour division. Among these visitors featured a considerable number of savants and technical experts from overseas. We are fortunate in that the reactions of these individuals to the

*Email: P.M.Jones@bham.ac.uk

[1]The Archives of Soho comprise the business papers of the B&W steam engine partnership, 1775–1800, and its successor companies; the private papers of Matthew Boulton, proprietor of the Soho Manufactory; and the private papers of James Watt, steam engineer and partner of Boulton, and his family. The Archives are located in Archives and Heritage, Birmingham Central Library, Birmingham, West Midlands, United Kingdom.

ISSN 1937-8629 print/ISSN 1940-8374 online

http://dx.doi.org/10.1080/19378629.2011.618187
http://www.tandfonline.com

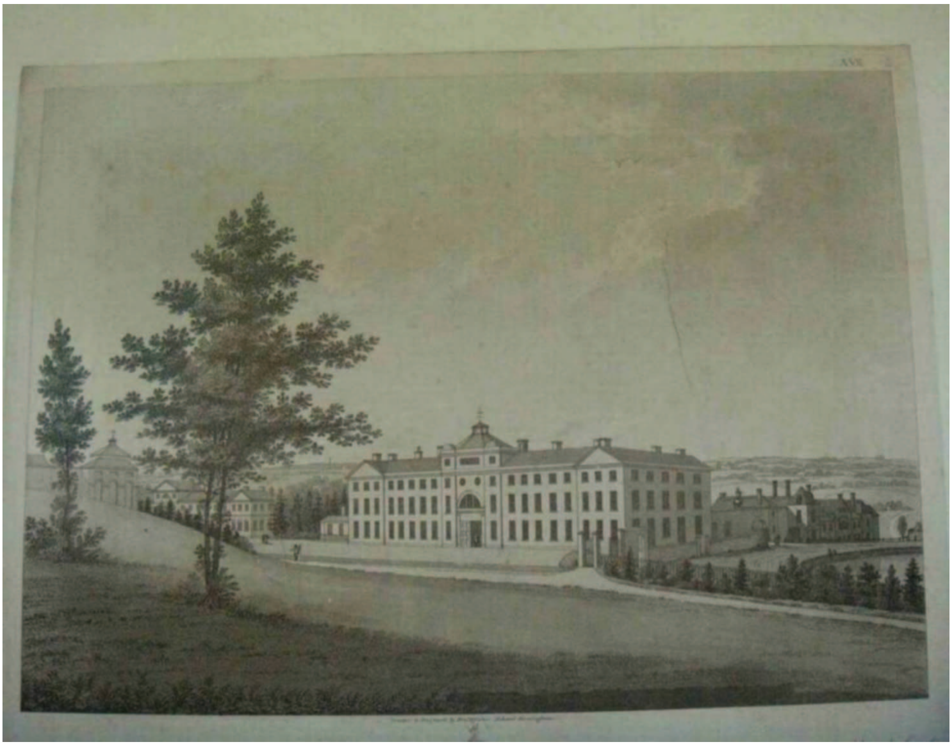


Figure 1. The Soho Manufactory *c.* 1800. Source: Birmingham Central Library, Archives and Heritage Timmins Collection. Reproduced with the permission of Birmingham Archives & Heritage.

manufacturing activities they observed whilst touring factories in Birmingham and other industrial sites are exceptionally well documented. By linking evidence drawn from the holdings of the Archives of Soho to the reports drawn up by French, Prussian and Scandinavian savants on returning to their home countries, it is possible to explore two areas of interest to historians of science and technology in a period that tends to be covered rather sketchily in secondary accounts.[2] The first area concerns the characteristics of engineers as an emerging occupational and professional group and, the second, the spatial context in which scientific knowledge and technological 'know-how' were circulated in the late eighteenth century as engineers went about their business.

Our focus will mainly be on the mechanisms of exchange between British and French engineers, although reference will be made from time to time to the United States and several European countries. In the post-independence decades, America looked primarily to Britain and to France for science 'in-put' and engineering capability, and the travel accounts left by American industrial entrepreneurs often shed revealing light on the different situations and practices they encountered in these two distinctive engineering environments. This said, however, there seems little

[2]See Armytage, *A Social History of Engineering*; Buchanan, *The Engineers*; Skempton, *Civil Engineers and Engineering*; Skempton et al., A *Biographical Dictionary of Civil Engineers in Great Britain and Ireland*, xvii–xxxiv; and Cannadine, "Engineering History or the History of Engineering?," 163–80.

doubt that an equivalent analysis could be undertaken in respect of the engineers issuing from Prussia or Sweden as well. Prussian government ministers of the pre-reform era and the Swedish Ironmasters' Association (*Jernkontoret*) despatched well-qualified technicians and engineers to Soho on repeated missions of investigation and information gathering from the 1750s onwards, and much of the documentary evidence accumulated as a result of these missions has survived.[3] Yet even if German and Swedish engineers participated actively in the exchanges taking place between British and French savants and industrial entrepreneurs, as seems probable, these other 'national' instances of 'industrial enlightenment'[4] still invite study in their own right.

British engineers as an occupational group

The first point which needs to be made is that the history of engineering as a craft activity and subsequently as a profession developed rather differently in Britain from France and the rest of continental Europe. Perhaps this is to state the obvious. The relatively unimportant role of government in managing economic activity is a constant of the eighteenth- and nineteenth-century history of the British Isles. It is possible to point to numerous social and economic spheres in England in which private enterprise and *laissez-faire* operated in the place of government interventionism. As the young Voltaire would observe, England enjoyed at the start of the eighteenth century a comparatively free society in which individuals were permitted to get on with their lives and make contractual arrangements with minimal interference from vested interests and corporate bodies. This was the case whether those bodies happened to be religious institutions (churches), economic institutions (guilds) or socio-political institutions (governments). It is also worth noting that by comparison with her continental neighbours, eighteenth-century Britain never maintained an extensive military establishment whose sinews structured private as well as public life.

