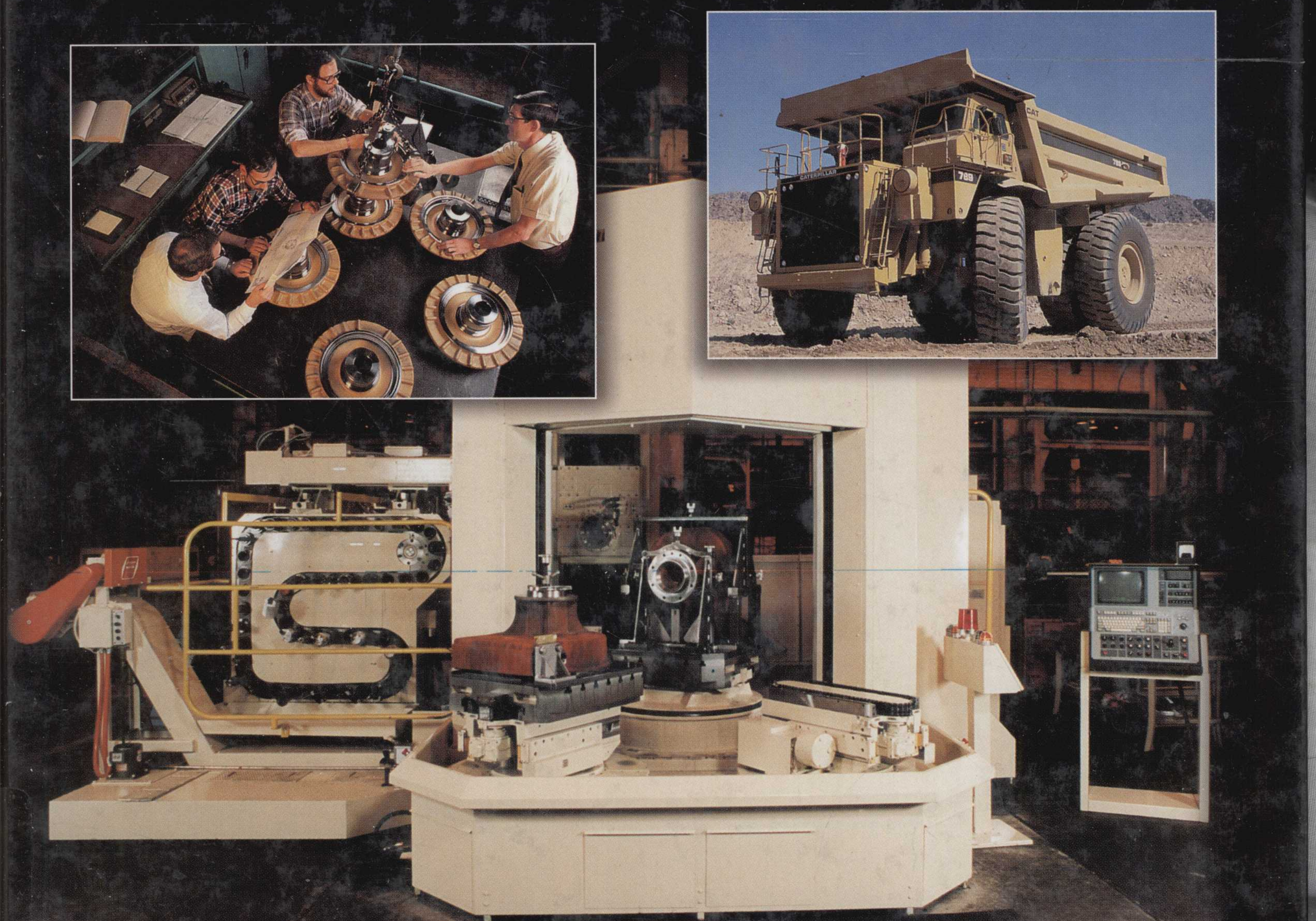
MACHINE DESIGN

FOR MOBILE AND INDUSTRIAL APPLICATIONS



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Machine Design for Mobile and Industrial Applications

by
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PREFACE

This book is intended for engineers and engineering students whose goal is designing machines. It provides the designers of mobile and industrial machines methods for selecting and designing machine components. It is a practical and useful text which is concerned with the actual application of machine design, not just the theory.

