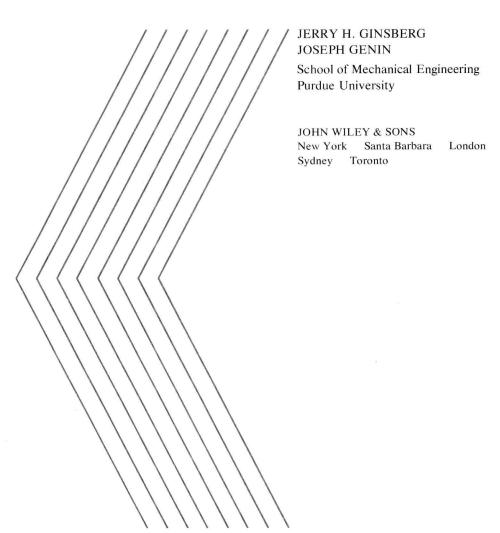
STATICS

JERRY H. GINSBERG JOSEPH GENIN

DYNAMICS



DYNAMICS: COMBINED VERSION

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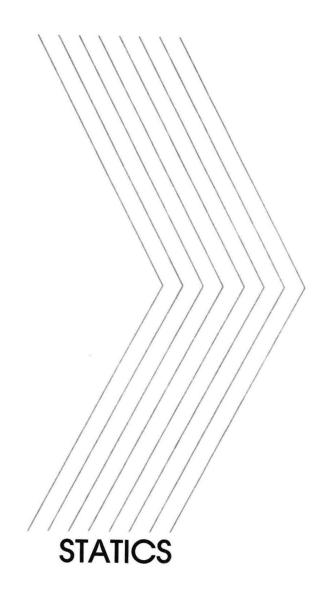
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PREFACE

There are two fundamental goals to be attained in the basic engineering mechanics courses of statics and dynamics. The first is to develop an understanding of the physical laws governing the response of engineering systems to forces. The second is to enhance the reasoning powers required in engineering; that is, to develop the ability to solve problems logically, using the concept of mathematical models for physical systems.

To meet these objectives this book is written in modular form. The modules are broader in extent than the conventional grouping by chapters, being largely self-contained in order to minimize the amount of cross-referencing necessary to develop the material. This organization was also chosen because it is our desire to let the book communicate directly to the student, with a minimum of amplification and clarification required of the instructor.

To achieve this goal it was necessary to develop a consistent approach to problem solving that could be applied for a broad class of problems. This approach is founded on the recognition that there are two distinct aspects to the learning experience in mechanics. Clearly, one must first develop an understanding of the fundamental principles. Only then can a group of these principles be applied selectively to the solution of a broad class of problems.

In this book the comprehension phase is addressed in a conventional manner. After each principle or technique is derived, it is keynoted by remarks regarding common systems that illustrate its implications, as well as critical comments regarding its applicability. This is then followed by one or more solved examples. The examples directly illustrate how to employ the derived principle, and, equally important, serve to enhance the understanding of the physical meaning of the derived principles and of the system responses that result from these principles.

A primary goal in several of the modules is the synthesis of the basic principles and procedures into a unified approach for solving problems. Toward this end, at key locations in the modules, a set of sequential steps detailing the multiple operations necessary for the solution of general problems is presented. These steps are merely a logical sequence to follow. (They are certainly not the only possible sequence.) With these steps, where appropriate, we indicate places where common errors are made.

By presenting a systematized approach to problem solving we hope to enhance the student's senses of logic and deductive reasoning. Thus, the steps are not intended for memorization. Instead, as a student gains proficiency in problem solving, the steps will be performed intuitively.

The steps are then employed in a series of three or more solved problems, called illustrative problems, whose solution requires the synthesis of the concepts previously developed. The illustrative problems are cross-referenced directly to the steps for problem solving. This allows the student to isolate a particular aspect of the solution that may prove troublesome. Numerous homework problems are presented after both examples and illustrative problems; in general, those following the latter are broader in scope.

The sole difference between the approach outlined above and the approach for the applications modules is that steps for solving problems are not presented in the latter. Emphasis in the discussions and solutions of examples in the applications modules is placed on the development of a logical approach using the basic methodology, and each group of solved examples is followed by a broad range of homework problems.

The development of physical understanding in mechanics is addressed in the solved problems, as well as in the formal text material. Where appropriate in these problems, care is taken to discuss the qualitative aspects of the solutions. Also, the mathematics presented does not overwhelm the physical aspects of the problem, for each solution is implemented with the aid on only that level of mathematics appropriate to solve the problem at hand. Hopefully, this overall philosophy will give the student better insight as to how an engineer thinks.

Note from the Contents that the conventional ordering of the subject matter has been retained. Nevertheless, the viewpoint and treatment of many of the topics are not contained in other texts. In particular, the systematized treatments of virtual work and energy methods, and of the kinematics and kinetics of rigid bodies in three-dimensional motion, are entirely new. Our methodology makes these topics accessible to students with a broad range of backgrounds.

Another feature of the book, beyond the systematization it provides, is the flexibility it affords the instructor. It was written to provide the greatest opportunity for adjustments and accommodations in instruction, in order to communicate clearly with students having a broad range of individual experience. The text is equally suitable for courses using innovative instructional approaches, such as self-paced and self-taught classes, as well as for those using the more conventional methods.

Note also that this book does not attempt to address the organizational problems involved in self-paced and self-taught courses. However, it is possible for instructors wishing to utilize such an approach to employ the book as a framework that is to be supplemented by material addressing the problem of the interaction between the student and the instructor. The self-contained aspect of the modules makes the text especialy valuable for such courses.

