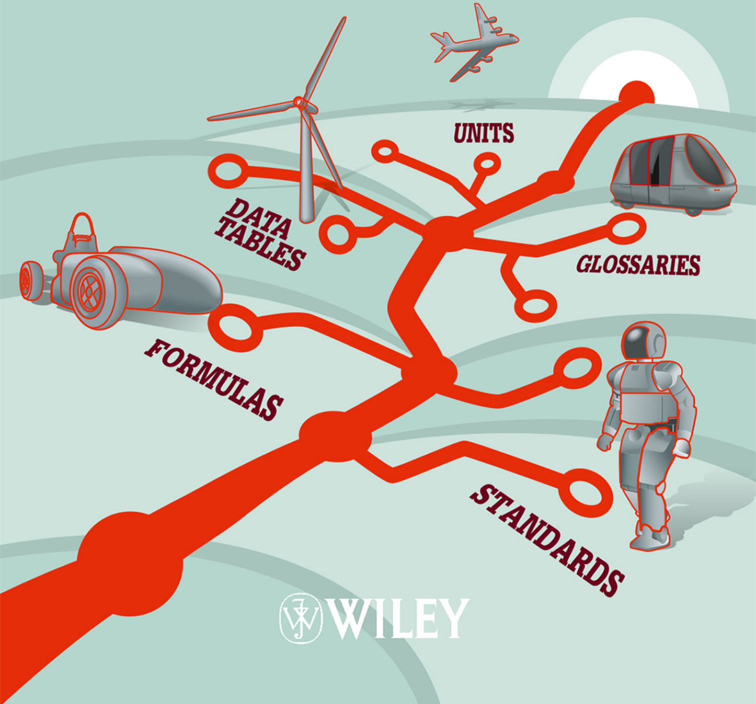
Clifford Matthews

ENGINEERS' DATA BOOK

Institution of MECHANICAL ENGINEERS

Fourth Edition



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Improving the world through engineering

Engineers' Data Book

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Fourth Edition

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Foreword

This book is an essential tool to help you as you embark on your career in mechanical engineering, providing a wide range of useful information you will need during your studies, and later as a professional engineer.

The Institution of Mechanical Engineers (IMechE) is your dedicated partner throughout your career and we are committed to supporting you through your studies to graduation and beyond. Home to 98,000 engineering professionals working in the heart of the country's most important and dynamic industries, we will ensure that you have the skills, knowledge, support and development advice you need at every stage of your career.

Because we set the standard for professional excellence in mechanical engineering our members are recognised for their professional competence and enjoy enhanced career opportunities as a result. To achieve this recognition of your skills and to manage your career development, it is important that you maintain your membership of IMechE and take advantage of the opportunities available to help you fulfil your potential.

As an Affiliate member, during your studies you will benefit from career advice and support as well as regular information about engineering and how to get involved in your local IMechE community. By becoming a member, you also have access to Career Developer, our suite of online reporting tools, enabling you to record your professional experience as soon as you start your industrial placement.

Upon graduation you can apply to become an Associate Member of IMechE and begin the journey towards professional registration. With appropriate work experience and support from IMechE to develop your skills and knowledge, you can apply for registration as an Incorporated or Chartered Engineer. Your membership of IMechE will bring ongoing support for your continued professional development, through a range of member resources, events and activities. Engineers need to continue their professional development to keep their skills fresh and progressive, so we will help you stay up to date, broaden your knowledge and deepen your understanding of your chosen industry.

We hope that your relationship with IMechE will be a lifelong one that supports you throughout your career. As you join this exciting and essential profession, we wish you luck and look forward to helping you stay ahead in an increasingly varied, dynamic and rewarding industry.

Preface

This significantly updated 2012 edition of the *Engineers' Data Book* replaces the three successful previous editions published in 1998, 2000 and 2004. Since the data book's inception, feedback from engineers and students has indicated that, despite the proliferation of technical information in published and electronic format, there is still a need for a source of core mechanical engineering information in a readily available form. The 2012 data book has increased in content by approximately 60 percent compared to the first edition. As well as an increase in the coverage of basic units, data, and engineering rules, the content has gradually been extended to cover vital aspects of structural integrity and reliability of engineering components: these are important current issues in the engineering business.