When one of us teaches design, he tells the students that good designers need to "know everything." Expert designers are true Renaissance men, with a wide and deep body of knowledge. This book attempts to provide a basis from which an engineer can build competence and continue his or her education. Obviously, only a portion of the accumulated knowledge of machine design can be included in any one book. It is primarily the differences in content which distinguish machine design books from each other. We have selected the material that we feel is most important for this book. Each of the authors has practiced engineering for both large multinational manufacturers and for smaller firms. The material was selected based on those experiences and what we think is important for the machine designer to know in the near future.

We have significant University faculty experience teaching engineering design and have been honored with local and national teaching awards. The pedagogic approaches in this book are based on what we feel are the best ways to systematically develop knowledge in the content areas. Since engineers often learn well from examples, many examples of design problems are included. Because U.S. engineers unfortunately still have to deal with both customary and metric units, we have used both systems.

Each design situation is different. A designer should not blindly apply the material from this book. Rather, the designer should seek the guidance and advice of an experienced engineer in the particular subfield to determine what are the appropriate assumptions, guidelines, design procedures, and uses for the various components. This is especially important when operation or failure can pose a danger to humans or property. This book is a compendium of material based on widely varying design experiences. A particular methodology may or may not be applicable to every specific design situation.

There have been many contributors to this book, unfortunately too many to properly credit. But special recognition should be given to Drs. Larry Gaultney, Lester Thompson, and Michael Mailander for their substantial contributions to the material on linkages, hydraulics, and strain range, respectively. Specific credit should go to our families, colleagues, secretaries, and students who endured with us while we were writing this text.

Gary W. Krutz
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TABLE OF CONTENTS

CHAPTER ONE

PHILOSOPHY OF DESIGN

The purpose of this book is to help you improve your design capabilities. One quality that makes a good designer is the willingness to develop a personal philosophy of design. The philosophy of design includes organizing the methodology needed to proceed from concept to final product, determining which technological resources (such as mathematical relationships) to use, and considering economics, timeliness, reliability, and safety during the design process. In developing a design philosophy, design engineers should add to skills already learned and those included in this book to create products that benefit humanity and improve the quality of life now and for future generations.

Design is a highly innovative, cross-disciplinary process that uses the most acceptable, aesthetic, efficient, and economical means to satisfy people's needs. A good designer has a wide background of technical knowledge. As technology changes, methods and philosophy of design change. For example, the advent of computer design techniques has enabled designers to quickly design more efficient and lower-cost components.

For engineering students or engineers seeking to improve themselves, the art of design requires gradual progression from the level of intellectual development that considers answers either right or wrong to a higher level of creativity. There is more to design than simply plugging facts into equations. Actual design is often a culture shock to new engineers. Designers must develop their own methodology or philosophy of defining the problem, making assumptions, gathering data, and devising some new structure, machine or system. Only after reaching the peak of intellectual development can a person successfully design products. The designer needs to first look at all possible solutions, then choose a course, stick with it, and continually modify and improve it until all conditions are satisfied.

1.1 Formulating a Procedure

Design requires that a configuration be devised and created to perform a function. At the same time, the configuration should be evaluated for adequate strength and minimum cost. Often this evaluation cannot be done until the machine is built and loads measured, but it is better to make assumptions and calculate major loads than to proceed without approximate calculations.

Experience can, to some extent, be substituted for calculations as is evidenced by the success of tinkerers and mechanics in building usable machines. Usually, however, their designs can be further improved by an engineer's ability to evaluate. Engineers do not have a monopoly on inventiveness and ingenuity required of a good designer. In fact, formal engineering training might inhibit these qualities because a young engineer might not want to proceed until he or she has all the information, whereas an educated mechanic would proceed by trial and error, and based on substantial experience.

