

ENTERTAINMENT ENGINEERING



JOHN W. WESNER

Entertainment Engineering

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PREFACE

This Book, *Entertainment Engineering*, is derived from a course originally created by John Wesner for upper level undergraduate Mechanical Engineering students at Carnegie Mellon University.

The original concept for the course was to introduce Mechanical Engineering students to the exciting career opportunities to which they might aspire in many aspects of the entertainment industry. Outside of a high school class trip to observe roller coasters at a local amusement park, few engineering students have been exposed to the many ways in which engineering serves entertainment. This is made more difficult by the fact that most of the engineering behind entertainment experiences is deliberately hidden, so as not to distract the people being entertained from the total entertainment experience.

The course started by looking at the entertainment industry, with a focus on delighting the customers (“guests”). In the latter part of the course the students were shown specific examples of key engineering in many different types of entertainment. The course was always offered in the spring semester, so that the class could as a class project design, create, and operate a Midway Booth for Carnegie Mellon’s annual Spring Carnival celebration. This gave them a chance to experience engineering an entertainment experience first hand.

Each semester, a few students from other parts of the campus community took the course — generally a couple of Production majors from the Drama Department, and a small number of graduate students from the Entertainment Technology Center. These students came to learn what they might expect from engineers during the courses of their own non-technical careers. In addition to helping to broaden the perspective of the engineers in the class, these students played key roles in the development of each Spring Carnival Midway Booth.

The success of the course and several derivatives from it (Workshops, Seminars, and Independent-Study experiences) led to the idea of creating this book, to share with a wider audience.

ACKNOWLEDGMENTS

Colleagues and friends who provided invaluable help as the original course and this book were being developed include:

Charles F. Bartel, Jr., Moog Inc., Motion Systems Division

Drew Davidson, Director of Carnegie Mellon's Entertainment Technology Center. Drew encouraged me to write this book, reviewed my manuscript as I developed it, and wrote the chapter on video games.

James Futrell, Historian for NAPHA: National Amusement Park Historical Association.

Prof. Francis McMichael from Carnegie Mellon's Civil and Environmental Engineering Department, who helped me to understand open channel flow

George Pike, model rocket hobbyist

Mario Scarabino, PE, Manager of Worldwide Attraction Safety & Transportation, Walt Disney Parks & Resorts

Jesse Schell, Distinguished Professor of Entertainment Technology, Carnegie Mellon Univ.; CEO of Schell Games.

Mark Sumner, Walt Disney Imagineer with a wealth of experience designing water rides

Frank Wesner, who started playing computer games in the days of the *Colossal Cave Adventure*

I want to recognize another group of people at Carnegie Mellon in 2003 who made special contributions to the original design of the undergraduate course in Entertainment Engineering upon which this book is largely based:

Prof. Cristina Amon, from Mechanical Engineering and the Institute for Complex Engineered Systems, currently Dean of Engineering at the University of Toronto Canada.

Todd Camill, an Entertainment Technology Center (ETC) student

Scott Douglass, from the Psychology Dept.

Tim Eck, an ETC student

Prof. Bill Messner, from the Mechanical Engineering Dept.

Prof. Randy Pausch, from the Computer-Science Dept., Co-Founder
of the Entertainment Technology Center

Prof. Lynn Reder, from the Psychology Dept.

FOREWORD

John Wesner is ideally qualified for writing a book on entertainment engineering. After a thirty-year career doing and leading the physical (mechanical) design of consumer communications products, he returned to Carnegie Mellon to share his “real world” experiences with students. After meeting Randy Pausch and affiliating with CMU's Entertainment Technology Center, John created a course in Entertainment Engineering in the Carnegie Institute of Technology—the Engineering College of Carnegie Mellon. Over the past ten years John has helped train many of the people who provide the engineering backbone of our entertainment activities ranging from movies to games, themes parks and home entertainment. His courses have been broadly interdisciplinary, merging engineering, computing, arts and design perspectives in their structure and attracting students from all Colleges of Carnegie Mellon.

John brings his extensive interdisciplinary expertise in the writing of this book. He establishes right from the outset, that the goal of entertainment engineering is not the engineering in its self but the quality of the generated experience. The best entertainment engineering is the one that produces immersive, safe, economically viable entertainment experiences. It is engineering that solves very complex problems without making the experience user aware of the engineering challenge. The user is free to focus only on the experience. Accordingly, John goes through many of our entertainment experiences and draws back the curtain to show us the engineering structures that underlie the success of these experiences. He also discusses problematic engineering approaches and points out how they fail the overall entertainment experience. John covers experiences that we all know to be engineering heavy (digital films, games, theme parks) but also simpler analogue and physical entertainment experiences

(like traditional board games) where the contribution of engineering is not always obvious.

John's awareness of the interdisciplinary nature of entertainment engineering results in a balanced book that recognizes the interplay of the key components of successful entertainment experiences. John discusses how the engineering processes that underlie entertainment relate to other key components like story and narrative, perception and safety. John also writes this book as an entertainment engineer; with a focus on informing and entertaining the reader. The book will be useful to entertainment engineering novices, amateurs and experts as it is not only a "how it is done" book but also an informed survey of entertainment engineering and an experienced discussion of the collaborative processes that are required of diverse teams.

Enjoy

Thanassis Rikakis
Vice Provost for Design, Arts and Technology
Carnegie Mellon University

PART I

Engineering in the World of Entertainment

In this first part of the book we begin by looking at the entertainment industry in general, with a focus on delighting the customers.

Entertainment is one of this country's largest exports. It has more influence on our culture than almost anything you name,

In Chapter 1 we ask what is unique/special about the domain, Entertainment. We look at the broad scope of Entertainment, and end by asking the reader to think about their own entertainment preferences.

Chapter 2 addresses the "Big Five" considerations in entertainment, including the overall experience, the role of engineering, the importance of safety, and entertainment as a business.

In Chapter 3 we take a Systems View, pulling together all the pieces and also looking from both the customer's ("guest's") viewpoint and the provider's viewpoint.

The focus in Chapter 4 is on psychology.

Part I wraps up with a look at the role of storytelling, in entertainment and also in engineering in general.

CHAPTER 1

Entertainment??

Entertainment. “**3** : something diverting or engaging: as **a** : a public performance **b** : a usu. light comic or adventure novel” (Webster 2000, pg. 386)

Entertainment comes in many forms, from sedentary activities to theme parks to gambling. This is definitely not an exhaustive list:

- Animatronics
- Games of all sorts
- Home Entertainment
- Movies
- Music
- Print Media
- Spectacles
- Star Gazing
- Thrill Rides
- Gambling
- Hiking & Camping
- Live Theater
- Museum, Zoos, and Aquariums
- Parades
- Simulator “Rides”
- Sports (Doing, Watching)
- Theme Parks
- Water Parks

Engineering. “**1** : The activities or function of an engineer. **2 a** : the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people. **b** : the design and manufacture of complex products .” (Webster 2000, pg. 383)

Engineering, too, comes in many forms, from chemical and electrical and mechanical to civil and software.

What, then, is

Entertainment Engineering

What is unique about the application of *Engineering* to the domain *Entertainment* that warrants special attention?

Try these for starters:

- Entertainment is an important business that surrounds us all the time, from portable music players to TV and far beyond.
- There are many opportunities for engineers to contribute to making entertainment happen.

If you do not normally associate “engineering” with “entertainment,” consider this statement by a leader in the world of entertainment:

“The Pleasure Beach is 42 acres of amazing engineering with the greatest rides that the amusement industry has dreamt up.”

Amanda Thompson
Group Deputy Managing Director,
Blackpool Pleasure Beach, Blackpool, England
(Valianatos, 2004)

If you start looking for evidence that engineering plays a role in the world of entertainment, it should be fairly easy to see it in some of the varied forms of entertainment listed above.

Thrill Rides may have come immediately to mind, particularly if you accompanied a middle- or high-school class on a visit to a local amusement park. But *Print Media*? Consider this: someone had to engineer the press that made this book possible, durably made and for sale at a reasonable price. The relatively tiny portable music device

required clever engineering to make it work so well, to make it durable, to manufacture it reliably, and to make it attractive and easy to use. We could go through most of the remainder of the list, and find some ways in which engineering contributed to each aspect of entertainment the *something diverting or engaging* identified in the dictionary definition at the start of this chapter.

What sorts of engineering can be found in the realm of Entertainment Engineering? Almost all of the major types:

- Chemical
- Civil
- Computer (Hardware)
- Electrical
- Materials
- Mechanical
- Software

Even some of the more specialized engineering specialties show up at times—like Agricultural, perhaps involved in creating topiary “statues”.

Another interesting thing to think about is how changes in technology over time are reflected in changes in how various types of entertainment are implemented. A very simple example is the hobby of *model railroading*. In the early part of the 20th century, model trains were made from stamped sheet metal, with details painted or printed on. These trains were “driven” by being towed across the floor by a string. As time went by, pull-toy trains were replaced by trains with wind-up motors, and then electric motors—with electricity first provided by automobile batteries and eventually by AC from the wall. They were still made from stamped sheet metal.

Accessories like train stations were also made from stamped and painted sheet metal. Then fairly simple die cast metal trains were made. Before World War II there were kits for hobbyists to assemble their trains and accessories from wood and paper. After World War II kits started to have die-cast metal detail parts, and beautiful hand-crafted brass locomotive models were being imported from Japan, as they recovered from their war-time losses. Along the way, injection molding of plastic improved dramatically in its ability to produce finely detailed parts very economically, and for years plastic models of all sorts dominated the hobby. By the beginning of the 21st century, excellently-detailed plastic models challenged the hand-made models, and laser-cut wood and plastic models of scenic accessories like buildings had become common, enabling greater variety with improved detail at less cost. Simple direct-current control of train speed and direction was being overtaken by “digital command control,” involving a simple “computer” (“decoder”) in each model locomotive, with commands distributed from hand-held “throttles” by a computer-like network.

The Plan of This Book

We begin by looking at the broad scope of Entertainment, and what are the major issues in engineering entertainment activities, venues, products, etc.

We then consider how people and entertainment interact.

To bring our engineer readers up closer to the thinking processes of our colleagues already deeply engaged in the entertainment business, we look at the role played by *stories* and *story telling* in entertainment—concepts not fully appreciated by many engineers.

The view then changes from a broad look to examining several forms

of entertainment in depth, to see (and experience) how engineering plays its roles in making these types of entertainment “entertaining”.

Along the way, we suggest some books and articles you might read, some videos you might watch, and some organizations you might want to learn about.

To create a reasonable, carry-able book, we have cut the list of types of entertainment that we will discuss in depth to

- Print Media
- Live Theater
- Movies
- Animatronics
- Amusement Parks and Theme Parks
- Thrill Rides
- Simulator “Rides”
- Home Entertainment
- Video Games

Toward the end of the book, we look very briefly at some of the other forms of entertainment where the engineering may be less obvious.

Thought Exercise

Think a about your own personal entertainment preferences and experiences.

What are your favorite Entertainment activities (e.g., computer games, movies, thrill rides), and why?

(A suggestion: write a couple of paragraphs that you can come back to and read later, after you have read more. Would you keep the same list, or perhaps change it?)

Supplementary Reading/Viewing

You may want to get yourself a copy of *Walt Disney Imagineering*. We'll occasionally suggest parts to read to supplement this book. If you can access a copy, at this point you may want to read the front matter and Chapter 1.

Theme parks provide a very interesting window on the breadth of the topic *Entertainment*. Typically many different forms of entertainment are available in the single setting of a Theme Park. Can you remember an experience of your own, visiting a Theme Park, where you took note of how many different entertainment activities were available to you there? If you can't, you might want to take a look at one of the excellent videos that illustrate the wide variety of entertainment that you can find at venues like theme parks. One that does this very well is *A Day at Disneyland**.

Some old-fashioned *Amusement Parks* also offer a wide variety of entertainment opportunities within their gates. *Kennywood Memories**, a video about an Amusement Park in Pittsburgh, Pennsylvania, shows this well.

Thought Exercise

If you can delve back into your memory of a visit to a Theme Park, or if you do view one of these videos, see how many different forms of "Entertainment" you can see—from our list and more!

* Details about these videos are given in the Bibliography at the end of this volume.

In addition to the obvious Theme Park, were you able to recall or find

- A Tourist Train
- Live Music
- Live Theater
- Animatronics
- Marionettes
- Roller Coasters
- A Flume Ride
- A Simulator Ride
- A Carousel
- Several “Round and Round” Rides
- Strolling Actors
- A Playground
- A Movie Theater

CHAPTER 2

The “Big Five” Considerations in Entertainment Engineering

What Should You Take Away from the first part (the “broad” view) of this book?

These five concepts provide a coherent and pretty complete structure:

1. It’s the “total entertainment experience” (“total guest experience”) that determines success.
2. Engineers have a potentially very big role in many forms of entertainment.
3. Engineering is but one of several contributors to the total entertainment experience.
4. Safety is a major driver of what can be done in entertainment.
5. The Bottom Line: Entertainment is a *business*

“Total Guest Experience”

The “guests” we entertain are a group of customers who spend their money and time to experience our entertainment offerings.

Indeed, some people speak of the work we are talking about as the *Experience Design Industry*.

Early in my thinking about this subject, this concept of the Total Guest Experience was mentioned to me by more than one person—but no one had a nice “standard” definition for me. I asked a friend at Walt Disney Imagineering, thinking they might have a sign on their

wall, reminding them of this important concept.

There was nothing quite so straightforward. My friend asked some of his colleagues for their understanding of the concept. Here are some thoughts they offered:

- “complete immersion”

“The more a guest feels immersed in an experience, the better that experience seems to be. We know that the immersion is achieved by various art forms all coming together to tell one story. The background music, the landscaping, the texture of the ground we walk on, etc., all contribute to the total guest experience.”

(Alec Scribner, personal communication)

- “detail”

“The more detail, the more immersive the experience. But the detail does not have to be completely realistic to a period or time or place.”

- “complete sensory experience”

Another Imagineer offered that “the basic definition of ‘total guest experience’ is the complete sensory experience that is provided by any particular purposefully created environment, ... completely enveloping a human into its environment.”

The Imagineers also identified these things that can interfere with the Total Guest Experience:

- Confusing or conflicting information
- Incongruities

How important is this? Several years ago in a Disney University short course about *Creativity*, we were told about guest “Magic Moments” and “Tragic Moments”. The point was made that it takes 37 Magic

Moments to make up for one Tragic Moment. Think for a moment about this. If you truly enjoy some entertainment activity, you will enthusiastically share that enjoyment with your family and friends. If you do not enjoy some entertainment activity—if you have a *tragic moment*—you share that as well. Usually not quietly, but loudly and far and wide among your acquaintances. “Never try XXX; we had a miserable time...” It is overcoming this widespread impact that requires 37 Magic Moments.

What do the guests expect for the money and time they invest? In the world of product design, engineers speak of “satisfying” the customer, by meeting the customer’s expectations. More recently, some product design organizations have taken this a step further, and aimed at *delighting* customers—*exceeding* their expectations. In many cases this has been tied to enhanced definitions of *quality*, focusing on the idea that providing a product or service of the highest quality will *delight* customers. This is clearly applicable in the entertainment world.

The action sequence needed to accomplish this can be simply described:

- create Customer Expectations
- fully engage the Customers
- meet (or exceed) the Expectations we have created

Using the term borrowed from the Walt Disney World people, we want our guests/customers to have only *Magic Moments* (and lots of them) while they are experiencing our entertainment offerings.

How do we achieve this ?

Every guest who comes to our entertainment venue or attraction comes with a full burden of the world of their daily life. If we want to *delight*

them, we need to so fully engage them that they forget for a time that daily life. We want them to believe that the world we are telling them about or showing them or otherwise exposing them to is, for the moment at least, the “real” world.

This sounds very similar to the concept of “suspension of disbelief,” which is important in the literary genres of fantasy and science fiction. How do you make the story so complete and so “bullet proof” that readers totally lose themselves in the story, no matter how far it goes away from the world around them?

There is no question that some people more easily “let themselves go” into the alternate world offered to them. Engaging the others heightens the challenge...

A very important first step is to conceive the story that lies beneath the entertainment activity. This plays a major role in keeping everything consistent, and in keeping the design and development team working together toward a well defined and well understood goal.

Attention to detail was identified above as an important part of creating the *total guest experience*. Things need not be absolutely realistic or perfect, but they need to be sufficiently complete, consistent, and unambiguous that the guest can be fully engaged, and not be shocked back to the “real world” by something that just does not fit or work right.

Here is a fairly simple example, involving two different “simulation” rides at two theme parks. One is super successful: *Star Tours* at Walt Disney World. A group of guests are taken on a wild, adventurous ride through part of the world of the *Star Wars* movies. The guests sit in a room that is themed to look like the passenger compartment of a space shuttle, with a movie projected on a screen in front of them

representing what they are seeing “out the front windshield” of the shuttle. The seats are mounted on a “motion base” that is programmed to tilt them this way and that, so that they perceive that they are experiencing the maneuvers seen “through the windshield”. The picture is complete: the guests can see nothing that distracts from the planned experience.

The other ride, at a park owned by a different chain, offered the experience of riding with a jet fighter pilot executing fast and complex maneuvers. But the guests could see beyond the edges of the screen on which the movie was being projected, to see the warehouse-like room in which they were actually sitting. And instead of the entire set of seats moving together, the seats were paired on separate small motion bases—allowing a guest who looked to the side to see the mechanism beneath the neighboring pair of seats. The illusion was not complete and there were conflicting sights, so the experience was not nearly as engaging or exciting.

Big Role of Engineers

So where do we engineers fit it? Consider this view, offered by a Carnegie Mellon Entertainment Technology Center alumnus:

“Everything that is engineered needs to serve the illusion.”

The Walt Disney Imagineers offer some bounds to the engineer’s role:

“...we are not so much concerned about technology for technology’s sake as much as we are in using it as a means to tell the story. For us to succeed, the story must be so captivating that the amazing technology supporting it goes completely unnoticed.”
(The Imagineers, 1996)

In later chapters we will look at many of the specific ways in which engineers contribute to creating entertainment experiences.

Engineering is one of several contributors to the total experience

Engineers do not bear the entire burden of entertaining the guests. Depending upon the type of entertainment under consideration, there are many other folks who contribute to making the entertainment happen, and to delighting the guests. Consider

- The people who see the opportunity in the first place, and then create the underlying story. (These people are akin to the Marketing, Product Management, and Research people in a product design environment.)
- The people who design the hardware and/or write the software that provide a “structure” for the entertainment.
- The operators, stage hands, cameramen, etc., who breathe life into the structure.
- The actors who bring the story to life upon the structure.

Like all of the above except for the actors, the engineering is at its best when it is “invisible” to (not noticed by) the guests.

Safety is a major driver

Guest safety is absolutely critical. No entertainment activity can afford to injure a guest.

Inadequate assurance of safety is the one true “deal breaker” in the entertainment world. Not being able to almost guarantee that no guest will be hurt is the one thing that can kill an otherwise promising and exciting entertainment idea.

People are injured; accidents do happen. If nothing else goes wrong, some object might fall from the sky—a piece of an airplane, a meteorite, or chunk of man-made space debris. Several years ago a freak windstorm ripped the roof off a ride at an amusement park in Western Pennsylvania, and dropped it onto a guest, killing her. But these are events that cannot be predicted. To the extent possible all predictable risks need to be accounted for, and the activity created so as to minimize the possibility of their occurring and, should they occur, of their causing guests to be injured.

Some entertainment activities (like thrill rides) are intended to make guests think that they are at risk. But deep down inside, the guests have to be sure that while they will be scared, they will not really be at risk of injury. Otherwise they will not participate in the activity.

Entertainment is a *Business*

In addition to the guests, who bring the money, there are two other sets of “customers” for entertainment activities who the engineers must consider:

- The craftspeople who build the physical part of the attraction, and the technicians who keep everything working. We’ll consider these people more later on.
- The owners/operators/investors, who provide the initial funding and the environment in which the entertainment is experienced, as a means for making money.

For this last group of engineers’ customers, *Entertainment is a business*—a way to make money. Without their participation, there will be no way to bring the entertainment to the guests. Their needs must be met.

CHAPTER 3

Systems View

Pulling It All Together

So, how can we work to create this elusive but critical *Total Guest Experience*?

One important thing we can do is undertake creating any entertainment activity with what engineers might term a *Systems Engineering* approach. In the present context in which engineering is only one piece, it is perhaps better expressed as a *Total Systems Approach*.

Here is a suggested outline for getting started:

- Set up at the start a *Multidisciplinary Design Team*, comprised of people representing all the disciplines that need to be involved in the project.
- Be sure that the team's coach is a "true believer" in the Systems Approach, who understands the dynamics of a multidisciplinary team and how to get the most from the team.
- Have a story that has been provided by the person who convened the multidisciplinary team, or created by one of more members of the team, that everyone on the team understands and buys into.
- Make a comprehensive list of the needs of all the team members, and issues that can be expected to need to be addressed.

Teams

What is so important about forming a *team*?

There is a growing acceptance of teams as the best way to organize to develop any sort of product or service. Teams have been around for a long time; what is new are

- an expanded view of who should be on a development team—that the team should be *multidisciplinary*, representing all of the interests and skills needed to carry out the complete job. In this environment, no one has to wait to be told by someone outside of the team what is needed from their function.
- the changing roles of team members and their management.

“The premise is that a group of empowered employees working as a team, depending more upon each other than upon supervision, will have ideas, energy, etc., that are greater than the sum of the individual contributions from the people who make up the team.” (Wesner 1994)

Data seems to show that multidisciplinary teams make better use of participant abilities and intelligence. In this environment, people work together and share the work load, so that they add dimensions and variety to the job.

Further, members of *empowered* teams (teams not closely led by a non-team-member manager) tend to develop a sense that they *own* the work and the outcome, and so produce even better results.

For people not familiar with the functioning of multidisciplinary teams there are some things worth knowing about how teams get going and how they work best.

A team goes through several stages as they organize and get under way. Bruce Tuckman (Tuckman 1965) identified these stages:

- Forming
- Storming
- Norming
- Performing

The importance of forming the correct team is discussed above. In addition to being multidisciplinary, there is value to having a *diverse* team, to insure viewing the job in as many ways as possible.

It is critically important that all the team members are willing to share the common goal or set of goals. Everyone on the team needs to be pulling the same way.

Storming. For a time after the team is launched they will appear to be thrashing about, as they get used to one another, select and develop their relationships with a leader, and develop their relationships with their coach. Storming *will occur*, and everyone must resist the temptation to give up rather than work through the stress.

This is a necessary and important time. It is the time when *team-building* begins. It may be an appropriate time to have a “formal” team-building activity—an exercise, a game, an outing, or simply a meal and movie together.

Norming. As they move past Storming and begin to get under way, the team should

- Formalize objectives and goals to which everyone on the team subscribes
- Perhaps select and schedule training activities to fill important gaps (e.g., specific processes, new tools, and interpersonal skills)

Performing. As the team gets going, consider enhancing team performance by establishing a climate of ongoing activities that help strengthen the relationships in a team. These might include regular meetings, working at least part of the time together in a laboratory or conference room, going to lunch together, and ordering in pizza during a late-night work session.

Another way to enhance team performance is to give all the members of a team the same* reward (e.g., salary increase or bonus)

Deviation from this policy can occur if the team recommends that one member receives “special” treatment (better, or worse...) because of their contribution (or lack thereof).

A warning about working with teams is appropriate: some may think that working in teams allows some people to “get off easy” while other team members bear the brunt of the work. Even more than groups of people with similar skills working together and/or helping one another, teams require that each team member be a strong contributor.

The Customer (“Guest”) Viewpoint

In accounting for the needs of customers, two aspects we have not already considered are

- “Selling” the customer, so that they want to experience your entertainment activity
- “Psyching” the customer: taking advantage of things you know or believe they enjoy, to maximize their enjoyment of this experience.

Both of these are discussed at some length in Chapter 4.

*“same” here means “same percentage” rather than necessarily the same absolute value of raise or bonus

The Provider Viewpoint

We discussed in Chapter 2, in the section where we considered that engineering is only one of several contributors to the total experience, the roles of marketers, product managers, researchers, developers and designers, “manufacturers” (creators), operators, maintainers, and actors.