A final technical matter for consideration here is the question of physical units. We strongly believe that the SI system of metric units is the best for engineering. Hopefully, by the time this is read, the SI system will have been adopted universally. However, recognizing the transitory nature of this problem, and noting the large number of physical systems

which have already been built according to the U.S.-British system of units, the numerical problems have been divided approximately into a two to one proportion between SI and British units. This proportion allows for a sufficient number of problems for courses using only one system of units.

We gratefully acknowledge the encouragement of our colleagues at Purdue University, whose helpful comments proved invaluable. We also thank the faculty of the École Nationale Supérieure d'Électricité et de Mécanique at Nancy, France, particularly Professor Michel Lucius. By providing an academic environment for Professor Ginsberg during his sabbatical leave, they greatly expedited the completion of this work. We are indebted to Rona Ginsberg for her excellent editorial comments, as well as for typing the manuscript, and to Dr. Joseph W. Klahs for his technical review of the *Dynamics* manuscript. Finally, we note the knowledgeable assistance of the staff of John Wiley, especially our editor. Thurman R. Poston, in all phases of the production process.

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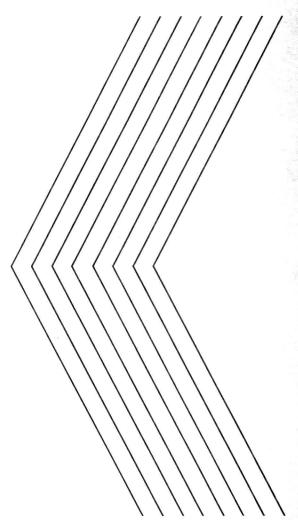
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MODULE I FUNDAMENTAL CONCEPTS

A. MECHANICS

Many times when touching an object we wonder how it has been affected physically. Thoughts of this kind are basic to the field of *mechanics*, where the general concern is the study of the effect of *forces* acting on a body.

To a certain extent the concept of a force is intuitive, because forces are not actual objects. In spite of this, *force* does have a basis in our fundamental sensing system, especially in the sense of touch. For instance, the sensations our brain processes when our fingertips contact another body are a measure of how hard and in which direction we push or pull on the object. In mechanics this is referred to as the external force exerted on the object.

The study of mechanics is divided into two broad categories, *statics* and *dynamics*. *Statics* is the study of physical systems that remain at rest under the action of a set of forces. *Dynamics* is the study of physical systems in motion. This text is devoted to the study of *statics*.

A key phrase used above is "physical system." By it we mean a collection of basic atomic elements that combine to form bodies. In the field of mechanics, for the convenience of problem solving, we tend to categorize these collections of elements into three broad groupings: particles, rigid bodies, and deformable bodies.

PARTICLE A body whose dimensions are negligible is said to be a particle. It follows, then, that a particle occupies only a single point in space.

RIGID BODY A body occupying more than one point in space is said to be rigid if all of the constituent elements of matter within the body are always at fixed distances from each other.

DEFORMABLE BODY A body is said to be deformable if its constituent elements of matter experience changes in their distances from each other that are significant to the problem being investigated.

Clearly there is a certain amount of ambiguity in these definitions. For instance, is the group of molecules that compose a gas a system of particles or is it a deformable body? Another basic question we could ask is whether any body can correctly be considered to be rigid; for all real materials deform when forces are exerted upon them.

There are no absolute answers to these questions, for the *model* of the system we form depends on what knowledge we wish to gain about the response of the system. This leads to the next topic, which is the modeling process.

B. THE MODELING PROCESS

The general approach in the static analysis of a physical system is to consider first the nature of the forces acting on the system and the type of

information we seek from the subsequent analysis. On the basis of those considerations we construct a conceptual model of the system. That is, we consciously consider its components to be either particles, rigid bodies, or deformable bodies. Then, by applying the laws of mechanics we determine the interrelationships among the forces acting on the system. An analysis of these forces should provide us with the information we desire. This general approach to the subject of statics can be summarized in the conceptual diagram shown in Figure 1.

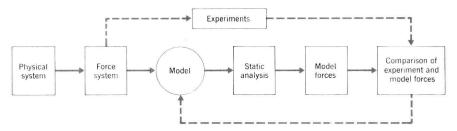


Figure 1

The dashed paths in Figure 1 illustrate a key feature of the modeling process. That is, to be sure of the validity of the model initially chosen to represent the physical system, it is necessary that the model display any relevant phenomena that are experimentally observed. If not, the model must be improved. Hence, modeling is an educated trial-and-error procedure. That is, the modeling process is, in part, an art based on prior experience and physical intuition. On the other hand, the modeling process is also a science based on a knowledge of the function that the system is designed to perform, and of the analytical methods available for studying the phenomena exhibited by the system.

As an example, consider an object in the shape of a sphere. If this sphere is a small ball bearing resting on a flat level surface, as a first attempt one would tend to model it as a particle occupying a single point in space. We shall see in later modules that this model would result in a successful analysis.

Suppose that we now step on this ball bearing, placing the ball bearing at the edge of the sole of our shoe. Our later studies will show that considering the ball bearing as a particle leaves us unable to explain why it tends to slide out from under foot when we press on it harder and harder. In this case the nature of the forces acting on the ball bearing changes drastically from the case where it was merely resting on the ground. Modeling the ball bearing as a rigid body, as opposed to a single particle, would allow us to resolve this problem.

Continuing with this example, suppose that instead of stepping on a steel ball bearing, we were stepping on a tennis ball. Needless to say, the shape of the ball would be altered considerably as we stepped on it.