This chapter is intended to formulate a basic process for designing machines and equipment. The effective and efficient design engineer needs to have the capability to use analytical, empirical, and creative methods. Besides the analytical methods which are ably taught in most engineering colleges, the engineer needs to take advantage of the experiences of peers, and utilize personal contacts and the embedding of experiential knowledge in codes, standards, handbooks, and catalogs. Many design problems are so complex that they are best solved by building upon the work of others rather than attempting to solve the problem from first principles. This book supports the practical use of such methods when choosing bearings, V-belts, and other standard components.

The teaching and learning of creativity in the design process is still an object of controversy. Some engineers and engineering educators feel that instruction in breaking mental barriers and brainstorming can be useful. Some have developed formulations of the design process. However, William Orthwein's view should be considered:

> No attempts will be made at pontificating on the design process. It has been the author's experience that the appropriate design process depends upon the type of product being produced, the number of units to be produced, the user's expected demands upon the item of equipment, its intended life, and so on. The key ingredient for a successful design in any situation is always an intelligent, well-educated design engineer who can also write and talk clearly.[1]

This book will contribute to that education so that you can develop and follow a good design philosophy. It will help you construct a sound base of knowledge upon which you can intelligently build using other sources.

1.2 Three Types of Design

Design engineers work on a wide range of designs from the seemingly simple (though the continuing imperative to improve reliability and function while reducing manufacturing cost makes no design easy) to the very complex. The continuum of designs can also be roughly categorized on the basis of originality:

1. *Transitional Design*: A sound, basic design is incrementally improved by using detailed refinements, often through such techniques as finite element methods and modeling.

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[1] William C. Orthwein, *Machine Component Design*, West Publishing, St. Paul, MN, 1990, p. xviii.

2. *Extensional Design*: An extrapolative procedure is used to increase the capacity of proven designs.

3. *Original Design*: A substantially original design is developed. Originality is judged on the degree of copying. The less a design resembles existing designs, the more original it is.

An example of a transitional design might be the minor reshaping of an automobile fuel tank to improve impact resistance. An extensional design might be the design of another slightly larger model in a line of bulldozers. An often-cited example of original design was King Gillette's development of disposable razor blades when only straight razors previously existed.

Corporate management usually adds input to the design process. For example, sales, research, and marketing people may suggest ideas for new products, or current products might be found to be deficient in some way and therefore need to be redesigned. A typical flow of the design process is shown in Figure 1.1. Once given guidelines, the engineer usually sketches the idea, reviews constraints and standards, compares the idea with those of competitors, analyzes the structure, creates drawings, checks manufacturing practices, builds, tests, and finally sees the idea go into production. After 1 to 3 years (sometimes more, sometimes less, depending on product, firm, and industry) of hard work, this final step—production—gives the designer a feeling of satisfaction and accomplishment. This feeling is generally heightened by an appreciation of the many problems and constraints that were successfully overcome.

Engineers are not expected to remember all the analytical methods taught in their college classrooms, but they should remember the topics and be able to look them up, review them and their assumptions from original derivations, and then apply them to a design. General concepts must be quickly recalled when a relevant problem arises. Physical effects and relationships, such as centripetal effects, thermal stress, steam pressure, thermal expansion, Newton's laws, Poisson's ratio, friction, and Coriolis forces, should also be kept in mind while designing. Table 1.1 lists some conversions to remember.

1.3 Communicating Ideas

The process of design requires good communication between the engineer, prototype build shop, assembly plant, and management. If ideas are not accurately and fully understood, the project might be canceled and a good idea shelved. Engineers should therefore take the time to communicate their design to management, not mainly for self-promotion, but for the project's success. Oral discussions and engineering drawings are both part of this communication process.

