Forensic Biomechanics and Human Injury

Criminal and Civil Applications – An Engineering Approach

Harold Franck • Darren Franck

CRC Press
Taylor & Francis Group

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Harold Franck
Advanced Engineering Associates
St. Petersburg, Florida, USA

Darren Franck
Advanced Engineering Associates
Charleston, West Virginia, USA

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20151020

International Standard Book Number-13: 978-1-4822-5888-2 (eBook - PDF)

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Symbols and Units

In this section, we list the symbols we use throughout the book for quick reference. We have also listed common units used to perform calculations. Note that in many instances units are in the English system (pound, foot, second) and other units are in the metric system (kilogram, meter, second) also known as SI. The section on conversion factors allows for the easy conversion between the two systems. Unfortunately, in the United States, an attempt to convert all units to the metric system has not succeeded to follow the rest of the world. Consequently, some conversions are necessary but are relatively simple.

Greeks	**Letters**
φ	Golden ratio of the Greeks = 1.618034…
x_n	Fibonacci numbers = 0, 1, 1, 2, 3, 5, 8, 13,…
K_e	Kinetic energy (ft lb)
w	Weight (lb or kg)
g	Acceleration due to gravity (ft/s^2 or m/s^2)
$\boldsymbol{v}$	Velocity (ft/s or m/s)
V	Volume (ft^3 or m^3 or gal or L)
a	Acceleration (ft/s^2 or m/s^2)
d	Distance (ft or m)
F	Force (lb or kg)
m	Mass (kg or slugs or lb)
x, y, z	Distance in the particular direction (ft or m)
σ	Stress
A	Area (ft^2 or m^2)
ε	Strain
δ	Deformation
ρ	Density
l or L	Length (ft or m)
E	Young's modulus
τ	Shearing stress
t	Thickness
P_n	Normal load
P_t	Transverse load
ν	Poisson's ratio

e	Dilation
p	Pressure
k	Bulk modulus
T	Torque
ρ	Radial distance
$\boldsymbol{J}$	Polar moment of inertia
G	Shear modulus
φ	Angle of twist
$\boldsymbol{I}$	Area moment of inertia
S	Section modulus
M	Moment
Q	First moment of inertia
V	Shear in the section
r	Radial arm
μ	Coefficient of friction
K	Effective length factor
S_x^p	Sensitivity of P to x
V_{xj}	Variability of x
x_{am}	Arithmetic mean
x_{gm}	Geometric mean
$\boldsymbol{a}_t$	Unit vector in the tangential direction
$\boldsymbol{a}_r$	Unit vector in the radial direction

Note: Vectors may be represented by a **boldface** symbol.

Preface

There are many reasons why people write books. Our intent for writing this book is threefold. The first reason is to bring together information about the strength of biological materials from a variety of sources in a concise, comprehensive manner that is readily accessible to the reader or practitioner. Most of the information on the characteristics of biological materials, from an engineering standpoint, is difficult to find unless the reader has a fairly comprehensive library or does a significant amount of research. A considerable amount of the information exists in an outdated published form. Some of the information must be gleaned from animal studies simply because it is not available and tests have not been performed on humans. The reason for the lack of data on some human properties is simply that those studies could not be performed on humans. There is insufficient concise information on the subject in one text that is readily accessible to the investigator without performing extensive searches. In order to find some of the information, multiple sources from biology, anatomy, strength of materials, and medicine must be researched.

Let us turn for a moment to the topic of animal studies and why they are appropriate in our context. Animal studies have been utilized to determine the characteristics of scientific scrutiny in many forms, including the response to chemicals and carcinogens to which it would be inappropriate to subject humans. In our context, we simply include animal studies to correlate the similarities of the physical properties of various tissues to the human anatomy. When data for humans are not available, the correlations we have included afford the investigator a reasonable range of values of the characteristics of the particular tissue.

