Supplementary Material
Technology: A Second Level Course
Engineering Mechanics: Solids

MECH S235

Course Guide

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1 Introduction

This Course Guide gives you important information on the material in the course, including those items provided by us, and those that you need to provide for yourself.

On behalf of the Course Team may I say that I hope you find this course of value and worth the effort that you will be investing, and hope that you will reap the benefits for many years to come. We look forward to meeting you at Day-long Schools.

2 The course aims

This course introduces the subject areas of Kinematics, Statics and Dynamics, in the context of Engineering Mechanics. The course is mainly concerned with the application of these topics to the analysis and design of solid bodies, as distinct from the closely related areas of Fluid Mechanics and Thermodynamics.

Kinematics is the study of motion. Statics is the study of forces on stationary objects. Dynamics is the study of forces on moving bodies. These are the analytical tools used by the design engineer.

The aims of the course are therefore twofold. Firstly, to teach the basic analytical methods, that is, the fundamental concepts and techniques of solid engineering mechanics. Secondly, in a limited way, to show the implementation of these methods in engineering design. The limited time available to study the course has meant that we have had to lay the emphasis on the analytical methods. We believe that if you acquire a sound foundation in analysis from this course, then its implementation in design will become apparent to you, both in your future courses and in the mechanical engineering that you see around you every day.

3 The course components

On the basis that 'it is better to do a few things well' the Course Team has adopted a policy of simplification of course components. Our watchword has been 'if in doubt, leave it out'. This half-credit course therefore comprises:

- Fifteen Unit texts, many bound in pairs.
- Supplementary notes with CMAs and TMAs
- Eight television programmes
- Audio CDs
- Day-long Schools

4 The course structure

The course is divided into nine Blocks covering fifteen Units. Table 1 gives full details in order of study. Six of the Blocks consist of two Unit texts bound together on associated topics, with one TV programme, one CMA and half a TMA. The remaining three Units of text relate to individual topics, but are also supported in general by CMAs, TMAs and television. The Presentation Schedule for the course gives details of cut-off dates for the assignments; these are usually during the week following the last study week for a Block.

The course finishes with a revision component (Unit 16) which consists of audio-cassettes with accompanying written notes, and the Specimen Examination Paper. The audio-visual material is designed to reinforce your understanding of some important aspects of the course, including for example free-body diagrams and problem-solving techniques.

5 Unit contents

UNITS 1 and 2 introduce some simple mechanisms and show how combinations of mechanisms are used to form complex machines. The fundamental concepts of motion, such as position, velocity, acceleration and jerk, are explained along with the idea of scalar and vector quantities. Methods are given for the analysis of machines.

UNIT 3 introduces the ideas of forces, moments and strength, and employs these quantities in static analysis – the analysis of forces and moments on stationary bodies. You will also meet Newton's laws of motion and in particular the application of Newton's first law to statics problems.

UNIT 4 is devoted to explaining how to select free bodies in static analysis and how to draw the related free-body diagrams. A procedure for using free-body diagrams to solve statics problems is set out.

UNIT 5 introduces methods of representing and analysing motion in mechanisms: the kinematics of mechanisms.

UNIT 6 extends the kinematic explanation and analysis of Unit 5 to the construction of velocity diagrams for mechanisms and for components of mechanisms.

UNITS 7/8 are used to introduce the fundamentals of dynamic analysis – the analysis of forces (and moments) on moving bodies – using Newton's laws of motion, especially the second and third laws. Procedures are presented for dynamic analysis of both particles and rigid bodies, where appropriate in both translational and rotational motion. The analysis concerns the relationships between acceleration (including angular acceleration) and the forces and moments applied to a rigid body.

UNIT 9 is concerned with two topics, namely compensation forces, centrifugal force for example, in analysis relative to moving axes, and the construction of acceleration diagrams for simple mechanisms.

UNIT 10 explains the concepts of stress and strain and the use of stress analysis to predict the performance of components.

UNIT 11 introduces simple structural components, such as ties, beams and struts, together with the static analysis of such components under load.

