David H. Allen

How Mechanics Shaped the Modern World

Springer

David H. Allen

How Mechanics Shaped the Modern World

Springer

David H. Allen
Civil Engineering Department
Texas A&M University
College Station, TX
USA

ISBN 978-3-319-01700-6 ISBN 978-3-319-01701-3 (eBook)
DOI 10.1007/978-3-319-01701-3
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013946340

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

To my wife Claudia, who, despite the fact that she is neither a scientist nor an engineer, read this entire manuscript repeatedly, providing valuable insight and much-needed encouragement

Preface

This book was born from my lifetime of study of the scientific field of mechanics. I feel fortunate to have had a fulfilling career in such a challenging and enlightening field of study.

I was born in 1950 in the United States, the son of a World War II Army Air Corps veteran. My father was educated in Engineering at Cal Tech, and he was in every sense of the word an "engineering nerd." I was somehow endowed by him with sufficient talents to follow in his footsteps, thus I subsequently enrolled in Engineering in college, and over a 12-year span of time that included three and a half years in the U. S. Air Force, I obtained degrees in Aerospace Engineering (B.S.), Civil Engineering (M.E.), and Aerospace Engineering (Ph.D., focus on Engineering Mechanics) at Texas A&M University. Somewhat serendipitously, I also studied meteorology for a year in graduate school in preparation for my time in the Air Force as a weather forecaster. I would not realize until much later how important that experience would be to my understanding of mechanics. I have subsequently spent my entire career as a Professor (until recently), teaching at a number of universities both in the U.S. and abroad.

Now, as I look backwards in time, I find myself to have been exceedingly fulfilled by my professional career. Nonetheless, I feel the need to impart my take on the history of my discipline. I say "my take," because it would not be appropriate to call this text a history book. It is rather my own peculiar view of the universe, one predicated upon my experiences, which are admittedly biased by my long and somewhat narrowly focused view of my own field of study and its impact on the world. I must therefore apologize in advance to those who find error with, or worse, are offended by "my take." In some cases there are clearly enormous gaps in the history of mechanics found within the pages of this text. In other cases, I have chosen to discuss details that may seem insignificant to some readers. Such is the nature of each person's view of what is important to this subject. In that sense "my take" is surely highly idiosyncratic, but hopefully not offensive. For those who seek a more technical and in-depth coverage of the history of mechanics, I refer you to the excellent book entitled *A History of Mechanics*, by René Degas (Dover 1988).

I'm a big fan of Carl Sagan. I won't go into his life or his achievements, since through one of the miracles of modern science and technology you can simply Google his name and find out everything you ever wanted to know and more. But suffice it to say this—at the time that he was writing, Dr. Sagan brought the wonders of science to more people than anyone else in the history of this planet. Yes, he was a brilliant scientist as well as a prolific author. And yes, he was taken from us far too soon (at the age of 62). But as far as I am concerned, it is his skill at making science accessible to so many that is his enduring legacy.

You may ask why I choose to elevate "showmanship" to such a lofty pedestal. No one can doubt that Carl Sagan was a showman, and a brilliant one at that. His New York accented way of saying "billions and billions" became a trademark phrase for a generation of Americans. It has even been whispered that Dr. Sagan was passed over for election to the National Academy of Science because his showmanship crossed over the boundaries of science. I will not dispute this conjecture.

What impresses me is what Dr. Sagan clearly knew, and what he was trying to do with that knowledge. I have learned so much from him. And this is what I learned—I learned the importance of education. I learned that education of our species is the driving force behind our success on this planet. I do not believe that I would have ever completely understood that fact had it not been for Carl Sagan. He not only understood it, he "put his money where his mouth was," so to speak. To be sure, he never stopped doing important scientific work during his lifetime, but he devoted a substantial part of his time here on Earth to imparting that wisdom to the rest of his fellow humans. He understood that without education we are nothing. Without education we would still be foraging for food along with the other species. Without education, almost everyone alive on this planet today would never have been born. And so he devoted his life to education. As I said, I'm a big fan of Carl Sagan.

In this book my intention is to explain how the science of classical mechanics has affected our world in ways that are commonplace and accessible to the average person as opposed to scientists and engineers. As such, it should be considered non-technical in content. Nonetheless, I hope that these two latter groups will find pleasure in my somewhat purposefully simplified exposition of the subject.