The second reason for writing this book is to educate the public, and in particular, engineers, attorneys, and judges, on the methodologies utilized to compute the forces, stresses, and energies required to produce injury to the human body. The calculations are actually quite simple. The trick is to determine how to apply the equations to the human body with relatively accurate dimensions and material strength characteristics to properly model the forces and stresses on the particular body part resulting from a particular incident. The intent is also to argue the simple fact that biomechanical engineers are the most capable individuals to perform these calculations. Again, let us emphasize that biomechanics is not a science of diagnosis but rather a science of causality and correlation to injury.

The third reason is to allow a relatively inexperienced person a method to perform the calculations, which may be especially true for a criminal investigator who is given the task to assign blame for the incident. The criminal investigator may need to perform some basic calculations to assess whether an incident should be included in the category of criminality or not. As an example, it may be alleged that the injuries suffered in a homicide case are due to a fall down a staircase. Some basic calculations may yield a completely different scenario in which it may be shown that the injuries could not have been created by a fall but rather by multiple blunt trauma to the body. Another example of a criminal case may involve a broken tibia alleged to be caused by the fall of a female. Calculations may show the injury to have actually resulted from physical abuse by a boyfriend or husband. A third example may involve shaken baby syndrome by a guardian in which it was alleged that the baby simply fell on the floor. Of course, in the case of injury or death, medical imaging or an autopsy would validate such findings of the forensic biomechanical investigator. All the parts of the puzzle must fit together in a cohesive manner. In this context, we have produced a variety of examples to compute the damaging events. Furthermore, we have included some calculations into which the investigator can easily plug typical values of known data and calculate the unknown. The pertinent equations are already included in the calculations with some typical values. Here, the investigator only needs to change certain parameters to fit his application. The parameters that may need to be entered to fit the particular case are found in the applicable sections of the book.

By writing this book in a relatively simple manner, without the complex medical terminology and anatomical description found in most treatises, we hope to educate and elucidate practitioners on the subject of injury to humans. Some mathematics and terminology are required to properly comprehend the subject matter, which is especially true of medical terms that confound most of us. We hope that the medical terminology encountered from the description by doctors will mostly be found in this text without the need to perform further searches. We have, however, simplified the material substantially and allowed the reader the opportunity to investigate how and under what conditions humans get hurt. Much of the medical terminology on the minor components of the human anatomy has been disregarded because we are looking at the major or most common types of trauma that occur. For example, we do not address the forces that may cause a broken toe because that type of injury can occur simply by stubbing the toe against an object while walking.

Acknowledgments

We express our gratitude to our families, including Maria, Amanda, and Janice for all the help and support received during the process of producing this book. Without their help, this book could not have been written. We also express our gratitude to the staff of CRC Press, in particular to Mark Listewnik, who encouraged the development of the topics in this treatise.

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Authors

Harold Franck founded Advanced Engineering Associates Inc. (AEA) in 1989 and has a home office in Charleston, West Virginia and a satellite office in St. Petersburg, Florida. Since that time, he has been involved in thousands of forensic engineering investigations involving vehicle accident reconstruction, origin and cause fire investigations, and electrical incidents. He is a registered professional engineer in the states of West Virginia, Michigan, Ohio, Virginia, Kentucky, and Florida. Harold received his BSEE from the West Virginia Institute of Technology (WVIT) in 1970 and an MSEE from West Virginia University in 1973. He began his academic work as an instructor of electrical technology at WVIT in 1970, eventually becoming associate professor of electrical engineering in 1981 before retiring in 1990. Harold has presented and attended various courses and seminars through the years, lists many publications, and has completed two books:

Forensic Engineering Fundamentals, 2012. Coauthor: Darren Franck. Boca Raton, Florida. CRC Press, Taylor & Francis Group.
Mathematical Methods for Accident Reconstruction, 2010. Coauthor: Darren Franck. Boca Raton, Florida. CRC Press, Taylor & Francis Group.

Darren Franck is a registered professional engineer in the state of West Virginia. He is president of AEA, Inc. and has been with the company since 1995. Darren received his BSCE from Virginia Polytechnic Institute and State University in 1999 and an MSME from the Georgia Institute of Technology in 2005. Darren's areas of expertise include forensic engineering investigations, structural analysis and design, accident reconstruction, computer-aided design, and 3D animations. He has been involved in various consulting, construction management, and design activities throughout West Virginia. Darren is also coauthor of two the books listed earlier.