Finally, it is important that the content of this data book continues to reflect the information that is needed and used by student and experienced engineers. If you have any suggestions for future content (or indeed observations or comment on the existing content) please let me know on: enquiries@matthews-training.co.uk

Clifford Matthews

Introduction

The Role of Technical Standards

What role do published technical standards play in mechanical engineering? Standards have been part of the engineering scene since the early days of the industrial revolution when they were introduced to try to solve the problem of sub-standard products. In these early days they were influential in increasing the availability (and reducing the price) of basic iron and steel products.

What has happened since then? Standards bodies have proliferated, working more or less independently, but all subject to the same engineering laws and practical constraints. They have developed slightly different ways of looking at technical problems, which is not such a bad thing – the engineering world would be less of an interesting place if everyone saw things in precisely the same way. Varied though they may be, published standards represent good practice. Their ideas are tried and tested, rather than being loose – and they operate across the spectrum of engineering practice, from design and manufacture to testing and operation.

The current trend in Europe is towards harmonization of national standards into the Euronorm (EN) family. Whether you see this as rationalization or simply amalgamation is not important – the harmonized standards will have significance for the mutual acceptability of engineering goods between companies and countries. Some recent 'standards', such as the Machinery Directive and Pressure Vessel Directive have real statutory significance, and are starting to change the way that mechanical engineers do things. They may be written by committees, but they are not without teeth.

Since the first edition of the Data Book, the number of EN harmonized engineering standards has increased significantly. However, their influence is still to be felt in many areas.

Engineering companies that have been used to working to existing British and US standards can be reluctant to change, with the result that many companies still prefer to work to superseded standards. In some disciplines (pressure equipmentis a good example) the amount of equipment being manufactured to the new EN standards is quite small. Things are changing, but slowly.

Technical standards continue to be an important model for technical conformity in all fields. They affect just about every mechanical engineering product from pipelines to paperclips. From the practical viewpoint it is worth considering that, without standards, the design and manufacture of even the most basic engineering design would have to be started from scratch.

Section 1

Engineering Careers

1.1 Introduction: what is an engineer?

You can hear, and read, long opinionated, but largely inconclusive, arguments as to what the title ‘engineer’ actually means. For every view that the title should be limited to those with a certain level of qualifications, or have attained a prescribed level of Institution membership, there is a contrary view that says it should relate equally to those who can prove a level of practical or craft skill, or demonstrate so many years of vocational experience.

Unlike some countries, where the designation is better defined, the situation in the UK remains liberal and self-regulated. In many industries the titles ‘engineer’ and ‘technician’ are used freely and interchangeably, without causing too much chaos. Older, more traditional industries often have more a definitive intenal understanding of what the titles mean to them. This owes as much, or more, to their own hierarchical structure and heritage, however, as to any technical interpretation they really ascribe to the terms. This older view of the world, whether you are called ‘technician’ or ‘engineer’, paints to them a picture of whether or not you sit in an office or get your hands dirty, what you wear, and how much you get paid.

Looking back in time to the start of it all, it becomes clear that job titles and delineations are much more artificial than they appear. The earliest engineers conceived the ideas, designed their innovative steam engines, bridges and ships, raised the funds, and did many of the jobs themselves. This was born of necessity, because there were no ready-trained technicians waiting to take on the engineers’ concepts and turn them into reality. Once under way, however, industry matured quite quickly and separate job roles soon started to crystallize out,

Engineers’ Data Book, Fourth Edition. Clifford Matthews.

driven by people's preference to concentrate on things that they naturally did best.

Over the last 100 years or so, with increased maturity of the industrial society, the division of labour has continued, each engineering specialism soon fragmenting into several subspecialisms of its own, and so on. This is why the argument as to what exactly delineates an *engineer* from a *technician* has no real answer, and probably never will have. It is simply too difficult to draw a line in the sand, within such a large and varied continuum of skills, on which everyone will agree.