It should come as no surprise, therefore, to discover that the occupation or trade of engineer and the practice of engineering were shaped within this context. In English the word 'engineer' seems first to have appeared in the 1690s, although it was written with various spellings. By the 1720s it was in fairly widespread oral use, but the activities to which the word referred were emphatically craft-based. Subsequently, 'engineer' and 'engineering' would climb the social scale. A rapid survey of the database *Eighteenth Century Collections Online (ECCO)*[5] which contains the bulk of the literature published in the English language between 1700 and 1799, reveals that the term 'engineer' scarcely features in the title of any work before the decade 1740–1749, and only then in five imprints. Over the following decade nine imprints employed the term in their titles, principally as an authorial description. Only in the 1760s did recognition of a professional status linked to the occupation of 'engineer' start to gather some linguistic momentum. No doubt this recognition reflected the start of the canal-building boom. By the 1790s when this boom was at

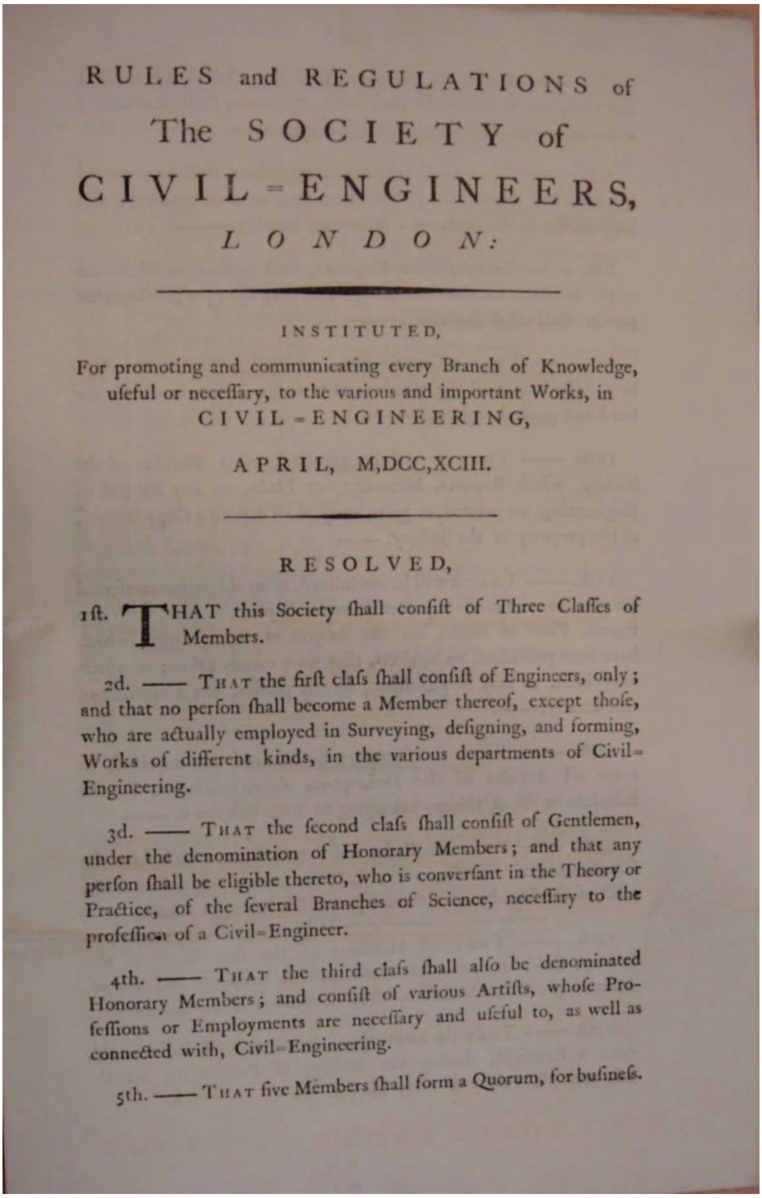
[3]See, for example, Rücker, *R. R. Angerstein's Illustrated Travel Diary*. Also Flinn, "The Travel Diaries of Swedish Engineers," 1957–58, 95–108.
[4]For this concept, see Mokyr, *The Gifts of Athena*, 28–77; also Jones, *Industrial Enlightenment*.
[5]University of Birmingham, Main Library, E-resources, *Gale Cengage Learning, Eighteenth-Century Collections Online* (accessed March 20, 2011).

its height we find 28 imprints with titles containing the word 'engineer.' By this date, moreover, it is evident that the market for infrastructure engineering capability had been enlarged to include not only canals, river navigations and land drainage works, but also dock and harbour schemes. Indeed, the more precise label 'civil engineer' appeared in print for the first time in the 1760s although it may already have been in common oral use.[6]

This rudimentary exercise in bibliographical quantification cannot capture the multiple dimensions of the expanding role of the engineer, of course. Nor can it tell us very much about contemporary connotations of the term. But if we carry out an 'entire document' survey of the same database of printed material, traces of the wider currency of the word 'engineer' and of the contexts in which it was starting to be used begin to emerge. In the *ECCO* corpus of English print literature the word 'engineer' is recorded on 277 occasions between 1700 and 1709; on 672 occasions between 1740 and 1749; on 1142 occasions between 1760 and 1769 and on no fewer than 2059 occasions during the final decade of the century. By this latter date most of the references evoke the practices of engineering in the civil, mechanical or mining domains, as we would distinguish them nowadays. The label 'hydraulic engineer' crops up for the first time in 1799.[7] It is significant that references to military engineers, or engineering for military purposes, are infrequent. When they occur (for example, in five out of the nine publications containing the word 'engineer' in the titles dating from the 1750s), the works in question often turn out to be translations of treatises by military engineers of French origin.[8]

It is apparent that the earliest English and Scottish civil engineers were not schooled to a high level. They were craftsmen first and foremost. James Brindley (1716–1772) was apprenticed by his father to a Macclesfield millwright and never achieved full literacy, whereas Thomas Telford (1757–1834) and Robert Mylne (1733–1811) began their careers as, respectively, an apprentice stone mason and an apprentice carpenter. Even John Smeaton, probably the first Englishman to be labelled in his own time as a 'civil engineer,' began his working life as a tool and instrument maker although his father had practised as a lawyer in Leeds. In Britain there was in the eighteenth century no state incorporation of civil engineers equivalent to the French Ecole des Ponts et Chaussées (established in 1747), or the Spanish Escuela de Caminos de Madrid (1802). An informal Society of Civil Engineers (also known as the Smeatonian Society) had been founded in London in 1771 and would be re-founded in 1793 (see Figure 2) it is true.[9] After a lacklustre existence it would be supplanted by the creation, in 1818, of an Institution of Civil Engineers with a more closely defined professional remit. By the time this body secured a royal charter in 1828 membership stood at around 134.[10] Not until 1861,

[6]John Case, Thomas Yeomans and John Smeaton FRS are all listed as surveyors and civil engineers in Mortimer, *The Universal Director; or, the Nobleman and Gentleman's True Guide to the Masters and Professors of the Liberal and Polite Arts and Sciences*.
[7]Coffey, *A Treatise on the Pipe-water Works of the City of Dublin*.
[8]For example, Clairac, *The Field Engineer*; Le Blond, *The Military Engineer*.
[9]James Watt is listed among nine members in the first class (practising engineers), and Matthew Boulton must have joined shortly afterwards since his diaries record appointments to dine at the 'Civil Engineers Club' on 16 May 1794 and 8 May 1795, see Birmingham Central Library, Archives and Heritage (henceforth BCL) MS 3782/12/107.
[10]Buchanan, *The Engineers*, 63.



RULES and REGULATIONS of
The SOCIETY of
CIVIL-ENGINEERS,
LONDON:

INSTITUTED,
For promoting and communicating every Branch of Knowledge, uſeful or neceſſary, to the various and important Works, in CIVIL-ENGINEERING,

APRIL, M,DCC,XCIII.