Communication of a design begins with the drawing. A good layout needs to be drawn so it can be easily reproduced (see Figure 1.2). Techniques and drawing systems vary from company to company: some engineers make their own layouts, whereas others utilize drafters or designers. Computer-aided-design (CAD) techniques (see Figure 1.3) have replaced

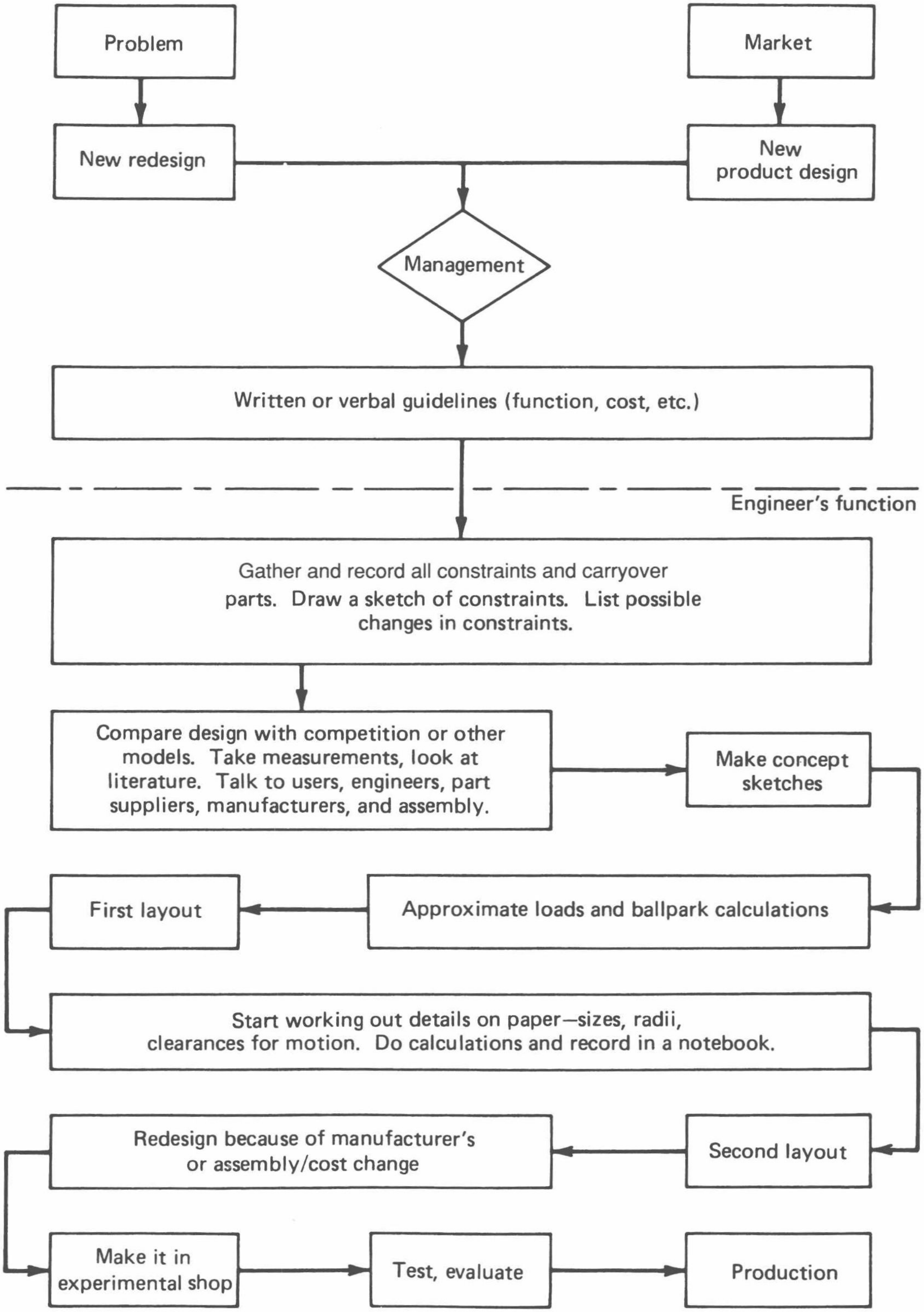

Figure 1.1
Typical organization of a design process.