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1 Introduction

Humans are prone to injury by a variety of methods with no limitations. The three most common methods include disease, war, and accidents. The first method of injury that is produced by disease is essentially the purview of the medical expert. The proclivity of the human condition to the various maladies associated with disease is not the subject of this book. Injuries produced by war and conflict are well documented and can be categorized as being caused by extremely violent acts. These acts usually involve the detonation of explosives, weapons of mass destruction, or sophisticated armaments that are designed to cause permanent injury and more likely death. Again, we are not concerned with these types of injuries although their results may be similar to the types of injury that we encounter in this book.

A third method by which humans are injured is through what is commonly referred to as an accident. Accidents come in many forms and include slips and falls, car accidents, or may be equipment or humanly produced. For clarity, we choose to refer to this type of injury as an incident rather than an accident. The main reason for the reference of an incident is because these injuries may not be accidental in nature. They may be caused by a variety of events some of which cannot be categorized as accidental. Additionally, they may not be injurious but are claimed to be so. Others may actually be predicted by the events that precede them. Actions or events may be put in place that determine a root cause for the event or incident. A simple example of such an event is a football player who suffers a head injury, returns to the game, and is then diagnosed with a closed head injury. Some of the most common incidents involve humans in perfectly acceptable activities such as sports. Some of these injuries may be caused by sudden, forceful actions in the activity being performed or they may be produced by continued cyclic activity that degrades the affected tissue. Knee, shoulder, and elbow injuries associated with sports such as football, baseball, and tennis come to mind. These injuries may be sudden as when a soccer player changes direction rapidly or they may be produced by cyclic loading resulting from swinging a tennis racket over many years. Irrespective of the type of injury, forensic engineers performing biomechanical calculations are mainly concerned with the forces and accelerations that the activity or incident produced. They are interested in the strength properties of the affected material. These forces can then be correlated to the strength of the affected tissue structures in order to determine if the energies were sufficient to cause the injury.

It is well understood that the potential for injury increases with increasing age. The human system, as with any other system, is affected by wear and tear. Barring the effects of disease on the human body, the human structures that make us up will eventually wear out. Age-specific maladies include the degradation of the joints, muscles, bones, tendons, and ligaments. The strength of these biological materials decreases with age and should always be considered when analysis is performed for the potential of injury by a particular incident. Whether a person is young or old, when the human structures affected are subject to excessive loading beyond their limits, the structures are subject to failure. This failure may take many forms including stress, strain, rupture, or catastrophic failure as in the form of a compound fracture. Compound fractures are those that cause the bones to protrude through the skin and are deemed the most severe and have a greater potential to cause death via infection.

From a historical perspective, it should be pointed out that biomechanical calculations were not carried out before the twentieth century although Newton's laws were well-known for at least two centuries prior. The reason for this late development in calculating and quantifying the forces and energies required to injure biological tissue is threefold. First, investigators were not aware that biological tissue was subject to the same laws that applied to nonanimate structures such as wood, steel, cement, and others. These biological structures were simply not studied. The science of biomechanics and strength of materials had not emerged and matured. Second, the properties of biological materials were not known. Stresses, strains, and loading of biological structures were not known. Humans and animals had not been subjected to the forces and accelerations in order to quantify the effects of severe loading. Before the advent of mechanized motion, humans and animals were not stressed by significant velocities. These velocities only emerged as a result of the machines that were primarily invented in the twentieth century. Prior to the industrial revolution, injuries to humans were produced by jumps, falls, weapons, war, and human mayhem. Technology had not advanced to the point where velocities and accelerations produced by machines affected a large portion of the population. Additionally, the surfaces that impacted humans when exposed to falls and slips were generally much softer. For example, there is a marked difference when falling from a horse at 20 mph onto a grassy field when compared to striking a wall riding a motorcycle at the same speed. Although concussions have been medically known for a long time, the propensity of the sports, actions, and machines available today have a much greater effect on this type of injury. Our mechanized world has produced the third element in the proliferation and scientific study of biomechanical loading.

