Dynamics for Engineering Practice

Second Edition

Louis J. Everett
University of Texas at El Paso

Alan A. Barhorst
Texas Tech University

m^3P Engineering Publications
Lubbock, Texas

To Our families

The first edition of this book was published by McGraw-Hill Custom Publishing, 2004.
ISBN 0-07-301547-4.

This book was typeset using the LaTeX typesetting environment. The authors appreciate the efforts of the TeX User Group (TUG) community.
Cover design Alan A. Barhorst.
Layout design Louis J. Everett.
Line artwork by Louis J. Everett, Alan A. Barhorst, and various student helpers.
Printed by Action Printing & Communications, 2407 82nd Street, Lubbock, Texas 79423.

m^3P Engineering Publications
A Division of m^3P Engineering
6715 3rd Street, Lubbock, Texas 79416

Dynamics for Engineering Practice, Second Edition

ISBN 978-0-9832672-0-1

World Wide Web
http://www.m3pengineering.com

Supplements to the textbook can be found at http://www.m3pengineering.com.

Disclaimer
Although great care has been taken in the preparation of this textbook, neither the authors nor the publisher, nor anyone else associated with this publication, shall be held liable for any loss, damage, or liability directly or indirectly caused or alleged to be caused by this book. The material within this textbook and any associated supplemental material is not intended to provide specific advice or recommendations for any specific scenario.

Preface for Instructor

As instructors we do not expect the students to read the entire book. The book is designed to be used by students with various learning styles. We expect this textbook to be easy to teach with. It is divided into lessons. Each lesson is expected to be a typical one hour class period. A few lessons will need more than one hour. We have provided many more lessons than needed for a typical semester long course. This allows the instructor to pick and choose the more advanced topics. It also allows the book to be used by instructors in a quarter system, over a period of two quarters.

Each lesson comes complete with examples and homework problems which can be assigned. In the lessons, we provide theory sections when applicable; these sections are used to formally derive the concepts being introduced. We also usually provide an application section. Where possible, the application section reduces the theory to a procedure. New concepts are derived or defined, procedure is stated, and examples demonstrate its use. The lessons are written so that either the theory or application sections could be read exclusively. Not all lessons have theory sections. This is especially true when the new material is mostly definitions.

The book provides technical contributions. It introduces kinematics and kinetics as differential equations. The book integrates mathematics and physics reviews into the new engineering material. The student can easily skip over review material if they choose by using reader guides (in the form of margin notes). This allows the student to realize the importance of science and math concepts yet not distract them too much from the presentation of new material.

The book also makes educational contributions. It is structured for active or passive learning/instruction. The instructor can teach with a number of methods: (1) lecture over theoretical issues contained in the lesson, (2) discuss the procedures described in the application section, (3) solve example problems or (4) use an active coaching mode. The instructor has clearly defined lesson objectives, a lesson summary, and group discussion items. The lesson objectives clearly express what the student is expected to learn and what skills they should have when the lesson is over. This allows the student to extract the important information from the unimportant information while reading the material before class. The summaries capsulize the material covered in a few paragraphs making review easier. The discussion items are liberally and relatively uniformly distributed throughout the text. If desired, the lecture time can be broken up with the discussion items highlighted as "Group Work".

The text material is intended to motivate the study of Dynamics by presenting material in a just-in-time format, as much as can be implemented. We also try to add a flavor of professional consultation that the modern engineer is very likely to enjoy in their career. We also try to add a little humor. Of course humor is relative, and we hope we can engage both the student and instructor. The student begins solving "real" dynamic problems nearly immediately. Complexity is added as the material progresses. Throughout the text, a recurring system is analyzed. This helps demonstrate the usefulness of the various techniques introduced, it also adds an element of design that underlies the entire text. We try to avoid naming every nuance of Newton's law(s). This is in an attempt to get the student to realize that there is only a few things that need be remembered in solving dynamics problems, the rest can be easily derived. We stress a procedure for utilizing dynamics as a tool, not "have I seen an example like this before" situations.

Since we treat dynamics as differential equations of motion, the resulting equations are much more difficult to solve. This complexity is dealt with by using computer technology. We use a computer algebra package and spreadsheets. If the instructor does not plan to use technology, the details of how solutions are found can be skipped. Since each example is solved in a uniform manner, it is easy to predetermine where technology will be found in each example; this way it can be easily skip if desired. Whenever we make an important point during the solution phase or derivation/definition, the material is highlighted using marginal notes. In this way, the reader can skip the areas of non-interest or skip to areas of interest.

Preface for Student

About Dynamics

Based on the reader's studies thus far, it has probably been deduced that Engineering is a quantitative discipline. Engineers utilize known, or at least well understood and experimentally verified, laws or descriptions to establish a predictive ability relative to a system or process of interest. This interest derives from many factors, not the least being the fact that one has to make a living. It is not enough to have a visceral feeling about how a system will respond. To design a reliable and efficient device, one has to know to a large extent the nature of the system's response. The response can be determined by building a prototype and seeing if it works, then if it does not work in a satisfactory fashion, modifications can be made and the process repeated. As one can see this can become a high cost and time consuming approach to design.