TABLE 1.1 A DESIGNER'S LIST OF CONVERSIONS TO CONSIDER

Input	Output	Conversions		
Mechanical	Mechanical	Hooke's Law	Poisson's Ratio	Newton's Law
		Buoyancy	Lever	Wedge
	Electrical	Generator	Microphone	Piezoelectric
	Heat	Friction Heat	Refrigerator	Heat Pump
Chemical	Electrical	Battery	Combustion	Fuel Cell
	Heat	Combustion	Heat of Solution	Metabolism
Electrical	Chemical	Electrolysis	Electroplating	
	Heat	Resistance Heating	Thermoelectric	Spark
	Mechanical	Motor	Solenoid	Electrostatic
Radiation	Chemical	Photographic	Photosynthetic	

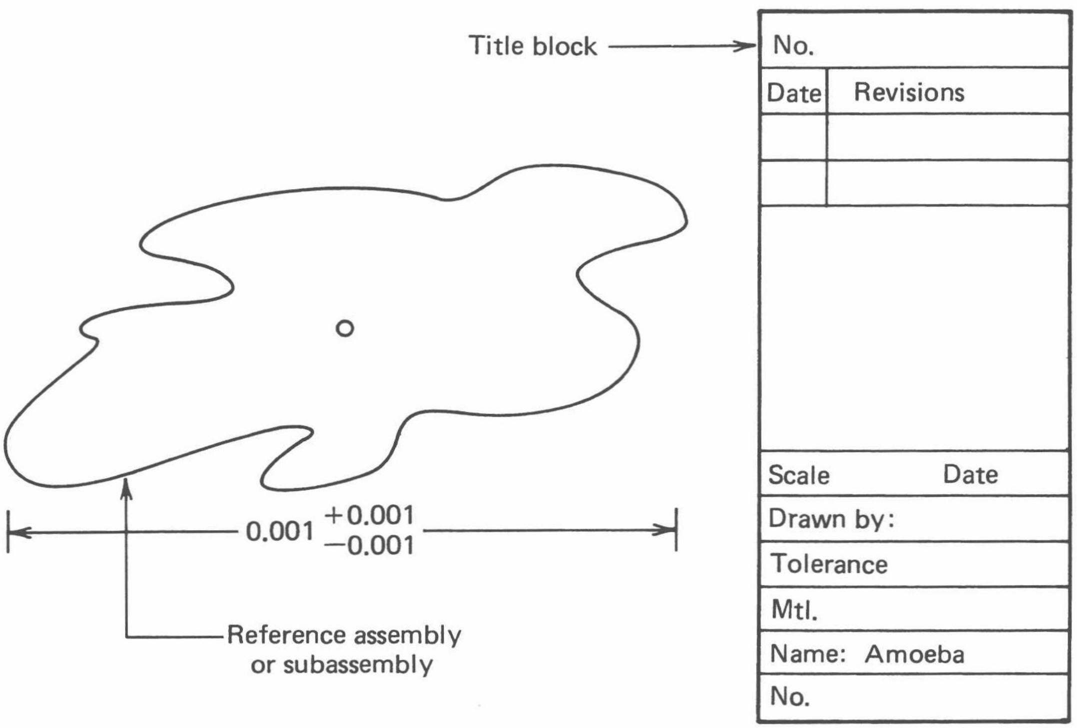

Figure 1.2
Sample engineering layout.

Figure 1.3
Using computer graphics to design a hydraulics system.

manual drafting in many firms; however, this has not happened without its share of problems. The designer must make sure that lines meet exactly, fillets are properly constructed and other details are absolutely correct so that the computer-aided manufacturing (CAM) can proceed without additional problems.

A list of items needed for transmitting ideas to the build shop might be:

1. Layout drawings should be made so that major dimensions can be determined. Areas of part interference or clearance should be shown. Two orthographic projection views or a single view with sections are generally needed. CAD machines may provide three-dimensional additions to a drawing, which can aid in comprehension. All critical dimensions should be calculated from a layout; they should never be scaled because of paper stretch.

2. Standard conventions should be established and followed. For example, for automobiles and trucks, 0,0,0 is at the center of the crankshaft on the top of the frame at the front face of the engine block. All other critical dimensions should be calculated once this location is established. Critical joining dimensions such as bolts, holes, and welds must also be specified.

3. Reference drawings that control other drawings should be identified, e.g., "This drawing controlled by layout LN-3462."