UNITS 12/13 introduce the ideas of work, energy, power, momentum and impulse, and present procedures for using these concepts in dynamic analysis.

UNIT 14 explains the basic concepts of free and forced vibration for simple spring–mass systems (with or without damping), including natural frequency, amplitude, phase and resonance. The principles of vibration isolation are also illustrated.

UNIT 15 is a case study, based on the mechanical design of an electric lift, intended to show the application of many of the concepts and procedures which are given in the preceding Units to a practical engineering design.

UNIT 16 provides scope for revision at the end of the course. There is no conventional bound volume of written material. The revision element consists of audio-cassettes with supplementary printed material, and the Specimen Examination Paper.

6 Items you must provide

Calculator It is essential to have a scientific calculator. A calculator will ease the burden of routine arithmetic and hence allow you to concentrate on the important aspects of problem solving – namely the new methods that you are learning. It should have exponential number entry, find the sine, cosine and tangent of an angle and find the angle from these functions, give powers and roots, logarithms and antilogarithms for both base 10 and *e*, and preferably work with angles in degrees or radians by choice.

Drawing instruments There are a number of drawing exercises for which you will require drawing instruments. A 'school geometry set' will give excellent results if properly used. You will need a 250 or 300 mm rule, a 180° protractor, a 30°/60°/90° set-square, a 45°/45°/90° set-square and a pair of compasses. You will find it helpful to have available A4 size (the size of this page) plain paper, and graph paper with a millimetre grid. To draw accurate lines requires a sharp pencil of appropriate hardness. I favour 2H, sometimes 3H, but in any case you will need a means of achieving a good sharp pencil (sandpaper is useful), and if you make as many mistakes as I do, then you will need at least one soft eraser!

7 Using the course components

Please begin a Block or Unit by reading any guidance notes provided with the related supplementary material.

The Television Notes give a resumé of the programmes, and explain how they relate to the Unit texts. There is never any need to wait for a programme before proceeding with a Unit. The programmes are designed for television viewing, but of course the use of a video recorder can be advantageous.

The audio-visual packages should be used in accordance with the given oral and written guidance.

At Day-long School you will be using your newly acquired theoretical knowledge on some interesting design projects.

The same applies to the tutorial support. The name 'tutorial' is probably unfortunate in this respect. You should not go to a tutorial expecting to receive a lecture or to be taught from scratch on any topic. The tutor time available to you is much too precious to be used so crudely. The tutorials should be looked upon as a chance to iron out specific detail difficulties that have arisen whilst you worked the Units. You should arrive at a tutorial with the basic information absorbed, and able to enter into an informed two-way discussion to resolve residual difficulties. This will enable you to benefit a great deal more from contact with your tutor.

8 The art of problem solving

The solution to an Engineering Mechanics problem is much easier to follow than to create. It is like the difference between watching someone playing the piano, and doing it yourself. To carry the analogy further, we, the Course Team, have done our best to explain how we solve the various types of problem. This is like writing music down, and telling you which note corresponds to which piano key. With care, looking at the music, you can play the notes in the right order, although rather slowly. To play the tune requires a tremendous amount of practice. So it is with Engineering Mechanics. We can tell you the steps to take in a problem, but you have to do it many times to become good at it. If as a newcomer to piano playing you tap out the tune following the written music once or twice, it is no good going into an examination and trying to play correctly at full speed from memory!

To take another analogy, if I described to you how to drive a car, would that make you a good driver? Of course not – it requires a great deal of practice. That may seem ominous, although I am not trying to alarm you, just to make a point about the course: please do *not* try to learn by just doing the CMAs and TMAs and seeking out what you need in the Unit texts. This will result in you missing 'notes' that you will need later.

Please work through the Unit doing all the SAQs. Then do the assessment material. The SAQs are not there for you to glance at the solution and say 'OK'. This is an easy but fatal mistake! Try all the SAQs. If you have a difficulty refer to the solution to get going again.