RESOLVED,

1ſt. THAT this Society ſhall conſiſt of Three Claſſes of Members.

2d. —— THAT the firſt claſs ſhall conſiſt of Engineers, only; and that no perſon ſhall become a Member thereof, except thoſe, who are actually employed in Surveying, deſigning, and forming, Works of different kinds, in the various departments of Civil-Engineering.

3d. —— THAT the ſecond claſs ſhall conſiſt of Gentlemen, under the denomination of Honorary Members; and that any perſon ſhall be eligible thereto, who is converſant in the Theory or Practice, of the ſeveral Branches of Science, neceſſary to the profeſſion of a Civil-Engineer.

4th. —— THAT the third claſs ſhall alſo be denominated Honorary Members; and conſiſt of various Artiſts, whoſe Profeſſions or Employments are neceſſary and uſeful to, as well as connected with, Civil-Engineering.

5th. —— THAT five Members ſhall form a Quorum, for buſineſs.

Figure 2. The rules and regulations of the Society of Civil Engineers, April 1793. Source: Birmingham Central Library, Archives and Heritage MS 3219/4/323. Reproduced with the permission of Birmingham Archives & Heritage.

though, did government statisticians acknowledge ‘civil engineering’ as a separate professional category for the purpose of census taking.[11]

The same broad trajectory applied to ‘mechanical engineers’ as well. More often than not they started off as millwrights or as surveyors who acquired skills and knowledge on the job. Despite earning his keep as a canal surveyor before he became

[11]Birse, *Engineering at Edinburgh University*, 1983, 15.

better known for his mechanical talents, James Watt was not invited to join the Society of Civil Engineers until 1793. When, the following year, a correspondent asked him about the training of the skilled operatives employed at the Soho Manufactory he responded with the comment:

> most of our engineers who have not been regularly bred to the theoretical or practical part of the business, have been bred to analogous ones, such as millwrights, architects, surveyors etc. which having almost all the previous learning it is easy to step to the other, otherwise it must be uphill work.'[12]

The point holds for mining, too. Hugh Torrens[13] has noted that before the middle of the nineteenth century little attempt was made in Britain to institute formal instruction for minerals engineers. Yet James Watt was scarcely unaware of the need for formal training. After all, in 1787 he sent his eldest son to study under Abraham Gottlob Werner (1749–1816) at the Freiberg *Bergsakademie* in Saxony, and his partner Boulton contemplated a similar episode of applied study for his son.[14] By this date mine technology was developing so rapidly that it threatened to outstrip the capabilities of even the most competent of artificers. Mechanics familiar with the characteristics of the Newcomen atmospheric engine could not simply be redeployed to work on the successor machine then being developed at Soho. 'When I began first to construct my engine,' reported Watt, 'I found the workmen or Engineers accustomed to the erection of former engines so opinionated and obstinate that I had to discontinue employing them, and not only to form my own Engines but also my own Engineers.'[15]

This is not, however, to suggest that Britain's entrepreneurs and industrialists discounted or despised the contributions of learned men in the domain of engineering. Thanks to the Archives of Soho we know that James Watt spent much of his life in correspondence with savants and a strong case can be made that he considered himself to be a 'philosophical engineer'[16] whose experimental practice was informed by his grounding in theoretical knowledge. Numbering among his correspondents was John Robison (1739–1805), mathematician and professor of natural philosophy at Edinburgh University, who in 1797 wrote to his old friend to propose an academic *cursus* for those whom he termed 'Scientific Engineers.'[17] The skilled engine erectors and machine builders whom Boulton & Watt (B&W) 'bred' to the job at Soho in Birmingham, or at the Albion Mills in London, were often highly proficient individuals, too, whether in terms of their theoretical knowledge or their practical skill levels.[18] Several would go on to become eminent engineers in their own right [William Murdoch (1754–1839), John Southern (*c.* 1758–1815), John Rennie the elder (1761–1821), Peter Ewart (1767–1842), James Lawson (?–1818) and so

[12]BCL MS 3219/4/124 J. Watt snr to P. Wilson, Birmingham, 27 August 1794.
[13]Torrens, *The Practice of British Geology*, 151.
[14]Jones, *Industrial Enlightenment*, 103.
[15]Robinson and Musson, *James Watt and the Steam Revolution*, 42–3.
[16]See Miller, *James Watt, Chemist*, 9–10, 59–84, 109–10.
[17]A "Collegium or Corporation of Scientific Engineers, with three degrees of Bachelor Master and Doctor – not merely academical honours, of no more value than the offices of a Mason Lodge, but to have civil consequences – As a man must have a diploma to entitle him to a consulting fee, so should an Engineer, etc." Cited in Robinson and McKie, *Partners in Science: Letters of James Watt and Joseph Black*, 273.
[18]See Tann, "Two Knights of Pandemonium," 47–72.

forth]. Robert Buchanan has described these Soho men as, 'the most significant group of mechanical engineering expertise anywhere in the world at the end of the eighteenth century.'[19]

Nevertheless, the fact remains that around the year 1800 the majority of engineers in Britain were considered by and large to be craftsmen or tradesmen, and engineering to be a 'practical art' rather than a theoretically informed activity. As such the engineer could not expect to enjoy much social esteem. Even those at the apex of the profession – in the estimation of Buchanan[20] they probably numbered around 260 at the height of the canal frenzy – scarcely felt secure in their pretentions to gentlemanly status. Only about a quarter of the members of the Smeatonian Society between 1771 and 1800 are listed as Fellows of the Royal Society.[21] James Watt's insecurity in this regard has been examined by David Miller,[22] but he at least had solid intellectual collateral in the shape of his paper on the composition of water which was read to the Royal Society in 1784.

Before the 'heroisation'[23] of the engineer which historians generally associate with the early and mid-Victorian era, technology, unlike science, was not 'polite,' then. It follows that engineers were not particularly well rewarded either. Until the canal-building speculation began to gather momentum in the late 1760s, the majority of civil engineers managed on modest incomes. Unlike their counterparts on the Continent, they touted for work in a marketplace in which the state was not an active player. When Matthew Boulton and James Watt were offered an inducement of 2400 *louis d'or* by the French government in 1786 to come to Paris and act as consultant engineers to the Marly waterworks refurbishment project, they would have regarded the invitation as an unusual and exceptionally well-paid commission. We know, too, that they were intensely flattered to be accorded the status of 'celebrated engineers' by the savants of the French capital. This adulation would have been the more gratifying in that their credentials as natural philosophers were regarded as rather provincial back at home.