Whether or not all of these groups are represented on the multifunction team, all of their needs and points of view must be considered. They also need to be encouraged to “buy in” to the project, so that they are willing to work so that the guests receive the full potential of the experience.

Here are some considerations of the needs of the “production team”—the people who fabricate, operate, and maintain entertainment activities.

“What happens when I hand my animatronic figure over to the operations and maintenance crew? The maintenance people, especially if they are very busy, may turn down gains and volumes so things don’t wear out so fast or need oil so often. But then the experience is no longer what I designed. Or, they may have a limited maintenance budget for your attraction. You may have to tell them ‘don’t turn off the fog’.” (Todd Camill, personal communication)

One way that entertainment engineers can approach serving the needs of the production team is to design a product with all of the “DFXs” (“Design fors...”) accounted for—especially

- Quality
- Usability
- Reliability
- Maintainability
- Safety —for themselves as well as for guests

CHAPTER 4

Entertaining the Guests

Understanding the Customers

Pre-Reading: If you have access to a copy of the *Imagineering* book (The Imagineers, 1996), you may want to read Chapter 2 before proceeding.

What makes an attraction “entertaining” and perhaps “thrilling”? How people respond to entertainment experiences depends in great part upon how they are affected physiologically and psychologically. Let’s consider three possible ways we can affect guests to make this happen:

Physiological effects

The Psychology of Entertainment

The guests’ psychological predispositions, and the ways in which the entertainment activity interacts with them.

Guest Expectations, which we strive to create with reputation, feedback from others, advertisements, and “theming,” where guests are presented with words, sights, sounds, etc., related to the attraction, before they actually begin the experience.

Physiological Effects

Physiology is most clearly an issue in *thrill rides* and *simulator rides*, where we will discuss it. But also consider

3D Movies and TV shows, and the glasses people need to view them (more about this later)

Seemingly trivial “4D” physical effects in experiences like Disney’s *Honey I Shrank the Kids* and *It’s Tough to Be a Bug*, that rely more on surprise than actual physiological impact on the guest.

To effectively and safely design entertainment attractions that have more than trivial physical effects, it is necessary to have an understanding of the human body and how it reacts.

Since neither the author nor the anticipated readers are medical doctors, there are limits to the detail with which these can be discussed—but do keep in mind that, as always, the engineering serves the story, including via forces on the human body.

Another consideration is *accessibility* for the physically challenged. Theme parks and amusement parks typically have provisions on many rides for guests in wheelchairs. But what about, for example, obese people? And what about thrill rides? These are worth the attention of experience designers—especially since there always appears to be legislation pending that would require increased accessibility to entertainment venues.

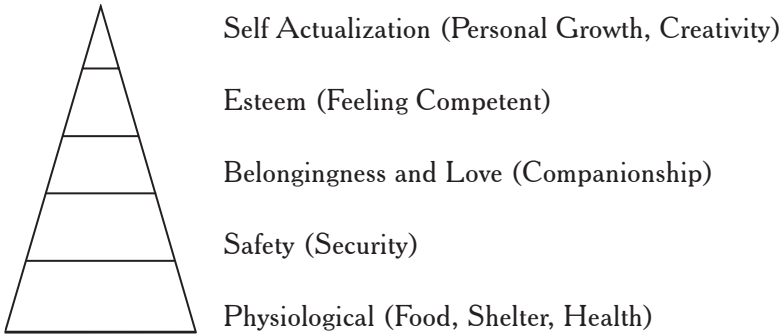
The Psychology of Entertainment

This was discussed with some university Psychology faculty, in the hope that there were some “magic formulas” that would help to understand it, and which could be applied during the design of entertainment experiences. No easy answers were offered concerning how the entertainment experience interacts with guest predispositions, but a tool was identified that can provide some insight into guests’ psychological predispositions:

Sensation Seeking

This interesting tool can help experience designers to better understand their potential customers.

To begin, think back to Maslow's *hierarchy of needs*, which you may have studied in a beginning psychology class. (Maslow 1954)



The underlying concept is that until a person's lower-level needs are met, the individual will not be concerned about higher-level needs. A person without food and shelter will usually not be actively seeking companionship.

At the highest level, *Self Actualization*, Maslow postulated that people seek and enjoy novel and "peak experiences" that are quite arousing, as part of their search for growth and change.

Berlyne & Madsen (1973) considered the capacity of stimuli to command attention, excite the nervous system, or influence behavior. They found that the qualities of stimuli that determine their arousal potentials are intensity, size, color, sensory modality, affective connotations, novelty, complexity, degree of change from preceding stimulation, suddenness of change, surprisingness, incongruity, and uncertainty.

To what extent do people seek out activities that "command attention,

excite the nervous system, or influence behavior”? This leads to a consideration of *Sensation Seeking*.

“Sensation seeking is a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal, and financial risks for the sake of such experience. ... Risk-taking behavior is a correlate of sensation seeking but not an essential part of the definition.” (Zuckerman, 1994)

Zuckerman identified four categories of sensation seeking:

- Thrill and adventure seeking (TAS)
“do it”
- Experience seeking (ES)
“through the mind and senses”
- Disinhibition (Dis)
“even if unconventional or illegal”
- Boredom susceptibility (BS)
“intolerance for repetitive experience”

In his book, Zuckerman includes a short “test,” together with a self-scoring chart, so that an individual can determine their susceptibility to sensation seeking. A person who rates “highly susceptible” on Zuckerman’s “test” in any one of these four categories is likely to actively seek a different sort of stimulus. The bulk of Zuckerman’s book discusses each of the categories in depth, and what demographics tend toward high sensation seeking in one or more of them.

Curious about how you rate? Try Zuckerman’s forty-question test and find out. Information for self-scoring is provided along with the questions.

Pulling It all together: Attracting and Keeping Customers

One of the first things we need to think about is, who are our customers (guests)?

Cedar Point, Walt Disney World, and Kennywood Park; TV stations; a Broadway theater; and the local movie theater all have different audiences.

Consider the three amusement parks listed above. Cedar Point, where they keep adding higher and steeper roller coasters, is competing to offer the biggest & baddest thrills to an audience willing to travel to experience them. Walt Disney World has a nation wide (actually global) clientele, but of families rather than of dedicated thrill seekers. Kennywood, in suburban Pittsburgh, PA, has a local clientele of families. They have world class rides—but none that are too extreme.

TV programmers are incredibly attentive to who their customers are. Channels, time slots and individual programs are almost always focused on a particular demographic niche. Gender and age are very important to them.

Having decided who our customers are, and what sort of entertainment they want so that they will keep coming back, we need to take steps to let them know what we have to offer, and attract them to come experience our offerings.

What are some "tools" for attracting customers? Consider these:

- Location
- Uniqueness
- Superlatives

- Reputation
- Advertising
- Themes

Think about each of these.

Location

- “Nearby” a lot of potential customers
 - It is easy to get to a nearby attraction
 - It costs less to go to a nearby attraction
- In an area with other Attractions
 - On the New Jersey Shore
 - In Las Vegas
 - In Orlando, Florida

Uniqueness — “There’s nothing else like ours!”

- National Parks and Monuments
 - The Grand Canyon
 - Yellowstone’s geysers
 - The Statue of Liberty
- Some Las Vegas attractions
- Punxutawney and the Groundhog

Superlatives — Ours is special because it is

- The Biggest
- The Fastest
- The Longest

- The Longest Running
- Has the Best Cast
- ...

Reputation

- Corporate
 - Disney, Universal Studios, Six Flags
- Movies rely on
 - Stars & Directors
 - Based upon Books
 - Sequels
- Theater relies on
 - Authors
 - Stars

Advertising

You've probably encountered all of these (and some more) forms of advertising.

- Movie Posters and “Trailers”
- Paid ads everywhere...
 - As Universal Studios competition in Orlando heated up, Disney started putting up roadside billboards along the road toward Walt Disney World, advertising specific Disney rides.
- Reviews in newspapers and magazines are “ads”
- Awards Presentations are “ads”

- Awards shows on TV
- “We won an Oscar, so we must be good!”
- “Product Placement” in movies, TV

Themes and Theming

Once we’ve caught their attention, how do we get them to participate?

One way is with a *theme* that catches and keeps their attention, and makes them want to have *more*.

While not always necessary, a well-executed theme can add a lot to the total guest experience.

A theme certainly can make an attraction more memorable. Which would you remember more positively, a tiger pacing in its barred cage or a tiger seen from the walls of a ruined Indian temple?

Theming Can be Used in Different Ways—as an enhancement to the attraction’s experience, as an attention-getter, and as a means of keeping up interest:

- The Theme integral to the Attraction
- Theming “Outside”
- Theming on the way in
- Theming on the way out

Giving the attraction a theme—so that it is not just another roller coaster but it is the Cyclone, or the Wooden Warrior—which usually involves added sights and/or sounds that add to the experience, and so makes it easier to remember.

Some other examples of themed attractions are

- Classic “Dark Rides” (Tunnel of Love)
- “4-D” Movies/Shows
 - *Honey I Shrunk the Audience*
 - *It’s Tough to be a Bug*
- Special Attractions
 - *It’s a Small World*
 - Disney’s *Haunted Mansion*

Theming outside of the attraction can include

- Distant ads, to catch your interest (and maybe re-direct your path)
 - *Wall Drug* in South Dakota
 - Early movie trailers (6 months out...)
- Local ads to attract your attention and overcome your resistance
 - Posters and other ads within the park or on the theater building
 - Radio and TV ads
 - Testimonials
 - “Pre Show” for *Golden Globe Awards*

Theming on the way into the attraction serves a couple of purposes:

- Sets the stage and creates a mood
 - Gallery of famous fliers at *California Soarin’*
- Keeps you from noticing the wait
 - “Travel Agency” entrance to *Star Tours*
 - Movie trivia questions before movies
 - A country music group in the outer lobby of the *Grand Ole Opry*

Theming on the way out of the attraction

- Solidifies the (Sponsor's) Message
 - GM Product Show at Epcot's *Test Track*
 - At the end of Epcot's Norway Pavilion ride you are led in order to a brief movie, a travel desk, and a gift shop.
- Capitalize on your Interest
 - Epcot's Imagination ride leads you to an imagination-themed activity area
 - Several Walt Disney World attractions lead you to themed sales areas.

Keeping Our Customers—Building Loyalty

- Provide an excellent *Total Guest Experience*
 - “I liked being there/doing that.”
 - “They care about *me*.”
- Keep Current
 - Constant updating

Thought Exercise

Consider your own personal entertainment experiences:

Pick some Entertainment attraction (park, movie, play, etc) that you and your family or some friends visited/attended and enjoyed. (To help you see the relationships to what we've been considering, you may want to write a couple of paragraphs about the experience.)

1. What was the attraction and what led you to you decide to go there?
2. Which category of motivator (location, uniqueness, superlatives, reputation, themes, advertising) best describes what it was that led you to decide to go there?
3. Did the attraction meet the expectations that the motivator had created? Why or why not?

CHAPTER 5

The Role of Story

What do *stories* have to do with engineering?

While *stories* are pervasive in the world of entertainment, engineers are not usually taught to think of their design work in terms of *telling stories*. But if you think about it, almost everything, artifact or action, has a story associated with it. Where did the underlying idea come from? What needs will it meet? Why has it acquired the form it has? How was it developed, from concept through details? Peter Lloyd (Lloyd 1998, pg. 120) says it succinctly: “by telling a story, one is saying ‘this is how this something came to be this something’.”

“Storytelling merges the product’s potential capabilities with the vision of what the ultimate experience could be for the user.” (Cagan 2013)
Seemingly engineering design could benefit from taking this classic tool in entertainment and “redefining it for corporate life and as a methodology to drive product innovation for consumers.” (Cagan 2013)

Mk Haley, a Walt Disney Imagineer who has also taught in the Entertainment Technology Center at Carnegie Mellon University, shared this from a conversation she had with astronaut Story Musgrave: “humans only actually learn from stories. ‘fire is hot, put your hand on it, it hurts, ouch, lets not do that again, the end.’ Few humans can comprehend math by just numerical data alone. We learn by adding things, apples, trains, family members, to other things, that we get more things. The story gives the work context, and therefore easier comprehension.”

Paul Steif from Carnegie Mellon has followed this idea in a *Mechanics of Materials* text he recently published (Steif 2011). Prof. Steif does not start out with even the most elementary of formulas. The first illustration the student sees in the introductory chapter is of a bookshelf that is bending under the weight of the books lined up on it. An attached text balloon says “I need to do something about that sagging shelf.” Steif goes on to say that “Mechanics of Materials can help with that,” and from there begins a discussion of how statics can lead to a better design for the shelf.

Lloyd cites an even more fundamental tie between designing and storytelling: “Designing is described as an activity that depends largely on experience, and as storytelling is a way of explaining experience, it seems a particularly apposite means of explaining designing.” (Lloyd 1998, pg. 121)

Storytelling has clear applications throughout engineering development, design, and manufacture.

How will the customer or other end-user use the device? Can you tell a story, following the user through the steps of preparing the device for use, and then actually using it? Could any steps be made simpler or more intuitive? Could any change make the device safer to use? What about the user interface? What sort of feedback does the user receive during use? Could the feedback be made more meaningful or useful?

What about manufacturing? How are the individual parts made? For example, if a part is to be turned on a lathe, what sequence of steps best enhances productivity without compromising safety? How about assembly? Will all the needed parts, including fasteners, be available when needed; has anything been overlooked? Is the assembly sequence optimized for either machine or human assembly, as appropriate?

All of these activities can be portrayed by stories, following the users or manufacturers through the steps they take. A Storyboard (described later in this chapter) can help visualize the story, and also can easily be adjusted to see if changes in work or use flow might enhance the device.

If you have ever unpackaged a brand-new Apple Macintosh computer, you have encountered an excellent example of where the manufacturer has thought through the user's "getting started" scenario—their "story": the first thing you encounter when you open the outer shipping carton is an inner package labeled "Open Me First". This contains setup instructions, the instruction manual, and other things you will need to get going with your new computer. Then you get to the computer itself.

It is not hard to see that the story associated with a product or service can serve as

- a customer (guest) motivator/attractor
- a starting point for concept development
- a guide along the way as the concept is fleshed out

Stories may help you to convey to your customers, your colleagues, and your leaders what you are trying to accomplish.

Cagan and Vogel point out additional value that may derive from fully understanding the needs expressed in the customer's story. Obtaining a product that really meets their needs enables the customer to feel great satisfaction—almost a "heroic" feeling—that they have successfully completed a quest. (Cagan 2013, pp. 238-241)

Concept Development

Once you have the basic story in mind, what next?

In any creative activity, including engineering design, *concept development* is a necessary and difficult early stage.

Based upon your knowledge and what you have read in Chapter 2 of the *Imageneering* book, what are some ways of getting ideas for a new design concept?

How about:

Brainstorming. The purpose of *brainstorming* is to generate ideas—lots of them—to meet a goal or solve a problem. The idea is to bring together a group of people who have some stake or interest in solving the problem, and encourage them to put forth as many ideas as possible.

The ideas are all spoken aloud as they are being recorded, creating the possibility that one person's idea will spark another member of the group to think of yet another possible solution. Critical to the free flow of ideas is that there can be no criticism of any idea put forth during the initial brainstorming session. Any critical statement (or even critical facial expression) may not only squelch the idea being criticized, but may also make other members of the group reluctant to put forth any of their own “wild” ideas.

Once the flow of ideas has stopped, the group can then begin to evaluate the collected ideas, seeking the few that may be worth pursuing to another level of detail.

If you wish to learn more about brainstorming, see (Osborn 1963).

Idea Mapping. “Idea Mapping is a graphic method of stimulating creative thinking. It is based upon Mind Mapping®, developed by creativity consultant Tony Buzan in the mid 1950s. This tool involves a visual pattern of connected Ideas similar to a roadmap or blueprint.” (Coursebook 1995)

Figure 5-1 shows a representative *Idea Map*, to help developers identify what needs to be done to come up with a plan for creating a new themed restaurant. Starting with the end goal in a central

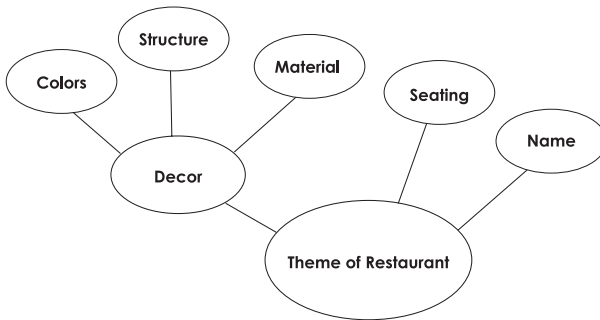


Figure 5-1

balloon or box, add other balloons feeding into it that identify the major topics that must be resolved to achieve the end goal. Then consider each of these major topics (“décor” in the example), and add balloons feeding into it that identify the subtopics that must be answered to realize that major topic.

Concept Art. If someone (perhaps the person who suggested the new product or service or entertainment activity in the first place) has created a picture describing their idea, this can be a really good starting point for Concept Development.

Role Play. This is not just for people playing games, although there exist a number of well-developed and exciting role-playing games (RPGs). (To learn about some, check out the program

from a game players convention, such as *Origins* or *Gencon*.)

Acting out (role playing) how some product might be used or how some service might be implemented can provide useful ideas from which to get started with development.

Script. Much like a piece of concept art, an already-written script describing how something is used or carried out can provide an excellent launching pad for undertaking development.

Storyboarding. A *storyboard* is a display clearly showing how a story flows, from its start (“concept”) through its culmination.

A *storyboard* is a sufficiently useful tool, both during its development and in its completed form that the idea is considered at length in the next section.

(A script can be viewed as a “text storyboard”.)

Storyboarding—A Very Useful Tool

“A *storyboard* is a visual representation of the steps needed to bring an idea to fruition. It is the bridge from *dreaming to doing*. Storyboarding is also an effective presentation tool. It enables your audience to ‘see’ your vision in an organized and logical progression.” (Coursebook, 1995)

Traditionally, a *storyboard* is a panel (perhaps a large bulletin board) or other large flat surface on which are mounted conceptual text clips, sketches, or other graphics, which, much like the panels of a comic strip, show the flow of a story. Probably originally used for the development of a motion picture film, a storyboard can aid in developing any story so that it is complete and flows smoothly to its conclusion.

Does this sound like any tool commonly used by engineers? How

about a flow chart? Except that an engineering flow chart typically

- is created on a sheet of paper, instead of on a large, public space,
- is built from individual boxes each of which refers to a known activity or process or an intermediate milestone, and
- the passage of time (intervals) defines the positioning of the boxes on the flow chart,

Flow charts and storyboards are quite similar. The biggest differences are that storyboards

- go into much greater detail, sometimes as far as each panel representing a single scene in a movie,
- communicate their ideas to everyone who cares to check them out—often inviting suggested changes.

A colleague related this story: before filming of a movie began Alfred Hitchcock would cover his office walls with detailed drawings of each shot he wanted. Then these would be bound in a scrapbook and handed to the cameraman. Hitchcock didn't need to look through the camera. He knew what would be in the picture.

The concept of developing a storyboard is straightforward: once you know what it is you want to create, build the story leading to that end result in ever-increasing detail by adding “panels” to a display that is pinned or taped or magnet-ed to a bulletin board, a wall, or some other large surface. Each panel can include words or pictures or both. Start with a beginning (perhaps a goal statement) and an end (a description of what it is you want to create), and fill in the middle. Add increasing levels of detail where it is useful to understanding, and move chunks around to improve flow. One thing to be sure of is that the “story” should always be clear to someone who views the developing storyboard.

Figures 5-2 and 5-3 illustrate the beginning of a storyboard.

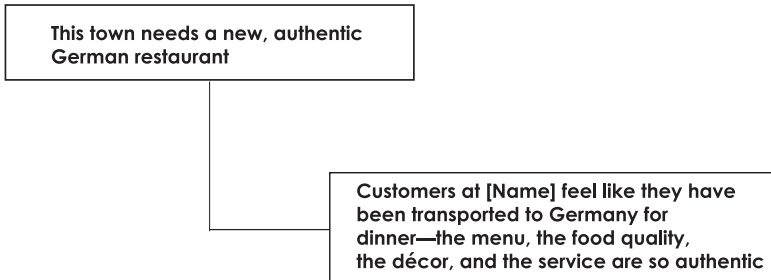


Figure 5-2

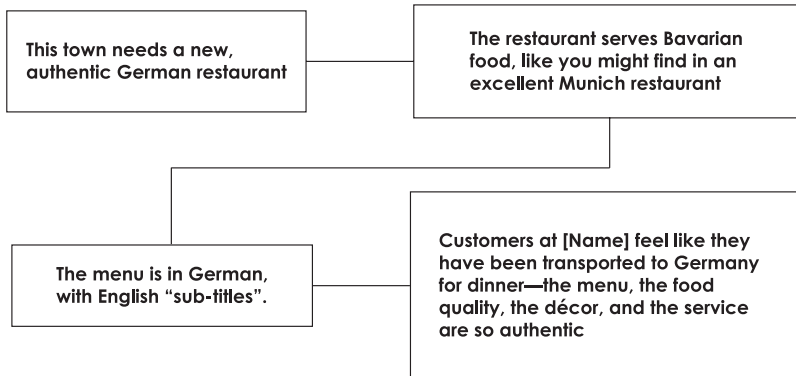


Figure 5-3

The Walt Disney Company has from their beginning used storyboards as a method for creating movies. As an example of how key storyboards can be to developing an entertainment experience, my page-a-day Disney calendar for 2003 said on one day's page that *One Hundred and One Dalmations* "was the first Disney animated film to have a fully written script. Previously, the plots were worked out primarily in storyboards."

Special effects company Industrial Light and Magic uses storyboards to carefully plan their effects. “From the shooting script and verbal instructions from the director, a *storyboard* is created. It becomes the blueprint for the special effects. Each drawing fits on a standard form with an area for a drawing of the scenes and below that, an area for a list of specifications... When the storyboards are completed and the sequences are finally approved, they are duplicated and put in large three-ring binders. ... A complete set of these storyboards is also put on a bulletin board that runs down the main hallway in the center of ILM. If anyone is ever in doubt about what a shot looks like or where it belongs in a sequence of shots, they refer to those storyboards. In the case of *The Empire Strikes Back*, there were almost 500 pages of storyboards. On *Return of the Jedi*, there were close to 1,000—a storyboard for nearly every special effects shot in the show.” (Smith 1981)

I once saw the plan for a new *Boy Scout Handbook* in the form of a storyboard filling an entire hallway at the Boy Scout national headquarters in Texas.

Creating the Story Board.

For flexibility in reorganizing things or adding detail, use individual sheets of paper, or file cards (3 x 5 or larger), or Post Its®. Put one idea on each panel (sheet or card or note). Expand ideas on additional pages, which are inserted into the developing story at the appropriate places. (You’ll end up moving panels around a lot!)

While the story typically flows in a straight path through the storyboard, there may be branches. An example would be in a movie, where the special effects needed to enhance some part of the story appear in the storyboard as a branch entering where they will appear in the movie. Or in a storyboard representing the development or manufacture of a

product, information or components needed from an outside source might also appear as in-feeding branches to the main flow of the story. It may also be important to superimpose the storyboard upon a schedule of critical dates such as deliverables.

Use color coding on the panels if it will provide clarity. The panels representing one particular department's work might be a unique color, so that viewers know who is responsible for what.

Next Steps

Once the concept seems to be well developed, the next step to more complete understanding might be to create

- animatics (rough video or moving picture versions of a storyboard)
- mock-ups or models
- refined script, concept art, storyboard

Or it may even be time for a clear “go ahead:” “OK to shoot” the movie, or “OK to develop” the product.

At this point, parts of the refined storyboard may become the flow chart for ongoing development, the manufacturing process, or perhaps even the marketing campaign.

Try It: A Do-It-Yourself Exercise

Try one or more of these tools, to get a sense of what they might do for you at some future time.

If you've never participated in a *brainstorming* exercise, look for an excuse to try one. If someone you know has brainstorming experience, maybe you can enlist that person to lead the exercise. A group of four or

five people may be large enough to be fun and provide some interesting results.