Satisfying all of these disparate groups simultaneously is a difficult challenge, and it is at least in part for this reason that I have chosen to restrict my views to classical mechanics. This term is intended to imply that field of mechanics that developed prior to the advent of quantum mechanics, thus encompassing the pervasive field of Newtonian mechanics. Furthermore, I will not delve deeply into the subject of either special or general relativity in this book. Similarly, because it does not fall under the cognomen of classical mechanics, I will eschew the subject of quantum mechanics. These all-important subjects are amply explained in a number of exemplary volumes published in recent times, so much so that I fear my coverage of these developments would fail to measure up. Thus, as I said, I will confine my coverage to the subject of classical mechanics and henceforth in this book when I utilize the term mechanics, it is implied to be synonymous with the term classical mechanics.

The perceptive reader may ask exactly what is meant by the title of this book. This is indeed an excellent question. I have purposefully chosen a duplicitous title, and for good reason. There are in fact two objectives that I have set for myself herein, and the title of this text bridges both. First, it is my aim to explain in layman's terms how mechanics played a role in the development of so many achievements throughout the history of the universe as we know it. In some cases we do not really know how this happened, but as the reader will soon discover, this will in no way hinder me from conjecture. Second, and perhaps more importantly, it is also my intention to describe the more obvious meaning within the title—how specific developments that involved mechanics actually served to *shape* our modern world. This latter goal is indeed a lofty ambition. With this in mind, I hope that "my take" does not disappoint.

I may be reaching high, but it is my desire that the admittedly unusual perspective contained within this book will somehow accomplish the same thing for mechanics that Dr. Sagan did for Astronomy, Astrophysics, and whatever else he chose to write about—to enlighten not only those familiar with my discipline, but also those who may not be well-versed in the subject and are simply curious to know more about mechanics. If so, then my aim is indeed not too high, but has squarely struck my intended mark. And so, dear reader, I wish you both an enlightening and enjoyable read.

David H. Allen

Acknowledgments

I would like to thank all those who helped to make this textbook come to fruition. I am especially indebted to my Editor at Springer, Michael Luby, who made valuable suggestions that improved the final text, and his assistant Merry Stuber, who patiently answered any and all of my questions. In addition, I would like to thank those who reviewed and critiqued the manuscript. Their careful and selfless efforts contributed significantly to the quality of the final manuscript.

Introduction

Those who educate children well are more to be honored than they who produce them; for these only gave them life, those the art of living well.

Aristotle

Webster's Dictionary tells us that mechanics is "the branch of physics that deals with the motion of material bodies and the phenomena of the action of forces on bodies" [1]. Note that this definition implies that there need not be human intervention for mechanics to occur. There are several different fields of physics, and many more within the domain of what we call science. This book is concerned with the physics of mechanics, but as the reader will discover in this book, mechanics is so ubiquitous as to pervade virtually every other field of scientific endeavor, and ultimately, the fabric of both the universe and all humankind.

Science is defined to be "knowledge gained through experience" [1], thus implying that principles are postulated that can be experimentally disproven. Science is therefore inextricably related to experiments, and virtually all experiments involve the measurement of the motions of bodies. It can therefore be inferred that mechanics is essential to every field of science. As will also be seen herein, mechanics may arguably also be the oldest of the sciences. These are some of the underlying reasons that mechanics is ubiquitous in our world today.

When I was a young man, the world was in the early stages of a technological revolution, one that I confess I did not completely perceive at the time. I remember going on a tour of a research facility with a group of my fellow high school students when I was about sixteen. The tour guide showed us a computer, something that was a relative oddity at the time. Communication with the computer by humans was accomplished by using a tape that was encoded with information. Within a couple of years this antiquated method of human–machine communication was replaced by a much more expedient deck of cards that was punched with holes, thus resulting in the now extinct term "keypunch." This essentially mechanical means of communication remained the primary means of interfacing humans with computers for more than a decade, a span of time that included most of my undergraduate and graduate studies.

I grew up using a slide rule, perhaps the ultimate purely mechanical device for performing computations with deceptive simplicity. During my senior year as an undergraduate in college (1971–1972), the world was introduced to Hewlett-Packard (HP) pocket calculators, and a short time thereafter, Texas Instruments (TI) pocket calculators came on the market. That was perhaps my most vivid evidence that the world was changing. Some called it "the computer age," but in my mind, as I look back now, 40 years later, I realize that it was much more than that. The world was in the early stages of transforming from a primarily mechanical one to a world that is now both mechanical and electromagnetic.

I honestly had no comprehension as to the magnitude of the revolution that was germinating during that period of time. I thought that computers were like slide rules—just another tool for calculating faster. Had I understood, I might have chosen a different career field within the broad discipline of engineering, but I confess that I did not.