Another approach is to narrow the field for which the design can exist. This is accomplished by performing mathematical analysis on the system (the subject of this book, relative to mechanical dynamics). It must be understood that the analysis is not a catch-all but it will give the engineer better educated guesses as to what has to be modified or tested so the device will perform satisfactorily. Just imagine how well any of the NASA spacecraft and missions would have succeeded if the engineers did not have a firm grasp of the nature of dynamics. It is safe to say we would have never left the ground.

An example that everyone with some physics background probably marveled at is the job that the Jet Propulsion Lab (JPL) did in re-steering, or for that matter, planning, the trajectories of the Voyager planetary probes. From distances of hundreds of millions of miles, the JPL engineers and scientists, with the aid of Newton's laws, possibly fine tuned a bit for gravitational effects, were able to re-program the flight plan so more planets could be visited. Getting a prototype scenario to do this in one's lifetime is unrealistic.

From a less glamorous point of view, consider the pumps that are used to inject the fuel into the Space Shuttle's main engines. These motors consume fuel like a football team consumes rib-eye. Therefore, the pumps must be able to function at very high speeds. To reduce the costs of building a pump such as this, or in reality to know how to begin to design a pump such as this, dynamics must be well understood.

With this motivation in mind, it can be stated that dynamics is just another tool in a well educated engineer's tool bag. It is the intent of the authors to instill in the student a genuine affection for the subject that will make the daily toil for one's bread, or grade in the immediate case, a truly enjoyable adventure. Dynamics is exciting because things move and sometimes what is expected initially is not what happens.

About This Book

The classical approach to teaching undergraduate engineering dynamics is to break the subject into several compartments. Usually, kinematics and kinetics of particles, kinematics and kinetics of systems of particles, and kinematics and kinetics of rigid bodies. This compartmentalization often leaves a student unprepared to perform real analysis because the real world is not compartmentalized. No one will tell practicing Engineers whether or not they should apply rigid body analysis or kinematics alone in a real situation. In this text the authors attempt to address compartmentalization by providing a general procedure for attacking problems. By using the procedure for simple and complex problems we will no longer need to "classify" the problem before starting its analysis. The main drawback to this is that it will take longer to solve problems. Rather than relating new problems back to "one just like it," the student is expected to attack it fresh. The authors feel that this methodology will provide a more lasting and beneficial tool called Dynamics.

Where possible, lessons contain a theoretical and an application section. In these sections we have provided a different approach to the material. The lesson's new material is covered in both sections so both need not be read, individually choose the section that makes most sense. Please discuss with the class instructor which section is recommended. Some lessons do not have a theory section. This is especially true when the new material is mostly definitions. In very few lessons the application section is missing.

Each lesson also provides a list of objectives. This list is intended to be a self check and should help the reader discern the lesson's most important points. The lesson also provides a summary which covers the pertinent information in a few paragraphs.

On many occasions the mathematical problem derived in the text is solved. This solution process is mostly a matter of mathematics and is most likely covered in detail in mathematics classes. Since many students tend to gloss over the routine mathematical solutions, marginal notes highlight important points within the text. Be sure to look for them.

This is a marginal note.

Since true understanding often comes from discussions with the class instructor and peers, we have placed discussion questions in the text. The questions are highlighted via marginal notes labeled "Group Work." If the opportunity for discussion does not arise, please ask the instructor and classmates their response to some of the questions listed. This interaction will help round out general understanding of dynamic principles.

In summary, each lesson begins with motivational material which attempts to explain why the reader's current knowledge is incomplete and hence the upcoming lesson is needed. Following the motivation we list objectives, things that are expected to be learned in the lesson. Next the material is presented along with many examples. Homework problems follow which test gained knowledge. Finally, a summary is used to capsulize the contents of each lesson.

One more point, we have tried to make the book enjoyable to read, even for the less "gung ho" of our readers, by adding what we think is humor. If this same opinion is not held by the reader, please keep it to yourself!!

How to Read This Book

There are two basic types of knowledge described in this textbook, conceptual knowledge and procedural knowledge. Conceptual knowledge includes definitions and derivations. For example, position, velocity, and acceleration are concepts. Procedural knowledge are rules of thumb, good habits, and memorization tricks that are useful in solving problems. We encourage the reader to try to identify the different types of knowledge.

Conceptual knowledge will always be introduced and discussed formally outside of example problems. Procedural knowledge (the authors think) is best learned inside examples. As a result, the reader will find most examples written in great detail. One problem with this strategy is that readers often "gloss over" the examples. To make sure the reader does not miss any important procedural information, we will use marginal notes to remind the reader to read the text!

What are marginal notes used for?

The authors recommend each student keep a loose leaf notebook divided into six sections. The six divisions correspond to the six steps in the general solution procedure used in the text. Whenever a marginal note is encountered in an example, read the context around the note and record an entry in the appropriate section of the notebook. The authors also recommend each record include the page number of the source marginal note.