Using either the results of the brainstorming or some problem you'd like to solve, try creating the start of an *idea map*. The problem could be real, for work or home or a hobby, or it can even be something totally fanciful, like taking a trip to Mars.

Storyboarding can be both more difficult and more fun. If no new idea comes to mind, you could try creating a storyboard for some familiar story, perhaps the current story arc in your favorite comic strip. If you can think about something new and personal, like going on a camping trip, try creating a storyboard for how you would get ready for that trip. Avoid doing a simple “process flow chart.” Visualize yourself getting ready for the trip, starting with psyching yourself and your companions to getting excited about going camping at some exciting new place—perhaps a National Park.

PART II

Engineering in Specific Types of Entertainment

Part I of this book basically set the stage for our study of *Entertainment Engineering*. After presenting some basic introductory ideas, and guiding you, the reader, to think about your personal entertainment preferences, we considered some fundamental issues that affect the way engineering contributes to the world of entertainment:

- the importance of the “total guest experience” in determining the success of an entertainment activity
- engineering’s near-ubiquitous role in entertainment activities
- engineering is one of many different contributors to the entertainment experience
- the critical role of *safety* in entertainment
- entertainment is a *business*

We also took a *Systems View*, pulling together all the pieces, and then looking at the final entertainment “product” from both the customer’s (“guest’s”) viewpoint and the provider’s viewpoint. As part of this we considered the influence of a guest’s psychological perspective on their experience.

Finally we looked at *storytelling*—a concept that while commonly a part of entertainment activities probably has a greater potential role in engineering projects of all sorts than most engineers think about.

In this second part of the book, we will look at the specific roles that engineering plays in different types of entertainment. We start with “passive” types of entertainment, where the “guest” sits back and is entertained

by a book, a theatrical production, or a motion picture. Then after an introduction to more “immediate” forms of entertainment by looking at the animatronic characters you might encounter at an amusement park, we look at parks themselves, and then features of parks like thrill rides—including “simulators” which provide a ride experience without the guest actually “riding” anywhere.

We wrap up by looking at forms of entertainment you can enjoy without leaving home, including the growing role of video games, and then by a quick look at several forms of entertainment that we may not always think of as “entertainment.”

As you read these chapters, keep in mind the key issues identified in Part I:

- the *total guest experience*
- the role of *storytelling* in providing the total guest experience and in creating the experience “product”
- important as it is, engineering is only one of many contributors to creating the entertainment experience
- the critical role of *safety*
- entertainment is a *business*, which must make money

CHAPTER 6

Print Media

Print Media (Briefly)

The technical apparatus and activities involved in printing take place behind the scenes, before the readers get hold of the product to be entertained by reading it. There is a lot of very nifty engineering employed in the printing business, but only very rarely is a member of the reading public exposed to it.

Let's first think a bit about the end product.

Syndicated comic strips are hot property these days, as are *graphic novels*. People are supposedly reading more books than ever. Surprisingly, young people have been reading a series of incredibly long books—that many predicted they would not take time to read: the *Harry Potter* novels.

A comic strip I enjoy is *For Better or For Worse*, a supposedly autobiographical strip written by the wife of Canadian dentist. One reality check: the outdoor model railroad which appears now and then in the comic strip was profiled in a model railroad magazine a few years ago.

Like many “comic” strips, this strip is not always “funny”... Consider for example the colored weekend strip in which the father speaks with a child he encounters in the supermarket, only to have the young girl's mother tell the girl not to talk to “that man—we don't know who he is.” He returns home shaken. His wife tries to comfort him by saying that the woman was just “protecting her child,” but he still feels (in the last panel) that “It's just that now and then, I hate the world we're living in.”

Ms. Johnston's Memorial Day and Veterans' Day strips have been especially poignant, focusing on the ones who did not come home to wear the poppies or march in the parades.

As her two oldest have gone to college, there have been a bunch of very recognizable stories about the trials and tribulations of parents with youngsters in college.

Are you at all familiar with the comic books published by Vertigo—especially those written by Neil Gaiman, Charles Vess, and their colleagues? Consider the *Sandman*, and the *Stardust* graphic novels.

How about *Bone*?

These are not your standard *Marvel* or *DC* comics, filled with super-hero adventures. They are also unlike the “soap opera” strips that also are newspaper comic page staples.

There also seem to be more printed books than ever. Some are by-products of computer technology, which has permitted individuals to self-publish small print runs of specialized books. There also seem to be more engineering text books, with new approaches to familiar engineering topics by teachers from around the world.

There is, of course, another side to the story, as the proliferation of “E-Book” readers makes it more and more possible to widely disseminate books and newspapers without ever printing them. At this point in time, there still appears to be a big market for printed books—if for no other reasons than the ease in dog-earing pages and highlighting text of personal interest.

Two questions that are still not settled are:

- providing E-publications with the same quality of experience and convenience that people are used to with printed materials. The trade-offs will surely continue to evolve.
- insuring the accuracy of material published without necessarily ever having been reviewed for content or language—which is the case for some E-published material.

But printing is still with us, so let's take a quick look at some of the engineering that underlies print media.

Printing

Printed entertainment material mostly comes in one of two forms:

- Newspapers—mostly large format documents, created and printed daily, with the pages assembled but not “bound” (fastened together).
- Books and Magazines—usually not larger than “letter” size paper (8.5” x 11”), printed in lots, with the pages usually bound together in some manner.

Where does engineering come into this picture? It all occurs before the documents are made available to entertain customers. The finished products are sold in many ways in many places, from dedicated book stores to on-line vendors.

The content of print media is created today using computers. The computer output is used to create printing “plates,” which are then used in printing “presses” to transfer the content to paper. Printing machines are called “presses” because for many generations, pressure was used to transfer ink from the printing plates to the paper.

Printing remains a *very* mechanical process. To see a newspaper being

printed and prepared for sale is a special experience. Huge rolls of paper are mounted to machines which speed the paper past printing plates mounted to rollers. The printed sheets are then cut, folded, and assembled on the fly. Some newspaper companies have presses arranged so that they can be seen from the street or some other space open to the public; if you get a chance to watch the process, do check it out!

The increasing use of color in magazines and newspapers is testimony to the continuous improvement of printing equipment and processes.

To learn something about printing presses, you might visit one or more of these websites:

- Pamarco Technologies
– www.pamarcotech.com
- Heidelberg
– www.heidelbergusa.com
- A. B. Dick Co.
– www.abdick.com
- Goss Graphics
– www.gossgraphic.com

This is complex, high-tech equipment!

Assembling Documents

Assembly of books and magazines is similar, with books being more complex.

Pages are first folded and gathered into *signatures*. A *signature* comprises a number of pages stuffed together against the fold. Think of a thin

magazine like a comic book. It is made from one signature, with the pages being held together by two or three staples along the fold. This is called *saddle stitching*; the stapling is done with the folded pages laid across a form of saddle that provides the backup for the stapler.

Technology used in this process includes machines for cutting, folding, and assembling the pages, and then another machine for stapling them together.

Something to think about: when the material to be printed is organized for the press, the pages must be arranged so that when they are cut, folded, and assembled into signatures, they are all in the desired order!

The process for creating a magazine or book is more complex because several signatures must be gathered together to form the product. Typically each signature is held together by thread stitched along the fold—a different form of saddle stitching. The several signatures that go into the book or magazine are then stacked, and glue is applied along the folded edge. A “standard” method for books is to place a piece of gauze-like material along the back edge of the signatures, and then to apply glue to fasten the signatures to the gauze.

A cover is then applied. For a magazine or paperback book, the cover may be glued to the assembled stack of signatures. For a “hard cover” book, the process generally involves including “end papers” in the assembled stack of signatures, and then gluing the cover to the end papers (Figure 6-1).

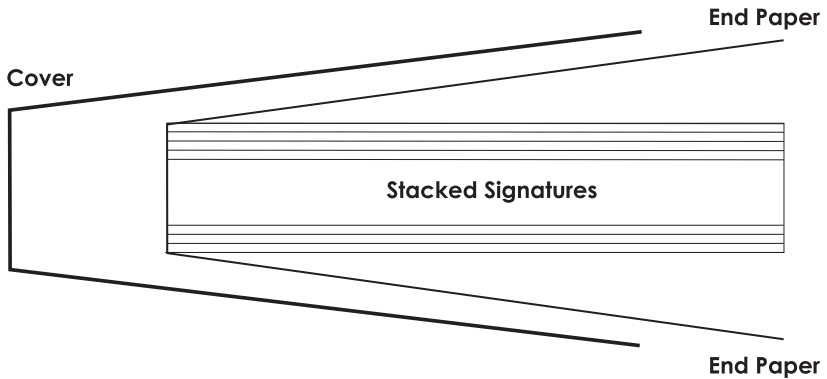


Figure 6-1

Assembling a Book

The machinery for doing all of this automatically in mass production is also very specialized and complex! Special books, with “fine” leather bindings (covers), get even more special treatment.

Afterword

We are surrounded by all kinds of printed material, from form letters and bills we get in the mail, through newspapers, and books of all sizes and sorts. Most people never think much about what it has taken to create these for us, at what are typically quite low prices. The behind the scenes technology is quite sophisticated and, via computers, becoming more so all the time. There is a lot of very nifty engineering employed in the printing business, but only very rarely is a member of the reading public exposed to it.

CHAPTER 7

The Theater

Introduction to the Theater

How familiar are you with the live theater? Have you ever attended a play? Did you enjoy it? Have you ever played a part in a play?

Whether or not you have attended a play, and if you have been in a play but it was a while ago, take a break before you go on, and read a play book that includes stage directions, production instructions and descriptions of sets and set changes. It should be easy to find one at a library. Pick a play that you have enjoyed seeing, if not live on stage perhaps in its movie form. As you read, pay special attention to notes about sets, and stage directions

What did you engineers see in the play that caught your engineering attention? How about set elements like part of a house that is sturdy enough to safely support actors “upstairs” yet light enough to be moved out of the way to provide space for a different set in the next act? What other engineering things go on to make a theater production happen. Here’s a scenario that may jostle your memory:

Here we are at the entrance to a Broadway Theater. It’s a hot, humid summer evening in New York.

We go in, present our tickets to an attendant, and are led to our seats.

Notice how comfortable it is. Mechanical Engineers who specialize in “Heating, Ventilating, and Air Conditioning” have designed systems to keep it that way.

The tickets say the show will begin at 8:00. At 8:00 sharp, as the last few patrons are being seated, the house lights dim (thanks to a control system), the curtain opens (powered by a winch), and we are looking at the inside of a two-story house.

Before we go any further, think of the level of reliability required for this all to happen smoothly, day after day...

The audience does not expect that at 8:03 a person in will come out in front of the curtain to say that the curtain drive motor has apparently failed, the repair person is on the way, and the play may be able to start by 9:00.

Somehow, everyone assumes that the systems will all work as planned. But that does not happen by accident, it happens by design.

A person enters from the left, throws a light switch on the wall, and the first floor is bathed in uniform light—that control system again. The person goes to the stairs visible at the back of the stage and calls a name. Upstairs another person comes out of a “room,” replies, and comes down the stairs. The temporarily constructed second floor and stairs are strong enough to support the actor—structural design at work!

An hour later, after a brief (15 min.) Intermission, the curtain goes up again. What? Where is the two-story house? We are now in a garden, with a fountain bubbling at the back left of the stage. Where did the house go? Where did the garden come from?

Another mechanical system lifted the house up out of sight and lowered scenery to form the garden. The fountain, powered by a mechanical pump, was lifted up from beneath the stage—by a hydraulic piston.

And this happens routinely, five evenings and two afternoons a week, hopefully through several seasons of extreme heat and cold. It only happens thanks to good design, using well-engineered, super-reliable components and systems.

The set is on stage to help establish the illusion that the actors are creating. The actors and the set are what the audience sees—and hopefully are captivated by.

The engineering contrivances are out of sight and out of most people’s minds. They are critical, but hopefully they remain invisible by performing as expected, “on cue”.

Have you ever experienced an engineering systems failure during a play that you attended? Probably not, they’re usually engineered very well.* The potential loss by disappointing an audience is too great to risk.

If you have a friend who is involved in a local theater activity, you can get an even better feeling for the role of engineering in the theater if your friend can arrange a behind-the-scenes tour for you.

Safety in the Theater

Because the stage is occupied by people who are deeply involved in the play, and the theater is (hopefully) filled with a live audience, there is a very strong focus on *safety*. One of the ways this is provided for is by using what may seem to an engineer to be unusually high Safety Factors in structural design in a theater:

- Objects hanging over the stage: 8:1

* There was a Spiderman play that had regular (and very public) failures.

- Objects hanging over the audience: 10:1
- “Flying” actors: 10:1

Safety is a special issue when actors “fly” above the stage. Body harnesses like those used in mountain climbing are used, with the general safety factor of 10:1. Systems are checked daily, and only certified operators can work the flying apparatus.

After an earlier effort died, there is at the time of this writing once again a project under way to come up with a standard for the design and use of manual systems for flying performers. This is part of an industry-wide Technical Standards Program, being worked by volunteers and in conjunction with the American National Standards Institute (ANSI).

Theater Problems

A good way to get a taste for how engineering concepts are applied in the theater is to try some problems. Let’s begin with three simple, static-load problems. Data useful to the solution is provided in Table 7-1, and solutions are provided at the end of the book.

Problem 7-1. A production requires hanging a set of electric lights under the theater *tension grid* (support structure), over the orchestra pit. They will be hung down from the grid with three picks (lengths) of cable to support a length of pipe from which the lights themselves will be hung. At each support point, a double wrap of chain around the pipe facilitates hanging the pipe from the cables, using a shackle. If the pipe is a 21 ft length of schedule 40 pipe (2.72 lb/ft), with 14 lights hung from it (25 lb each), what is the proper size for the shackle connecting the chain to each cable? (See Figure 7-1 for an illustration of a typical shackle, and Table 7-1 for shackle load data.)

Don’t forget to apply the appropriate safety factor(s).

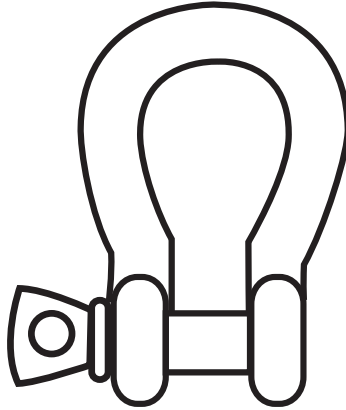


Figure 7-1

Used for attaching a chain to an object or cable

Problem 7-2. Another production is hanging a 1000 lb scenic portal. If the unit is hanging from four (4) picks of cable, what is the proper size jaw-jaw turnbuckle for an adjustable connection?

Again, see Table 7-1 for component data, and don't forget to use the appropriate safety factor.

A "jaw-jaw" turnbuckle has at each end a means for bolting it to an eye of some sort, like a shackle. You may have a small turnbuckle for tightening a wire diagonal brace on a home screen door.

Problem 7-3. For an upcoming festival, the producer wants to hang LED video screens in the theater, house right and house left in front of the sidewalls. The screens each weigh 3600 lb and come with rigging bumpers (the weight of the bumpers is included), but require an eyebolt for each of two picks. What size eyebolt is appropriate for this application?

Once again, see Table 7-1 for component data, and don't forget to use the appropriate safety factor.

Table 7-1

Here are basic data for the three common pieces of hardware called for in the three problems. WLL (Working Load Limit) is given in pounds, and there is an extra 4:1 safety factor built in to the WLL figures (which means that the actual load that can be supported is 4x the stated WLL).

* * * * *

Size	Shackle WLL	Turnbuckle WLL	Eye Bolt WLL
3/16"	666		
1/4"	1000	500	500
5/16"	1500	800	800
3/8"	2000	1200	1200
1/2"	4000	2200	2200
5/8"	6500	3500	3500
3/4"	7500	5200	5200
7/8"	13,000	7200	7200

* * * * *

If you talk to someone professionally involved in the theater about the roles engineers play in producing plays, you may encounter some resistance. There is a perception that engineers take too long to figure things out. A lot of theatrical design is done in-house, using experience, heuristics, and seemingly-high safety factors. Engineers do participate in the design work, but very often they are working behind the scenes for the companies that supply apparatus and equipment to the theaters and show producers.

CHAPTER 8

Movies

Engineered Special Effects for Sets

Motion picture sets are created in several ways, including

Full-Size Sets

Hardware Models

Digital Models

Matte Paintings

Combinations of any or all of these

Let's consider each of these

Full size three-dimensional Sets (“Practical”). The most common sorts of movie sets are “the real thing”—the movie is photographed using real buildings and their surroundings. These may be in the place where the action is supposedly taking place, using the actual city streets and buildings and paraphernalia. Or the set may be specially constructed for the movie, perhaps to represent a frontier town or a battlefield. If such a set is large enough, it will be out-of-doors. If small, it may be on a *sound stage*—a large indoor space outfitted with lights and other necessities to facilitate shooting the movie.

We've all heard about sets that consist only of false fronts along a street. But how about the front part of a battleship? In *Pearl Harbor*, such a set was used to photograph a scene where as the ship capsizes, sailors fall from the deck into the water. The complex movements of individual sailors falling off the tilting deck into the water would have been hard to portray with computer graphics, so a model was constructed of the front

fifth of the ship, from the bow back to the first of the main turrets. This was mounted to a structure that could be rotated and tilted. Stunt actors were filmed struggling to maintain their footing on the tilting deck. These shots were later mated with digital images of the rest of the ship and the raging battle. (For more on this, see the article by Jody Duncan in *Cinefex* #86, July 2001.)

A special category is *augmented make-up*, where an individual who is going to play a part in a film is made up to look like some specific other person, or perhaps a non-person such as an alien, a zombie, or an animal. A good example is when the “creature” is larger than the actor inside the make-up, so movements are mechanically extended and enhanced.

Augmented makeup often involves *prosthetics*—pieces, often of special rubber formulations, glued to a person to make them look different: older, or like some non-human creature. These range from separate pieces, to whole-head masks. In the movie *Harry and the Hendersons*, which is about a family that adopts a gentle and soulful Sasquatch they have inadvertently run down on a mountain road, the Sasquatch is played by a 7'-2" actor, but suitably animating the long face was beyond the actor's abilities. Make-up wizard Rick Baker constructed a prosthetic for the eight-foot-tall Harry that included animated eyebrows and mouth—mechanized by radio-controlled airplane servos operated by three puppeteers! Baker won the Academy Award for make-up for this film—but only after convincing the Academy judging board that his work *was* makeup, and not just special effects. Crucial to the decision *was* the fact that the actor's eyes were Harry's eyes.

To learn more about the use of special effects in movies, take a look at *Cinefex* magazine, a quarterly journal for the trade. Each issue presents an in-depth examination of three or four films. The ads are typically

for special effects consultants, tool vendors, and even schools teaching about special effects in movies. They sell subscriptions, and also single copies for people interested in the effects employed in a particular film. For information visit their web site

www.cinefex.com.

For a good discussion of *augmented make-up*, see the article on *Harry & the Hendersons* in *Cinefex* #46.

With the development of ever more sophisticated computer graphics tools, many movie effects that might in the past have been created using engineered special effects are being provided digitally. There are nevertheless situations where the performance of a live person, or interactions of people with their surroundings are still better portrayed with special effects rather than by digital simulation. With a lot of interaction, especially of several actors, using a full-size set is easier than working with models or computer graphic images.

Hardware models are created in many sizes for many purposes. Often the same model will be created in several sizes for different parts of the same film.

Models may be either immobile, serving as sets, or mobile, like models of ships, planes, or sea creatures.

Extensive use was made of models in the *Star Wars* movies, in an array of scales. They ranged from a full-scale R2-D2 droid to various vehicles each in multiple scales to characters like Jabba the Hut and a Storm Trooper.

In *E.T.: The Extra-Terrestrial*, the space ship and also the boys on flying bicycles were models. In *Indiana Jones and the Temple of Doom*, much of the sequence of Indy and his friends escaping from the temple in

the mine car was shot with a group of models.

Peter Jackson made extensive and very clever use of models in the *Lord of the Rings* trilogy. He favors models over matte paintings and computer graphics because you can freely move the camera around. Models were not just used in the background and for brief shots. The tower and underground workshop models for Isengard were executed to a truly fine level of detail, so that they could be used in close-ups and for sequences several minutes in length. He also likes larger models, because they can be lit more realistically. Some of the models were so large that while they were built to scales like 1:32 and 1:24, they were jokingly called “bigatures” rather than miniatures.

Digital Models. The topic here is not digitally-created animated movies (more on that later in this chapter), but digital models used to enhance movies involving primarily live actors and actresses.

Many movie computer generated images (CGI) begin with physical prototypes—models or people. A model of a creature—a *maquette*—may be constructed to guide the software people on modeling shapes, poses, expressions, etc.

If a digital stand-in is to be created for a live actor, to create some “impossible” or unsafe action, videos may be taken of that actor moving in ways similar to those which will be created digitally. The actor may be fitted with lights on critical points like hands, elbows, knees, etc., to facilitate capturing the essence of their movement. This helps the digital image to fully represent the live actor.

While in this book we are more interested in hardware than in computer generated images, it is worth noting that software tools intended for advanced engineering analysis are also sometimes used in the movies.

In *Reign of Fire*, *The Perfect Storm*, and *Pearl Harbor*, Computational Fluid Dynamics (CFD) tools were used to model fog and water.

Matte Paintings are two-dimensional “backdrops” used to provide an appropriate background scene for a full-size 3D set that can not readily be placed against the desired background. Consider a false-front western town photographed on a sound stage. How can this be viewed against the Rocky Mountains? Or how can the proper background be provided for action on an alien planet? A large painting or photomural can be created and placed behind the set. Or, the set and action can be photographed with a plain blue background (“blue screen”), which is later replaced in post-processing with a desired background, either painted or separately photographed.

Models and Time

Integrating models into a movie so that they appear to be full-size objects moving at “normal” speeds can pose some intriguing problems. A big issue is *time*.

When small models are being photographed, high frame rates can be used to give the miniature the appearance of being full-sized and more massive (and thus subject to normal gravity and momentum). “Most explosions filmed at ILM (Industrial Light and Magic) are shot at speeds in excess of 100 frames per second... Consider the effect of a small explosion that rips apart a miniature spaceship; the entire action may take a half of a second to occur when filmed, but if filmed at 240 frames per second this half-second event becomes a five-second explosion. When accompanied by a powerful sound, it is a convincing event.” (Smith 1981)

Since motion at any instant is effectively linear, the frame rate for shooting the movie so that the action appears “normal” needs only to be faster

than the usual frame rate by the ratio of the linear dimensions of the modeled object to the dimensions of the model:

$$\text{Frame Rate} = 24 \times (D/d)$$

(24 frames per second is a “normal” movie frame rate. With the new *Hobbit* film, it will be interesting to see if 48fps takes off or not)

“When extremely high speeds are needed to achieve the effect desired, there is a technical complication: the faster the camera runs, the more light is needed to expose the film. The miniature landslide shot for *Dragonslayer* at 250 frames per second required more than 10 times as much light to film as it would have required at normal speeds. ... In addition, a miniature shot is more effective when shot at a high f/stop in order to keep both close and distant objects in sharp focus—again the need for a great many lights. Sometimes the lights are so intense and hot that they can only be turned on a second or two before the shot is made, and then must be extinguished the moment the shot is over so the model doesn’t melt!” (Smith 1981)

Another place where time is a factor in making models believable in a movie is when liquids are involved. Water actually presents a variety of modeling problems.

One area of difficulty is with water droplets. The problem is that water droplets do not change size just because you are working with a model. Water droplets are water droplets. They tend to be in a certain size range, and unfortunately, this size range does not scale well. Movie makers have dealt with droplets by doing things like blowing big fans on them, to break them up. This does not work everywhere, because the fans also may move the droplets away from where you want them.

There is a scene in *Indiana Jones and the Temple of Doom* where Indie,

his “friend” Willie, and the boy Shorty are escaping from the temple via a mine car. A wall of water pursues them through the mine. They exit “just in time” onto a precarious cliff face. If you were able to look closely at the water droplets, you would see that they are just too big. The thing that saves the scene is that the viewer is not able, in the available time, to focus on the droplets.