Assuming that you have no wish to spend the next forty or so years worrying about a question to which you know there is no answer, here is another way to look at it. Think of engineers and technicians as all being part of the wide spectrum of engineering. A spectrum has no gaps between its colours, each one leads seamlessly on to the next. Now think what it would look like viewed in black and white rather than colour – they are now all the same colour (grey) differentiated from each other only by the depth of their shade of grey.

What if the shades of grey represented *technical difficulty*? The light grey shades would represent job roles that are easier to learn, with the dark ones being progressively more difficult. Difficulty might also be associated not only with the technical depth of the subject or role but also with the *time* it would take to learn to do it well. At no point in this continuum from white (easy) to black (difficult) could we draw a definitive line dividing 'light' from 'dark', all we can say is that the spectrum consists of varying degrees of lightness and darkness and that every shade forms part of the complete picture. So this is our conclusion:

- Generic job titles such as 'engineer' and 'technician' cannot, realistically, be accurately defined – they are simply parts of the continuous spectrum of job roles in the engineering industry. However ...
- One way to view the difference in roles is to consider how *difficult* each one is, and how long it would take to master it (properly!).

1.2 A rough guide to industry breakdown

There are many hundreds of different industry types, roles, job descriptions and specialisms in the world of mechanical engineering, all of which are spread over a multitude of different industry sectors. There are various systems that attempt to categorize these into standard industry classifications (SICs) using code numbers or letters, but they are complicated and do not always fit well with each other.

Simplistically, you can think of the engineering industry, and the job roles within it, as a matrix. To keep this matrix to any sort of manageable size means that it needs to be generalized – providing an overall picture rather than a detailed or comprehensive analysis.

Figure 1.1 shows the matrix. The more basic industries lie near the bottom, rising to the increasingly complex and technologically advanced ones towards the top. Although pure science elements exist at all these levels they become more prevalent (and are used in greater detail) in those industries near the top of the matrix. There is no implication of value or worth to industry in the position of any entry in the vertical scale, it is just a crude grading based on the overall complexity and resultant difficulty of the subject. The horizontal axis of the matrix is different. This shows the basic allocation of job roles which is equally applicable to all the industry sectors in the vertical scale. There may be a few differences, but the basic breakdown is much the same for all. The horizontal axis is based on a chronological (time) scale, running left to right. Unlike the vertical axis, the differences in complexity and difficulty are less well spread across the horizontal axis. Product conception and design fit naturally together as a discrete skill-set, but the others are fairly well separated out, representing discrete and identifiable job roles.

The left-hand end – conception and design – suits those people with high levels of innovation and conceptual skills. They can spot an idea, visualizing its final function and form, but lack a full set of skills suited to turning it into hard engineering reality. At the right-hand end, plant operators and technicians have the business and practical skills to operate a

DISCIPLINE AREA	ROLES			
	Conceptual design	Manufacture	Installation/ commissioning	Operation
Pharmaceutical production	x	x	x	x
Medical / Optics engineering	x	x	x	x
Aerospace	x	x	x	x
Weapons engineering	x	x	x	x
Process engineering design	x	x	x	x
Metallurgy	x	x	x	x
Production engineering	x	x	x	x
Power generation	x	x	x	x
Automotive/marine engineering	x	x	x	x
Consumer products	x	x	x	x
Paint/coatings	x	x	x	x
Forging/casting	x	x	x	x
Structural engineering	x	x	x	x
Fabrication manufacture	x	x	x	x
Domestic services, heating etc	x	x	x	x

Figure 1.1

plant or a range of products on a commercial basis, but lack the skills to conceive, design and build a plant or product range from scratch. They need others to provide those skills.

You can use this rough matrix to plot your current position in the industrial landscape, or to plan where you might like to be in the future. It is neither complete nor exhaustive (there would need to be 40+ vertical categories to accomplish that), but as a broad career route map it is not a bad place to start.

1.3 Training and professional development

Whatever you do, don't confuse these two. It is best to think of *training* as your initial academic qualification: craft training or whatever – an activity whose prime purpose is to get you into your first engineering job. It also provides essential (and useful) technical background to get you onto the doorstep of your subject, but does not yet provide you with any of the full skill sets you need to move forward. This training is a benchmark, slotted into the system to differentiate between those who have it and those who do not.