Make a note of any SAQ that you cannot complete without referring to the solution and try it again later. Of course this is time consuming, but learning, as opposed to just reading, is time consuming. The Course Team has done its best to ensure that you have an amount of work that can be done thoroughly in the time available.

9 Timing

Based on a standard 18-hour OLI unit, the Course Team has allocated 4.5 hours for reading the Unit text, 9 hours for practising problem-solving, that is doing the SAQs, and 4.5 hours for CMAs, TMAs and television.

The SAQs, CMAs and TMAs should therefore occupy at least eight of the twelve hours. I do not apologize for saying again that this is necessary because you can only learn by doing – not just by reading or watching.

This very large proportion of time devoted to problem-solving makes it difficult to estimate the time you will take, because it is easy to lose a lot of time getting stuck, or just by having to refer to the text often. To avoid excessive waste of time you should not spend too long looking vacantly at a problem wondering what to do. Obviously there is a line to be drawn between giving up too easily and persevering, and only you know in your own mind where that is for you. On the whole I recommend, if you are falling behind, that you look at the SAQ solution (or text example) rather more readily, provided that you do try the SAQ again a day or two later.

If you find that self-help groups have on previous courses been an effective use of your time, then please try to make similar arrangements for this course.

10 Assessment

You will be assessed by means of an examination and the CMAs and TMAs. The overall mark distribution is based on 50% for the examination and 50% for the continuous assessment, of which 15% is for the CMAs and 35% is for the TMAs. The course is operating on the system in which *all* the CMAs and TMAs can contribute towards your final mark. For the TMAs the computer will discard your one lowest score. Two of the lowest CMAs will be discarded in the same way. This means that if you fail to submit one TMA or two CMAs it is not a disaster, but it is still to your advantage to submit all TMAs and CMAs.

The intention is to use CMAs to ask short questions, and to use the TMAs to set much longer problems in which you will need to bring together ideas from the relevant Blocks. Although any particular TMA contains specific questions, it is there to see if you can answer questions of a similar type, not just that specific example. You should show adequately how you arrived at your answers. Do not expect to receive full marks simply because your final answer is correct.

11 Extra reading

Everything that you will be assessed on is contained in the Units – there are no set books. You can, of course, consult other texts in Engineering Mechanics for background reading, but no study time is allocated for this purpose.

12 Errors and mistakes – ours

In common usage the words 'error' and 'mistake' have a similar meaning, but in scientific work we use them differently. Let me make clear the distinction in our use of the terms. If I try to measure the width of the page that I am writing on, and I have just tried it, I get 219.0 mm. If I misread my rule and get 119 mm, or 218 mm that would be a *mistake*. However, even if I do not make such a mistake, my result is still inexact because of several factors, including for example the limit to the precision with which I can read my rule. Such inexactitudes are *errors* in the reading, not mistakes. If you press the wrong key on your calculator, that is a mistake, but in any case, it can only represent a number to probably eight or ten decimal places, so 3.141592654 is not exactly π, there is a small error (quite negligible for our purposes).

In this course you may uncover both mistakes and errors introduced in the written material. You may find some misprints. Usually they are recognizable. If it occurs in an SAQ solution, for example, that the intended result 2.1 m s^{-1} is printed as 3.1 m s^{-1} either because the Course Team produced the wrong solution, or a typographical mistake slipped through, we can only apologize. If you seriously doubt any of our answers please consult your tutor who should advise us in order to warn future students.

On the other hand there will certainly be errors! A scale drawing can never be perfect. A scale drawing is already in error to some degree when produced by the Course Team, and by the time it appears in print it may be detectably inaccurate. At the time of writing this I do not know whether this will cause any difficulties, but when comparing your graphical constructions with our solutions, do bear in mind that our printed solutions are not perfect. However, do not use that as an excuse for sloppy work.

13 Errors and mistakes – yours

You will be marked down, but only a little, for arithmetic mistakes in TMAs and the final examination. You can avoid many mistakes by checking your results dimensionally, as described in Unit 3, and also by considering whether the results are realistic values or not.

When marking, tutors will be mainly concerned with your grasp of the methods required. However, in real engineering the designer does not get credit for his method if the building falls down due to an arithmetic mistake.