A more technically tractable issue involving water in a movie stems from the fact that models do not behave the same as full-size objects do in water. Model ships in a pool do not necessarily behave like big ships in an ocean. For one thing, big ships pitch and roll very differently in waves.

The applicable engineering here is Fluid Mechanics—especially the role of *similitude*. In Fluid Mechanics, we learn about representing fluid phenomena with *dimensionless variables*. They can be applied through the concept of *similitude* to model fluid flow.

Let’s consider how we can apply these concepts to help movie makers use model ships to represent real naval battles.

There are three conditions of similarity. “*Geometric Similarity* requires that the model and prototype be the same shape, and that all linear dimensions of the model be related to corresponding dimensions of the prototype by a constant scale factor.” (Fox & McDonald, 1985) This will certainly be true for a good scale model.

Kinematic Similarity requires that “the velocities at corresponding points are in the same direction and are related in magnitude by a constant scale factor. Thus two flows that are kinematically similar also have streamline patterns related by a constant scale factor. Flows that are kinematically similar must be geometrically similar.” (Fox & McDonald, 1985)

Dynamic Similarity (“Similitude”) exists when “two flows have force distributions such that identical types of forces are parallel and are related in magnitude by a constant scale factor at all corresponding points.” The two flows “must possess both geometric and kinematic similarity.” (Fox & McDonald, 1985)

It may not always be possible to attain complete dynamic similarity between model and prototype. This is especially true for surface ships. Resistance on a surface ship arises from skin friction on the hull (viscous forces) and surface wave resistance (gravity forces).

What “standard” dimensionless variables do apply in this sort of problem, and how can we apply these so that the ships in the movie do not appear to be models? Reference to a standard fluid mechanics text tells us that for ship models two dimensionless variables must be constant between the model and the ship being modeled:

$$\text{Reynolds Number} \quad \rho VL/\mu = VL/\nu$$

$$\text{Froude Number} \quad V^2/Lg$$

The Reynolds Number is the ratio of inertia to friction force, while the Froude Number measures the ratio of inertia to gravity force.

When surface waves are formed, gravity forces are involved, for the weight of an element of fluid near the free surface is not completely counterbalanced by buoyancy. The critical question is, can both the Reynolds Number and the Froude Number be held constant in modeling ship performance?

The answer is “no”. Complete dynamic similarity requires that both Reynolds and Froude Numbers be duplicated between model and prototype.

Matching Froude numbers between model and prototype establishes the velocity ratio:

$$V_m/V_p = (L_m/L_p)^{1/2}$$

That leaves only the *kinematic* viscosity to be varied to match Reynolds Numbers.

$$\nu_m/\nu_p = (V_m L_m)/(V_p L_p)$$

But there are no fluids other than mercury with kinematic viscosity less than water, and it is only about an order of magnitude less. Mercury would also yield a dangerous and bad-looking substitute for water in which to float the models.

How, then, can we operate the models so that the ships in the movie do not appear to be models?

Experiment has shown that the “wave making” and resistance of the model are sufficiently similar when the Froude Number is held constant. Since g is effectively constant, we end up using

$$V_m/V_p = (L_m/L_p)^{1/2}$$

Thus a 20-foot model of a 500-foot ship expected to steam at 25 knots should be towed at a corresponding speed of 5 knots to hold the Froude Number constant. Then you photograph it slowly, so that when the film is played back at normal speed, the ship appears to be roaring along at 25 knots.

We'll encounter the Froude number again when we consider open channel flow in flume rides.

Animated Movies

“The first duty of the cartoon is not to picture or duplicate real action or things as they actually happen,’ he [Walt Disney] wrote, ‘but to give a caricature of life and action.’” (Canemaker 2012)

Snow White and the Seven Dwarfs (1937) was the world’s first full length animated feature movie. “Its character and personality animation offered, for the first time, a full range of emotions, from laughter to tears.” (Canemaker 2012)

Early animation was created with thousands of hand-drawn transparent *Cels*. Transparent cels reduced the work by drawing the slowly-changing backgrounds on separate cels. Walt Disney developed a revolutionary *multiplane camera*, which featured up to seven layers of background artwork shot by a single camera to give the movie a three-dimensional effect. The distant background was on the farthest plane, with trees and other “background” details on intermediate planes, and the moving characters on the front plane. Moving the camera to track the moving characters had the effect of moving the intermediate planes relative to the far background, creating the impression that a 3D model was being photographed.

The Little Mermaid was the last film to use hand-painted cel animation.

As was pointed out in Chapter 5, Disney animators from their beginning for a long time used storyboards as a method for creating movies. *One Hundred and One Dalmations* was the first Disney animated film to have a fully written script. Up to then, the plots had been worked out primarily in storyboards.

Another way to create animated movies is with *Stop-Motion Animation*. Models with movable parts (arms, legs, etc.) are photographed one

frame at a time, with the models being slightly re-posed between frames. When the frames are projected as a movie, the models appear to be moving naturally.

A form of this is *Clay-Mation*, where the movable models are made of modeling clay. This permits a wide range of modelable motions.

Where does engineering fit into this? Here is a quote from Disney animation artist Rich Moore:

“The artists and writers who design the movie, the animators and actors who bring the characters to life, the engineers who make it all possible, the production team who keeps it all moving smoothly...”
(Frye 2012)

Engineers clearly brought Walt’s multiplane camera to life. They also certainly have had roles in creating some models and modeling tools.

Mixing computer graphic images (CGI) with live actors and full 3D sets has become common. In the middle of the twentieth century combining hand-drawn animated elements into movies was a big step. The first movie in which this was done was Disney’s *The Three Caballeros*, in 1945. Another early application was having an animated bluebird sit on the shoulder of Uncle Remus in Disney’s *Song of the South*.

New Directions in Movies

In the second decade of the 21st century there has been an explosion of movies in 3D. Viewers must wear special glasses, with the two lenses being of different colors or with different polarization. More of the complex cameras and projectors are needed as more films are being shot in 3D and then shown in more theaters.

These techniques are not completely new; 3D movies have been around for a long time but were for years restricted in the theaters in which they could be shown. They also tended to be made only when the action being portrayed warranted the extra cost. Think of the results of an explosion appearing to fly into the audience, or of a bug seemingly flying right up to your nose.

Another “new direction” is so-called 4D movies, where senses beyond sight and sound are stimulated. In the 20th century there were a few attempts at creating “smell-o-vision,” where various perfumes (not always sweet smelling) were blown into the theater at appropriate times. At the Disney theme parks, a couple of “4D” movies sprayed some water on the audience (from the backs of specially-equipped seats), or actuators in the seats and seat backs gave the impression that something (a bug?) was moving behind you in the seat. These clearly required engineering input to create so that they would portray the desired effect without being obtrusive.

CHAPTER 9

Animatronics

Definition

When we speak of *animatronics*, we are talking about life-like, 3D animated figures, human or animal, usually life-size.

These figures are not robots. They are usually not free-ranging, they usually do not gather data from their surroundings, they are externally controlled, they may be externally powered, and they usually do not do any useful work beyond entertaining us.

Simple animated creatures have been around for a long time. Among the most famous are the figures that come out to perform when the clock chimes at the Rathaus in Munich; they are relatively young, dating from 1908. The goal with animatronics has been to create realistically animated figures.

History

Chapter 3 in *Walt Disney Imagineering: A Behind the Dreams Look at Making the Magic Real* contains an excellent introduction to animatronics in the Disney theme parks.

Walt Disney's interest in animatronics began shortly after World War II. Initially Walt wanted to develop a diorama populated by moving miniature figures. He put two of his best mechanical geniuses, Roger Broggie and Wathel Rogers, to work on this. After many weeks of trying, they confessed that they were no further advanced technically than 17th-century automatons. They encouraged Disney to consider full-sized animations, with more room for controlling mechanisms.

Broggie believed that there were aircraft control devices that could let them achieve their goals.

When Disneyland opened in 1955 there were two fairly simplistic animated figures in action entertaining guests. Motion picture special effects man Bob Matthey, Sr, helped to develop the Indian Chief who, while sitting on a horse, waved at the boats traveling on the Rivers of America, and a dancing native found along the shores of the Jungle Cruise. “These ‘cam and lever’ figures, however, were only capable of simple, repetitive motions.” (The Imagineers 1996, pg. 118)

The early 1960s brought many “space-age” advancements in hydraulics, pneumatics, electronics, and computer controls, which enabled the sorts of animation Disney sought.

Plans for Disneyland included the Hall of Presidents, an entertaining introduction to United States history. The central figure of the Hall of Presidents would be a totally animated Abraham Lincoln. Disney’s challenge was to create a talking and moving Lincoln with all the dignity and refinement that a presentation like this would call for.

Disney selected Blaine Gibson, one of the studio’s finest sculptors, to create Lincoln’s head. Working from a life mask of Lincoln taken in 1860, Gibson made Lincoln look “real” by sculpting his model slightly larger than life. (Gibson felt that the attraction’s theater environment would dwarf a six foot, four-inch Lincoln.) A plaster mold was made from Gibson’s clay master, and a flexible plastic material called Duraflex was poured into the mold to create the facial skin.

Wathel Rogers and his team of WED “imagineers” (as they were beginning to be called) designed and built the audio-animatronic Lincoln to rise up out of his chair and address the audience. This mechanical

Lincoln had 14 hydraulic lines to the body and 10 air lines to the hands and wrists. 16 air lines to his head made the face capable of 15 different expressions, from a smile to a frown to a wink.

The ultra-complicated Lincoln project was put on hold when Walt returned from vacation with an idea to create at Disneyland a Polynesian restaurant where mechanical birds would perform at the end of the meal. “As the attraction developed, the performance got longer and the characters became more sophisticated, and finally the meal was eliminated. The ‘Enchanted Tiki Room’ grew into a 17-minute performance, which included 22 ‘audio-animatronic’ ‘performers.’

The entire attraction was controlled by a 14-channel magnetic tape that fed 100 separate speakers and controlled 438 individual actions, right down to turning on the house lights and rewinding the tape player for the next show.” (Poor 1991).

It was the fact that the motions of these early animatronics were controlled and synchronized by the same multi-track audio tape that gave them voices that led Disney to coin the copyrighted term “Audio Animatronics.”

In 1960, Disney got the idea that he could showcase some of his ideas for Disneyland at the 1964 New York World’s Fair—and then bring the shows back to California after the fair to use at Disneyland. He arranged to provide four shows, for Ford, General Electric, Pepsi Cola, and the State of Illinois. For Illinois, at the special request of fair president Robert Moses, the WED imagineers completed Mr. Lincoln. The Lincoln audio-animatronic character was by far the most sophisticated project the WED imagineers had undertaken. They achieved their original goals of having Lincoln move with dignity and refinement. Mr. Lincoln became one of the 1964 World’s Fair’s most memorable Exhibits. It was not alone; the four Disney attractions were later selected as four of the five most popular attractions at the fair.

The General Electric Carousel of Progress from the fair, which today operates at Walt Disney World's Magic Kingdom, was the first "live" stage show ever with a cast comprised entirely of Audio-Animatronic performers.

After the fair, the success of The Enchanted Tiki Room and Mr. Lincoln led to further projects, beginning with Pirates of the Caribbean. If you still have access to the *A Day at Disneyland* video, take another look at the segments on the Tiki Room and Jungle Cruise.

Epcot includes a host of animatronic attractions. The most impressive audio-animatronic applications at EPCOT appear in the "American Adventure." In a 29-minute presentation, a total of 35 superb audio-animatronic characters celebrate the American spirit, from our nation's earliest years up to the present time. Ben Franklin and a cigar-puffing Mark Twain are the guests' animated hosts. At an early point in the presentation, Ben Franklin seems to climb a few steps and walk across the stage; he does not really walk, but it's a great illusion. An animated Will Rogers performs an incredible rope trick, and the hand and body movements of Chief Joseph are nothing short of fantastic. This is a show for audio-animatronic buffs to experience over and over.

The below-stage mechanism that animates the "American Adventure" presentation would make a great show in itself. Underneath the entire theater is a movable carriage on tracks, called by the Imagineers "the war wagon." It measures 65 by 35 by 14 feet and weighs 175 tons. The war wagon carries most of the animated characters in a total of 10 different sets. It moves forward and backward under the control of a gigantic hydraulic cylinder, to position the appropriate set underneath the exact point of the stage, at the precise time it is to be raised into position. Height restrictions under the stage require that certain sets unfold as they are being raised into position and contract as they are being lowered.

Disney has created one seemingly-free-ranging animatronic figure, *Lucky* the dinosaur. Lucky is not really “free ranging.” He tows a cart that provides stability and contains the required power supply and controls. Lucky’s movements are controlled by the “handler” who accompanies him.

Power

There are many ways to animate an animatronic figure, including

- cams, levers, and wires—like an automated puppet, or the old animated figures in German bell towers
- model airplane servos
- stepper motors
- hydraulic actuators
- pneumatic actuators

Cams, levers, and wires are pretty straightforward. Given a low-speed motor, some plywood, some pulleys, and some thin wire rope any of us could probably build a simple figure.

But these figures must be anchored to one spot, so the drive wires can enter correctly and be kept taught.

Model airplane servos are handy. You can buy an entire system, from servos to a control “console” at any well-stocked hobby shop. They give quite precise control. The down side is that they are low powered and have limited motion. In an animatronic figure, they can be used for moving facial features.

Stepper motors come in many sizes and can drive from fine to gross motions, from low to high power. Means must often be built to convert their rotary motion to linear motion, and feedback is often required. High power motors are large. They can require elaborate control systems

Where power is needed for extensive motions of large, heavy figures, hydraulics are very effective. Since the driving “motor” (the pump) is outside the figure, you can get lots of power in a fairly small space. Actuators can provide either linear or rotary motion. On the down side, the high pressures involved require well-maintained sturdy systems; a leak can quickly create a large mess that is likely to be hard to clean up.

Where needed forces are not too high, linear motion is needed over a range of distances, and a compact system is desired, pneumatic controls can be used. They share with hydraulics the advantages of an off-board “motor” (an air compressor). Pressures are not so high, so systems can be quite small. The consequences of a system failure are much less messy.

Multiple manufacturers offer complete arrays of components in several sizes. (See Figure 9-1) There is even a system of very small components sold to model railroaders, to control their track switches and other automations.

Referring to the figure, moving the Input Rod back and forth (manually, mechanically. or electrically) causes the Output Rod to extend or retract. The 4-Way Valve routes compressed air through one Feed Hose to one end of the Cylinder, forcing the Output Rod to move; the other end of the Cylinder is simply vented via its Feed Hose to the room. Inserting Throttle Valves into one or both Feed Hoses enables separate control of the speed at which the Output Rod moves in each direction. Cylinders are available in a range of diameters (larger for more power) and lengths

(for different distances of travel of the Output Rod).

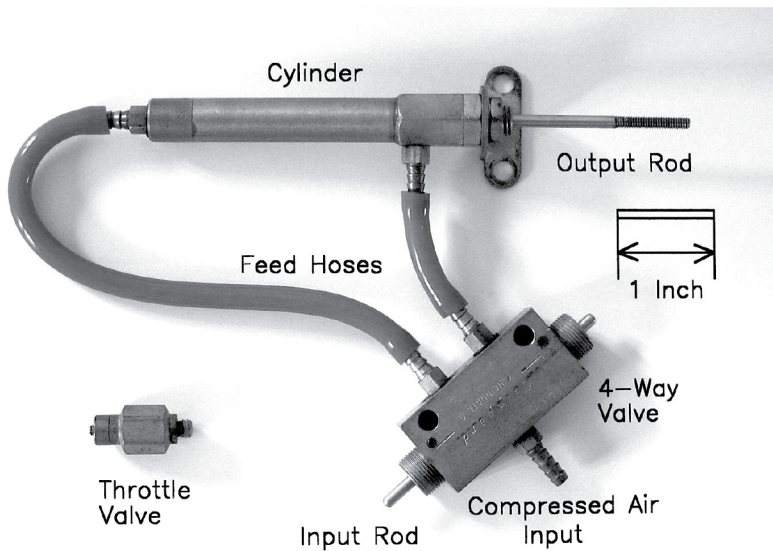


Figure 9-1

Miniature Pneumatic Components

(Clippard “Minimatic”, manufactured by Clippard Instrument Laboratory, Inc., Cincinnati, Ohio)

Control

Different methods have been used over the years to control animatronic figures.

Cams have been used for a long time to control simple, repetitive motions.

The multi-track audio tapes that were used in Disney’s early animatronic figures have been discussed above. They permit a much larger range of motions since they are not limited to the “once around” motions of

cams. The frames of movement were recorded on reel-to-reel magnetic audio tapes. When played back, the tapes generated audio signals that triggered the mechanisms that caused the figure to move—synchronized with the recorded dialogue, music, and special effects.

Where the animated figures are not designed to go through repeated cycles of motion, as in movies where each scene or shot may require different sequences of motion, control consoles may work best.

For complex animation, especially in a theme park application where the show must go on repetitively for a long time, a digital system gives ultimate reliability. Special-purpose digital controllers can be designed and built

Programmable Logic Controllers (PLCs) offer similar capability “off the shelf,” where the sequences of motions can be written in the provided control software.

Depending upon your application, budget, and complexity of animation, you might pick any of these today.

Reliability

This is potentially very critical. Consider the environment of a theme park, where a show is repeated every few minutes, twelve hours a day, perhaps 350 days a year, for ten to twenty years. Yes, shows can be shut down for maintenance or repair, but this leads to disappointed guests. It’s an impossible ideal to create an animatronic show that never needs maintenance, but minimum down time certainly helps with guest satisfaction.

There are two places to focus: the initial design itself, and the maintainability of the device. The attraction wants to appear to be operating at the edge: large, frequent movements at relatively high speeds. The designs

must be such that this appearance is provided, but with ample design margins so that failures are non-existent, or at best very rare. Beyond that, potential failure modes must be understood and accounted for (probably using FMEA), and the easiest possible maintainability designed in to prevent, or, if need be, to repair any failures.

Another consideration is operator satisfaction. If an animatronic attraction is operating on the edge of failure, operators might be motivated to lower the chance of failure by toning down the animation—having it go a bit slower than the designed speed, or reducing some range of motion. While this might make their lives easier, it can disappoint guests who have come with the expectation of operation at the designed limits. Proven reliability can convince the operators to let the attraction operate as designed, since it will not tax them unduly.

A Closing Note

Whatever means, simple or complex, that are employed to bring animatronic figures to “life,” remember that these figures are created for one purpose: to bring the story to life.

CHAPTER 10

Amusement Parks and Theme Parks

Whether you consider a permanent *Amusement Park*, a transient *Carnival*, or a full-fledged *Theme Park*, you are thinking about one of the most concentrated examples of engineering/technology applied to entertainment. You are liable to find anything from a simple set of contorting mirrors in a fun house to a heart-pounding thrill ride. Think about a roller coaster train that must develop enough energy when it plunges down one hill to enable it to get to the top of the next hill, or a swinging ride that must get going fast enough that the car can swing up and over the top, completing a full vertical circle

If this is not challenging enough, think about a traveling carnival, with rides that in a relatively short time can each be taken down and stowed on a set of highway trailers, to be trucked to the next location—where the cycle is repeated.

Then there are theme parks, where each attraction has the added requirement that its substance and décor support the overall park theme — that might range from motion picture creation at Walt Disney World’s *Hollywood Studios* to Universal Studios’ *Wizarding World of Harry Potter*.

Or think of something as seemingly non-technical as how you pay for your day at the park. Years ago (and still in some places today), you paid for tickets for each ride or attraction. Often you would buy a packet of identical tickets, and each ride required a specified number of tickets, different for different rides. In the early days of Disneyland, you would buy a packet of differently-valued tickets, each valuation identified by a letter. The packet contained more of the lower-valued tickets, and only a couple of the most valuable “E” tickets. Different attractions specified which ticket was

needed for that attraction. The most thrilling and desirable rides required E tickets—which led to a general usage that the top rides in any park were “E Ticket” rides.

At some point, many parks changed to a single-price admission ticket, which entitled the park guest to enjoy all (or almost all —there might be some special “extra fare” ride) of the park’s attractions.

By the start of the 21st century, Walt Disney World resorts were providing guests with magnetic-stripped plastic cards resembling credit cards, that served as hotel room keys, park entry tickets, and charge cards for charging expenses in the parks back to your hotel bill. Cards were inserted into “slot” readers where the information encoded in the magnetic stripe was read. In the spring of 2013, the cards looked the same, but contained RFID (Radio Frequency ID) chips in addition to magnetic stripes. At many places in the parks the slot readers were replaced by round pads, against which the user placed the card to open the room door, enter the park, or pay for a meal.

This is said to be the precursor to replacing the plastic cards with wristbands including RFID chips. It will only be necessary for a guest to hold their wrist near the pad reader to enter their room, enter a park, or make a purchase. It is actually anticipated (James 2013) that the chips in the wristbands will be encoded with more data, like the wearer’s name. Imagine a youngster approaching a Disney character at a meet-and-greet, and being welcomed by the character by name!

Amusement Parks

The United States’ first amusement park precursor, Vauxhall Gardens, opened in New York City in 1767. It was a *Pleasure Garden*, a simplified derivative of similar gardens that by then had existed in Europe for quite a while. Compared to the most exotic current amusement parks,

it was a simple affair, offering quiet relaxation, summer concerts, food (including that exciting new invention, ice cream), and an outdoor wax museum. In the early 1800s they were offering theatrical productions and one of America's first carousels. (Futrell 2011)

An interesting step came with the advent of the *trolley park*. In most cities with growing systems of trolley cars providing public transportation to get people to and from work, the trolleys were not busy—and so not making any money—on weekends. Some trolley companies decided that a way to fix this and start making money on the weekends was to open an amusement venue in an empty space along an out-of-town part of their system. The first *trolley parks* offered cool open spaces for relaxation, accented with amenities like picnic grounds (bring your own food!), musical concerts, and even dance halls. Group events were sponsored, like company outings (e.g., *the XYZ Company Summer Outing*) and ethnic festivals (like *Italian Day* or *Croatian Day*) featuring appropriate music and food.

A number of *trolley parks* remain in business today (2013). A notable one is *Kennywood Park* in the Pittsburgh, PA, suburb of West Mifflin. *Kennywood* was started in 1898, by the Monongahela Street Railway Company, which was controlled by Andrew Mellon. Today's *Kennywood* still contains two major buildings dating from 1898, a carousel pavilion and a restaurant (originally the Casino). In 1987 *Kennywood* was designated a National Historic Landmark. (*Kennywood* 2012)

At the turn of the twentieth century, *Kennywood* was engaged in a fierce battle for survival with about a dozen other trolley parks and amusement resorts in Western Pennsylvania. The Pittsburgh Street Railway Company wanted to get out of the amusement park business in 1902; in 1906, Pittsburgh Railway Company assigned its lease to A.S. McSwigan

and Frederick W. Henninger. (Kennywood 2012) Their families remained the owners until around 2010.

In 2013 Kennywood is still very much a family park, and still features events like *Nationality Days*, *Community Days*, and high school band parades. Kennywood has a few rides aimed at dedicated thrill seekers, but keeps a number of “tamer” rides suitable for the whole family. More than one of their roller coasters has made a “Top Ten” list at one time or another.

Not every amusement park has followed this path. There are some that strive to attract people from around the world who want to ride the tallest or fastest or “baddest” rides. Cedar Point, located on the shore of Lake Erie in Sandusky, Ohio, is this sort of park. They bill themselves as *The Best Amusement Park in the World*, and have a collection of extreme roller coasters and other rides to back this up. (Cedar Point 2012) Amusement parks like this do become “destination parks,” to which thrill-ride aficionados travel one time, or at most occasionally, in order to enjoy the unique set of experiences. This contrasts to “family” parks which cater to a more local clientele who will make repeat visits.

The attractions in amusement parks are varied and not necessarily related. The planning concept is to provide a variety of attractions that will attract the attention of, and provide enjoyment for people representing a large variety of ages and interests. In addition to thrill rides and a limited number of slow but exciting *dark rides* (once exemplified by the *Tunnel of Love*), amusement parks typically have games of skill, like Skee Ball or the chance to win an oversized plush animal by throwing baseballs at (weighted) wooden “milk bottles”. They do not usually have sit-down shows or other non-participative attractions.