Thus, I chose to study mechanics, a field that has become quite mature over the past 40 years. In fact, I would go so far as to say that the world has been revolutionized by the science of electromagnetics within the span of my lifetime. We are now well into "the computer age," just one of many offspring of the science of electromagnetics.

Some may trace the science of electromagnetics to the experiments of Michael Faraday, or even further back to those of Benjamin Franklin, but for my part, I consider the true father of electromagnetics to be James Clerk Maxwell, the Scottish scientist who published his theories regarding electromagnetism beginning in 1861, while he was on the faculty at Cambridge University.

Unfortunately, he died young (in 1879 at the age of 48, from abdominal cancer), but his contributions cannot be overestimated. They are truly monumental to our world today. In fact, one could go so far as to say, prior to the year 1861, the world as we know it was essentially mechanical, and since that time, the world has become increasingly electromagnetic, and most of the resulting technological changes have only become apparent to society as a whole since the fading days of World War II, when two atomic bombs were exploded in Japan, in part due to Maxwell's discoveries.

Let us now begin our journey with a short overview of history. Our estimate as to the age of the universe keeps increasing. For the past half century, scientists have developed a consensus that The Big Bang, that enormous conflagration that initiated the spread of matter throughout the universe, occurred sometime around 13.7 billion years ago.

Similarly, scientists now believe that our Solar System, including our planet, is about 4.5 billion years old, when gravitational forces agglomerated enough mass for our Sun to undergo sufficient pressures for nuclear reactions to be initiated. As recently as 150 years ago, this span of time seemed not just unlikely, but impossible to most humans. But geologic as well as astrophysical data now seem to agree on this estimate. Think about it—4,500,000,000 years—that is a lot of zeroes!

Now let's consider that enormous span of time in relation to the species of Homo sapiens. There seem to be three intrinsic time constants in relation to our species: the span of a heartbeat; the time for gestation; and the span of a human lifetime. All of these are much less than either the time span of our universe or our Solar System. Thus, in case it is not obvious, it can be said that—compared to the astrophysical timescale—*we humans are relatively short-lived.*

Of course, these can all be related to time constants for our planet: the span of a revolution of the Earth on its axis (a day); the span of a revolution of the moon about the Earth (about 29.5 days); and the span of a revolution of the Earth about the Sun (a year). Note that all of these time spans are measured via mechanics. As Isaac Newton so aptly put it in his book, *The Principia,* "...common time, is some sensible and external measure of duration by the means of motion..." [2].

As we delve deeper into the time span of our species, we are struck even more so by the incongruity of our evolution with respect to the evolution of the universe. As recently as about 15,000 years ago (that is only 3 zeroes!), our species appears from the archeological record to have been doing what virtually every other species of animal was doing on this planet—hunting and gathering—in order to survive from day to day [3]. Thus, it seems likely that not too very long ago, the end of each human life was not unlike the end of life that we observe in most other species today—within the stomach of another animal! Thus, we are unlikely to ever unexpectedly find any large ancient cemeteries containing the remains of humans on Earth.

To put it concisely—something very significant happened within the last 15,000 years on this planet, because we are not doing what we did as a species 15,000 years ago, and virtually every other species on this planet is functioning just the way they were then, despite the fact that most of their gestation times are significantly shorter than ours (meaning they could have evolved genetically more rapidly than we humans).

What happened? How could it have happened so quickly, a mere blink of an eye on the astronomical timescale? Had visitors to our planet passed by 15,000 years ago, they would have concluded that there was no intelligent life on this planet. How did a species (our very own) take over a planet in such a short span of time, a development that is so far as we know unprecedented in the history of the universe?

The answer to this question is one of the greatest achievements by humans. Sometime around 13,000 years ago (we do not know exactly when because carbon dating is not perfect), a person or persons, somewhere in the area of modern day Iraq, where the Tigress and Euphrates Rivers flow, attempted to use the river for irrigation purposes, perhaps designing and employing an implement for digging trenches and diverting water from the river for the purposes of nourishing plants to produce food for the village [4].

Until that point in time it was simply not possible to support villages with populations greater than about 400 humans via hunting and gathering. There just wasn't enough game within the radius that a human could walk in a day to support a larger population. But with the advent of farming, cities of perhaps 5,000 people sprang up within a single century.

Organized farming had created civilization. And that person or persons, whoever they were, we may regard today as the first engineers on Earth. While it is certainly true that there were ingenious (from whence the word engineer comes) humans before then, there was no civilization, so that there were no ingenious people creating on behalf of civilization—the definition of an engineer. So that is how it all started. Civilization on our planet was initiated by agricultural engineers.