Apart from the esteem deficit, the absence of the state from the arena had other consequences. In Britain the domestic occupation of engineer, like every other occupation, remained almost completely unregulated and it was left to each and every employer to make a judgement as to competence, and to strike the appropriate bargain for work to be to be undertaken. Whilst it is true that an elite of multi-talented engineers was starting to emerge in the final decades of the eighteenth century, the reservoir of jobbing millwright—engineers of varying abilities was constantly being replenished from below. In 1785 James Watt grumbled to his wife that the engineering profession had been much diminished since the days of his youth as a mathematical instruments maker in Glasgow, for it:

> 'is now in general in the hands of very illiterate people the world seeming to think that science and genius are not necessary in it, but that self-conceit, ignorance, impudence & a little experience may very well supply their place. Consequently men of real knowledge & abilities not being paid as they deserve have deserted the calling.'[24]

[19]Buchanan, *The Engineers*, 41–2.
[20]Ibid., 42.
[21]Miller, "The Usefulness of Natural Philosophy," 188.
[22]Miller, *James Watt, Chemist*, 60–2.
[23]MacLeod, "James Watt, Heroic Invention," 96–116 and MacLeod, *Heroes of Invention*.
[24]BCL MS 3219/4/123 J. Watt snr to A. Watt, Birmingham, 31 October 1785.

This seems an unduly negative judgement and perhaps a self-serving one on the part of a man whose persistent insecurities would only be partially allayed by his election to the Royal Society in November 1785 (in acknowledgement of his prowess as a chemist rather than for his practical skills as a steam engineer). After all, we find in the Archives of Soho a printed prospectus dating from 1802, or thereabouts, headed 'Mr Roebuck's charges as for business as scientific engineer' which would appear to show that some jobbing engineers were flourishing in the free-wheeling environment of Britain's rapidly globalising economy.

The document details a scale of charges for engineering consultancy work:

> 'Opinion or advice verbally, when called upon at his house, respecting any object of mechanism, manufactures, or mineralogy; or the application of the powers of animals, water, or steam to mechanical purposes, one guinea, if the consultation does not exceed one hour.
>
> A written answer or report on the above subjects to a case or a letter, provided it can be comprehended in two sheets of paper, and exclusive of charges for making drawings or plans, two guineas [. . .]
> [etc.]'[25]

However, there *is* a sense in which Watt's pessimism is understandable for the boundaries of the profession of engineer in Britain at the turn of the century were indeed rather poorly defined and, it would seem, entirely un-policed. In the British context the ambiguities surrounding professionalisation showed most clearly on those occasions when it proved necessary to articulate the difference between an 'engineer' and a 'mechanic.'

If we refer to the proceedings of 1796–1799 which the firm of B&W brought against the engineers Hornblower & Maberly for allegedly infringing Watt's 1769 engine patent, it soon becomes apparent that contemporaries (not to mention so-called expert witnesses) often found it hard to unravel this conundrum. Arguments rooted in formal professionalisation or institutionalisation evidently did not apply since, prior to the middle of the nineteenth century, the vast majority of engineers in Britain had no corporate status in contrast to their counterparts on the Continent. To judge from the close reading of the B&W trial papers which David Miller[26] has carried out, it transpires that the real discriminator was what Boulton and his partner described as the 'philosophical' element; that is to say the quantum of scientific knowledge which a capable engineer should be able to draw upon, but which a mere mechanic certainly could not. Even so, the positioning of this frontier seems to have been rather subjective. One of the witnesses called in the Hornblower case – the chemist and science journalist William Nicholson (1753–1815) – declared that the difference of approach when employing a 'first rate Engineer'[27] as opposed to a mechanic would be that, whereas the latter needed to be equipped with detailed technical drawings in order to build a viable steam engine, the former would not. So, were the Soho engine erectors 'mechanics' or 'engineers,' we might to ask? The firm issued them with detailed assembly guides for use when installing engines for clients, which would seem to imply that they were competent mechanics, but equally we know that a number of them set out

[25]BCL MS 3219/4/44 "Mr Roebuck's charges as for business as scientific engineer.
[26]Miller, "Watt in Court," 43–76.
[27]Ibid., 64.

actively to acquire scientific knowledge.[28] In other words they were, or rather could become engineers.

This discussion might lead to the conclusion that Britain produced only civil engineers, whereas France chiefly produced military engineers. Indeed, this is the conclusion that Margaret Jacob comes close to drawing.[29] But even if we allow that the term 'civil' would often be employed in English usage to embrace mechanical and mine engineering in the second half of the eighteenth century, this does not seem to me to constitute a safe generalisation. After all France possessed a School of Civil Engineering from 1747 and a School of Mine Engineering from 1783 and, in any case, Britain *did* have a military engineering establishment. A Corps of Engineers was instituted in 1716 (renamed the Corps of Royal Engineers in 1787) following Britain's participation in the War of the Spanish Succession. Its principal task was to build fortifications in the overseas territories of the expanding British Empire (Gibraltar, Minorca, Nova Scotia, South Carolina, Louisburg, Jamaica, West Africa, etc.).

Perhaps this is the point that should be emphasised: military engineers were rarely put in charge of major infrastructure projects in mainland Britain – at least not before the Revolutionary and Napoleonic invasion scares of the turn of the century. As a group they were largely invisible to the public at large, therefore. They were not particularly numerous in any case. In 1717 a Royal Warrant specified that the military engineering establishment of Great Britain should consist of one chief engineer, two directors, two sub-directors, six ordinary engineers, six extraordinary engineers, six sub-engineers and six practitioner engineers.[30] It is true that a military engineering school of sorts, known as the Royal Military Academy, came into being in 1741 as an outgrowth of the Arsenal at Woolwich to the south-east of London. Its remit specified that it was to educate 'good officers of Artillery and perfect Engineers.'[31] Deficiencies uncovered during the later Peninsular War in Portugal and Spain from 1808 also led to the founding of a field engineering school at Chatham. However, neither the Woolwich nor the Chatham creations seem to have made much impact on the private-sector world of the engineer, and it is significant that on the few occasions in the late 1790s when B&W became involved in engineering consultancy work for the military arm, the link was forged more often than not by *émigré* French military engineers.

Such refugees from revolutionary and war-torn Europe no doubt found it odd that private-enterprise engineering establishments such as Boulton's Soho Manufactory and Foundry had so few formal connections with army contractors and engineers, or with state-owned establishments such as the Woolwich Arsenal. In 1816 a deputation from Woolwich which included Sir William Congreve (1772–1828), the rocket designer, was actually denied access to the Soho Foundry on the ground that the travelling party were chaperoning Grand Duke Nicholas of Russia who was reputed to have industrial spies in his entourage. A minor diplomatic incident resulted, but the elderly James Watt stood firm.[32] In Britain, in other words,

---

[28]See Jones, *Industrial Enlightenment*, 116–29.
[29]Jacob, "The Cultural Foundations of Early Industrialization," 71.
[30]Royal Engineers Museum website: www.remuseum.org.uk/corpshistory.
[31]Ibid.
[32]BCL MS 3219/4/120 J. Watt snr to J. Watt jnr, Birmingham, 26 December 1816.

owners of industrial premises containing leading-edge technologies could not be cajoled by government, no matter how eminent the would-be visitor might be.