This book has several chapters that encompass the biomechanical forensic engineering field. Before we continue with a discussion of the chapters in the book, it is important to differentiate the term biomechanical from biomedical. The term biomedical is the purview of professionals trained in medicine. Medically trained professionals, whether they are doctors, nurses, or physical therapists, have a completely different perspective on injury to humans. They are trained to diagnose and correlate injury and disease. They are trained to repair and mollify injury. They are not necessarily trained to determine the correlation between injury and the forces required to produce that injury although their experience allows them to correlate certain activities to the degradation of biological structures. Their experience and training also allows them to determine the detrimental effects of these structures due to aging or repeated loading. For example, older individuals are prone to degradation of their joints, such as their knees, whereas young people are generally not subject to these conditions. Similarly, baseball pitchers are commonly subject to shoulder and elbow degradation as a result of their particular sport. In this context, medically trained personnel are the most qualified individuals to determine the correlation between activity, age, and injury.

In contrast, biomechanical engineers are generally not trained to correlate the previously mentioned injury and causation or diagnosis. Their training is geared toward the forces, energies, velocities, and accelerations that will cause biological materials to fail. The tools of analysis for a biomechanical engineer involve the application of Newton's laws and Strength of Materials principles to the structures that make up the human body. In terms of the physical structures, bones, muscles, tendons, ligaments, and organs, and other animal structures, the terms of forces, accelerations, stresses, and strains all behave in predictable and known ways. That is, these biological materials have properties that can be studied within the context of their strength, stress, and strain. The literature is replete with the physical properties of these materials. Consequently, the scientific literature on the onset for injury to biological materials is well understood, studied, and documented. Biomechanical engineers can perform calculations using the known scientific literature about the strength of tissues and correlate the potential for injury to a particular event or incident. They are generally not trained to diagnose injury or disease unless they are trained in the medical sciences. Biomechanical engineers are normally not doctors or nurses; however, they are certainly capable of understanding human anatomy and terminology. Consequently, they are well suited to perform the calculations that correlate injury to the human body to the forces that produce injury.

In many jurisdictions, the sitting judge will not allow a forensic biomechanical engineer to testify to the potential or correlation to injury as a result of a particular event. These judges only allow medically trained professionals to testify to the correlation between injury or the potential for injury.

This condition promulgated by the sitting judge may actually be inaccurate or erroneous because the medical expert may or may not be trained in the mechanics of injury. In many instances, the medical expert simply correlates the potential for injury to the statements of the involved parties which may or may not be accurate. Simply put, the involved parties are not disinterested participants and may have a stake or concern with the outcome of the diagnosis. Someone with a preexisting condition, such as a herniated disc, may be involved in a minor collision and seek treatment based on the preexisting condition, claiming that the injury was produced by the minor accident. In fact, this accident may not be the cause of the injury which can be determined by the forensic biomechanical engineer through the calculation of the forces, accelerations, and the strength of the affected biological materials.

In actuality, biomechanical engineers are eminently qualified to make such calculations but may not be permitted by the court to render such opinions. The necessary and sufficient conditions required to make the calculations and render the opinion are quite basic—these are a basic knowledge of the mechanical laws of physics, an understanding of strength of materials science, basic dimensions of the affected tissues, and their physical properties in term of stresses, strains, and ultimate strength. The fact that the judge may not allow the opinion of the biomechanical engineer is beyond the scope of the purview of the biomechanical engineer and simply depends on the enlightenment of the presiding judge. Why some judges choose to allow medically trained personnel to opine on the cause of an injury who do not possess the background in biomechanics is not understood by the authors but is recognized. It is simply a fact of life and part of an imperfect judicial system.

In reality, the most qualified individuals to perform biomechanical calculations are professionals involved in biomechanics. These individuals are engineers, scientists, physicists, and other similarly trained professionals who are involved in testing and calculating the necessary forces that injure human tissue. The ideal biomechanical professional would have training in medicine and engineering. Although these individuals do exist, the nature of each of these fields makes them a rare commodity. The intensity of training involved in both fields makes it very difficult to achieve this level of competence and knowledge. In the opinion of the authors, training in engineering with knowledge of the strength of biological materials suffices to render opinions concerning injury to humans.