Remember when giving numerical results to include the relevant SI units, if any. Thus, for example, a force might be 6.7 kN not simply 6.7, and an acceleration of 5.4 m s^{-2} should not be given as 5.4. The units are an essential component of the marking scheme.

You should also pay attention to accuracy in expressing the results of calculations, for example in deciding how many significant figures should be retained in an answer. In a practical engineering context, of course, the accuracy of a calculation is highly dependent on the accuracy of the input data, which will often have been obtained by test procedures. The accuracy to which an answer should be quoted also depends upon that needed for the application of the result. For example, if you wished to estimate the time required to travel a distance of 350 km by car on a motorway at a steady speed of 110 km h^{-1}, you would express the answer as 3 hrs 11 mins not 3 hrs 10.9091 mins.

In this course you will often be required to compare your numerical results with given values, in SAQs and CMAs for example. In these circumstances it is advisable to carry forward on your calculator full working accuracy as far as possible at all stages. If you do this then your results should agree closely with the given solutions or correct options. This also applies when the answer to one question is used in the solution of a following question. Options are generally given in the CMAs to 3 or 4 significant figures. This number of significant figures is given so that you can compare the results of your numerical calculations with ours (using the same input data), and does not necessarily mean that it makes sense from a practical engineering viewpoint to quote answers to this level of accuracy.

In some parts of the course you will be using graphical techniques. In these cases, of course, you cannot expect such good agreement, no matter how careful you are. In general try to draw any line in a diagram to ±0.5 mm and $\pm0.5°$. As a rough guide you may assume for these problems that your answer is correct if it is within $\pm5\%$ of a given value.

14 Notebook

Because this course is written in a way to try to make learning as successful as possible for you working alone as an individual, it is rather diffuse compared with a conventional textbook. This may make revision rather difficult, and it may sometimes be difficult for you to find the explanation of a certain topic. It is therefore highly advantageous to keep a notebook in which you should record selected information, especially procedures and formulae, including their conditions of applicability. The quantity of material is a matter of personal preference, but it is easy to overdo it and end up with such a thick file that it is worse than the original. I suggest that you aim for about two sides of A4 per Unit.

The exercise of making up such a notebook – actually selecting and writing it down – is of considerable value in itself.

15 How to pass MECH S235

- Read the Units
- Do all the SAQs
- Keep a notebook
- Take full advantage of Unit 16, especially the audio-visual material
- Work the Specimen Examination Paper thoroughly

16 SI units

As has been the practice in science and education in the United Kingdom and most other countries for many years now, in this course we express all physical quantities in terms of SI units, that is the Système International d'Unités. You are probably already familiar with many of these units and they are also discussed in Section 1.3 of Unit 3. A brief summary is given here for ready reference.

The system of units comprises base units and derived units. In this course we will be using three of the base units, namely metre, kilogram and second, as listed in Table 2.

All the other physical quantities that you will meet in this course are combinations of these base units. Some of these combinations are given names, such as watt for the unit of power, but others are not. The principal combinations which are used in this course are given in Table 3, with names, where appropriate.

To avoid writing and working with very large, or very small, numbers SI units are often expressed in powers of ten times the quantity in question. Recommended multiplying factors are powers of 10^3. The ones which are used in this course are listed in Table 4.

For example, a force of 2 000 000 N can also be written as 2×10^6 N or 2 MN, in words, two mega-newtons. It is not obligatory to use the names of these prefixes, but you may find them a useful shorthand.

