Statics and Applied Strength of Materials

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Preface

Mechanics is a subject that can be studied at various levels of mathematical and analytical sophistication, as even a casual examination of available texts will quickly reveal. Some books on the subject require a working knowledge of arithmetic only; algebra is eliminated entirely by the provision of all possible variations of formulas. Often such texts do not draw upon previous mathematics or science courses the student may have taken; indeed, in some textbooks the latter chapters are actually independent of the earlier ones.

While such books assume no mathematical maturity and do little to develop it, at the other end of the spectrum there are texts employing partial differential equations and tensor analysis. These books are written with the expectation that students will take giant steps in understanding mathematical analyses. They present problems requiring great resourcefulness on the part of the student.

This book has been written on the assumption that the reader has a working knowledge of algebra and trigonometry and will mature mathematically as he or she goes along. Thus, steps will get bigger and the analysis more complicated as the text advances. In most cases the student will have had, or will be currently enrolled in, a first course in technical calculus. Accordingly, calculus is used very lightly in the statics portion—but enough so that instructors may emphasize, reinforce, and apply the principles of calculus, should they wish to do so. Hence, the early usage is light enough to serve as an introduction to calculus, or even to be ignored altogether if desired.

As we proceed to strength of materials, however, the use of calculus and the level of mathematical sophistication increase. Many of the derivations and a few problems are calculus-based. Yet the material is presented and the problems structured such that those who do not wish to emphasize calculus can satisfactorily use this book. (This of course precludes those solutions which are calculus-based, such as finding beam deflections by successive integration.)

Engineering technology has been described as applied engineering. A book written for engineering technology must emphasize the potential applications and practical importance of the material, but it should also—and fundamentally—emphasize an understanding of the material. Students should know when an equation applies and when it does not, what its limitations are, and what is going on physically. Forces need to be intuitively understood as well as calculated. Stress patterns should be visualized, and their equivalence to the forces producing them should be appreciated. Throughout the book, therefore, I have emphasized application *and* understanding, and have avoided rote substitution of unfamiliar variables into even less familiar formulas.

I have tried to write a book that will be read, bearing in mind that students tend to read books that are either sexy, violent, funny, or helpful. Lacking the talent or experience for the first two, I have concentrated on the last two. If, as you read, you occasionally smile, I will be pleased. In attempting to be helpful, I've included a large number of example problems. In most cases enough detail is presented to allow the reader to understand the material without the assistance of the instructor. I have tried to be sensitive to those concepts we expect students to know but find that many have difficulty with. To convey the idea that I'm on the student's side, I have used a conversational tone. (This is not a style I recommend for technical papers, however!)

The order of the material is traditional. Topics and entire chapters may be omitted without loss of continuity for shorter courses or those with a different emphasis. In such cases the instructor must be selective in assigning problems. The amount of material exceeds that normally covered in a two-semester sequence. A solutions manual is available that includes suggested topics for courses of various lengths.

Because understanding of the material is a primary objective of this book, most equations are presented with some argument justifying their existence. Sometimes these arguments are intuitive; sometimes they are mathematical; sometimes they are both. I firmly believe that a student who understands where an equation comes from is far less likely to misuse it. I also believe that many technology students are put off by derivations regardless of their utility or mathematical elegance. These students are convinced by example—and since all students are helped by example, in this book examples abound. They are followed by a large number of student problems; answers to two-thirds of them (excluding those divisible by three) are in the appendix.

A unique feature of this book is the use of unit vector notation. This is presented in an optional fashion. Some students who use this text will study mechanics further; others will work in environments where they will encounter this notation. It is therefore presented here in friendly territory for their benefit. No use is made of vector algebra (dot or cross product) or vector calculus.