Historical Developments

Before the twentieth century biomechanical calculations were not performed. There was simply no interest or need for the quantification of the energies involved in the injury to humans. This lack of interest changed with the events leading to the Second World War. In particular, Germany and Japan undertook an effort to study the effects of forces that injured humans. Some of these efforts were in fact cruel, immoral, and without regard to the sanctity of human life. Some of the experiments were barbarous and have been well documented historically. However, cruel this type of experimentation was, it did yield some valuable information on the strength of biological materials.

A second source of human tolerance to injury came from the U.S. space program and the X-plane tests performed at various facilities by the Air Force. Live subjects were placed in a variety of conditions that tested the limits of tolerance of the human body. These studies revealed just how strong and tolerant humans are to forces and accelerations. These studies were necessary to determine if humans could be placed in rockets and accelerated to the escape velocity necessary to reach orbit and then return to earth. Typical orbital velocities attained by a variety of propulsion methods to reach space produce accelerations of approximately 8–9 times the acceleration on gravity, commonly referred to as 8–9 *g*'s. Actually, humans have been subjected to accelerations in excess of 30 *g*'s under controlled conditions without injury to the human test subjects. Keep in mind that these individuals were physically fit, and strict control was used in the experimentation. It should not be assumed that all humans are capable of withstanding 30 *g*'s or more. However, it is very reasonable that normal humans can tolerate accelerations of 8–9 *g*'s. In fact, tests with human subjects of all shapes, sizes, and physical conditions place the onset of injury at about 12 *g*'s. The scientific literature indicates that soft tissue injuries begin at about 12 *g*'s and that by 17 *g*'s the possibility of soft tissue injury is most certain.

The third source of information on human tolerance comes from academia and professional societies. These sources have been most active in the past 50 years since the mass proliferation of the automobile and the mayhem that it causes. A significant amount of testing on humans and cadavers has taken place and is still very active. Testing on cadavers is performed with the consent of the deceased and family members and is conducted in a proper and dignified manner. In fact, restraint systems were developed as a consequence of this type of testing. Seat belts and air bags were the result of this testing, and the design of these systems is based on the scientifically known tolerance to injury. As an example, we might consider the deployment of the air bag. The deployment is activated by a speed change of approximately 12–14 mph depending on the vehicle and the manufacturer. This speed change correlates to an acceleration of between 10 and 12 *g*'s. Why was this value chosen? Surely not by a lucky guess but rather as a result of numerous tests that yielded the tolerance of humans to noninjurious forces and accelerations. If humans were injured at accelerations of approximately 4 *g*'s and the air bag systems did not deploy until a level of 12 *g*'s was reached, then the air bag systems would be deemed ineffectual. Alternatively, if air bag systems are deployed at 4 *g*'s produced by a typical medium bump on the road or a broach on a curb, then drivers would be very unhappy with their vehicles. It is conceivable that numerous law suits would be filed for the unnecessary deployment of the air bag system. It is necessary to note that there are experts who claim that humans can essentially be injured at any velocity. If that were the case, it can be reasonably argued that we, as an evolutionary animal, would not have made much progress in the course of our development as a species. How could humans have evolved if minor forces would cause injury and subsequent death? Scientific testing and calculations simply do not support these claims. That is not to say that there is not great variability in the strength of human tissue. Of course there is, but there are upper and lower bounds as with any material. When biomechanical calculations are carried out, this variability in the strength of human tissue is always taken into account. Not to do so is misleading and, to a certain degree, incompetent because the physical properties of that individual are never known to an exact degree. To err on the side of caution, the calculations are always carried out over the range of known scientific possibilities for the strength of these biological materials. This point will be explained further in other sections of the book as we carry out examples of the possibility for injury.

This book contains information on the strength of biological materials of other animals. The question that may arise is why such information is provided. From an evolutionary standpoint, it is well-known and understood that we, as a species, are not very different from our nonhuman relatives. The development of the human species can be traced to our earliest roots for approximately 500 million years to the Cambrian explosion. The Cambrian explosion signifies the rapid development, diversity, and similarity in the life forms that evolved during this period of earth's history. In a simple narrative, it can be said that rudimentary life forms underwent significant changes in their procession toward more complex life forms and developed very similar characteristics that have continued to this day. These similar characteristics include the development of four limbs, a backbone, a tail, a circulatory system, and a gastrointestinal digestive system to name a few. Although in outward appearances, most life forms have very distinct characteristics, the basic parts are generally similar under strict scrutiny.