Although the evidence is indirect it seems likely, too, that refugee military engineers from France would have found the practices or culture of engineering, as well as the institutional structures, rather different from what they had been accustomed to. In place of the highly analytical and increasingly mathematical representation of the function of the engineer prevailing in France, they would have encountered a more practical, hands-on approach to problem-solving which drew its inspiration from the intensely competitive commercial environment in which the vast majority of British engineers, surveyors and architects found themselves operating. As Michel Cotte points out, these contrasting engineering styles were noticed particularly by American trainee mechanics and technicians in the 1820s and 1830s who often sought to complete their education with extended periods of study both in France and England. The letters home of Moncure Robinson (1802–1891), for instance, record, in the words of Cotte, 'sur le plan technique, l'opposition radicale qu'il rencontre entre les traditions pratiques des uns et les habitudes théorisantes des autres.'[33] The experience of Isambard Kingdom Brunel is instructive in this regard. His father Marc had been schooled in France and would see service in the Marine before fleeing from the Revolution to America and subsequently to Great Britain, and it is clear that he intended that his son should receive the same breadth of training. Yet for all his unquestioned prowess in mathematics, the younger Brunel remained profoundly distrustful of book knowledge, whether it was couched in French or in English. The true science of practical mechanics, he once informed a correspondent, was chiefly to be found 'in a blacksmiths and wheelwrights' shop.'[34]

We know, too, that touring French engineers were often struck by the innovative use of materials they encountered during their tours of Britain, particularly the structural use of iron in bridges, industrial buildings and waggon-ways. The larger steam engines manufactured at Soho were mostly fitted with cast iron beams from the turn of the century, Watt having ascertained by experiments on one of the Albion Mills engines in London that the oaken beam was subject to torsion of five-eighths of an inch.[35] Yet for all his reputation as a 'conservative' innovator, the Birmingham engineer was hugely impressed by the ingenious applications that were now being found for his steam power technology. He remarked on the progressive adoption of iron in major infrastructure developments in a letter written to the director of the Ecole des Ponts et Chaussées Riche de Prony, adding the further observation that John Rennie, the superintending engineer of the London Docks project, had even succeeded in carrying out the piling by steam. A second engine was being used to drain river water from the site, whilst a third was employed in grinding mortar for the cement.[36] The Ponts et Chaussées engineers at this time had still to be convinced of the reliability of iron as a constructional material.[37] It is true, of course, that on

[33]Translation: "the sharp contrast in the technical sphere which he encountered between traditional craft practices on the one hand and theorising habits on the other," Cotte, *De L'espionnage industriel à la veille technologique*, 244.

[34]Buchanan, *The Engineers*, 163. For similar sentiments expressed by the marine engineer, John Bourne, see MacLeod, *Heroes of Invention*, 281.

[35]BCL MS 3219/4/267A J. Watt snr to A. Watt, London, 4 February 1787.

[36]BCL MS 3219/4/118 J. Watt snr to G. de Prony, Birmingham, 2 January 1803.

[37]Picon, *L'Invention de l'ingénieur moderne*, 167–70.

the Continent cast metal was a far more costly alternative to traditional building materials.

One comment that crops up repeatedly in the reports of visiting foreigners on infrastructure engineering projects in France is the lavishness of the expenditure on items that were not critical to the purpose at issue. Arthur Young,[38] for instance, was both impressed and appalled on beholding French highways schemes at the close of the *ancien régime*. His comments implied that they were either grossly over-engineered, or absurdly costly in relation to the amount of heavy-duty traffic that was ever likely to make use of them. The Portuguese savant João-Jacinto de Magalhães made remarks of a similar character. Following a visit to Périer's new steam-engine works at Chaillot outside Paris, he reported to Watt that the buildings were 'superb' adding, 'I don't think any of these machines ever were built in so fine and so showy a manner abroad or at home.'[39] French architects and engineers, he concluded, liked to construct on a grand and expensive scale.

The diffusion of engineering knowledge and 'know-how'

The restless energy with which Europe's intelligentsia travelled in pursuit of knowledge in the second half of the eighteenth century is now well documented.[40] Engineers were no exception in this regard. As we have noted Swedish mine inspectors toured Britain's metal-working districts at regular intervals, and it is largely thanks to the thoroughness of their recording that a connected history of mining and iron-founding in England, Wales and Scotland in the eighteenth century can be written. French savants started to cross the Channel in significant numbers on the conclusion of the Seven Years War (1756–1763). Their counterparts from the German-speaking lands followed a decade or so later as states such as Saxony and Prussia started to develop in earnest their mineral resources. Britain was not the only target for these enquiring minds, of course: from the 1770s the Ecole des Ponts et Chaussées despatched its ablest pupils on missions to inspect the hydraulic installations of the Netherlands as well. Yet it does appear that there were two key periods when the momentum of technological knowledge diffusion in Europe speeded up: the 1780s and the 10 or 15 years following the restoration of peace to Europe in 1814–1815.

The Archives of Soho allow us to study this acceleration in microcosm for, by the 1780s, nearly every touring continental engineer would add Birmingham to his itinerary in the hope of obtaining sight of James Watt's latest improvements to his steam power technology. The list of visitors is impressive. To cite only the names of French engineers, it includes: Jacques-Constantin Périer (1742–1818), Ignace de Wendel (1746–1795), Aimable-Marie de Givry, Pierre-Charles Lesage (1740–1810), Gaspard Riche de Prony (1755–1839), Joseph Cachin (1757–1848), Jean-Rodolphe Perronet (1708–1794) and Charles-Augustin de Coulomb (1736–1806).[41]

Something of the sort happened in 1814–1815 as well. Engineers and technicians who had only been able to travel within a French-dominated Europe since 1803 converged on England from all directions. The metal-working districts of

[38]Young, *Travels in France*, vol. 1.
[39]BCL MS 3219/4/91 J. H. de Magellan to J. Watt snr, London, 28 August 1781.
[40]See Jones, *Industrial Enlightenment*, 96–7, figures 3.1, 3.2.
[41]See Jones, "Commerce des Lumières," 66–7.