The strength of materials portion of this text is based on the author's *Applied Strength of Materials*. Reviewers for that text were: Donald E. Breyer, California State Polytechnic University, Pomona; T. M. Brittain, University of Akron; Stanley M. Brodsky, New York City Technical College; Donald S. Bunk, Dutchess Community College; Eugene F. Kruetzer, Illinois Valley Community College; Dan M. Parker, Southern Technical Institute; John O. Pautz, Middlesex County College; Richard S. Rossignol, Central Virginia Community College. The statics portion of this text was reviewed by Stanley M. Brodsky, New York City Technical College; Karl S. Webster, University of Maine at Orono; James Ehrenberg, California Polytechnic State University; Donald Buchwald, Kansas Technical Institute; John Jackson, Vermont Technical College; and Donald E. Keyt, Spring Garden College. My colleagues at Oklahoma State University, Jack Bayles, John Scheihing,

and Larry Simmons, used the material at various stages of development and made many helpful suggestions.

My editor at John Wiley, Susan Weiss, has been a gentle taskmaster and friend. Fran Maurizzi typed the portion on strength of materials, and my children, Raymond and Paige, typed the statics portion. My friend Charles Kroell of General Motors picked more nits than I care to mention, but niggling was needed. To all I offer my thanks.

Raymond F. Neathery

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Introduction

As you begin this study, you begin an adventure that can reward you throughout your technical career. For some of you this constitutes a "related" course, one that you are required to take, perhaps without really understanding why. Maybe you've heard it's difficult and are apprehensive. It is true that many find it so, for various reasons. It is also true that if this is a "related" course, your professional life will not be heavily dependent on it. You are not likely to routinely work problems of the type found in this text. Nonetheless the course can be a rewarding lifelong adventure in two aspects. First, the problem-solving approach presented, reviewed, assigned, summarized, exercised, tested, and—if possible—pounded into your head, has value on its own. Successful completion of the course should result in the ability to reliably quantify and analyze. These skills are extremely valuable to anyone working in the engineering field. Second, virtually all areas of modern technology—electronics, fluidics, microcomputers, fiber optics, aerospace, astronautics, robotics, communications, and so on—have mechanical handles. We interact with this technology mechanically. A thorough understanding of mechanics will allow us to manage the interface.

For others this study will be not only a rewarding adventure, it will be an essential journey. For those who will design, manufacture, or construct our automobiles, bridges, airplanes, homes, refrigerators (the list goes on and on), or their components, this subject is a basic science. These people *must* understand mechanics, and in their professional lives, many will routinely solve problems based on this subject.

1.1 MECHANICS (WITHOUT A TOOLBOX)

As a freshman in college I visited an elderly woman who had watched me grow from infancy. She was extremely pleased to learn I was in college and asked what I was studying. I puffed up and beamed as I told her I was going to be an engineer! I was certain that I faintly heard a minor drumroll and a trumpet fanfare as I proudly proclaimed my proposed profession. The music was halted abruptly as she responded, "Aw, Raymond, you don't want to drive no train!" She was right, of course: I never have driven one. Given her response to "engineer," I am glad I did not know at the time that I would ultimately study "mechanics"!

Just to clear the air early, our study of mechanics will have nothing to do with the repair of automobiles. With all due respect to "Mr. Goodwrench," our tools will not be screwdrivers, ball peen hammers, socket wrenches, or ignition analyzers. We will have tools of an entirely different sort, and we hope to add to our toolbox as we go. The "basic beginner's set" includes an understanding of and computational ability in algebra and trigonometry, the ability to read carefully and to translate words into physical situations, the ability to interpret drawings, the ability to follow directions, and the ability to reason logically. As the course progresses, we will improve our skills with these tools and add to them as well.

Well, if a course in mechanics is not about dropping the transmission in the old Chevy, what is it about? Mechanics is the study of forces and the effect they have on objects. It includes the transmission of forces, how they are carried internally, and the motion they produce. In this course, statics, we are concerned primarily with forces on bodies at rest. Unless you are reading on the bus, the seat you are sitting on is not moving; it is at rest. From the principles of statics we can determine the force you exert on a chair and the forces the chair exerts in turn on the floor. The floor reacts with opposite forces on the chair as shown in Fig. 1.1. We

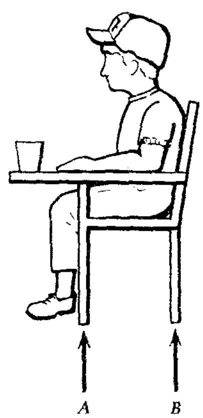

FIG. 1.1 The floor exerts forces on the chair.

can further find the *internal* forces in the legs of the chair. From mechanics of materials (or strength of materials, as it is commonly called) we can determine how this load is carried and the deflection it produces. In the study of dynamics we are concerned with bodies in motion. We study the description of the motion as well as the forces causing it. We can also study the mechanics of fluids—statically and dynamically. That is done in courses in fluid mechanics or hydraulics.