Table 2 Base SI Units

SI symbol	*Name*	*Quantity*
m	metre	length
kg	kilogram	mass
s	second	time

Table 3 Derived quantities

Quantity	*Unit (name)*	*Symbol*	*Alternative combinations*
velocity	–	–	m s^{-1}
acceleration	–	–	m s^{-2}
angular velocity	–	–	rad s^{-1} (or s^{-1})
angular acceleration	–	–	rad s^{-2} (or s^{-2})
force	newton	N	kg m s^{-2}
plane angle	radian	rad	m/m
work, energy	joule	J	N m (or kg m^2 s^{-2})
power	watt	W	J s^{-1}
pressure, stress	pascal	Pa	N m^{-2}
frequency	hertz	Hz	s^{-1}
density	–	–	kg m^{-3}
moment (of force)	–	–	N m
momentum	–	–	kg m s^{-1}
impulse (of force)	–	–	N s

Table 4 Multiplying factors

SI symbol	*Prefix*	*Multiplying factor*
G	giga-	10^9
M	mega-	10^6
k	kilo-	10^3
m	milli-	10^{-3}
μ	micro-	10^{-6}

As I remarked earlier, SI units are now universally used in science and are increasingly common in engineering. They are also being rapidly adopted worldwide. Nevertheless you may still occasionally meet quantities expressed in Imperial units, or need to convert from a value in SI units to Imperial units. I will not list all the conversion factors here, but they can be developed, as far as this course is concerned, from two basic relationships.

These relate to the foot and the unit of mass, the pound mass, often written as lbm, as distinct from the pound force (lbf), the unit of force in Imperial units. The basic relationships are:

1 ft = 0.3048 m (or 1 m = 3.2808 ft)

1 lbm = 0.4536 kg (or 1 kg = 2.2046 lbm)

For example, to convert from m s^{-1} to m.p.h. (mile h^{-1}) we can deduce that:

$$1 \text{ m s}^{-1} = \frac{\text{m}}{\text{s}} = \frac{3.2808 \text{ ft}}{\text{s}} = 3.2808 \text{ ft s}^{-1}$$

But there are 5280 ft in one mile and 3600 s in one hour. Thus

$$1 \text{ m s}^{-1} = \frac{3.2808 \times 3600}{5280} = 2.2369 \text{ mile h}^{-1}$$

17 Useful data

Table 5 provides a listing of the Greek alphabet, with both lower-case and upper-case (capital) letters.

Tables 6 and 7 (over the page) give some physical data that you may find useful in your work.

Table 5 Letters of the Greek alphabet

Capital	*Lower-case*	*Name*
A	α	alpha
B	β	beta
Γ	γ	gamma
Δ	δ	delta
E	ε	epsilon
Z	ζ	zeta
H	η	eta
Θ	θ	theta
I	ι	iota
K	κ	kappa
Λ	λ	lamda
M	μ	mu
N	ν	nu
Ξ	ξ	xi
O	o	omicron
Π	π	pi
P	ρ	rho
Σ	σ	sigma
T	τ	tau
Y	υ	upsilon
Φ	ϕ	phi
X	χ	chi
Ψ	ψ	psi
Ω	ω	omega

18 Course Team

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Table 6 Useful physical data

Quantity	*Value*
Mass of Earth	5.98×10^{24} kg
Mass of Moon	73.5×10^{21} kg
Distance, Earth to Moon	380×10^{6} m
Radius (mean) of Earth	6.37×10^{6} m
Radius (mean) of Moon	1.74×10^{6} m
Density of air* (ρ_{air})	1.225 kg m^{-3}
Density of pure water† (ρ_w)	1000 kg m^{-3}
Density of sea water‡ (ρ_{sw})	1025 kg m^{-3}
G, gravitation constant	66.7×10^{-12} N m^2 kg^{-2}
g, weight per unit mass of body at the surface of the Earth	9.81 N kg^{-1} (= m s^{-2})

* at sea level, at 15°C
‡ typical value at 15°C
† at 15°C

Table 7 Typical coefficients of limiting friction

Material A *on*	*Material B*	μ
PTFE	Most things	0.04
Wood	Most things	0.4
Steel	PTFE polymer	0.04
Steel	White bearing metal	0.4
Steel	Brass	0.5
Steel	Steel	0.6
Normal car tyre	Tarmac (clean and dry)	0.9*
Racing car tyre	Tarmac (clean and dry)	1.5*
Normal car tyre	Ice	0.1
Any two greasy surfaces		0.1

* This is a typical value, but it can vary significantly with load.