Theme parks, in contrast, have a different variety of attractions, and

tie them together through focus and décor and other means so that they exemplify a chosen theme. They typically have rides, including some that are quite exciting and others that are competitive (like *Toy Story Midway Mania* at the domestic Disney parks), and they also have stage shows and movies that support the theme. They may have a few skill games that tie into a specific theme; games you might find at a seaside boardwalk are offered at the *Boardwalk* section of Walt Disney World and at Disney's California Adventure.

Entertainment Engineering may be at its most visible in amusement parks—especially those that feature the “biggest and baddest” rides. Many Americans got their first introduction to large-scale engineering projects during a high school science class field trip to their local amusement park.

The engineering of thrill rides is addressed in detail in Chapters 11-14.

Theme Parks

Disneyland, which opened to the public in 1955, was the first Theme Park. Walt Disney had gone with his two daughters to local carnivals and parks, and was not happy with the variety of attractions. There were few carnival attractions that served both children and adults, and there were too many things (like *side shows*) that he felt were not appropriate for youngsters. He wanted to create a new kind of amusement park, that transcended the carnival environment, that parents and their children could share. He sought to marry technology and storytelling to take children and their parents into virtual worlds.

An interesting challenge to a theme park is the desire to have the park be a “destination” that people come from afar to visit, while at the same time featuring attractions that appeal to all members of a visiting family.

This means that instead of having an array of super-exciting rides, the theme must catch and keep the attention of guests, add a lot to the total guest experience, and make them want to have *more*. The theme park must offer enough enticing attractions that visitors will want to spend more than one day. To fully support this, it must have lodging facilities nearby, and if possible be open year-around. A theme that is known to attract visitors, like a very successful multi-generational motion picture (like the *Harry Potter* series) also contributes.

The attractions in a theme park need to support the theme. It's not just a "Roller Coaster," it's *Space Mountain* in *Tomorrowland*, or a Runaway Mine Train in *Adventureland*. *Splash Mountain* in the Disney parks is based upon the movie *Song of the South*. Execution of an attraction to support a theme certainly can make an attraction more memorable. Which would you remember more positively, a tiger pacing in its barred cage in a zoo or a tiger seen from the walls of a ruined Indian temple in Disney's *Animal Kingdom*?

Epcot is a special sort of theme park. *EPCOT* stands for *Experimental Prototype Community of Tomorrow*. In the early 1960s there was interest in several places across the United States in creating a "new city," that would embody all of the modern ideas about how a city might better serve its populace. There were ideas like concentric circles of activity, starting with shopping and governance (and no cars) in the center, surrounded by an urban residential circle, which would in turn be surrounded by a manufacturing circle, providing employment for the residents. One of the most famous of these proposals was the Minnesota Experimental City, proposed for a location in northern Minnesota.

Most of these never were realized, because of laws that would need to be re-written, the existing populations who were not willing to deal with the complications of creating the new city, and the general fear people have

of things that are new and different. But Walt Disney was not subject to these issues: the company owned a huge piece of ground in Florida where they could pretty much do what they wanted. So Walt continued where the others stopped, and worked on his plan for an experimental city of tomorrow.

EPCOT as it was realized did not do everything that Walt or the other experimental city champions wanted, but there were some steps in the desired direction. When many years later in 1994 the community of Celebration, Florida, was opened for occupancy, the residential part of EPCOT was finally realized. Celebration has many of the experimental city features, like a car-free downtown. Different sections of the town deliberately capture the flavor of traditional homes in different parts of the USA.

Further Resources

If you want to learn a lot more about Amusement Parks and Theme Parks, you may be interested in one of these three organizations:

IAAPA. The International Association of Amusement Parks and Attractions. This is a trade organization, but a subscription to their magazine, FUNWORLD, is available to anyone interested. See the IAAPA web site, www.iaapa.org.

NAPHA. The National Amusement Park Historical Association. Contact them at P.O. Box 871, Lombard, IL 60148-0871 or www.napha.org.

ACE. American Coaster Enthusiasts. This is a very active organization that sponsors coaster-riding trips and a roller coaster museum. Contact them at 1100-H Brandywine Blvd, Zanesville, OH 43701 or www.AmericanCoasterEnthusiasts.org.

CHAPTER 11

Thrill Rides

Entertainment Engineering may be at its most visible in Amusement Parks—especially those which feature the “biggest and baddest” rides.

What Makes a Ride “Thrilling”

Is it a question of physiology, or of psychology, or both? What are the “thrilling” elements of rides?

I asked Walt Disney Imagineer Mark Sumner this question. Sumner observed that there may not be a definitive answer. “Thrill does not necessarily come from dynamic motion alone. Consider a scary movie that can make a person jump with no motion at all. Sometimes subtle motions can enhance audio and visual clues, such as in *Soarin’ Over California*.” Or how about being “attacked” by a 3D bug in *It’s Tough to Be a Bug*? (Sumner 2005)

Prof. Alfred Clark from the University of Rochester suggests that there are many elements of a ride that can be thrilling: acceleration, drop, jerk, inversions, zero Gs, sounds, etc. (Clark 1988)

Major considerations are

Providing Extreme Thrills: how to do it? How do you get the roller coaster train launched up the first hill? How do you insure that it will have the energy needed to get over the next hill? This is discussed in some detail in Chapters 12-14.

Physiology: How sharp can the turns on the Wild Mouse coaster be? What about the sequence of features on the roller coaster: do you need “recovery” time between a loop and a heartline roll?

Psychology: How do you “scare” people without really endangering them? This was discussed in Chapter 4—including the propensity of some people to seek out exciting sensations. To what extent does an individual’s predisposition to (or from) sensation seeking affect their response to a ride? “Do low sensation seekers avoid risky behavior because of a tendency to overestimate risk?” (Zuckerman 1994)

Safety: Guest safety on the extreme roller coaster—or on the *Sky Coaster*. And cast safety.

Reliability: Why is the wooden coaster ride so “jerky” at the end of the season? You don’t want to have to tell the guests waiting to ride the Whip that “sorry, it broke”. Or disappoint the person who finds on a sign at the park entrance that their favorite ride is down.

Considering just the *physiological* aspects, and in the light of safety considerations (about which more later), it seems clear that if you were to design a ride, you would need to have a good understanding of the human body and how it reacts.

Sights and Sounds

Sights and *Sounds* contribute a lot to the thrill. Can we separate these into *physiological* and *psychological* components? Probably not.

There are sights both before and during a ride that can add to your sensation of “thrill”.

Of course, just watching an exciting ride even before you decide to commit to the queue has a major impact. It can either draw you in or drive you away, depending upon your ride preferences.

Sights and Sounds in the Queue. Then there are sights along the queue, beginning with the warning to guests with heart trouble, or preg-

nant women, to “avoid this ride”. Even if you don’t fit the description, the fact that such “potential danger” exists surely will get your adrenalin running a bit more than usual. Theming along the queue both distracts you from the frustrating wait to enjoy the ride and helps to build your anticipation. You may also be given an occasional glimpse of the ride from the queue, to remind you of what you are waiting for.

Sights and Sounds During the Ride. And finally there are the things you see—or don’t see—along the ride!

Have you ever ridden a roller coaster with your eyes closed, or in a roller coaster train set to run backwards? How have you felt when you could not anticipate the next turn or drop? For most people it heightens the excitement.

This is part of the excitement of Disney’s *Space Mountain*. Not only can you not see what is about to happen to you; you are given glimpses of other trains seemingly racing frighteningly close in front of you. You *know* you won’t crash, but...

When you can see your surroundings on a roller coaster, they come up so fast that the tunnel, or the narrow chasm, or the swing through the town street, or even the overhead bar that seems too low can up the excitement. Will we *really* dip into that stream we seem to be heading for??

Then there are slow rides that depend almost entirely upon sights (and sounds) to create a thrill. Old-time “Dark Rides” do this, and I am sure that the first time I rode through Disney’s *Haunted Mansion* I wondered just how did that ghost appear to be sharing the car with us?

And then there are the *sounds*. The sounds you hear during a ride can have a big impact. Consider the start of a roller coaster ride. The “classic” sound is the “clank clank” of the lift chain. The long lift hill with the clanking chain has the effect of building the riders’ anxiety about what is

going to happen to them when they reach the top... Some modern coasters “launch” the train up the first hill. The start is faster, but some people miss the “clanking”.

Do you yell when you ride a roller coaster? Have you noticed that people who yell don’t only yell during the most “thrilling” moments of the ride, but also in anticipation? Do you think that other people’s yelling may have an effect on you?

What about the music and other sounds you may hear in a less physical ride? Have you visited the *Haunted Mansion* at Disneyland or Walt Disney World? That’s a physically tame ride—but there are lots of wild sounds to excite you, catch you off guard, or whatever.

We can’t ignore the other side of sound—when it is *not* wanted. There are machinery sounds that would detract from your experience in an attraction. You also do not want to be distracted by the sound from another nearby attraction. Dealing with these issues may require input from an acoustical engineer, on means and methods of sound isolation and mitigation.

Safety

Safety is the thrill ride industry’s number one priority. (Funworld 2002) Disney has actually named a *Chief Safety Officer*. In 2012, the person holding that job was also Disney’s *Vice President of Worldwide Safety & Accessibility*.

The situation is challenging: the goal is to make you feel like your life is in danger, while insuring that you are absolutely safe.

It is a tough juggling act.

Some people always seem to be asking, when does an amusement park ride go from being a dose of fun to a danger to your brain. A few years back, U.S. Representative Ed Markey from Massachusetts was leading the charge. He had collected data that attributed 8 deaths and 50 other brain injuries to normally operating thrill rides.

The blame is put on *G Forces*.

On the other hand, consider this data:

- In the 10 years in which Rep. Markey's 58 injuries occurred, there were 3 billion amusement park rides per year.
- In 2000, there were 6,600 amusement park injuries, and 87,000 skate board injuries

Two University of Pennsylvania physicians studied the topic of brain injury on rides. They found that the highest estimated peak head accelerations induced by roller coasters were far below conventional levels that are predicted for head injuries. One of the Penn physicians, Dr. Douglas Smith, has said that "you're far more likely to get hit on the head with a golf ball" than get hurt on a coaster. (Funworld 2002)

Most ride injuries come from either accidents or exposure to too-high forces. Here are two observations about the causes of ride accidents:

"Most accidents occur when someone comes out of a ride—often from irresponsible behavior." (Himmelberg 2002)

"...patron error accounted for 76% of all amusement park ride accidents in Florida" during 2000-2002. (Field 2003)

The son of one of my work colleagues was killed during summer employment at an amusement park. He was on a daily “test” ride on one of their roller coasters, and he stood up...

G-forces are a different sort of problem, because they result not from a rare “accident” but from “normal” ride performance. As will be shown in the next chapter, ride designers can set the maximum G-forces to which a rider will be exposed during the ride.

Back in 2002 New Jersey received a great deal of publicity regarding its development of a design standard including G-force limits. ... Subchapter 7 of these proposed regulations is similar to the then recently-bal-loted new ASTM standard (Z9591Z). (Bertus 2002) “Under the proposed standards, front-to-back G-forces (were not to) exceed 5.6 for more than one second, and side-to-side G-forces (were not to) exceed 2.5 for more than a minute.” (Yoshino 2002)*

Here are the maximum G-Forces on some well-known rides:

- *Taz’s Texas Tornado*. Six Flags Astro World. 6.5
- *Batman and Robin: The Chiller*. Six Flags Great Adventure. 5.0
- *Rock’n’Roller Coaster*. Disney’s Hollywood Studios. 5.0
- *Son of Beast*. King’s Island. 4.5

Yoshino pointed out that “at least once a year an outside firm tests the Cedar Point attractions with a bionic man they call ‘Fred,’ who is hooked up to a laptop computer as he rides. The dummy, much like those used

*For the latest status, check the New Jersey Dept. of Consumer Affairs web site, at www.state.nj.us/dca/codes/ruleproposals/carnivalridereg-webversion.pdf

in the auto industry, measures head and neck movement, G-forces, and other factors of the ride.” (Yoshino 2002)

Of course, even with the best design, it is still possible for a person to get hurt, by being careless or thoughtless. Yoshino reported the case of “a 24-year old Japanese woman who developed headaches and subdural hematomas—blood clots—after riding *several* large roller coasters...”

The bottom line is that *safety is critical*. People can get hurt, and there are people watching for it to happen. The best approach is for those engineering new rides to be aware and be prepared: design rides to be thrilling but safe.

Reliability

Another design and manufacturing issue is *reliability*. The duty cycle on an amusement ride is very high: rides are expected to perform flawlessly, every few minutes, for perhaps fifteen hours a day, seven days a week, for many years. This can seriously impact customers: think of the person who travels down from New York City to spend a day at Six Flags Great Adventure, in Jackson, NJ, only to discover that their favorite ride is out of commission. Sure, the person could have called ahead, but how many people would do that; they simply expect the park to be “up and running.” It’s even worse for the father who has planned for almost a year for his children’s first trip to Walt Disney World, and has regaled them about the wonders of the Big Thunder Mountain Railroad ...

Seasonal parks often plan significant maintenance programs for their off seasons. During a behind-the-scenes visit to Kennywood Park, I learned of their program to replace all of the wooden parts in their wood roller coasters every ten years, a fraction each year. Parks that are open year-round must squeeze their scheduled maintenance (and their unscheduled

maintenance!) into nights or at least minimum down time, or widely advertise when a selected ride is to be shut down for an extended period for refurbishment.

What this means is that the design process for an amusement ride has to include strong doses of Design for Reliability and Design for Maintenance

Additional Reading

If you want to read some interesting stories about thrill ride design, check out *Roller Coasters, Flumes, and Flying Saucers: the Story of Ed Morgan & Carl Bacon, Ride Inventors of the Modern Amusement Parks* (Reynolds 1999).

CHAPTER 12

Thrill Rides: Roller Coasters

Roller Coaster History

Although there are many more milestones in the development of roller coasters, here are a few dates of “game changers”:

- The earliest roller-coaster-like rides were sleigh rides down slopes or inclined planes, in Russia. In 1799, a wheeled “Russian Mountain” gravity ride opened in Paris.
- The first roller coaster open to the public in the US was the Mauch Chunk Scenic Railway in PA, which had formerly been used as an inclined plane to transport coal from a mine. It opened for amusement in 1873.
- The first “continuous” roller coaster (the ride ended where it started, with the train ready to go again.), was built by Philo M. Stevens in Chicago, in 1883. (Futrell 2012)
- The first modern steel coaster with tubular track was The Matterhorn at Disneyland. It was designed and built in 1959 by Ed Morgan and Karl Bacon, who formed Arrow Development (Later Arrow Dyamics). (Reynolds 1999)

What’s Fun on a Roller Coaster

There are a variety of experiences a rider encounters on a roller coaster that create special thrills. Consider these:

- Wood versus Steel
- Going up the lift hill
- Big drops

- Inversions
- Rider Posture
- “Air Time”

Wood versus Steel. Both *wooden* and *steel* roller coasters have their fans. Most people do have a preference for one or the other.

This, of course, is not merely a “material” issue. Rather, it is an issue of what can be done differently on a strap-metal track versus on a track comprising a set of parallel metal tubes. It is an issue of cars that rest on the track and are guided on the sides versus cars with wheels that surround the tubular track.

A good example of the fundamental difference is that steel roller coasters can safely incorporate all sorts of inversions, while for the most part wooden coasters must be designed so that the ride wheels never leave the track and the car is never oriented so that the weight vector is more than 90° from the vector from the center of mass to the track centerline.

Another difference perceived by the rider is that a steel coaster can be perfectly smooth. Between CAD design, CAE analysis, CAM manufacture, the symmetry of round tubing, and the smoothness of ground welds, the track can follow any profile desired by the designers—and stay that way.

Even if they start out smooth, wooden coasters tend over time to develop “rickety” rides. This is due to the shifting of strap rails, growth and shrinkage of wood, etc. I recall riding one famous wooden coaster, where the ride was so rough that the roughness partially masked the designed excitement of the ride. This is one reason behind the constant refurbishment of Kennywood’s wooden coasters.

On the other side of the discussion, there are some people who find the “liveliness” of a wooden coaster very important to their ride experience. They really enjoy the motion that comes from the flexibility of the wooden structure. For them the smooth ride of the steel coaster is not satisfying.

Going Up the Lift Hill. Chain lifts still exist, but there is a trend toward Linear Induction Motors or other (e.g., compressed air) “propulsion” systems that “launch” a coaster very rapidly. There’s no time to miss the nostalgia of the chain lift... Still, there are people who miss the “clanking”.

Big Drops. Big, exciting first drops have been with us for a while. The wooden *Mr. Twister* in Denver’s old Elych Gardens location had a sharply curved first drop that was breathtaking.

Kennywood’s steel *Phantom’s Revenge* also has a curving first drop. The big excitement on the *Phantom’s Revenge* is the drop that plummets straight down over the Monongahela River hillside!

By the late 1990s, the latest “big drop” thrill was to drop people at or near straight down toward the ground. Cedar Point’s *Top Thrill Dragster* does this.

Inversions. Inversions began with *shuttle loops*, through which you went first forward, and then back. Six Flags Great Adventure called theirs *Lightning Loops*. There were a pair side by side.

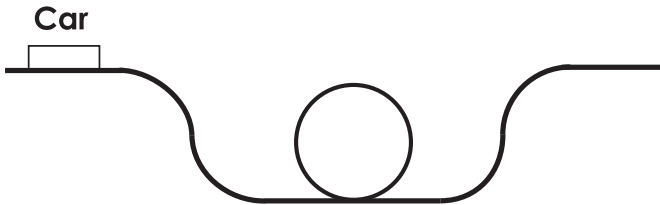


Figure 12-1

The *Tidal Wave* was an early shuttle loop at *Great America* in Santa Clara, CA, and also at Kennywood. An especially interesting aspect of this ride is that the distance the coaster train went up the tall straight vertical section was in part determined by the total weight of the passengers. Thus the maximum height varied from ride to ride.

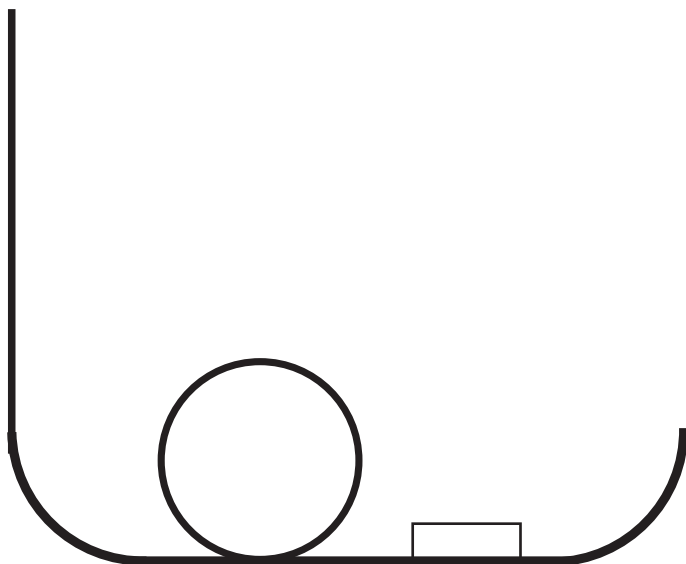


Figure 12-2

I remember feeling that when you reached the top, a long time passed before the cars started to roll back down; it was really only probably a second or two. I came to believe that the only way you could really understand this ride was to ride it several times, each time concentrating on one segment of the ride: the launch, going forward through the loop, going up, hanging at the top, coming back down, going through the loop backwards, and finally rolling backwards up the short hill and then coming to rest at the station.

Next came *corkscrews*, and then the big non-circular loops (that provide

a much smoother-feeling ride than pure circles). Then designers added all sorts of things like *butterflies* and multiple loops in sequence.

Rider Posture. At first, steel coasters had riders seated in cars atop the track, just as they had always been in woodies. Then people started to take advantage of the new medium and the new design tools.

Shock Wave was Great Adventure's first *stand up* coaster.

Then came *suspended coasters*, with the riders swinging beneath the track, in cars that were still closed. Then they let people's feet hang down...

And then came yet another innovation, introduced on a *Superman*-themed ride that had the riders "flying" just as Superman would—lying face downward in a form of carrier.

X, built by Arrow Dynamics at Six Flags Magic Mountain, did it all, utilizing a pair of extra rails that rotate the rider at various points along the ride—from sitting upright to lying back to "flying".

"Air Time". "Air Time" is when you are lifted out of your seat—negative Gs. It happens mainly at the tops of hills. Not only big hills: some of the most fun Air Time occurs in a series of closely-spaced tiny "bunny hops". The *Phantom's Revenge* includes a couple near the end of the ride.

Roller Coasters—The State of the Business

In the spring semester of 2002, a Carnegie Mellon University mechanical Engineering senior named Zuley Clarke did an Independent Study, looking at trends in Roller Coaster Design. Here are some of her conclusions:

Clarke studied coasters from four Manufacturers:

- *Arrow Dynamics*. In business since 1946.
- *Veķoma*. In business 25 years. Mainly shuttle and inverted coasters.
- *Intamin*. Big on linear induction motor starts.
- *Boliger & Mabillard*. 50 coasters since 1998. Unique coasters, like stand up and “flying”.

Speed. Average speed was slowly increasing, although many new coasters do not push the speed envelope. B&M went for the fastest, although in 2002 Intamin had the record at 100 mph.

Height. Height was also slowly increasing. Each company tended to stay within a height range. In 1997 Intamin built a 400+ foot high coaster, and in 2000 they built one just over 300 feet high. These were quickly challenged in Japan and at Cedar Point.

Inversions. There seemed to be no real trend with inversions. Inversions first appeared in the 1960s, grew to four by 1976, and to seven by 1988. Since then up through 2002, each year had seen coasters with from 0-7 inversions.

Duration vs. Length. Roller coaster rides in 2002 seemed to last between one and three minutes, with the majority in the range 2.0-2.5 minutes. The longest, at nearly 6000 feet, ran 2.5 minutes. The next longest, around 5400 feet, ran 4 minutes. Few exceeded 4500 feet in length.

After speaking with people at Kennywood about their criteria for selecting new rides, Ms. Clarke used her data to propose a new roller coaster: *The Renegade*. It had these characteristics:

- Steel

- Designed to feel like you are riding a *luge* (a competition sled)
- Each car holds 3 people behind each other, “lying on their backs”
- Maximum height between 150-200 feet
- Maximum speed 80 mph

Ms. Clarke believed that this would be a coaster ride “that will linger in the hearts of guests of all ages.”

Roller Coaster Dynamics

Prof. Alfred Clark from the Department of Mechanical Engineering at the University of Rochester (NY) published in *Roller Coaster Magazine* (Published by the American Coaster Enthusiasts) an excellent set of articles on *roller coaster dynamics*, and how to solve roller coaster design problems. Any one seriously considering carrying out roller coaster dynamics problems should read these articles. (Clark 1988, Clark 1989, Clark 1989(2))

The whole thing is about **ENERGY**.

You drag—or blast—the train to the top of the high first hill, to give it lots of *potential energy*. The rest of the ride is based on converting that *potential energy* into *kinetic energy*, the last of which is dumped in the final brake run.

Every feature—hill, helix, spiral, loop, corkscrew, or whatever—is designed so that the kinetic energy is never quite lost or converted all back into potential energy. A few coasters have intermediate lifts, to inject some energy, but in general everything after the first hill is a rolling ride home.

Loads and Forces must be considered in several regimes:

- Forces experienced by the Rider
 - Due to Track Geometry
 - During launch
 - During Braking
- Forces experienced by the Car
- Forces experienced by the Structure

Each of these must be considered during design of the Roller Coaster. It begins with the Rider, and the need to balance the desired level of *thrill* with the required level of *safety*.

Prof. Clark focuses on *rider* dynamics. His basic equation for the forces the rider feels is

$$S + mg - mac = \theta$$

The most important for basic calculations is S , the force the car exerts on the rider. On a plane, curved hill where the center of curvature is below the track, this becomes:

$$S = -m[g \cos(\theta) - (V^2/R)]n$$

(R is the radius of curvature, θ is the tilt of the car from horizontal, and “ n ” is the unit vector normal to the track.)