1.2 GETTING THERE IS HALF THE FUN: AN APPROACH TO PROBLEMS

A major benefit of a course in mechanics is the development of good work habits in the solution of analytical problems. We emphasize that now and throughout the text. You should begin now to emphasize it and continue throughout the course because, if for no other reason, many instructors will begin to emphasize it now—in their grading. We illustrate what we mean by the following problem.

Example Problem 1.1

A ballast is to be cut from steel bar stock that is 2 in. wide and $\frac{3}{4}$ in. thick. The ballast should weigh 12 lb. How long does the ballast need to be?

The solution to this problem is given in Fig. 1.2. Follow along in the figure as we go through the solution. The first thing to notice is the paper itself. Using a grid paper keeps the work neat and orderly. It also helps in making sketches, which are very important in solving mechanics problems. Use sketches generously, copiously, even redundantly! The "engineer's pad," which lets the grid printed on its back side show through faintly, has become very common and popular. I recommend it.

The first step in solving the ballast problem is to read it carefully. Some students write the question out in longhand to force themselves to examine the problem thoroughly. You should try this on a few problems and see if it helps you, but I'll not emphasize it. Instead I'll read through the problem in detail and list the essential data. This is shown as step 1 in Fig. 1.2. (Of course, it's not necessary to write "step 1," etc., in your solution.) Step 1 is to find what is "given." As we reread the problem we note that the material is steel and record that under "Given." Next we note that the cross-sectional area is 2 in. by $\frac{3}{4}$ in. We record this, and the desired 12-lb weight. We note the length is to be found and record this dimension under "Find." We also give length the symbol L so that we may manipulate it algebraically. The "Find" statement is labeled step 2. In step 3 we make a sketch of the problem. We label and assign values to the elements of the sketch. The sketch will help us to take all the given information into account, get a physical grasp of the problem, and suggest a method of solution. We have indicated these three steps as being sequential, but more often than not they are interactive. In any case, all three should be completed before proceeding.