Birmingham and the Black Country remained one of the principal destinations, but no longer the only region for investigation. Confining the tally once again to engineers and technologists of French origin, we know that Charles Dupin (1784–1873) made numerous visits between 1816 and 1824; Georges de Gallois (1775–1825) toured in 1816–1817; François-Charles Cécile (1766–1840), Jean-Nicolas Hachette (1769–1834) and Louis Martin visited together in 1819, the same year in which Louis Becquey (1760–1845) sent the Ponts et Chaussées engineer Joseph-Michel Dutens (1765–1848) to England, and in which the hydraulic engineer Pierre-Siméon Girard (1765–1836) turned up at Soho with a letter from Prony to James Watt junior expressing condolences on the receipt of the news of the death of his father. Another civil engineer, Claude Navier (1785–1836) set off on a tour of Britain in 1821, whilst the mining engineers O.-P.-A. Petit-Dufrénoy (1792–1857) and Jean-Baptiste Elie de Beaumont (1798–1874) arrived in 1823. We know also that several other significant figures in the world of engineering crossed the Channel for purposes of industrial tourism or knowledge gathering before 1830: J. Cordier, Léon Coste (1805–1840), Auguste Perdonnet (1801–1867) and Louis-Antoine Beaunier (1779–1835), future director of the Ecole des Mines at Saint-Etienne.

What can an analysis of these movements tell us? First and foremost we learn that in the late eighteenth century knowledge transfer in the technological domain continued to thrive on personal contact. The French administration recognised this early on, under Daniel Trudaine, head of the Bureau de Commerce (1749–1769), and it appears likely that the scheme of Controller-General Charles-Alexandre de Calonne in 1786 to bring Boulton and Watt over to France was nurtured with the aim of persuading the two British engineers to relocate on a permanent basis. The minister seems to have been far more interested in involving them in his plans for the hardware works at La Charité-sur-Loire than in the refurbishment of the *machine de Marly*.[42] But personal contact could be established in a number of unanticipated ways as well. The French Revolution would cause many members of the *corps de génie* to exile themselves from France as Antoine Picon[43] has pointed out, and a number of these emigrant military engineers beat a path to the gates of the Soho Manufactory. It is possible to identify a handful of such individuals in Matthew Boulton's business and private correspondence: Anne-Philippe-Dieudonné de Loyauté, an artillery officer who fled France in September 1792 following the prison massacres; another artillery engineer named Jacques-André de Viette; Marc Brunel, father of Isambard, the future railway entrepreneur and marine engineer; and Comte Joseph de Thiville. The latter's invention of a hydraulic machine for reducing friction failed to impress James Watt, but he would go on to take out in Britain a patent for a type of gas lamp adapted for use as a means of street lighting.

In a context of increasingly bitter hostilities between Britain and France in the later 1790s, the artillery officers were the most successful in selling on their inventions. At the behest of the Woolwich Arsenal, Boulton agreed to build and test Loyauté's 'bombardière royale' (a species of catapult grenade launcher). Viette, too, seems to have been encouraged to make his way to Soho on a letter of recommendation from Lord Cornwallis for whom he had worked at the Royal

[42]The *Machine de Marly* was the pumping engine that raised water from the river Seine to the palace of Versailles. Completed in 1684, it no longer functioned adequately.
[43]Picon, *L'Invention de l'ingénieur moderne*, 229; see also James, *Family Capitalism*, 52.

Military Academy. Unfortunately, the sources do not tell us much about the technological process that he was seeking a backer for.

Beneath this visible level of knowledge exchange between accredited engineers there existed less visible circuits of mobility involving skilled and semi-skilled artisans as well. Their movements are much harder to track, as are the technological impacts of this type of mobility within Europe, or between Europe and the United States.[44] Yet we should not underestimate the importance of skilled workmen drawn from the metal-working and textile industries to the process of diffusion. Matthew Boulton played host, and sometimes reluctant host, to many a craftsman from Europe, often as a *quid pro quo* for selling his steam technology in the European marketplace. Craftsmen arrived from Russia, from Prussia, from Baden-Württemberg, from Bavaria, from the Kingdom of the Two Sicilies (Naples) and from Spain and Portugal – despatched in many cases by rulers and governments which hoped thereby to upgrade their own technological capability with an injection of British 'know-how' into their mines, iron foundries, textile mills, dockyards and hardware factories. In 1770 Matthew Boulton received a disarmingly candid letter from two Swiss entrepreneurs who, four years earlier, had been instrumental in enticing several of his skilled metal workers for the purpose of setting up a cut-steel jewellery manufactory in Pforzheim (Baden-Württemberg). They suggested that he might now wish to take his former employees back since their expertise in the cutting and polishing of metals had been successfully transferred to the native workforce.[45]

However, this type of engineering knowledge transfer was fraught with difficulty still in the 1780s, if only for the reason that the laws of Great Britain sought to inhibit the free movement of men and machines.[46] Although both Boulton and Watt expressed annoyance and even anger when dealing with artisans, and even on occasion when dealing with visiting engineers, who seemed bent on scooping up knowledge and 'know-how' without offering anything in return, they drew comfort from the fact that in the domain of steam technology, artisan transfer rarely seems to have conferred a measurable advantage on their competitors. Whilst they did not articulate the challenge of trans-national knowledge transfer in quite these terms, they were certainly aware of the cultural and ecological filters that operated in the intensely practical domain of engineering. We can assume that in their more candid moments they were fully cognizant of the fact that knowledge transfer in the industrial context was a multi-facetted process in which none of the participating parties could safely claim possession of the moral high ground. As James Watt once acknowledged in reference to the Birmingham and Wolverhampton japanning industry, the British had learned most of what they knew about the manufacture of varnishes from the French.[47]

However, most historians would agree that a step-change in the construction of a Europe-wide context for engineering knowledge took place on the conclusion of the Wars of the Revolution and the Empire. Indeed, Michel Cotte views 1814–1815 as a 'turning point.'[48] After this date the intensity of knowledge transfer involving

[44]But see Harris, *Industrial Espionage and Technology Transfer*; also Jeremy, *Transatlantic Industrial Revolution*.
[45]BCL MS 3147 Autran and Ador *fils* to M. Boulton, Pforzheim, 8 June 1770. Also, *Die Pforzheimer Schmuck-und Uhrenindustrie*, 92–7.
[46]Jeremy, "Damming the Flood," 1–34; Jeremy, *Transatlantic Industrial Revolution*, 36–49.
[47]BCL MS 3219/4/123 J. Watt snr to A. Argand, Birmingham, 17 April 1786.
[48]Cotte, *De l'espionage industriel à la veille technologique*, 236.

engineers and skilled craftsmen sharply accelerated, and so it seems did the rate of 'take-up.' This implies, of course, that some of the cultural barriers to transfer operating still in the 1780s had been substantially eroded, or even removed by this date. Had the very nature of 'government' in post-revolutionary Europe altered in a fundamental sense as has been suggested recently in respect of France?[49] Or maybe the *Zeitgeist* had switched decisively and durably from mercantilism and obsessive secrecy to a more *laissez-faire* outlook in the intellectual-property domain? There seems little doubt that governments ceased to worry about knowledge protection and secrecy in the 1820s as Patrice Bret has pointed out.[50] We know, too, that the prohibitions which supposedly prevented the emigration of British artisans were removed in 1824. Under the impetus of Lord Liverpool's liberal economic stance restrictions on the export of machinery were eased the following year as well, although they would not be repealed completely until 1843.