Another important relationship is *conservation of energy*. If we accept Prof. Clark’s approach to neglect friction and wind resistance, then the height of a hill and the velocity at the top and the bottom are related by

$$V_B^2 - V_T^2 = 2g\Delta H$$

Consider now a horizontal circular curve. The seat force equation becomes

$$S = -m[(V^2/R)i + g]$$

(i is the horizontal unit vector)

We can compute the bank angle:

$$\Psi = \tan^{-1}(V^2/Rg)$$

Loads on the car are calculated similarly. Braking forces are along the (usually straight) track and can be computed from conservation of energy. Forces on the support structure are based on the forces acting on the car.

Of course, “real” calculations, in which friction and wind resistance are considered, the track curves in three dimensions, and the structure is analyzed in detail, are very complex. Once done by hand, such now can be calculated with a computer; and they still are long and arduous.

Some Roller Coaster Problems

If you wish to try these problems, you should be able to solve them with familiar mechanics relationships and the equations from Prof. Clark’s articles given above. The problems deal with Rider Dynamics, Car Dynamics, and Support Loads.

Solutions to these problems are provided at the end of the book.

Consider a roller coaster like that proposed by Ms. Clarke:

- A one-car train
- 3 riders per car, seated one behind the other
- The car weighs 800 lb.
- Assume a maximum rider weight of 225 lb. each.

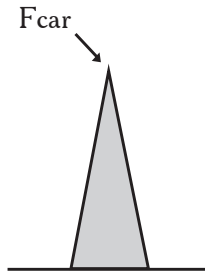
Problem 12-1. A car is moving at 70 mph at the foot of the first drop.

How high a second hill of what minimum radius will just make a rider weightless at the top of the hill? How fast is the car going at the top?

Problem 12-2. After topping the second hill, the car is going around a flat curve of 25 ft radius at 40 mph. What should be the bank of the track to keep S pointed to the bottom of the car? What is the magnitude of S? How high is this curve?

Problem 12-3. In the situation of problem 12 - 2, what is the net force of the car on the track? Give direction and magnitude.

Problem 12-4. Assume that the track supports are independent. (This may not be a very good assumption, but it is conservative.) The support at the center of the curve of problem 12 - 2 looks like this:



(Leg spacing is $1/4$ Support height.)

What are the maximum forces at the bottoms of the two legs of the support when a car is going through the curve? Describe the forces along the legs and also in horizontal and vertical components.

Problem 12-5. There are two 10 ft. high “bunny hops” near the end of the ride. The train is going 20 mph as it approaches each of them. What vertical curve radius is required so that the riders are just weightless at the top of each “hop”?

Problem 12-6. The car is approaching the station at 20 mph, when it

encounters magnetic brakes. What braking force needs to be applied so that the train comes to a stop without exceeding 1.3 Gs? How far does the car travel once it encounters the brakes?

Roller Coaster Design Software

If you would like to try designing your own roller coaster, here are two software packages that you may want to try:

Roller Coaster Tycoon is a computer game. It is available as a boxed CD game, for Mac or Windows.

You get to design a roller coaster, but you also need to create an amusement park and populate it with rides and amenities (e.g., restaurants and walkways and rest rooms) to keep your guests happy and spending money.

To learn more, visit

www.rollercoastertycoon.com

NoLimits is a full simulation tool rather than a game, downloadable from the web. Based upon thorough physics, it permits sufficiently detailed ride design that vendors have used it at the IAAPA* trade show to demonstrate proposed new rides to prospective customers. There are many demonstration coaster designs provided and also available for download, that you can ride from the front seat.

As you design your own coaster, *NoLimits* lets you tweak your design as you work along the track, to eliminate features that just don't work, or to smooth things out. As you traverse the track, at the top of the screen are constant readouts of speed plus accelerations along three axes. You

*International Association of Amusement Parks and Attractions

have the choice to watch the train go through its paces from alongside the track, or from any seat in the train.

Look for *NoLimits* at

www.nolimitscoaster.com

The Bottom Line

Roller coasters are among the most common “thrill” rides, and also potentially the most thrilling. We understand the technology, so well summarized by Prof. Clark, and we have design tools to help us.

Given these, designers keep seeking ways to make coasters ever more thrilling. But we need to keep in mind that while we seek to give people ever more exciting ride experiences, we need to be sure that while they may think they are flirting with danger, they are always kept within dynamic limits that do not endanger them. We do this not just to obey the law, but to give the guests positive experiences that keep them coming back.

CHAPTER 13

Thrill Rides: Other Dry Rides

What are Some Other Types of “Dry” Rides?

Introduction

Many of these rides do not provide “thrills” to nearly the same level as roller coasters. Most of them use fairly straightforward mechanical motions to provide some sort of excitement for riders. Let’s look at some of the ways these rides make use of technology to excite and sometimes thrill riders.

Rotating Rides

- Uniform Velocity
 - Carousel
 - Flying Elephants
 - Flying Wave (Swings; Wave Swinger)
 - Rotor
 - Enterprise (Tips Up)
- Non-Uniform Velocity
 - Whip
 - Monster Spin (spin within spin)

The carousel is a basic rotating ride; it simply goes around and around. Carousels trace their roots to medieval jousting training rides. Early “flying horses” *Merry-Go-Rounds*, dating to before 1850, had horses suspended from chains or metal rods. The first modern carousel in America was built in Philadelphia in 1867 by Gustav Denzel, a wood carver.

While horses are the traditional rides on carousels, many different animals can be found, from tigers to various mythical animals. Many of these go up and down as they go around, driven by rotating rods overhead (see Figure 13-1, below). There is a large diameter ring gear at the top of the carousel's central pillar; the gear on the rotating rod is turned by the ring gear as the carousel rotates, which causes the rod to rotate and raise and lower the animals on which the guests are riding. For those who prefer something more stable, most carousels also have some animals that stay still (usually in the innermost row), and some even have chariots positioned behind some animals

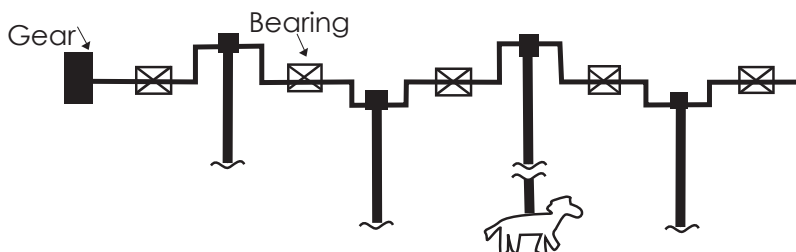


Figure 13-1

Mechanism for Moving Horses Up and Down

Another addition to the excitement of some carousel rides is a dispenser outside of the edge of the moving portion of the ride, pointing toward the outer row of animals, that dispenses a ring to a rider who reaches out to grab one. Traditionally every so many rings there is one that is gold colored; a rider who gets a gold ring often gets a prize—which may be as straightforward as a free repeat ride on the carousel.

For those interested in learning more about carousels and their history, there are several carousel museums in the United States, including one

in North Tonawanda, NY, at the former factory of the Allen Herschel Company, a prolific manufacturer of portable carousels during the first half of the twentieth century. There is also a *National Carousel Association*. Find them at

www.nca-usa.org

The flying elephants (*Dumbo the Flying Elephant*) ride at the Disney parks is a quite gentle rotating ride that provides an up-and-down motion another way. Each car (“Dumbo”) is connected to a central mechanism by an arm. As the central mechanism begins to turn, moving the cars around in a circle, the cars are first raised from the base (loading/unloading). Then as the ride continues to turn, the cars move up and down in a sinusoidal motion, driven by actuators in the central mechanism.

The *Wave Swinger* makes one think of the early “flying horses” merry-go-rounds, except that the swings have simple seats (with security lap bars so you won’t fall off). As the ride begins to rotate, the central pier rises, so that the riders’ feet quickly leave the ground and they soon find themselves swinging far out, quite some distance above the ground—a function of their speed of rotation. The chains have a bit of freedom of movement, so you find that some riders seeking extra excitement will get their swing seats rotating back and forth as they swing around.

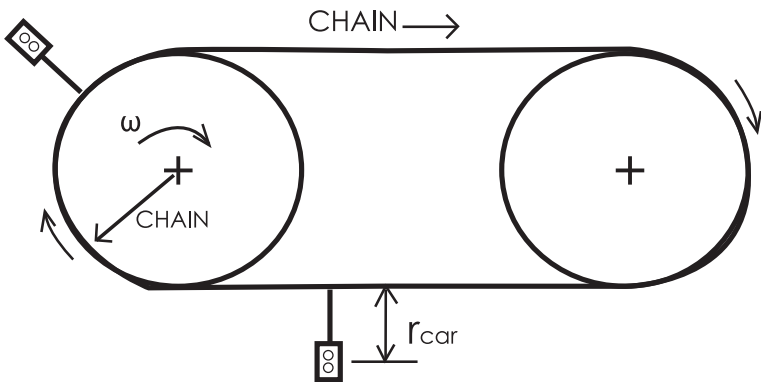
The *Rotor* is very easy to understand: the riders stand on a flat floor with their backs against the inside of a very large cylinder. The cylinder begins to rotate, faster and faster. The riders feel themselves pressed against the wall behind them. Suddenly the floor is lowered, and the riders are supported only by the force that is pressing them against the cylinder wall. It’s an unusual feeling, especially if you are wearing slippery clothing so that the clothes “stick” to the wall but you slide down a distance inside of them...

The Enterprise seems tame at first: you sit in your seat and the wheel begins to rotate. Suddenly a central arm tilts upward, and the wheel is no longer simply rotating around a vertical axis; the whole wheel is at an angle, and you are going up and down as you go around and around.

The Whip has simple, interesting mechanics. Here is a profile of the ride, showing the path of the drive chain and a couple of the cars with riders in them:

Figure 13-2

Whip Diagram



The drive wheel rotates at a constant angular velocity ω . This causes the chain to move with a constant linear velocity

$$v_{\text{chain}} = r_{\text{chain}} \omega$$

The car is attached to the chain in a way that keeps its arm perpendicular to the chain. So long as the car is traveling along the straight part of the chain, the car with the riders in it is moving at the same velocity as the chain,

$$v_{\text{car}} = v_{\text{chain}}$$

As soon as the car reaches the curved part of the chain, the linear velocity of the car and riders very rapidly becomes larger:

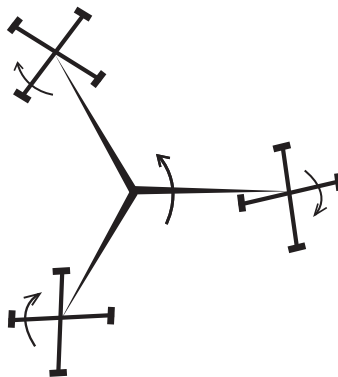
$$v_{\text{car}} = (r_{\text{chain}} + r_{\text{car}})\omega > r_{\text{chain}} \omega$$

This, together with some back-and forth spring-loaded movement of the car at the end of its arm, provides the “whip” effect: you suddenly find yourself going much faster, and being pressed toward the outside of the car. When your car reaches the other straight section of the chain, you slow down, only to be “whipped” again when you reach the other end curve.

There are also rotating rides where there are two levels of rotation in a single plane. The primary rotation is provided by the set of car-support arms moving around a central pivot point. Out at the end of each car-support arm, either an individual car rotates about its own axis, or one or more cars at the ends of a shorter set of support arms rotate around the end of the main support arm. Figure 13-3 shows the plan of the Scrambler (there is one at King’s Island in Ohio). The cars are at the ends of the short arms.

Figure 13-3

Plan View of the *Scrambler*



The arrows show the directions of rotation of the several sets of arms.

Round-and-Round Rides

- Caterpillar
- Swiss Bobsled (*Alpine Bobs*)
- Music Express

These are rides where the round-and-round motion is not provided by some central rotating mechanism. Instead, you sit in a train of cars that go around and around on a circular track. The track may undulate so that the cars go up and down as they go around the loop. Theming is a major differentiator among them, with musical accompaniment. The caterpillar has the added “thrill” of a cover being pulled over the train as it is going around. To onlookers the train takes on the appearance of a caterpillar; the riders find that their world has suddenly gone dark.

Wheels with Horizontal Axes

The *Ferris Wheel* was invented by Pittsburgh bridge builder George Washington Gale Ferris, who was seeking an attraction for the *World’s Columbian Exposition* in Chicago in 1893, that would rival Paris’ Eiffel Tower. This wheel was 264 feet high; it had 36 cars, each of which could carry 60 people.

To celebrate the start of the 21st century, London erected the huge *London Eye* or *Millenium Wheel*, 394 feet in diameter, with a maximum height of 443 feet. It was the largest Ferris wheel in the world when it was built in 1999. It has since been surpassed in size.

An interesting variation on the “standard” Ferris wheel is a wheel in which half of the gondolas are not fixed to the outer rim, but move about on small inner loops. As the wheel rotates, these cars move from the outer rim (when they are on the low side) to a location closer to the wheel’s

center (when they are on the high side). *Mickey's Fun Wheel* at Disney's California Adventure is this sort of ride; it is patterned after Coney Island's 1927 *Fun Wheel*.

Swinging Rides

The *Buccaneer* is a "pirate ship" that swings and is also partly supported by a track:

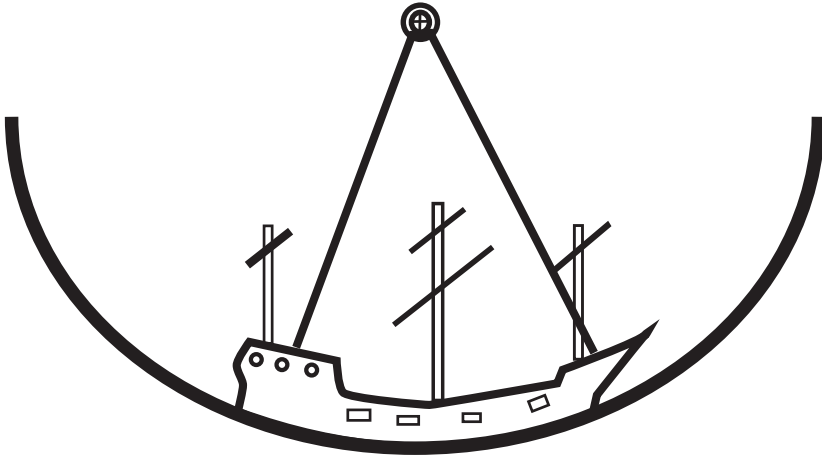


Figure 13-4
Buccaneer Swinging Ride

The riders sit in tiers of seats across the "ship", facing the middle. As the ride starts, the ship starts to swing back and forth, gaining speed and height on each pass. For the riders near the center, the ride is quite mild; they do not go up very far. For the riders seated at the ends of the ship the experience is different. On each pass they go up to the top of the track, seemingly hang there feeling weightless for a split second, and then start back down.

For those guests who want an even more exciting swinging-ride experience, there are rides where the side-to-side excursion is not limited to a mere 75 degrees. They continue to gain speed and height until they have sufficient energy to go all the way around, over the top. The riders, who are secured in their seats, all get to go upside down. *The Looping Starship* at Six Flags Great Adventure is an example of this sort of swinging ride.

Falling Rides

Parachute Jump was a famous old Coney Island ride. The ride begins with all the “parachutes” at ground level. Each guest takes a seat, the “cars” are all lifted to the top of the ride tower, and then dropped so that they leisurely drop back to ground level, giving the sense of a true parachute jump.

The next level of “drop” excitement is the Free Fall ride. In a typical ride of this type, the guests sit in an enclosed car, which is hauled to the top of the drop tower. The car is then let go, to plummet downward under the pull of gravity. Different means have been used to slow and stop the cars at the bottom. In an early ride of this type at Six Flags Great Adventure, the car rode a track that was vertical for most of its length. As it neared the ground, the car curved to a horizontal section of track, where it lost its momentum. Other similar rides have used magnetic brakes, much like those on modern roller coasters, to slow and stop the falling car.

With the *Tower of Terror*, Disney raised the excitement level even further. Rather than relying on a gravity-driven “free fall,” the car in the *Tower of Terror* is pulled down faster than it would fall on its own. The control system to make this work also permits varying rides, where you may drop part way down, go back up again, and fall again.

Dark Rides

These are usually not “thrill” rides in that they do not go particularly fast or have sharp drops or accelerations. They typically go through a themed area, which may tell a familiar story or perhaps even offer some unexpected and therefore exciting scenes.

Disney’s *The Many Adventures of Winnie the Pooh* and *Peter Pan’s Flight* feature scenes from familiar stories. Pooh struggles with the mystical *Heffalump*. In the Peter Pan ride the guests ride in suspended seats, which give a sense of flying over London.

Disney’s *Journey into Imagination* adds only minor thrills. It tells a new story, which is accented by such scenes as an inverted room, and a variety of odors in a “smell laboratory”.

Disney’s *Haunted Mansion* ups the excitement by carrying you past portraits that change as you pass them, corpses rising out of their coffins, holographic guests at a banquet, and, finally, letting you see in a mirror that a spirit has joined you in your car. Each of these effects is a fairly straightforward application of technology; presenting lots of them along the ride creates an experience that you want to repeat, to see them again and also to see if you missed any.

Two other Disney rides, *Buzz Lightyear’s Space Ranger Spin* and *Toy Story Midway Mania* add the element of target shooting. In the *Buzz Lightyear* ride you compete with your seat-mate by shooting a laser gun at a series of targets superimposed on the bad guys. In *Midway Mania* you again compete with your seat-mate, but you shoot (“throw”) computer-produced images of a variety of objects from darts to quoits at a variety of targets. At the end of each ride, you are also able to compare your score with the best of the day. Feeling challenged to do better?

You can get back in line (that can be quite long on busy days) to try again.

There are many rides in this general category that involve boats; they are discussed in the next chapter.

Dark Rides also have their own fan group, the *Dark Ride and Funhouse Enthusiasts* (DAFE). Check them out at

www.dafe.org

Other Rides

Amusement and theme parks frequently have other hard-to-classify rides that may or may not be “thrilling” but that offer other experiences.

A staple of amusement parks are *Bumper Cars*, in which guests drive helter-skelter around a large open space, banging into (or avoiding being banged into by) other cars, each of which is surrounded by a cushioned, shock-absorbing bumper. To allow the operator to stop the ride so that guests can leave and new ones enter, the cars are centrally powered. Power is supplied to the individual cars in much the manner in which trolley cars work: one contact is with the floor of the ride (by means of a shoe or slider under the car), and the other contact is made via a “trolley pole” that contacts the metal ceiling of the ride. The ceiling is high enough that no rider could possibly complete the circuit between the floor and the ceiling and sustain an electric shock.

Some spread-out parks offer *Sky Rides*. These resemble ski lifts with enclosed seats suspended from an endless moving cable. You get the excitement of riding high in the air, the enjoyment of an aerial view of the park, and the convenience of moving swiftly and effortlessly from one side of the park to the other.

Railroad train rides around the park (usually around the periphery) are tame, but they also give you an effortless view of what the park has to offer. The trains may be full sized or ride-behind very large scale models, powered by real steam locomotives, by real or model diesel locomotives, or by battery powered model locomotives.

Especially on the full-sized train rides, part of the excitement is riding behind an old-fashioned steam locomotive.

Some have multiple stops along the ride, so that you can use the train to get from one part of the park to another. Some even pass through special scenes; an example is the Grand Canyon panorama on the *Disneyland Railroad*.

An extreme example of a unique dry ride is the *Disney/GM Test Track* at Walt Disney World. You are propelled around the track in a modified automobile, through simulations of various tests to which real developmental cars are subjected —things like acceleration, cornering, and braking. It is a fast and very exciting ride!

Rider Dynamics

Let's look at took at the forces in an old rotating ride: the *Highland Fling*.

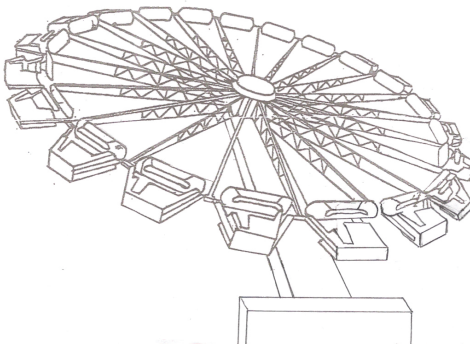


Figure 13-5
Highland Fling Ride

This has some characteristics in common with the Enterprise, but it rises to a higher angle.

The ride first accelerates to full speed with the axis vertical. The cars start out hanging straight down, but tilt outward as the ride speeds up, so that the seat force, S , is always perpendicular to the seat.

Once the ride is rotating at full speed, the main support arm rises 89 degrees, so that the axis of rotation is one degree from being horizontal.

A ride lasts two minutes. Assume this is divided into four 30-second parts:

- + Accelerate
- + Rise to 89 degrees
- + Back to Horizontal
- + Decelerate

Try These Problems. Using the data provided below, see if you can work these problems:

- 1) When the wheel is horizontal, what is the maximum g force the riders experience? At what tilt angle?
- 2) When the wheel is at maximum tilt, what are the maximum and minimum g forces the riders experience?
- 3) What power motor is required to accelerate the wheel?

(The solutions are at the end of the book.)

Highland Fling Data

- Maximum speed: 14.8 rpm

- Capacity: 42 Riders (2 per car)
- Wheel Diameter at Rider's Seat: 50.6 ft.
- Weight of Loaded Wheel: 83,780 lb.
- Maximum Tilt Angle: 89 degrees
- Maximum Height of Rider above Ground: 63 ft.

CHAPTER 14

Thrill Rides: Water Rides

Introduction

Ignoring Water Parks, where there is seemingly a constant flow of new types of attractions, and the few roller coasters where onlookers get to spray the riders with water at certain points along the ride, there are four basic types of water rides:

- “Splash” rides, which are generally short, one-way rides
- “Scenic” rides, where the attraction consists mainly of things viewed along the path of a quiet, generally flat ride
- “Flume” rides, which are rather like water-borne roller coasters
- Raft rides

There are also hybrid rides, combining the features of two of these types of rides

An issue with water rides is whether or not the riders get wet. Among other things, this can influence the decision of guests whether or not to ride. Getting wet is acceptable to more people on a hot summer afternoon than on a cool fall evening.

“Splash” Rides

These are the original water rides, originating in the late 19th century as *Shoot-the-Chutes*. These are simple rides involving a rather steep channel (chute) leading from a hilltop to a “lake” (pond or pool) at the bottom. It’s a one-way trip. “Passengers climbed up to the loading platform on top of the hill and boarded ten-passenger flat-bottomed boats for

the quick descent to the bottom. Once at lake level, the speeding boats skipped over the water like a pebble tossed across the lake, to the delight of rider and spectator alike.” (Reynolds, 1999)

Similar rides remain popular today. Six Flags Great Adventure has *Splashwater Falls*, and Kennywood has *Splash Down*. In both of these, both riders and spectators are not only delighted, they are usually soaked! At Great Adventure there is an observation bridge over the chute, where spectators get splashed as they look down at the boats. At Kennywood there is an innocent looking viewing platform near the bottom of the chute; spectators who gather to watch friends come down but have not watched an earlier ride get a big wet surprise when the boat hits the pool at the bottom of the chute.

Disney’s *Splash Mountain* is one of the “hybrid” rides alluded to above. In this ride a fairly long, slow journey through the realm of the *Tales of Uncle Remus* (as captured in Disney’s 1946 motion picture *Song of the South*) leads to a quite thrilling climax: a big drop ending in a big splash. The ride then continues around to unload at the starting point.

Flat Rides

Thinking of Splash Mountain leads us to this next category of water rides.

They can be categorized as themed rides using boats rather than wheeled vehicles.

A classic ride of this type is the “Tunnel of Love”. These *dark rides* were places young couples could find a few quiet moments alone. Over the years they have taken on many new identities, featuring many different themes. Kennywood for years had its *Old Mill*, which was still sort

of a “Tunnel of Love”. More recently Kennywood has re-themed this ride as *Garfield’s Revenge*, based on the famous cartoon cat.

These sorts of rides can be indoors or out. Two very famous rides at the Disney parks are the outdoor *Jungle Cruise*, known for its tongue-in-cheek narration and its many animatronic people and animals, and *It’s a Small World*, the indoor ride that features the background music you can never again get out of your mind. *It’s a Small World* is one of the attractions that Walt Disney originally had created for the 1964 New York World’s Fair, where it was featured in a Pepsi Cola pavilion.