Archeologists and anthropologists have determined that the invention of farming moved humans rapidly away from hunter-gatherer behaviors, and this produced a population explosion at places such as Uruk and Ur. Apparently, within a few short centuries there were cities of more than ten thousand persons in the Mideast. Population growth allowed for specialization of professions in these cities, and this led the way to the development of new technologies as more people specialized in the development of new ideas. In turn, the development of new ideas required some training, and the ability to transmit these developments throughout society necessitated the development of sophisticated language, both spoken and written, and mathematics.

Events thereafter began to occur at an ever increasing pace, as if time were continually being compressed. Inventions were spewed out with increasing frequency as the demands of humans for more and more life sustaining technology drove the needs of an exponentially increasing populace.

Yes, it is true that there were missteps and regressions along the way, such as the period we call the Middle Ages, but by and large, the rise of the human species is the most admirable example of *Darwin's Universal Law of Natural Selection* that can be conjured up anywhere in the universe, so far as we are aware. To wit, the number of life altering inventions just within the last century dwarfs all of the inventions within the previous 4.5 billion years on this planet. Indeed, the average life span of humans has nearly doubled in little more than a century, and advancing technology has played an enormous role in this achievement. There is no way to avoid the profundity of the world we live in today. It is little short of miraculous.

And yet, Anthropologists tell us that due to the statistical nature of microbiology, the gestation period of humans, and the complexity of our DNA, we are a species that requires around 10,000 years to undergo significant physical evolution. In other words, those people 13,000 years ago who were hunting and gathering were essentially genetically equivalent to us. Their brains were the same size as ours! They were smart; they were most likely just as intelligent as we their descendants are.

So why didn't they just invent everything on the spot, as soon as they had sufficient food? Why did it take 13,000 years? For one thing, there were only about 1 million humans on the planet 13,000 years ago. Today there are more than 7 billion humans on Earth. We can safely say that there has been a population explosion, and in many parts of the world, it is still underway. This population explosion has encouraged and supported specialization, thereby increasing the rate of growth of technology.

So what is going on here? Why has the way we humans live changed so dramatically, while other species have not? We have not evolved significantly genetically, and yet, here we are, the undisputed masters of this planet, far more so than any other species that archeologists have yet discovered.

The answer is of course—*education! Our species is the first species, so far as* we are aware, that has outrun our own physiological evolution, and we have accomplished this astounding feat via education [5].

Certainly, Darwin's law [6] played a significant role in our quest to educate ourselves, despite the fact that it was not even espoused until the mid-nineteenth century. And you thought that Darwin's law only applied to genetics. Nope, it applies to any means of evolution, and in the case of our species, we have trounced the genetic clock by applying Darwin's law to education. The fact is, we have been living our lives (and educating ourselves) according to Darwin's law, whether we have been aware of it or not. In fact, a new field of research called genetic programming has recently begun to result in many new technological developments.

Inventions led inexorably to the rise of education—a necessity for humans to survive. We used to have to compete with other species to survive. Today, each and every one of us humans must compete with other members of our own species to survive. While the higher education complexes on our planet are less than a 1,000 years old (The University of Bologna issued the first diplomas around 1088), our educational infrastructure goes back thousands of years. *It may be argued that* education is indeed the single most important invention in the history of humankind.

As I previously indicated, I chose to study mechanics. Thus, I rode the crest of a wave that, though it has now matured and one could even say—crashed upon the shore—it has nonetheless been an exciting ride in that I was there for the peak of the wave that is mechanics, one that is perhaps the most important wave of technology to ever affect humans and our world. And although it is perhaps premature to assume that mechanics is now receding, it is nonetheless instructive to trace the history of such an enormous development in the history of mankind. After all, I lived on the crest of that wave, and I of all people hope that the power of such a wave shall never be forgotten. Thus, if you will bear with me through the telling of this story, I hope that you will agree with me by the end of it that mechanics is by far the most important fundamental discipline of science that shaped our modern world.

References

1. Guralnik DB (ed) (1970) Webster's Dictionary. Prentice-Hall
2. Newton I (1687) Philosophiae Naturalis Principia Mathematica. (version utilized herein 1934) University of California Press
3. Diamond J (1993) The third chimpanzee. Harper
4. Sprague de Camp L (1993) The ancient engineers. Barnes & Noble
5. Sagan C (1980) Cosmos. Ballantine
6. Darwin C (1859) On the origin of species. John Murray

How Mechanics Shaped the Modern World

Contents