Testing of biological materials of humans is somewhat limited by ethical concerns. We simply cannot take a living human and break a leg, puncture a lung, or rupture a tendon. Such activity is considered inhuman and barbarous although such activity has been known to have occurred. Our society still has problems dealing with assisted suicide in the case of impending death in order to alleviate suffering. We, as a species, attempt to cling to life by any and all medical procedures that maintain some semblance to life.

The authors take no sides in this very complex debate but recognize that the criteria applied to other animals are different. Most of us consider euthanasia the humane approach when other animals, such as our pets, face suffering or impending death. Consequently, some of the testing on other animal subjects does not adhere to the same strict requirements imposed on humans.

Additionally, not all human testing of biological materials has been carried out. Some testing of biological materials of other animal species has been performed so that these tests can be correlated to human tissue. A statistical analysis of human versus other animal tissue reveals the similarity in the strength of the materials. When the strength of human biological materials is not known or determined, similar animal materials may be used.

This correlation between human and animal materials can invoke controversy as outlined by the Daubert versus Merrell Dow Pharmaceuticals case approximately 20 years ago. For those readers not familiar with this case, we offer a very condensed version of the case.

In 1993, the U.S. Supreme Court determined the standard for the admission of expert testimony in the federal court system. The *Daubert Court* articulated what is known as the *Daubert Standard*, which overturned the Federal Rules of Evidence as outlined in the *Frye Standard*. The *Frye Standard* stemmed from a 1923 case, which only allowed evidence to be admitted in court if the evidence was in consort with the general acceptance in the field. In 1975, Congress adopted the Federal Rules of Evidence, which included the Frye Standard as part of federal common law. Rule 702 of the Federal Rules of Evidence did not make expert testimony admissible depending on general acceptance. In the *Daubert* case, the plaintiffs contended that the drug Bendectin caused birth defects in humans based on animal studies, which had not gained acceptance in the scientific community.

As a result of these cases, the new standards that govern expert testimony must meet three provisions. First, the testimony must be based on scientific knowledge. Second, the testimony must assist the jury or the judge in understanding the evidence within a pertinent context. Third, the testimony must be scientifically valid, tested, subjected to scientific peer review, published, generally accepted, and rate of error known. A more concise set of guidelines for the new standard as promulgated by Rule 702 of the Federal Rules of Evidence can be summarized where the reliability of the evidence must meet a nonexclusive four part test. This test is as follows:

1. Can the theory or technique be tested?
2. Has it been subjected to peer review and publication?
3. Is there a known or potential for error?
4. Is there general acceptance in the scientific community similar to the Frye Standard?

The validity of the use of animal biological materials and their properties as a substitute for human biological materials is fully developed and correlated in Chapter 8, which is accomplished by correlating the materials and applying statistical deviations between the two to prove their relevance.

Beyond this introductory chapter, the book has an additional 14 chapters, applicable federal standards, and a bibliography. The chapters are grouped into four categories. The first category includes the need for biomechanical analysis and an explanation of how injuries occur relative to the activities of the human subjects. This category includes Chapters 3 through 5. The second category includes elements of anatomy, terminology, and physical characteristics of biological materials. These topics are covered in Chapters 6 through 10. The third category includes the applicable static and dynamic equations used in the analysis. Chapters 9, 11, and 14 deal with these subjects. The fourth category includes protective structures and standards that are covered in Chapters 14 and 15.

Chapter 2 deals with the court system and testimony of the expert. Preparation for depositions and trial along with presentations by the expert are covered. The demeanor and believability when testifying are the most crucial elements when the expert is on the witness stand. This chapter may be read at any time. However, the other chapters should be read in sequence for clarity of presentation. Chapter 15 on the Federal Standards is included because, in many cases, proving that a standard has been violated is prima fascia evidence. References to applicable sections are made throughout the book.