Professional development is the next step. This is any training activity that has a specific job-related objective or purpose. It is often mistakenly seen as comprising mid-career courses in generalized disciplines such as marketing, finance, QA, project management skills and similar. Such-temptingly-named courses are really not what it is about. Whilst they may look and sound good, they lack cutting edge in differentiating those people with real ability in the core skills of the industry from those who do not. They are too general, too short, and woefully lacking in core skills, technical content and bite.

Productive professional development must be centred on the core skills of your particular industry. To possess the quality of being able to differentiate between its participants, productive professional development has to be structured to have a pass or fail criteria, with a pass mark high enough (and overall pass rate low enough) to buy it credibility and give it some teeth.

The best time to start productive professional development is as *soon as possible* after your initial training is complete. For best effect try to run it in parallel with a role that gains you practical hands-on experience of the discipline in which you are employed. This will force the productive and professional elements to complement each other, multiplying the effect of them both. Coupled with sound initial training and a bit of hands-on experience, the way in which you choose to pursue professional development activities in the early career years seems to be one of the clear factors in determining those who progress quickly up the technical jobs hierarchy and those who do not.

1.4 Degrees of (engineering) excellence

You have probably decided that getting a degree is a good idea – or why would you be reading this book? The reason why any high-level qualification is required is always a good talking point. Opinions differ about why it is necessary, and what is the point of it all.

The time-honoured explanation you will be given is that it is all about training your mind. Engagement in the apparently endless carousel of mathematical examples, laboratory reports, descriptions and discussions will train your grey cells to address similar, even unrelated, problems in your future career – and all will be well.

This is interesting but, of course, untrue. Your mind is now as trained as it will ever be. It is at the pinnacle of its absorptive, innovative and recuperative powers – loaded, primed and ready to go. You are sitting at the end of 400,000 to 500,000 years of human development, a continuum of innovation, forward thinking and trial-and-error that turned the world from stone age caves and forests to what you see today. Most of the steps and discoveries were made by people under the age of 25, without any qualifications at all – which is a very recent development.

If we set the above aside as an illusion disproven by history, we find that the need for an engineering degree today is based on *four* main criteria. Consider them of equal weight: complementary criteria that naturally exist as part of a set, and each of which has little resonance or effectiveness without the assistance of the others.

1.4.1 A degree is a benchmark

As a benchmark for industry, degrees work reasonably well without being spectacular. Industries seem to like benchmarks, as it gives them something to aim for, or against which they can measure their success. Engineering companies use them as part of their recruitment policy, giving them some idea of whom to invite to interviews.

One of the strange properties of benchmarks is that they cannot be usefully produced by the part of organization that sees the benefit in using them. The profit-making parts of any engineering business (consisting of those people and groups that actually know how things work) are far too busy trying to extract profit from the market – whilst supporting the rest of the organization and its hangers-on – to get involved in recruitment policy, skill-sets or this week's current incarnation of the education system. The result is that recruitment policy and practices are administered by those on the *edge* of an organization rather than at its profit-making core. This fosters the practice of grabbing at plausible-sounding requirements that can be put in recruitment adverts, and slid into the candidate assessment procedure.

The actual detailed content of degree courses can (and do) remain a bit of mystery to many recruiters. The content of most benchmark qualifications are set in academia rather than by the 'customer' organizations because, as we know, they are simply too busy. Some comfort is offered by various third-party accreditations of degree courses and this, accompanied by a few subjective recollections of the reputation and specialisms of some educational institutions and courses, is usually good enough. The end result is that an engineering degree becomes a prerequisite for entering the recruitment and interview process of any engineering company.

1.4.2 A degree is a filter

This one works for you. The time and effort required to achieve an engineering degree gives you the opportunity to see if you like the subject. If it proves to be unsuitable for you, then it's best to find out sooner rather than later, to prevent your career becoming a necessary daily chore. If you decide that it is something you would like to do, then you will gain:

- The opportunity to make engineering your career.
- Access to the answers to the vast array of engineering questions that 99% of the general population can't answer.
- A guarantee (well, almost) of long-term employability – if you are any good. This may, or may not, offer good financial reward depending on which area of the subject you end up in. There are a few stratospheric salaries in engineering, a lot of good ones and some where you would earn as much driving a taxi. Your eventual destination will be decided by the sum total of your ability, willingness to seek knowledge, and the choices you make along the way.