These are interesting, but scarcely provable lines of enquiry in the present state of our knowledge. More promising, it seems to me, is the argument that the efforts of administrations in the economic sphere were now being seconded by an expanding constituency of entrepreneurs who no longer looked automatically to government ministers to launch the process of technological innovation and modernisation. After an initial flurry of official and carefully stage-managed missions of technological enquiry across the Channel between 1815 and the early 1820s in which able individuals drawn for the most part from the engineering administrations of the French state played the lead role, the baton seems to have passed to industrialists who were, in essence, little different from the Matthew Boultons, the Richard Arkwrights and the John Wilkinsons of the preceding generation. Michel Cotte[51] remarks upon this transition, and notes the arrival in Britain of the Séguin brothers of Annonay in 1823, and of numerous ironmasters and textile manufacturers from the centre and the east of France. We might add the name of François-Gracchus Cabrol (1793–1882), superintending engineer at the Decazeville complex of mines and foundries who crossed the Channel in search of the latest blast furnace technology in 1826. In focusing on this highly capable breed of French entrepreneurs we should not forget their Prussian and Swiss-German counterparts. Men such as Johann Conrad Fischer (1773–1854) came repeatedly to the Sheffield and Birmingham metal-working districts in pursuit of the technology involved in cast steel manufacture. It was Fischer, founder of the Schaffhausen ironworks, who would break Britain's cast steel monopoly on the Continent in the decades after the Napoleonic Wars.[52]

Conclusion

It is worth remarking that by the late 1820s technological deficits in the European arena were being evened out. Indeed, the 'knowledge economy' in engineering science and 'know-how' was approaching the point of equilibrium along its Anglo-French axis. With the rapid development of machine building capacity on the continent of Europe and in the United States, many of the improvements in the

[49]See Horn, *The Path not Taken*.
[50]Bret, "Genèse et légitimation patrimoniale d'une invention," 385–410.
[51]Cotte, *De l'espionnage industriel à la veille technologique*, 21–2, 124.
[52]*The Metallurgist Johann Conrad Fischer*.

textile and metallurgical industries which had been initiated in the British Isles during the second half of the eighteenth century had become commonplace. The imbalances that had so alarmed the very first wave of government-sponsored investigators when intercourse across the English Channel resumed in 1814–1815 had by this time greatly diminished.

Historians of science and technology, like economic historians, would therefore be advised to resist the rather lazy historiographical generalisation which posits that knowledge and 'know-how' flowed in one direction only (from Great Britain outwards). Even in the 1780s when experienced visitors[53] to Birmingham and Coalbrookdale first began to take note of the fact that an industrial 'revolution' was in the making in Britain, the trans-national context for engineering knowledge functioned very largely on the principle of exchange. Until the descent of nearly all European states into war or domestic turmoil which began in 1792–1793, engineering expertise, no less than scientific knowledge in general, circulated with remarkably few institutional impediments. Blissfully unaware of what the final years of the eighteenth century would hold in store, Britain's industrial intelligentsia took it for granted that they should have close links with their counterparts in Europe. They invested heavily in the mechanisms of associational culture (clubs, reading circles, masonic lodges, coffee house philosophical societies, etc.) which served as the main vectors for knowledge transfer, and they routinely sent their sons to the Continent in order to complete their technical education as we have noted. When James Watt's eldest son set out once more for France in 1792 he carried with him a shopping list of technical books to buy in Paris which included two copies of Prony's *Nouvelle architecture hydraulique* – one for the Manchester industrialist George Augustus Lee, the other for the promising young Soho engineer Peter Ewart (1767–1842).

Even in the aftermath of the 1814–1815 peace treaties, the engineering 'traffic' was by no means one way. Both Lee and John Leslie (1766–1832), the mathematician, presented themselves in Paris almost as soon as it was safe to cross the Channel, and Joseph Strutt, one of the sons of the Derby industrialist and inventor Jedediah, would follow in August 1816. His tour began with a visit to the *machine de Marly*, followed by inspections of the Austerlitz iron bridge, the site of the Bastille and the model machine collections in the galleries of the Conservatoire National des Arts et Métiers. A month later James Watt junior and John Rennie senior set off. Whilst Rennie soon left the French capital having secured permission to inspect the dockyards and sea defences of Cherbourg and Brest, Watt confined himself to Paris and its environs. He dined with the chemist Claude-Louis Berthollet and the mathematician and astronomer Pierre-Simon Laplace – presumably in their Arcueil retreat. Unlike Rennie, he seems to have avoided a meeting with the eminent hydraulic engineer Prony 'or any of the Ponts & Chaussées gentlemen,' as he put it in a letter to his father. The reason offered can be said to express the tension between the old-style Enlightenment civility practised by Matthew Boulton and James Watt senior and the more competitive technological environment in which British manufacturers were to find themselves by the second decade of the nineteenth century. 'I was much afraid,' he wrote, 'of being subjected to the visits of their emissaries, who would have expected a reciprocity of sights.'[54]

[53]For example, Alessandro Volta, see Pancaldi, *Volta*, 160–2.
[54]BCL MS 3219/4/36 J. Watt jnr to J. Watt snr, Paris, 24 October 1816.

Matthew Boulton died in 1809 and was buried in Handsworth parish church, where he would be joined by his business partner a decade later. Boulton's recognition as an engineer was rapidly eclipsed in the nineteenth century – in part by the praise heaped upon James Watt. Yet in neither case does the verdict of history seem entirely appropriate. Boulton was a consummate self-advertiser who saw little reason to correct visitors to the Soho Manufactory when they jumped to the conclusion that he was the chief architect of the improved steam engine. Watt, by contrast was a retiring figure, beset with anxieties. The extent of Boulton's own technological contribution to the development of Watt's engine will never be known in detail, but there is no reason to suppose that it was negligible. However, by the century's end the steam engine was out of patent and Boulton's reputation as an engineer in the eyes of overseas visitors was rooted elsewhere: in the spectacle of the steam-operated coining machines established in the Soho Mint.

James Watt, as this article has demonstrated, struggled with his status and the ambiguities of self-description throughout his life. The earliest letters in the correspondence files of the Archives of Soho tended to address him as 'James Watt, mechanic,' but in 1795 he informed Thomas Beddoes that he wished to be known to the public as James Watt, 'Engineer.'[55] Whereas for Boulton the label 'engineer' probably still carried the original connotation of inventive capacity, it is apparent that Watt was above all anxious to embed his status in a more advanced form of legitimation. 'Thou art a philosopher Watt,'[56] William Small remarked approvingly on reading Watt's 1769 specification for his prospective engine. We may conclude, therefore, that Watt, if not Boulton, inhabited the transitional zone of professionalisation identified by historians of 'expertise'[57] in which artisanal 'know-how' was increasingly allied to theoretical knowledge. For James Watt, being an engineer entailed becoming an expert.

Bibliography

Armytage, W.H.G. *A Social History of Engineering*. London: Faber and Faber, 1961.