On a stylistic note, the authors are aware that not all experts, scientists, and engineers are male. However, the clumsy constructions "his/her," "she/he," and their variations have been avoided for clarity's sake. It should be assumed that a masculine pronoun is not meant to refer only to the male gender. Mankind includes all of us.

2 Court System and Testimony

The practicing biomechanical forensic engineer has to be intimately aware and knowledgeable of the court system in the United States. Although there is some variability in the court system from state to state, most of the elements of the court system are the same. There is also some variability in the testimony and evidence that an expert is allowed to hear and know in a particular case. There may also be variability in the system from county to county in a particular state. Additionally, within a county, the litigating parties may agree to certain elements that are not necessarily within the norm of that particular jurisdiction. An attempt to describe all the different court systems is not the purpose or intent in this chapter. Some of the most common variations are discussed.

Our basic system of justice is predicated upon the English system of justice that dates back to the Magna Carta in 1215. The Magna Carta was influenced by King Henry I who specified that a limitation would be placed on certain of his powers. This limit resulted from and was influenced by the Charter of Liberties of 1100. After 1215 the Magna Carta underwent many modifications, and by the time that the early settlers reached New England, it was influential in their interpretation of law. As a direct consequence, the Magna Carta played an influential role in the development of the Constitution of the United States. The Englishmen who colonized America were greatly influenced by the Magna Carta when they established their charters. These included the Virginia Charter, the Maryland Charter, and the Massachusetts Bay Company Charter. These early colonists' interpretation of the Magna Carta was anachronistic in that they believed that it guaranteed trial by jury and habeas corpus and was a fundamental law. Habeas corpus essentially means "you have the body" and relates to the direction of a prison warden to produce the person so that the court can determine the status and legality of the custody of the prisoner. The court order concerning the production of the habeas corpus is known as a writ.

Consequently, the framers of the U.S. Constitution designed the legal system in the manner of English common law and the philosophy of John Locke who is regarded as the *Father of Classical Liberalism*. The significant influence of John Locke on the development of the founding documents of the United States cannot be underestimated. Locke was a true believer in empirical data in consort with the underpinnings of the beliefs of Francis Bacon. John Locke was extremely influential in social contract theory, liberal theory, republicanism, and their significance to the Declaration of Independence, the Bill of Rights, and the U.S. Constitution. Locke's ideas on liberty, social contract, property, price theory, monetary thought, political theory, religious beliefs, and the concept of self influenced many of the founding fathers of this country.

There are three main levels of the court system in the United States. At the top level there is the Supreme Court of the United States. Under this level of the court system, there are sublevels of the federal court system referred to as federal district courts. At the next level, there are the individual state supreme courts. These state courts are also made up of lower levels and include the district and county courts of the states. Litigation generally begins at the lowest level, which is the county courts and then the litigation proceeds from the state district courts to the state supreme courts. Thereafter, the litigation may work its way up through the federal court system and eventually end up at the Supreme Court of the United States.

The Supreme Court is made up of eight justices appointed by the president and confirmed by the senate. The chief justice is the ninth member, who is appointed and confirmed in the same manner as the other justices. The other justices are referred to as associate justices. Their appointment is for life and consequently may sway the opinions of the court in significant directions toward liberalism or conservatism. The cases heard by the Supreme Court are limited each year by the justices and proceed from federal or state courts. In other words, the appeals may arise from federal district courts or from state supreme courts. There are 13 federal district circuit courts of appeal. These federal appeal courts arise from 94 federal judicial districts of which 12 are regional circuit courts. The thirteenth district has jurisdiction over specialized cases relative to international trade and the Court of Federal Claims. There are 50 state supreme courts. Figure 2.1 shows the U.S. district courts. The numbers corresponding to the colored sections of the map in Figure 2.1 represent the various regional circuit courts of the United States.

Individual cases that may involve a practicing forensic biomechanical engineer would most probably not involve the opinions of the expert unless the case involves constitutional issues as with the Daubert case. The Supreme Court is the final arbiter of federal constitutional law and was established by the Constitution in 1789 in Article Three. These cases involve attorneys who present oral arguments on the merits of the case, and the forensic expert would not testify but his opinions may be cited.