The degree process filter acts as a long filter, rather than a particularly severe or fine one – but it works quite well.

1.4.3 A degree is a first step in the career race

Career progression is nothing more than a race against the clock. As you progress, the winning post either gets closer or recedes into the unobtainable distance, depending on where you have set it.

In any race, the first step is ***not*** the winning post. Sadly, you cannot *enter* any race without a first step, so the sooner you take it the better. Think of this first step as a mechanistic process, with the objective being its *completion*, rather than demonstrating a shining example of success. A degree is a sound first step, but it is not the winning post, which is where the prizes are awarded.

1.4.4 A degree gives you knowledge feedstock

The biggest advantage of an engineering degree is the knowledge feedstock it provides. It may be surrounded by the usual doubtful skills of management, sales, communication, and the like, but strip these away and it is an almost perfectly technical subject. You cannot progress without a critical mass of this technical information, much of which is packaged in the engineering degree syllabus.

Which degree is the best?

This matters less than you think. The number of engineering degrees available in the UK alone now runs into hundreds, each one comprising different combinations and permutations of pure or applied subjects and claiming to be shorter, more effective, or more (or less) intensive than the others.

Relax. With a few exceptions – all this creation is largely artificial. It proliferates from the needs of educational establishments to increase their numbers of student 'customers' rather than from the segmented technical needs of the industries they ultimately serve. At this level, all engineering has a fairly stable core of mathematics, chemistry and physics: equations, concepts and techniques that describe the engineering-related parts of the natural world. The multiple variation of degree subject combinations are nothing more than different patterns of the DNA of the subject, not different DNA.

The pattern of technical subjects learned will really only become useful to you when you are in about Year 4 of your post-graduate career. Before this, in Years 1, 2 and 3, the pattern of knowledge 'feedstock' amassed during your degree course will feature in only about 5% of the things in which you are involved. The rest will, for the moment, be forgotten. Sadly, it is impossible to know in advance exactly which 5% of your initial knowledge upload you will need, so you more or less have to learn it all.

In about Year 4 of a post-graduation career, everything changes. Only about 20% of graduates will still be with their initial role or employer and the demand will now almost certainly be for a completely different pattern of knowledge than the 5% you used when you first started. The new pattern of knowledge required will now start to present itself to you. The percentage of the core engineering subjects you use will start to rise, and any synthetic combinations of syllabus content of your original degree will quickly lose its significance. This will be followed in close pursuit by the title of your degree, its artificially created specialisms, and the name of the hallowed institution from whence it came.

Now the race is on.

1.5 Degrees and how to pass them

Passing a degree is more or less a mechanistic procedure. Assuming that you have been preprogrammed with the necessary basic education, and are blessed with an average-to-good mental processing ability, passing a degree comprises a fixed equation of 5% flair and natural ability, 5% chance, and 90% predictable, mechanistic procedure. Engineering degrees are no exception to this – in fact they fit the formula better than most. Here is the procedure:

- Step 1: Decide your target, C, B or A.
- Step 2: Get the syllabus, so that you know what's coming.
- Step 3: Weed out the syllabus so that you can manage it.
- Step 4: Establish a learning method.
- Step 5: Follow your learning method, tailored to the C, B or A decision target you have set.

This five-step methodology has always worked well, and its effectiveness is actually increasing owing to the recent proliferation of degree courses and increases in undergraduate numbers. It is helped along by the increasing contemporary assumption that most candidates should succeed, surrounded by a sparkling array of assessment structures, grades and subgrades. Here is Step 1 (the most important one) in a little more detail.