Ash, Eric H., ed. *Expertise: Practical Knowledge and the Early Modern State*. *Special issue of Osiris*, 25. Chicago, IL: The University of Chicago Press, 2010.

Birse, R.M. *Engineering at Edinburgh University: a Short History,* 1673–1983. The School of Engineering: University of Edinburgh, 1983.

Bret, Patrice. "Genèse et légitimation patrimoniale d'une invention: les archives de l'Artillerie à l'origine d'une innovation cruciale dans la Marine au XIXe siècle." In *Les Chemins de la nouveauté: innover au regard de l'histoire*, ed. L. Hilaire-Pérez and A.-F. Gaŕon, 385–410. Paris: Editions CTHS, 2003.

Buchanan, R.A. *The Engineers: A History of the Engineering Profession in Britain, 1750–1914*. London: Jessica Kingsley, 1989.

Cannadine, David. "Engineering History or the History of Engineering? Re-writing the Technological Past." *Transactions of the Newcomen Society* 74 (2004): 163–180.

Clairac, Chevalier de. *The Field Engineer*, Trans. Captain Charles Vallancey. The French of M. le Chevalier de Clairac. Dublin: Printed for John Smith, 1758.

Coffey, Andrew. *A Treatise on the Pipe-Water Works of the City of Dublin*, ed. Andrew Coffey. Dublin, G. Faulkner, 1799.

Cotte, Michel. *De l'espionnage industriel à la veille technologique*. Bélfort-Montbéliard: Presses Universitaires de Franche-Comté, 2005.

[55]BCL MS 3219/4/124 J. Watt snr to Dr Beddoes, Birmingham, 2 March 1795.
[56]Miller, "Watt in Court," 50.
[57]See Ash, *Expertise*, 1–24.

Die Pforzheimer Schmuck-und Uhrenindustrie: Beiträge zur Wirstschaftsgeschichte des Stadt Pforzheim. Pforzheim, n.d.

Eighteenth Century Collection Online (Gale Digital Collections).

Flinn, M.W. "The Travel Diaries of Swedish Engineers of the Eighteenth Century as Sources of Technological History." *Transactions of the Newcomen Society* 31 (1957–1958): 95–108.

Harris, John R. *Industrial Espionage and Technology Transfer: Britain and France in the Eighteenth Century*. Aldershot: Ashgate, 1998.

Horn, Jeff. *The Path Not Taken: French Industrialization in the Age of Revolution, 1750–1830*. Cambridge, MA: MIT Press, 2006.

Jacob, Margaret. "The Cultural Foundations of Early Industrialisation: A Project." In *Technological Revolutions in Europe: Historical Perspectives*, ed. Maxine Berg and Kristine Bruland, 67–85. Cheltenham: Elgar, 1998.

James, H. *Family Capitalism: Wendels, Haniels, Falcks and the Continental European Model*. Cambridge, MA: Harvard University Press, 2006.

Jeremy, D.J. "Damming the Flood: British Government Efforts to Check the Outflow of Technicians and Machinery, 1780–1843." *The Business History Review* 51 (1977): 1–34.

Jeremy, D.J. *Transatlantic Industrial Revolution: The Diffusion of Textile Technologies Between Britain and America, 1790–1830s*. Oxford: Blackwell, 1981.

Jones, P.M. *Industrial Enlightenment: Science, Technology and Culture in Birmingham and the West Midlands*. Manchester: Manchester University Press, 2008.

Jones, Peter. "'Commerce des Lumières:' the International Trade in Technology, 1763–1815." *Quaderns d'Història de l'Enginyeria*, 10 (2009): 59–74.

Le Blond, Guillaume. *The Military Engineer: or, a Treatise on the Attack and Defence of All Kinds of Fortified Places*. London: Printed for J. Nourse, 1759.

MacLeod, Christine. *Heroes of Invention: Technology, Liberalism and British Identity,1750–1914*. Cambridge: Cambridge University Press, 2007.

MacLeod, Christine. "James Watt, Heroic Invention and the Idea of the Industrial Revolution." In *Technological Revolutions in Europe: Historical Perspectives*, ed. Maxine Berg and Kristine Bruland, 96–116. Cheltenham: Elgar, 1998.

Miller, David. *James Watt, Chemist: Understanding the Origins of the Steam Age*. London: Pickering & Chatto, 2009.

Miller, David. "The Usefulness of Natural Philosophy: the Royal Society and the Culture of Practical Utility in the Later Eighteenth Century." *British Journal for the History of Science* 32 (1999): 185–201.

Miller, David. "Watt in Court: Specifying Steam Engines and Classifying Engineers in the Patent Trials of the 1790s." *History of Technology* 27 (2006): 43–76.

Mokyr, Joel. *The Gifts of Athena: Historical Origins of the Knowledge Economy*. Princeton, NJ: Princeton University Press, 2002.

Mortimer, Thomas. *The Universal Director; or, the Nobleman and Gentleman's True Guide to the Masters and Professors of the Liberal and Polite Arts and Sciences*. London: Printed for J. Coote, 1763.

Pancaldi, G. *Volta: Science and Culture in the Age of the Enlightenment*. Princeton, NJ: Princeton University Press, 2003.

Picon, Antoine. *L'Invention de de l'ingénieur moderne: l'Ecole des Ponts et Chaussées, 1747–1851*. Paris: Ecole des Ponts et Chaussées, 1992.

Robinson, Eric, and McKie Derek, eds. *Partners in Science: Letters of James Watt and Joseph Black*. London: Constable, 1970.

Robinson, Eric, and A.E., Musson. *James Watt and the Steam Revolution: A Documentary History*. London: Adams and Dart, 1969.

Rücker, Reinhold. *R. R. Angerstein's Illustrated Travel Diary, 1753–1755: Industry in England and Wales from a Swedish Perspective*. Trans. T. Berg and P. Berg. London: Science Museum, 2001.

Skempton, A.W. *Civil Engineers and Engineering in Britain, 1660–1830*. Aldershot: Variorum, 1996.

Skempton, A.W. et al. *A Biographical Dictionary of Civil Engineers in Great Britain and Ireland: Volume One: 1500–1830*. London: The Institution of Civil Engineers, 2002.

Tann, Jennifer. "Two Knights of Pandemonium: a Worm's Eye View of Boulton, Watt & Co." *History of Technology* 20 (1998): 47–72.

The Metallurgist Johann Conrad Fischer, 1773–1854 and His Relations with Britain. Schaffhausen: George Fischer Limited, 1947.

Torrens, Hugh. *The Practice of British Geology, 1750–1850*. Aldershot: Ashgate, 2002.

Young, Arthur. *Travels in France during the Years 1787, 1788 and 1789*. 2 vols. Dublin: Cross, Wogan et al., 1792.

Royal Engineers Museum http://wwwremuseum.org.uk/corpshistory (accessed April 2009).