The 50 state supreme courts are, in their function, essentially identical to the federal supreme court system in that they normally hear appeals and do not make any finding of facts. When the state supreme courts find errors in a particular state decision, they will order the court to retry the case. The case is remanded to the lower court. The state supreme courts vary in their makeup depending on the particular constitution of the state in which they reside.

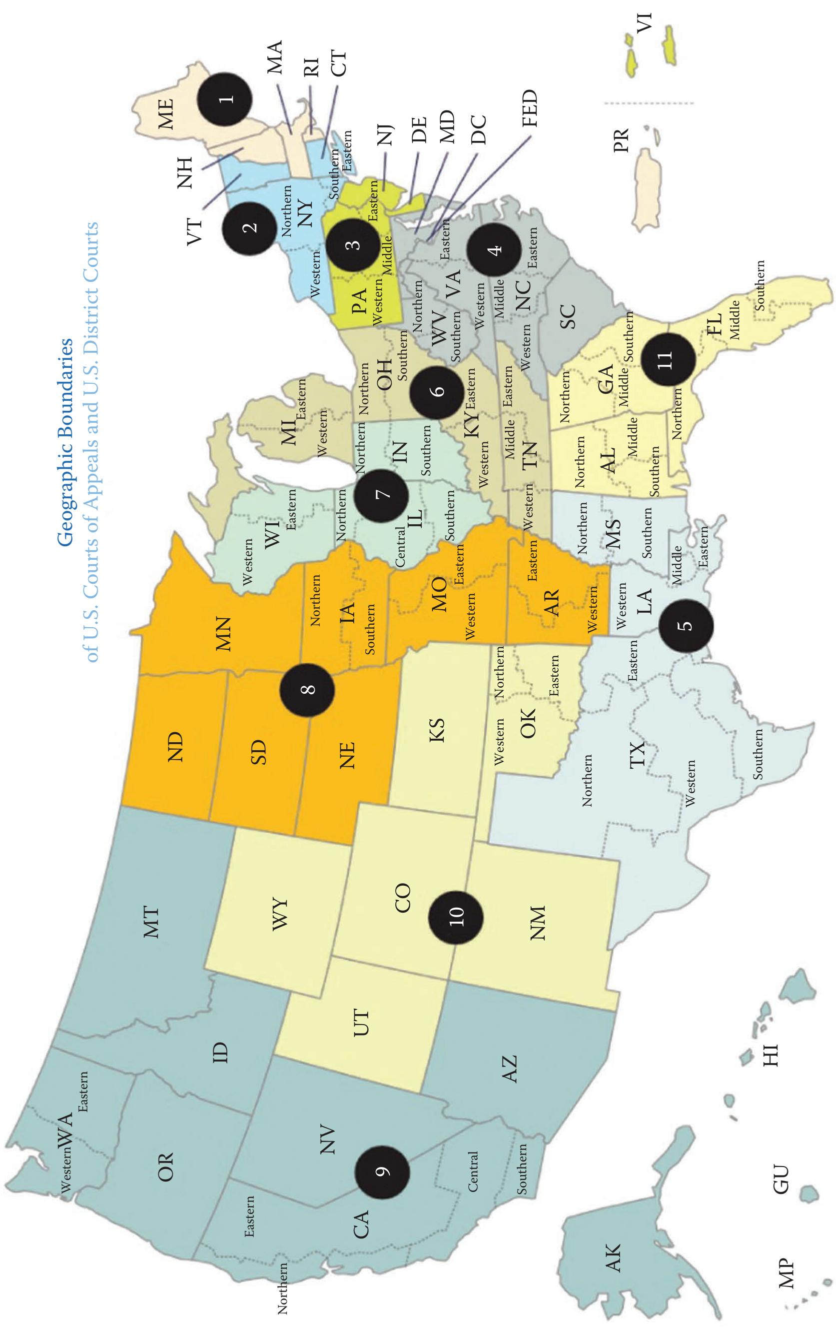

Figure 2.1 U.S. district courts.