4. All part number, torques, materials, and tolerances should be specified on the master layout.

5. A parts list can be constructed and should include quantities, material stock sizes, and material type.

6. The drawing nameplate on the right-hand side usually includes the machine part name, drawing identification number, material used, scale, date, and name of designer. Revision notes that accurately describe changes made during the design process should be listed chronologically.

Other pertinent information should be stored in a bound design notebook for patent protection and for future reference. Such information includes sketches and concepts dated and witnessed by two or more competent persons. The witnesses' statement on the concept sketch might read: "Understood and witnessed by me, *Don Jones,* date *May 2, 1993*." Innovative designs should be considered for patenting. Information on how to file for a patent, including necessary forms and drawing specifications, is available in *Code of Federal Regulations 37, Patents, Trademarks and Copyrights* [Ref. 3].

The design notebook should include all free body diagrams and assumptions used (reference drawings, textbooks, etc.). Calculations should be detailed, and the designer should remember that almost all parts are subjected to fatigue loads and stress concentrations at geometry changes.

The source of standard equations, such as moments of inertia for common cross sections, is important to practicing designers. The Appendix provides a starting point for finding various commonly used inertia equations previously learned in Statics and Strength of Materials courses. Many advanced texts and engineering handbooks provide standard solutions for more advanced structural loading cases. Suppliers should provide information on their standard components and raw materials. It is advisable to consider all sources of information when beginning a design.

1.4 Ethical Engineering Issues in the Future

Today there are many significant dilemmas concerning safety in engineering practices. These dilemmas result from the wording of a portion of the *Fundamental Principles of Professional Engineering Practice:*

> The Engineer, to uphold and advance the honor and dignity of the engineering profession and in keeping with high standards of ethical conduct:
>
> I. Will be honest and impartial, and will serve with devotion his employer, his clients, and the public;
>
> II. Will strive to increase the competence and prestige of the engineering profession;
>
> III. Will use his knowledge and skill for the advancement of human welfare.

Relations with the public

1.1 The Engineer will have proper regard for the safety, health and welfare of the public in the performance of his professional duties....

Difficult decisions arise when engineers are confronted with conflicts in the areas listed in section 1.1 of the Code of Ethics. If the public is endangered, the engineer is supposed to notify the proper authority and withdraw from further service on the project. A sample situation is considered in Smith's paper [Ref. 22]:

> During an investigation of a bridge collapse, Engineer A investigates another, similar bridge and finds that it is only marginally safe. The engineer concludes that the bridge might collapse in certain circumstances and informs the governmental agency responsible for the bridge of a concern for the safety of the structure. Engineer A is told that the agency is aware of this situation, and has planned to provide for repairs in the next year's budget. Until then, the bridge must remain open to traffic. Without this bridge, emergency vehicles, such as police and fire apparatus, would have to use an alternative route, which would increase the response time by about 20 minutes. Because the agency is confident that the bridge is safe, Engineer A is asked to say nothing about the condition of the bridge.

What course should the engineer take? The code of ethics requires that the engineer protect the public safety, but which public: the public that needs emergency service or the public that uses the bridge daily? Smith states that the concept of safety needs to be redefined because of its complexity and its interactions with risk factors. There is always some risk in designing products; the issue of how much risk an engineer should allow in a design is unresolved. This issue can be partially resolved by putting some financial value on safety and after doing an economic evaluation before proceeding with the design. Nevertheless, the question remains: Are these risks acceptable with current technology and engineering practices?

How safe must a product be? The degree of safety is questioned in the cases that follow.

Case 1.

In designing airplane components, considerations of safety must be balanced against considerations of weight. In the first DC-10s, for example, an electronic closing device was used for a cargo hatch, rather than a heavier hydraulic closing device, even though the latter was safer. As a result, the cargo hatch could appear to be securely closed when it wasn't and could blow out during a flight. The first crash of a fully loaded jumbo jet was caused by the opening of the cargo door in flight. The crash resulted in the death of 346 people.[2] Was this a reasonably safe design?

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[2] Paul Eddy, Elain Potter, and Bruce Page, *Destination Disaster From the Tri-Motor to the DC10: The Risk of Flying*, as excerpted in Baum and Flores Ethical Problems in Engineering, Troy, NY, pp. 248-261, 1978.