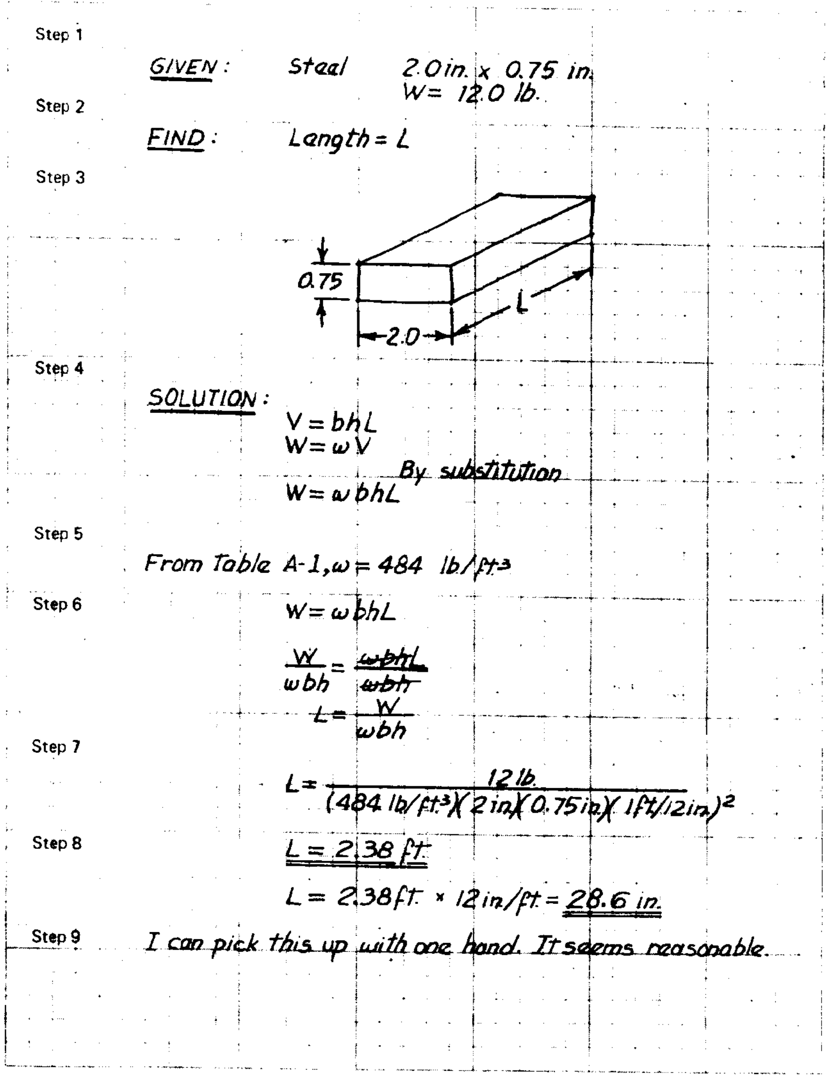

FIG. 1.2 Solution format.

Step 4 begins our solution. We recognize the volume to be

$$V = bhL$$

where b = width
h = height
L = length

and the weight is

$$W = wV$$

where w is the weight per unit volume (commonly but inaccurately called density). We record these in step 4 and recognize that neither L nor w is known. The material property w is not given in the problem, but such data are commonly available in tables such as Table A-1 in the Appendix. From this table we have $w = 484\ \text{lb/ft}^3$. In step 5 we cite the source of this value.

It is important to document references. This leaves us with the single unknown, L, which we seek. Solve algebraically for L *before* substituting in any values. This approach has all sorts of advantages over plugging in numbers and starting to do arithmetic—most importantly, it is less work and less vulnerable to error. As a rule, one should not pass up propositions that are less work and produce better results! Thus, in step 6 we solve for L. This solution is general. We can readily exercise it for different values of W, b, h, or w. We can even program the solution on our computer.

Now we solve our specific problem by substituting in the values we have (step 7). It is a good practice to write the units that go with numbers as we substitute them into the equation. Performing the algebra on the units will give us the units for the answer. We note that we have length in both inches and feet and make the appropriate conversion. Finally, at step 8 we write the result to an appropriate number of significant figures and with proper units. If desired we may convert the answer to other units. We mark the answer clearly so that it may be readily identified later.

Step 9 is often overlooked, even though it may be the most important of all. For this step we move back and look at the whole solution to see if it is logical, reasonable, and valid. Then we look at the answer itself. Here we want to test the answer against our intuition. Sometimes our intuition will indicate that there is an error in the solution; in some cases the solution will correct our intuition, and in other cases it is a standoff—we don't learn anything either way. As the great Dizzy Dean used to say regarding baseball, "You win some, you lose some, and some are rained out!" But this is no rainout. We can imagine picking up this bar with one hand, and we know we can pick up 12 lb. So we conclude that based on our intuition, it's satisfactory, although frankly, it's a little longer than I expected.

Figure 1.3 shows step 6 through the end of the solution in bad form. In addition to a wrong answer (although the arithmetic is correct), what other bad practices can you identify?

Many students believe that if they turn in neat and orderly work, they will receive a good grade and impress the instructor with their neatness and orderliness. As a result, students who solve problems in the most unorganized manner, actually doing the work on discarded computer paper, newsprint, paper bags, stationary pilfered from the office, fish wrappers, and who knows what else, often recopy it in the neatest possible format. Lettering approaches Leroy quality and multicolor presentations are not unknown. This totally misses the point! The process just explained is for the student's benefit, not the instructor's. This process will help