These themed and basically flat rides can also have exciting features inserted along the way. *Splash Mountain*, mentioned above, is an extreme case, with a really dramatic shoot-the-chutes ending. The Disney parks have other rides that have surprising but fairly tame “splash” elements along the way. Two examples are

- *Pirates of the Caribbean*
- *Maelstrom*, in the Norway pavilion at Epcot.

You do not usually get wet on either of these indoor themed water rides. From a technology viewpoint, these are “flume” rides, but with no or minor “thrilling” drops.

The water in these flat rides is typically kept flowing by booster pumps along the route.

Flume Rides

In addition to re-inventing the roller coaster, Ed Morgan and Karl Bacon of Arrow Development changed the world of water rides. The *flume ride* took the use of water to new levels, based upon principles of hydrodynamics and knowledge of how water behaves at high speeds and how it can be controlled.

In these rides, water is typically pumped to an elevated position and flows down hill. The shape and cross section of the flume determines the speed of the water flow and thus of the boats.

Much of the route is fairly slow. The water never stops, so loading often takes place on a large rotating platform, which matches the speed of the passing boats. Faster portions are interspersed among the slow areas.

If you do not manage the flow rates, you can make a mess really fast. More about this later.

Raft Rides

Raft rides are quite different. They simulate riding an inflated rubber raft down a usually lazy river that also has sections with exciting rapids. Unlike “real” river rafting, no one is controlling the raft, it is just moved along by the current of the “river”. In slow sections of the river it bobs along peacefully. When it comes to a section of rapids it speeds up, may-be whirls, and generally takes on some splashed water.

The expectation of a raft ride is that the riders *will* get wet. Just in case an exceptionally lightly-loaded raft bobs through the rapids without major splashing, there are often water cannons near the end of the ride, either automated or operated by cast members, which are fired to insure that the riders *do* get wet.

Raft rides are popular. Six Flags Great Adventure has *Roaring Rapids*, Six Flags Over Georgia has *Thunder River*, California Adventure at Disneyland has *Grizzly River Run*, and Walt Disney World’s Animal Kingdom has the *Kali River Rapids*.

Fluid Mechanics for Water Rides

Strictly speaking, all of these rides are *flume* rides. They are based

upon the concepts of *open channel hydraulics*.

A classic text on this topic, by Chow, defines a flume to be “a channel of wood, metal, concrete, or masonry, usually supported on or above the surface of the ground to carry water across a depression.” (Chow, 1959)

Another text defines open channel hydraulics to be “the study of the physics of fluid flow in conveyances in which the flowing fluid forms a free surface and is driven by gravity.” Open channel flow “is considerably more complex than closed conduit flow [flow in pipes] due to the free surface.” (Sturm, 2001) “Flow conditions in open channels are complicated by the fact that the position of the free surface is likely to change with respect to time and space and also by the fact that the depth of flow, the discharge, and the slopes of the channel bottom and the free surface are interdependent.” (Chow, 1959)

As was discussed in Chapter 8 about using model boats in movies, there are two dimensionless relationships that play key roles in free-surface hydraulics:

$$\text{Reynolds Number } N_r = VD \rho / \mu$$

$$\text{Froude Number } N_f = V/\sqrt{gD}$$

In open-channel flow, the Froude Number describes important energy states.

$N_f < 1$ “Subcritical” (gravity dominates, flow is slow)

$N_f > 1$ “Supercritical” (inertial forces dominate, flow velocity is high)

$N_f = 1$ “Critical” (potentially unstable)

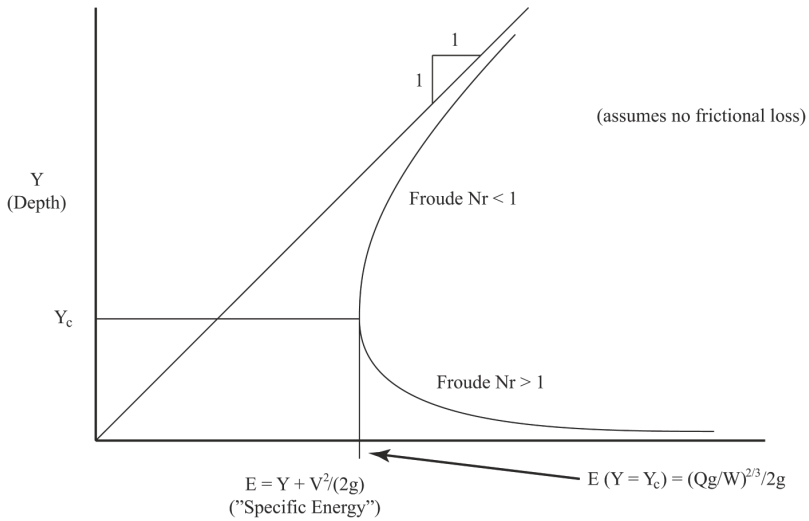


Figure 14-1
Specific Energy Curve

Note that except for at a single point [critical depth and critical energy, where $E = E(y_c)$], there can be two different water depths for any given specific energy. Water depths deeper than critical are said to be *subcritical* (deeper and slower) and water depths shallower than critical are said to be *supercritical* (shallower and faster).

Some flume rides are designed completely in the subcritical range. These are the rides we don't usually think of as "flume" rides—the slow, flat rides like the *Tunnel of Love* or Disney's *It's a Small World* (see above). The rides we tend more to call "flume" rides, like log flume rides and rapids rides, tend to utilize both flow regimes.

It is desirable to have relatively slow water (subcritical flow) in areas where boats can bump together, like at loading stations, at the tops of drops, or in other areas where boats can be stopped. "For long trough lengths, utilizing supercritical flow can minimize the number of boats required, and add thrill." (Sumner, 2004)

This all can happen at constant flow from the pumps.

You don't want to design a flume ride to operate at critical depth. Because the nose of the specific energy curve is rather broad, small changes in specific energy levels would cause large fluctuations in depth and the associated velocity.

The slope of a prismatic channel that “sustains a given discharge at a uniform and critical depth is called the *critical slope* S_c . A slope ... less than the critical slope will cause a slower flow of subcritical state... A slope greater than the critical slope will result in a faster flow of supercritical state”. (Chow, 1959)

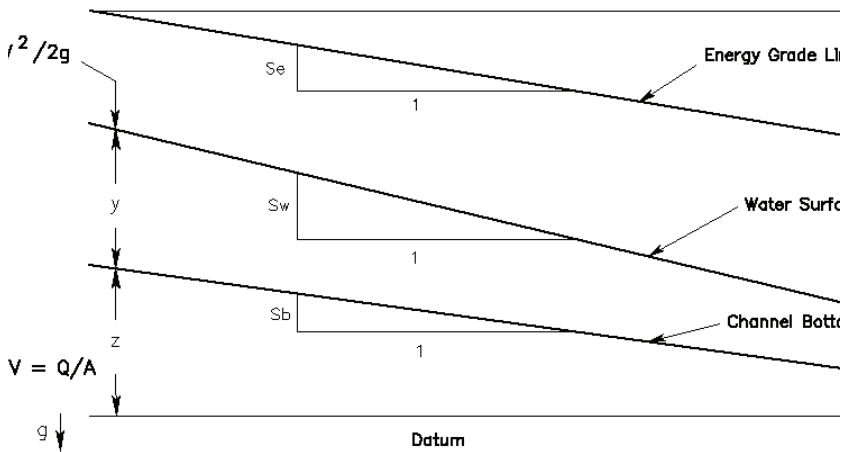


Figure 14-2
Energy Relations in Open Channel Flow

In designing a flume ride, the width, depth, and velocity are usually specified, and the slope is designed to fit.

- Show intent sets the speed (e.g., slow through a show scene)

- Width is usually a result of the style of boat to fit the show & meet ride capacity
- Depth usually is determined by the minimum required for the draft of the boat

Once you know the required velocity, depth, trough dimensions, and friction coefficient for the trough material, you can calculate the required flow rate, friction losses, and trough slopes.

Friction Losses. As water flows through a trough, friction between the water and the trough surface removes energy from the water. If you wish to maintain a constant depth and velocity between two points, the specific energy upstream must be the same as downstream. The lost energy must be regained, usually by sloping the trough down.

Other factors that must be considered when designing a flume ride include

- Varying trough cross-sections—often both rectangular and trapezoidal
- Varying speeds
- Bypass sections where boats are stopped
- Banked troughs to keep water inside a curve deep enough

We mentioned earlier that if you do not manage these considerations carefully, you can make a mess really fast. Karl Bacon told a story about an early flume ride installation at Six Flags Magic Mountain. “Hydraulic jumps happen when you try to slow it down. If you weren’t careful you’d get a hydraulic jump and lose all that energy. They lost all the energy. It slowed down from a super-critical flow into sub-critical flow and raised up over the trough and over the plantings.” (Reynolds, 1999)

Once you have designed the trough to meet the needs of the ride, other design considerations need to be addressed to complete and operate the attraction, like

- Pumps, piping, pump sumps
- Filtration and water treatment
- Maintenance access
- Loading and unloading areas
- Mechanisms for lifts, downramps, loading stations, brakes, etc.

Open-Channel Hydraulics Problem: Designing a Flume Ride

Try this Do-It-Yourself Exercise.

Friction Losses. *Hydraulic Radius* is defined to be cross section area/wetted perimeter

For a rectangular flume of width *W* and depth *Y*,

$$R = (WY)/(W + 2Y)$$

Typical values of the Manning coefficient of roughness (*n*):

- Smooth Fiberglass: $n = 0.010$
- Smooth Concrete, hand troweled: $n = 0.011$

Manning Formula:

$$S = (Vn/1.486R^{2/3})^2$$

Where

S = slope (ft/ft)

n = Manning coefficient of roughness

R = Hydraulic Radius (ft)

As water flows through a trough, friction between the water and the trough surface removes energy from the water. If one wishes to maintain a constant depth and velocity between two points, the specific energy upstream must be the same as downstream. The lost energy must be regained, usually by sloping the trough down.

Some More Key Relationships

Specific Energy (per lb of water):

$$E = Y + V^2/2g$$

Critical Flow Conditions:

$$E_{CR} = (Qg/W)^{2/3}/2g$$

$$Y_{CR} = [(Q/W)^2/g]^{1/3}$$

Where

W = width (ft)

Y = depth (ft)

Q = flow rate (ft³/sec)

g = gravity

V = average velocity (ft/sec)

Remember Sumner's admonition, that "it is not desirable to design a flume ride to operate at critical depth. Because the nose of the specific energy curve is rather broad, one can see that small changes in specific energy levels would cause large fluctuations in depth and associated velocity."

In designing a flume ride, the width, depth, and velocity are usually specified, and the slope is designed to fit.

- Show intent sets the speed (e.g., slow through a show scene)

- Width is usually a result of the style of boat to fit the show & meet ride capacity
- Depth usually is determined by the minimum required for the draft of the boat

Knowing the required velocity, depth, and trough dimensions, one can calculate the required flow rate, the friction losses, and the needed trough slopes.

The Problem.

A 100-foot long section of flume ride is to be designed using a five-foot wide rectangular flume section. It is to be constructed of smooth trowel-finished concrete. The design water velocity is four ft/sec, and the design depth is 2.5 ft.

- 1) What is the required water flow rate, in ft^3/sec ?
- 2) What is the specific energy of the water?
- 3) What is the required elevation drop over the length of the flume section?
- 4) Determine if the flow is supercritical or subcritical.

The solution is provided at the end of the book.

CHAPTER 15

Interactive Simulators

A *Simulator* attraction is something that essentially does not go anywhere, but gives the guest the sensations normally associated with a ride or other activity. This is achieved using films, various forms of mechanical motion, sound, odors, theming, and guest involvement.

“Simulation is used in today’s entertainment market to fool the rider into believing that they have been transported to a different place/time. A few months ago, one of the major theme parks began the development of a new ride. In the process of testing it, they built a prototype in a manufacturing facility. With a little magic, they transformed this manufacturing facility into a stage set, with the ride in the middle of it.

“To test the concept, they arranged with the local grade school for a parent/student night on this stage set. The kids, all being inquisitive and bright, could see that they were getting into a ride that was in this room. When this ride was over, one rider was seen staring up to the ceiling as he walked off the set. One of the operators asked the child what he was looking at or for. His answer was that he knew they had never left this room, but how did they get the stars and planets into this room! A truly simulating experience.” (Bartel, 2003)

At an American Coaster Enthusiasts event at Six Flags Great Adventure in 1990, to welcome the new *Shockwave* standup looping coaster, the president of Great Adventure expressed his belief that simulator rides would be important to the future of amusement parks, because it would cost much less to “renew” a simulator ride by making a new movie, a new software program, and a new theme, than to spend \$3 million to move a roller coaster from one park to another, as they had just done with *Shockwave*.

Not everyone agrees. In a note in the Nov 2002 issue of *Fun World* the new IAAPA chair is quoted as saying “They’ll have their place, but I think people will always want to get out and react with other people, share their experience, and then do it again. They want to feel the wind in their hair.”

Flight Simulators

Flight simulators have been used since World War II to train military and commercial pilots, particularly for instrument flying. The first flight simulator was patented in 1929 by Edward A. Link.

The crew being trained sit in a full-sized cockpit, mounted on a *motion base* which provides a variety of limited motions. They watch a film, perhaps of a landing sequence, and must use the realistic controls to “land” the simulated plane. Any errors are noted.

The motion base provides realistic roll, pitch, and yaw motion, but only limited up-and-down and forward motion. A mix of noticeable and unnoticeable accelerations, together with the film sequence, create the illusion of forward motion.

Involvement with the controls supports the illusion.

A futuristic war game named *Battletech*, which was being played as a board game, a miniatures game, and a role-playing game, provided an early opportunity for experiencing limited simulation for entertainment. *Battletech Center* was set up in Chicago, to enable several players to compete in a simulated battle.

Combat in the *Battletech* universe, for those not familiar with it, is conducted using giant man-like robots (“Mechs”), each driven by an individual soldier. This is essentially a VR experience, but it looks a lot like a simulator.

At Battletech Center, each player sits in a non-moving enclosed cockpit watching on the view screen a computer generated image of the other players' Mechs on a battlefield. An (almost too) full complement of movement and weapons controls in the simulated cockpit enables the player to “do battle” against the other players.



To succeed takes practice...

Disney's *Star Tours*. An early and excellent simulator “ride” was set up by Disney, first at Disneyland and then also at Walt Disney World. Based upon the Star Wars movies, this is a highly-themed ride with about 64 seats on a platform atop a single motion base.

The rider's view is constrained to “looking out a window” (looking at a screen placed where the forward view port would be), so the illusion is complete. Everything else you can see is themed to support the concept. In classic Disney fashion, you are in a themed environment from the moment you enter the attraction building. This psychs you up in preparation for the actual “ride”.

The concept is that you are taking a vacation journey in a shuttle to the Moon of Endor, home of the Ewoks in Star Wars Episode 6.

Once you embark on the shuttle, you find that the (robot) pilot is a novice. The trip rapidly turns exciting as you barely escape damage leaving the shuttle bay, and suddenly find yourself in the midst of a battle with the Empire.

The maximum motion is about five feet. The rest is roll, pitch, yaw, and the rapid, intense action of the movie.

As proof of the idea that simulator rides are easily renewed, Disney for a time had at Epcot a virtually identical “ride,” themed after the 1966 movie *Fantastic Voyage*. In *Body Wars* you were shrunk to nano size, and traveled through the blood systems of a human. Once again, plans went awry and the trip became exciting.

While the two rides were technically nearly identical, people reacted much differently to the two. Two people with whom I have spoken found *Body Wars*, with its trip inside a person, to be quite unsettling—to the point that they would not ride again. They both find *Star Tours* okay.

Star Tours has since been upgraded, to provide several different ride experiences, randomly selected for each new group of guests.

Not every simulator is nearly as well executed. I once experienced a simulator ride, the concept for which was that you would ride along with a Navy pilot in a high-performance jet fighter plane.

The pre-ride theming in the entrance queue represented the entrance to a hanger. The décor included photos of airplanes and famous flyers. Finally, one entered a large space appearing to be an actual hanger. In the hanger, many pairs of seats on individual motion bases moved in synch with a movie projected on a large screen.

The spell was broken because the illusion was incomplete. No “cockpit interior” masked the edges of the screen, which was not big enough to completely fill a guest’s view so that the rider could see the “hanger” beyond the edges of the screen. In addition, when my seat tilted far to one side I could see the mechanism under the adjacent set of seats. These incongruities broke the sense of “total guest immersion”.

Disney's Soarin' Over California. Several rows of seats, each attached to a motion control, are moved in close to a large curved screen. Motion is gentle, simulating a sailplane or hang glider ride over a group of famous California scenes (e.g., Yosemite, San Francisco). You see only the screen and feel the motion (and the breeze).

As people enter, the seats appear to be “usual” tiered theater seats. As the ride begins, six half-rows of seats rise and move toward the screen until the screen fills every rider's view. Then the action begins.

There are minor concerns with jarring transitions between scenes, such as a seashore suddenly giving way to a city or mountain, but otherwise the ride flows and the riders become totally immersed.

MaxFlight's Simulators. In these attractions, a two-person cabin is mounted at the end of an arm. The cabin can pitch and roll a full 360°. The arm can raise and lower the cabin, and move it in a circle. About the only thing it can not do is move forward or back a significant amount.

The cabin is entirely light-tight. A movie is projected on a screen close in front of the two riders, so that they can really only see the screen unless they sharply turn their heads.

This can provide a lot more motion than a *motion base*.

MaxFlight claims that passengers can customize their roller coaster ride from 38 million choices. They also have a dual steering Monster Truck Simulation and a “customer createable virtual Bobsled Simulator.” They bill their product as an *Interactive Ride System*.

MaxFlight Simulators are installed in many places, such as interactive science centers. If there is one near you, you might want to try it out.

Robot Arm. Could the sort of robot arm used to assemble automobiles support a simulator?

The German company Kuka Roboter is betting on it. They have enhanced the performance and reliability of the world's biggest robot, the six-axis KR 500, to turn it into the *Robocoaster*.

Then, to ensure their ability to enter the entertainment market, they worked with the German standards organization (TUV) to earn DIN 4112 certification for the design and manufacture of amusement rides.

“Robocoaster can simulate a lot of other rides—it has ride dynamics, movements, and sensations that you can get from different rides like a coaster or an LIM launching system, or an ejector seat sort of ride. What’s different about Robocoaster is that it can put them together in different combinations and in a flexible format that can be updated and changed. ...the thing that makes Robocoaster special is that it can accomplish the feats of other rides, but in a smaller package and at a much lower cost. Sporting a small footprint and a price tag of \$300,000, Robocoasters can find homes in FECs* just as easily as they can in major theme parks.” (Downey, 2003.)

As testimony to the potential of Robocoaster, right after it was shown at the 2002 IAAPA trade show, Legoland in Denmark signed up for ten of the units!

The Sum of All Thrills in Walt Disney World’s *Epcot* park is based upon a Kuka Robocoaster.

So, look for Robocoaster soon at an entertainment center near you...

*Family Entertainment Centers

Creating a Simulation Attraction

Much of this section is based upon information from the *Motion Systems Division* of Moog, Inc. (Bartel, 2003) Moog is a manufacturer of motion components in three of the four motion technologies: hydraulic, pneumatic and electromechanical. The only technology not covered by Moog is purely mechanical systems. Moog supplies components for such far ranging industries as flight control for missiles and space craft, commercial aircraft, candy making machines, and coal mining —and also for entertainment attractions like the *Spiderman* ride at Universal Studios.

(Yes, it's from the same family who produced some of the first computer-generated music, on the *MOOG Synthesizer*.)

The key components of a simulator ride are

- Pre-Show Area
- Simulator
 - Cabin
 - Motion Base
- Post-Show Area

Pre-Show theming sets the stage and psychs up the customers. Depending upon anticipated queue lines, this area may range from some stage-setting illustrations on the walls up to a detailed entrance to a spaceport.

The *Post Show* area, in addition to bringing you “back to earth,” may offer to sell you a photo of yourself in the ride, and may also route you through a concession offering lots of theme-related merchandise

The *cabin* creates the environment in which you experience the ride. It may range from a small, enclosed, one- or two-person cabin that you

would enter on a Battltech or MaxFlight simulator, to an entire “space shuttle” cabin like in Disney’s *Star Tours*. In addition to shutting out the “real” world to insure a complete experience, it provides the stimuli (visual, sounds, odors) and safety (secure, comfortable seating with appropriate restraints)..

The cabin is attached to the *motion base*. The motion base provides a variety of motions, depending upon the size (and mass) of the cabin and the way in which it is attached to the base. Does the cabin sit upon the motion base as in a flight simulator, or is it affixed to the end of a moving arm, as in a Robocoaster? Each of these can provide a variety of motions, taking advantage of the possible degrees of freedom and the amount of motion possible.

A *control system*, these days often a computer, is required to implement the desired sequences and magnitudes of motion.

CHAPTER 16

Home Entertainment: Bringing Entertainment to You

Some History

Engineering/Technology has had dramatic impacts on home entertainment. Many of the changes, especially early-on, were not made for the sake of home entertainment; when their potential was realized, entrepreneurs adapted them to the home. More recently, driven largely by electronics, a convergence of technology and the market have led to dramatic advances specifically aimed at enhancing home entertainment experiences.

Prior to the early twentieth century, most home entertainment was self-provided. People sang for their own entertainment. Think back to movies you have seen about the American Civil War, when many soldiers marched off to war singing. Late in the nineteenth century, many homes had upright pianos, which someone in the family could play. The family would gather around the piano, and sing.

People told stories, and also one family member would read aloud from a book—especially before electric lights were common in every home. People also played board and card games. Checkers, dominoes, and, later, Monopoly were common board game—Monopoly may be the best selling board game ever. Solitaire card games were adapted for group play, with all the players playing on a single set of Foundation stacks. Families and groups of neighbors played Bridge.

With the advent of electronic media, home entertainment moved from being entirely self-provided to being largely provided from outside the

home. With these changes came something else: home entertainment changed from activities that necessarily involved the whole family to activities that could be experienced by individuals if not everyone wanted to do the same thing.

The old home activities never really died. Some people still play musical instruments, perhaps motivated by participation in school bands and orchestras. Board games became more complex, but remain popular. Many activities evolved from home entertainment to hobbies. These are discussed later in this Chapter.

Music/Records

Music for home and individual entertainment has changed dramatically in the course of one century. We entered the twentieth century still singing around the piano in the parlor.

In 1877, Thomas Edison invented the phonograph. He initially had no dreams of changing home entertainment; he envisioned his new device as being useful as a dictating machine for offices. In 1887 the Gramophone made possible using Edison's invention to play recorded music at home. Early in the twentieth century, starting with Victor Records in 1900, recorded music became more available for playing in the home parlor. Edison's recording cylinders gave way to pressed vinyl disks. The evolution continued, from 10" and 12" 78 rpm disks with a single song on each side, until by 1948 the technology had evolved to where more information could be recorded on a single disk, and the LP (Long-Playing Record) was born.

A major step was the change from "mono" (monaural) to "stereo" (stereophonic) recording. This was first implemented on the more dense and more accurate LP records, with each track of the stereo (left

and right) recorded in a separate direction (up-and-down and side-to-side) in the grooves of the record. The two tracks were separated by the electronic amplifier system, and sent to separate left and right speakers. Over time, this has further evolved (following advances in movie theaters) into multi-speaker “home theater” systems.

After a brief flurry recording magnetically onto spooled wires, magnetic tape recording emerged. There were some early reel-to-reel home tape recorders, but the development of the 2-1/2” by 4” by 1/4” cassette quickly made this *the medium* for tape recorded music to play at home. The Sony *Walkman*® enabled the next step: taking your recorded music with you wherever you go. With ever-evolving computer technology, in the late twentieth century this was supplanted by the all-electronic portable *mp3* player.

Radio

After having been pioneered as a means for communicating, for example, between ships and from ships to shore, the first commercial radio broadcast took place in 1920 when radio station KDKA in Pittsburgh, Pennsylvania, broadcast election results.