Decide your target: C, B or A

Which of these three targets you choose will set the agenda for all the time you spend on your degree course. They are equally applicable to full or part time courses – they relate purely to the target you set yourself, and are therefore independent of the name, content or length of the course. One of the inherent properties of these targets is that if that you don't consciously choose one of the three, one will always choose itself *for you,* attaching itself to you without your knowledge. It is therefore best to choose one for yourself, so that you know what it is, and can fit in with it.

Target C

If you choose target C you have decided to do *just enough* to pass all the parts of the syllabus that you need to get your degree. Grade is not important to you, and you are happy to rely on a bit of luck to, hopefully, get better than you deserve. In submitting reports, dissertations and projects, and sitting exams, you are happy with recital rather than real understanding – indeed you may not know the difference. There is no need to feel isolated if you have chosen target C (or if it has chosen you) because about 50% of your fellow undergraduates will do exactly the same.

Target B

Target B undergraduates are target C ones in urbane disguise. Whilst fundamentally sharing the target C views, they have identified that the business of passing qualifications must have some *error margin* floating around. Aiming just to pass could mean that with a bit of bad luck, unplanned absence or misreading of exam questions, it might just be possible to fall victim to this error margin, and fail. Opinions differ on how big this error margin actually is, but intuitively it falls somewhere between 5 and 15%.

Target B undergraduates aim to try that little bit harder, to ensure that they place themselves firmly in the pass zone, cleanly above the error band. They intend to do this mainly in the continuous assessment or project work elements of the degree course – hoping that the examined parts (which are just that bit harder) will look after themselves. To help their chances in the continuous assessment modules, target B undergraduates tacitly accept that they will need to bring a little structure and organization to their work. This, however, will be largely *reactive* – they will do it when chased, or when they think they have to. On balance they are still (knowingly or unknowingly) being *managed by* the degree syllabus that is thrust upon them, occasionally being surprised when it goes too fast, too slow or when it suddenly expands to a depth that catches them out. When it does, they will discuss this apparent unfairness with some of the 35% of undergraduates who have chosen the same target B path.

Target A

Target A is *not* necessarily about getting the top marks in the class, grade A+ or A++ with gold and platinum star. These awards, say the 15% target A group, are for the birds – merely a crude and ephemeral illusion of early-career grandeur, rather than success in itself.

The real secret of target A lies in the *predictability* it brings to the whole affair. Target A undergraduates analyse the content, structure and timing of the course in advance. In this way, as they progress through the months and years of the course, they always know what is coming next, and can put the past and forthcoming parts of the syllabus in the context of the final examinations. Later parts of the syllabus come as no surprise and three notable things play a big part in this:

- Full familiarity with the basic 'ball skills' of the course subjects. To hit target A requires complete mastery of basic maths routines and its differentiation and integration methods until they become second nature. Recognizing mathematical formats and equation types is a requirement of many degree subjects so this will pay itself back in benefits many times.

Once you have achieved this mastery you will find yourself *attracted* to classroom and homework examples that contain them, rather than imaginatively avoiding them – which is what the target B and C groups do.

- Asking ***'why?'*** and ***'what else can I find out?'***. The target A philosophy does not end with doing the ten questions or examples you are given on any particular subject. Think of this as being about two-thirds of the journey – when you've done them, make an active attempt to find some different examples (harder, not easier ones), and do them as well. For qualitative, or description information and concepts, then ask *why?* two or three times, and search until you find the answer. You are constantly making things hard for yourself – but that is the environment of target A.
- *Planning and time management* is the bedrock of target A territory. You need to get the course syllabus in advance, see how long each part takes, make plans for doing it, learning it, revising it, sorting out your problems with it and then anticipating the way that its content will be slid into the examinations. None of this is random – it is all planned in advance so that ultimately there are no surprises. You are managing *it*, rather than it managing you.

Summary: Your choice of target

Seen from a distance, there is no single more important part of passing an engineering degree course than the target C, B or A, that you choose. Throughout the course it will determine;

- What you do
- How you do it
- When you do it
- How much effort you put in
- Whether you pass or fail – and what grade you get

1.6 Do you have any . . . experience?

Nature has thoughtfully provided you with a mental processing power. Your degree will give you the named folders in which to store the next four decades of accumulated data. All you need now is the universal tool for sifting the wide datastream that will