Network broadcasting began with NBC (the National Broadcasting Company) in 1926.

Early home radio receivers were big, bulky pieces of furniture, housing large (and hot) vacuum tubes. They rapidly evolved to compact table model radios, and then battery-powered portable radios (that were still maybe 6” by 9” x 3”). Electronics technology kept changing, and the advances were incorporated into radios, leading to “transistor radios” that eventually were made integral with the “Walkman-type” tape players.

In the middle of the twentieth century, all sorts of programming was

available on the radio. News, including weather reports, had become common. Live broadcasts from the sites of important World War II events were real breakthroughs. There were stories of all genres, aimed at many different audiences. *Captain Midnight* and *Sergeant Preston of the Mounties* excited youngsters, while their stay-at-home parents could follow the original *soap operas* (actually sponsored by laundry-soap manufacturers) playing in the background as they went about their home activities.

Movies and Television

In the first half of the twentieth century, “home movies” usually meant movies made on 8-mm wide photographic film. Movies (usually not mainstream theatrical movies, but a mix of “classics” from earlier days and special-interest films) could be purchased, or photographed live using one’s own 8-mm movie camera.

Television appeared first in the United Kingdom in 1927; it came to the United States in 1930. Regular U.S. broadcasts started in 1932; they were suspended during WW II.

The first TV sets had small cathode ray tube displays, showing black-and-white pictures. Color TV appeared in the 1950s. Screen size and in-home viewing space still supported a level of shared intimacy as the family watched the TV together.

Early television fare was much of the same as was available on the Radio, with pictures added. But with this “theater” in the living room, the range of offerings rapidly expanded. “Sitcoms” (situation comedies) introduced comedy alongside the drama of soap operas. News shows became much more appealing with on-the-spot scenes and interviews. The drama of sporting events increased (despite the vivid presentations of seasoned radio sports-casters). Weather reports could show maps of

what was coming. Movies could actually be watched at home.

Unlike the Movies, TV is more immediate. And *continuous*, with shows featuring weekly or even daily episodes (although movie theaters did show serials, often aimed at young people, which demanded that you return each Saturday to keep up with the exploits of your favorite cowboy hero).

With a mix of live and taped shows, less money & prep time had to be invested for each hour of entertainment. Adding “reality” shows to the mix cut this even further by not requiring scripted performances by expensive stars.

Continuing technological advances keep providing new directions for television—and ongoing opportunities for engineering to advance the medium. The replacement of bulky power-hungry cathode ray tubes with flat-screen displays of various types (Plasma and LCD by the early 21st century) has provided more compact and lighter displays using less energy—and at the same time has enabled production of ever-larger displays, bringing the sense of *theater* into the home. At the time of this writing, the popularization of 3D movies is driving the development of viable 3D TV sets, on which to show those movies (and beyond).

Games (Before/Beyond the Computer)

The topic here is not “gaming” in the gambling sense, but competitive experiences shared (usually) among friends. We consider the burgeoning world of computer games, which are increasingly technically complex, in a separate chapter.

People still play card games at home and with colleagues, often competitively. Bridge remains popular. Some familiar card games have become mediated by personal computers—there seems to be some sort

of solitaire card game on every PC. It's so easy to play solitaire on the computer: the computer takes care of the tedious parts like shuffling and dealing, so all the player has to do is choose what move to make (and deal with the all-too-common screen note that you have lost because there are no more valid moves possible).

Except for computer games, technology has not had a major impact on games, except to make it easier to manufacture and distribute ever-more-complex games.

Board Games. Games for young people, like *Candyland* and *Careers* and *Battleship* still can be purchased, as can adult games aimed at general users—games like *Clue*, *Monopoly*, *Scrabble*, and *Trivial Pursuit*.

For more serious gamers, there are many strategy and battle games on the market. Beyond the generic classic “war” game *Chess*, these range from games representing different battles in a particular war via a series of “scenarios” (ex.: *Memoir 44* for World War II, or *Battle Cry* for the American Civil War) to many games each focused on one specific battle (ex.: *Gettysburg* from the American Civil War, and *Saratoga* and *Monmouth* from the American Revolution). These games are generally sold at shops specializing in games.

Not particularly “family” games, people often play these games with friends or at game stores, who often offer “game nights” and local tournaments at their shops. There are also national and regional “game fairs;” *Origins* may be the longest running national game fair.

Another group of board games are based upon various aspects of rail-roading. They range from Monopoly-like “investment” games through “train make-up” games like *Freight Train* and *Express* to “track laying” games like *Empire Builder* and *Ticket to Ride*.

That said, it should be noted that digital technology is being incorporated into board game experiences. One recent version of *Monopoly* comes with a computerized tower that keeps track of the rules and turns for the players. And with the advent of the iPad and other digital tablets, hybrid playing experiences are being created where the game is either entirely simulated on the tablet, or is combined with physical parts for another experience.

Collectible Card Games are not quite board games. They do not come with boards, but are played with table-top card layouts that resemble board layouts but tend to get larger than a convenient folding board. *Magic the Gathering* is one of the earliest and best known. *Pokemon*, which started as a video game, appeared as a collectible card game 2-3 years later, appealing to a younger audience. There have been many more since, including games based upon movies (e.g., *The Lord of the Rings*) and even original “war games” (“Dixie” is based upon the American Civil War).

Miniatures Games. Rather like board games on steroids, miniatures games are played with scale miniature figures (frequently soldiers), clustered on bases that can easily be moved about on elaborate table-top scenic landscapes. These games are as much hobbies as games; devotees go to great lengths to paint plastic or metal figures to resemble real military units, ranging from ancient warriors to modern-day armies and navies to fantastic science fiction armies—often “weathering” them so that they appear realistically battle-worn.

The exquisitely detailed miniature figures (22 mm, 15 mm, or even 10 mm tall) are often made from pewter-like metals (lead has been banned for safety) in centrifugal casting molds.

Role-Playing Games. Picture five people sitting around a table, acting

out a *James Bond* adventure. Two assume the roles of Bond and one of his cohorts (a “Bond Girl” or his CIA friend Felix Leiter), two others assume the roles of Bond enemies (perhaps Ernst Stavro Blofeld or Dr. No, and one of their cronies); the fifth is the “game master” or referee. The game master establishes the adventure and sets the bounds, and then provides additional information and mediates the players’ decisions as the adventure unfolds.

Like many activities, this can be carried to an extreme: the *LARP* or “Live Action Role Playing” game, which takes place not around a table but up and down the halls of the game fair hotel or whatever venue is being used.

Toys and Hobbies

Unlike games, technology and engineering have had major influences on toys and hobbies.

The most apparent may be that dolls rarely just say “mama” anymore; they speak complex sentences, often in response to stimuli from the child playing with them.

Construction toys are still around, although perhaps not as common as they used to be; not every young boy has an Erector set. Tinkertoy is still around, albeit changed from wood to plastic. Lego, which is newer (it was introduced in 1958) has moved from being based upon a number of sizes of basic plastic bricks to elaborate kits utilizing special complex parts—undoubtedly aided by the ability to make lower-cost molds for their injection-molded pieces.

Model airplanes have advanced from tissue-covered balsa-framed planes driven by rubber bands (although there are still people who see how long they can get ultra-light rubber-powered planes to fly) through gasoline powered planes flying in circles on control lines to electrically-powered radio controlled planes and helicopters. The market is big enough to

have driven some of these technical advances, although the light-weight low-power motors and light-weight batteries are technologies that were adopted as they became available.

Radio-controlled racing cars have been advanced by some of the same engineering advances as the airplanes. Battery power is now standard, replacing model-airplane-type gasoline engines, with smaller, longer-life batteries that hold their charges longer and thus permit longer operating times. Radios now use newer communications technologies, eliminating limitations caused by there being only a few available channels.

Model rockets now rise thousands of feet on selected firing ranges out of the way of commercial airline flight paths. The record is around 100,000 feet. The rockets that do this are 6-10 inches in diameter by 10-15 feet long. They carry parachutes for landing, cameras, GPS tracking devices, altimeters and other telemetry, and on-board flight computers.

The biggest technology impacts on the model rocket hobby have been compact electronic altimeters and in-flight computers, and ammonium perchlorate composite propellant, which is basically the same fuel as was used in the space shuttle solid rocket boosters.

“Toy” trains have evolved from wooden pull toys through wind-up toys running on the floor (and later on simple tracks) to very complex electronically-controlled systems. It is now possible through *Digital Command Control* (DCC) to run several trains on the same tracks without having collisions; each locomotive carries an on-board computer (“decoder”) that is individually addressed through a wired local area network. Small, powerful “instrument” motors have low current draw, which works well with the microelectronic control circuits. Current draw is also kept low by illuminating locomotive headlights with light-emitting diodes (LEDs)

rather than small incandescent bulbs. The addition of radio control means that the person operating a locomotive can control their train with a “throttle” unit that does not have to be connected directly to the track with wires. Control of individual locomotives has also permitted adding realistic sound, with bell and whistle sounds enabled from the throttle unit.

Two other “high tech” advances in *model railroading* (as the hobby has come to be known) in the first decades of the 21st century are adaptations of modern manufacturing technologies, based upon reducing the cost of introducing a new model by no longer requiring very expensive plastic injection molding tooling. Laser cutting of both wood and plastic parts is being used for model structures for the scenic background. The availability of more durable materials has led to *3-D Printing* of parts for models, from railroad cars to background scenic details. Both of these have also reduced the break-even point for making a profit on a particular model (based upon tooling cost amortization), to where in 2012 at least one manufacturer offered to convert an individual hobbyist’s favorite structure into a one-of-a-kind model.

Small motors have also made practical smooth running and reliable model trains smaller than the common “HO” scale (1:87). “N” (1:160) and “Z” (1:220) scale trains enable elaborate layouts in small spaces. At the other end, the same advances in motors and batteries and radios that have supported the changes in model airplanes have enabled large-scale “garden railroad” model layouts to be constructed without electrical wiring of the track.

For all of the people who “tinker” with construction toys or by building model airplanes or race cars or rockets or trains, there are a lot of people who have never ventured into the world of making things for personal enjoyment and satisfaction. Recently, the “tinkering” hobby has become more popular, supported by the introduction of *Make* magazine

and *Maker Faire* events. These have helped solidify “tinkering” into a movement, with do-it-yourself “hacklabs” and workshops springing up in cities around the world. The *Maker* community encourages people to get involved, and to design and develop their own experiences.

CHAPTER 17

Video Games

Drew Davidson

Hardware and Software Engineering

Video games have become a major part of our popular culture, providing players with immersive, engaging experiences that are created by multi-disciplinary teams of producers, artists, designers and programmers.

Engineering comes into play both in the hardware and the software. Hardware limits set the specifications for the software engineering. Historically, games have often served as drivers for engineering innovations in both hardware and software capabilities.

Early Games

Some of the initial games made in the 1950s, like *OXO*, *Tennis for Two*, *Colossal Cave Adventure*, and *Spacewar*, were developed for mainframe computers that made the most of the computational and display technologies.

From the start, games were a great way to demonstrate and highlight the full capabilities of the systems for which they were developed. *Spacewar* is a great example of this, as it showed off the graphic and simulation capability of the new PDP-1 computer.

Arcade Games

The 1970s saw the rise of video games at arcades. Companies like Atari and Taito created coin-operated game cabinets that housed games like *Pong* and *Space Invaders*, and later, games like *Asteroids*, *Pac-Man*, and many more.

As before, we see hardware providing the context for software. Features of the games were determined by the limits of the hardware. There were advances in 2D graphics (both vector and bitmap) that games made the most of.

Home Consoles

At around the same time, we saw the rise in the development of game consoles meant to be used with televisions in the home. There was the Magnavox Odyssey and the Atari 2600. These consoles served as bases for cartridges on which games were written, so players could buy these cartridges and play a variety of games on the console.

Hardware engineers worked to create consoles and controllers that had the most features, and then software engineers worked to create games that made the most of these features.

Since the 70s, there have been about 6 generations of consoles released (roughly every 5-10 years) with Nintendo and Sony joining in, along with Microsoft. We currently have 3 consoles, the Nintendo WiiU, the Sony Playstation3, and the Microsoft XBOX360.

Personal Computers

A decade or so later, computers started making their way into homes. And as usual, games were a way to highlight the capabilities of these early PCs from Apple, Commodore, and Tandy.

There was an explosion of text-based adventures, like *Adventure* and *Zork*, as well as 2D and 3D graphic games. *Myst* was famous for it's beautiful graphics and immersive worlds.

This time also marked an explosion in genres of games (adventure, role-playing, platformer, etc.) that made the most of the technological

advances in the computers. In fact, there is a subset of computers with a full range of features developed specifically for playing games.

Handhelds

The late 80s also saw the successful rise of handheld consoles that let players take their video games with them. There was the Nintendo Game Boy, the Sega Game Gear, and the Atari Lynx.

As ever, the hardware specifications of these handhelds enabled the features of the games designed for them. And like home consoles, there have been successive generations of handhelds developed and released. Currently we have the Nintendo 3DS and the Sony PS Vita.

Online Games

The 90s saw the rise of online multiplayer computer games in which players were able to login online and play games together. Again, we see games taking advantage of technological developments, this time the internet. Some of the first games like this were Massively Multiplayer Online Roleplaying Games (MMORPGs) like *Ultima Online* and *Everquest* that enabled players to inhabit a persistent virtual world together.

Consoles followed online shortly thereafter. This enabled even more variety of multiplayer games, and the mainstreaming of online leaderboards and gameplay achievements.

Currently the king of the hill of online computer games is *World of Warcraft*, but we've also seen more online social games like *Farmville* and *The Sims*. At this time, almost every video game offers some form of online multiplayer version as an option and players compete for leaderboard positions and achievements.

Mobile Games

This last decade has seen the rise of games on smart phones. Like handheld consoles, this let players take games, like *Angry Birds*, with them. As always, the games make the most of the hardware they're on.

With the advent of the Apple iPhone and all the variants of Android Phones, we are seeing games driven by touchscreen capabilities and taking advantage of the phone's GPS and other tech features.

Engineering Innovations

The development of video games has always pushed the state of the art in terms of both hardware and software. With every technical advance, games were developed to make the most of all the potential features. Games can be seen as drivers for advances in engineering practices.

Throughout the history of games, we see advances in the complexity of what a game can display, and what players can experience. The earliest games were text only, and progressed to black and white vector graphics and 8-bit audio, to photo-realistic full-color 3D graphics and surround sound today.

Current and New Directions

At this time, we seem to be experiencing an explosion of video game possibilities. More and more games, like *LittleBigPlanet*, are being released with in-game editors so that players can create their own levels and modifications of the base game.

Mobile and social games are enabling games to weave their way into our daily lives in a variety of ways. *Gamification* is a term for how a game can be designed around almost any type of activity to make it an engaging experience.

We are also seeing the development of games for purposes beyond just entertainment. Games are being created to help with learning, training, health, and civic engagement.

Also, the internet has not only enabled multiplayer gameplay; it has also enabled the creation of independent distribution channels, like Steam, the iTunes App Store and Google Play, that allow more and more people to create and share games—which has seen the rise of the independent game developers and games created for art's sake.

And we're seeing innovations in hardware that are influencing games. There is the rise of embodied play and motion-tracking, starting with the Nintendo Wii, then the Playstation Move, and the huge success of the Microsoft Kinect. And there is a rise of independent hardware development, with open source consoles, like the Ouya, being developed to enable people even more control of the games they make.

Through both the hardware and the software, engineers have played a prominent role in the advancement of the industry and the range of amazing experiences we can have playing games.

CHAPTER 18

Other Types of Entertainment

Let's look briefly at how technology has influenced other types of entertainment.

Museums, Zoos, and Aquariums

These are all characterized by the guests moving past the exhibits, usually at their own (walking) speed.

Electronic “fences” have let zoos design less-visually-obtrusive animal enclosures and “safari” rides without compromising the safety of guests or animals.

New materials have made it possible to create “closer encounters” in aquariums, where guests walk through tunnels with the fish swimming all around them.

In addition to whatever advances technology has provided for the displays themselves, electronics have enabled enhanced guest enjoyment and learning by their receiving much more information about each exhibit. In many such venues, a guest can rent a portable device upon entering the viewing area that can pick up extensive pre-recorded information at each exhibit, much like a private tour guide might provide.

Hiking and Camping

Hiking and camping have been dramatically changed by the introduction of new “engineered” materials, many developed originally for military applications, and by electronics.

Tents made of heavy canvas have been replaced by tents made from nylon and other strong, light-weight materials. Tent poles have evolved from wood to metal (aluminum) to carbon-fiber.

Backpacks and outdoor clothing have followed similar paths of materials evolution.

Eating on the trail has benefited from improved food preservation methods, and from light-weight liquid-fueled portable stoves.

Finding your way on the trail has been modernized by portable global positioning system (GPS) devices, utilizing satellite-based technology.

Sports

Baseball bats provide an interesting example of the impact of technological changes on sports.

Professional baseball wants to insure that nothing changes, while amateur baseball wants to change to encourage participation and increase the sale of sporting goods.

“In the 1970s with the advent of high-strength aerospace-quality aluminum, designers were able to develop bats that had lighter swing weights than wood bats. These lighter bats translated to increased swing speeds and more control for the batter. Designers soon realized that bats could be tuned to achieve varying levels of batted-ball speeds.” (Smith, 2010)

Major-league professional baseball has used the analytical and testing tools to insure that the bat-to-ball performance does not change. Meanwhile, amateur bats have evolved from wood to aluminum to fiber-reinforced composites. There are some who believe that bats have evolved too much, so the analyses and testing are used to ensure that the amateur game does not change too much.

Football at all levels has seen increased focus on player safety. Concussions have become a major concern, from high school through the professional ranks. New helmet technology has helped, but more is seemingly needed and is being seriously studied.

Gambling

One of the most obvious technological changes in the world of “gaming” has been the replacement of mechanics with electronics in slot machines. No longer is it necessary to pull the handle of the “one-armed bandit” to set the wheels rolling. The push of a button starts a digital electronic sequence that simulates the rolling wheels, and makes them “stop” based upon a randomization algorithm.

Advances in communications and computing have made possible nation-wide lotteries (like Powerball), with instantaneous aggregation of bets placed anywhere. Also, slot machines are now on-line to help provide persistent experiences that are designed to make it even more entertaining and compelling to play.

Casinos have improved technology-based tools for spotting “cheaters” (e.g., card counters). Sophisticated camera systems and RFID-tagged equipment help to monitor the show floor and provide security and an enjoyable experience for the guests.

EPILOGUE

REVIEW

After a brief introduction to the big, broad world of *Entertainment*, we examined several considerations common to virtually all types of entertainment, including

- Providing a *Total Guest Experience*
- The role of *Engineering* in Entertainment
- *Safety* as a major driving force
- The *Business* of Entertainment
- The role of *Story-Telling*

In Chapter 2 we noted that the concept of creating a *Total Guest Experience* is so basic to this world that some people term it the *Experience Design* industry.

We then switched to a “customer” (guest) point of view. We considered how guests react to the complete entertainment package with which they are confronted, and the *physiological* and *psychological* experiences they have. We looked at how guests can be “sold” to come to the ticket window by creating expectations, and how meeting those expectations helps to “psych them up” to leave smiling—and prepared to sell their friends on trying out the same experience. We gave you a chance to look at what sort of entertainment guest you are.

From a quite long list of types of entertainment in which engineering gets involved, we then considered nine in some detail:

- Print Media
- Live Theater

- Movies
- Animatronics
- Amusement Parks and Theme Parks
- Thrill Rides
- Simulator “Rides”
- Home Entertainment
- Video Games

In Chapter 18 we took a quick look at several more ways in which people seek entertainment.

Along the way you had the opportunity to probe more deeply into some of the topics, through additional reading, viewing some videos, and looking at (and perhaps even trying to solve) some engineering problems.

Thought Exercise: Of all of this, what made the most important impression on you? What will you still be remembering a month from now?

ASSIGNMENT

As you visit amusement parks, theme parks, carnivals, plays, or other entertainment attractions, notice the engineering behind the magic—and, now that you understand what’s behind the scenes, have *more* fun than ever before!

If you *really* like what you have seen, perhaps you may want to check out career opportunities in Entertainment. To find out where you might look, try one or more of the trade association publications listed in the Bibliography, or, if you are interested enough to invest some time and money, you might go to an exhibition put on by one of the trade associations. For example, IAAPA has a big show each November in the US,

and also participates in some global trade shows. Participants in these exhibitions range from thrill ride manufacturers through companies offering entertainment to the public.

SOLUTIONS TO PROBLEMS

Chapter 7

The Theater

Chapter 7 Problems

Some Useful Definitions

Pick A cable or other support used to hang some apparatus from the theater's overhead structure

SF Safety Factor

TL Total Load to be Supported

WL Working Load

WLL Working Load Limit

Problem 7-1

The lights are to be hung overhead, so use a safety factor of 8:1.

Total load (TL) to be supported:

21 ft of pipe @ 2.72 lb/ft	58 lb
14 lights @ 25 lb	<u>350 lb</u>
	408 lb

$$408 \text{ lb} \times 8:1 \text{ SF} / 3 \text{ picks} = 1088 \text{ lb per pick}$$

Try a 3/16" shackle:

$$\begin{aligned} 1/3 \text{ ton WLL} &= 666 \text{ lb WL} \times 4:1 \text{ built-in SF} \\ &= 2666 \text{ lb per pick} > 1088 \text{ lb. It'll work.} \end{aligned}$$

The assumption is made here that with a consciously added safety factor of 8:1, there is no need to add the 4:1 catalog safety factor for the shackle.

Problem 7-2

The portal is to be hung overhead, so use a safety factor of 8:1

Total load (TL) to be supported:

$$1000 \text{ lb portal} / 4 \text{ picks} = 250 \text{ lb} \times 8:1 \text{ SF} = 2000 \text{ lb per pick}$$

Try a 1/4" jaw-jaw turnbuckle:

$$500 \text{ lb WLL} \times 4:1 \text{ cat SF} = 2000 \text{ lb. It'll work.}$$

Problem 7-3

The video screens are to be hung over the audience, so use a safety factor of 10:1

Total load to be supported for each screen:

$$3600 \text{ lb} / 2 \text{ picks} = 1800 \text{ lb} \times 10:1 \text{ SF} = 18,000 \text{ lb.}$$

Try a 3/4" eyebolt:

$$5200 \text{ lb WLL} \times 4:1 \text{ cat SF} = 20,800 \text{ lb WLL} > 18,000 \text{ lb. It'll work}$$

Chapter 12 Problems

Thrill Rides: Roller Coasters

Problem 12-1 Second Hill

Energy Balance, assuming no friction:

$$PE_1 + KE_1 = PE_2 + KE_2$$

$$mgh_1 + mV_1^2/2 = mgh_2 + mV_2^2/2$$

$$mg(h_2 - h_1) = m(V_1^2 - V_2^2)$$

$$h_2 - h_1 = H \quad V_1 = 70 \text{ mph} = 102.9 \text{ ft/sec}$$

$$(\text{mph} \times 1.47 = \text{ft/sec})$$

$$2gH = V_1^2 - V_2^2$$

$$V_2^2 = V_1^2 - 2gH$$

For weightlessness at the top of the hill,

$$V_2^2 = gR$$

$$R = V_2^2/g$$

We can tabulate results:

H (ft)	V2 (mph)	R (ft)	Drop to Reach 40 mph (ft)
-----	-----	-----	-----
110.7	40.01	107.4	0
120	36.38	88.8	9.3
130	32.03	68.8	19.3
140	27.0	48.8	29.3
150	20.7	28.8	39.3

The choice of minimum R will depend upon the design of the car.

Problem 12-2 Flat Curve

From Clark,

$$\Psi = \tan^{-1} (V^2/Rg)$$

$$V = 40 \text{ mph} = 58.67 \text{ ft/sec}$$

$$R = 25 \text{ ft}$$

$$g = 32.2 \text{ ft/sec}^2$$

$$\Psi = \tan^{-1} [(58.67)^2/(25)(32.2)] = \tan^{-1} 4.276$$

$$\Psi = 76^\circ 50'$$

From Clark Fig. 2,

$$mg/S = \cos \Psi$$

$$S = mg/\cos \Psi$$

$$mg = 225 \text{ lb}$$

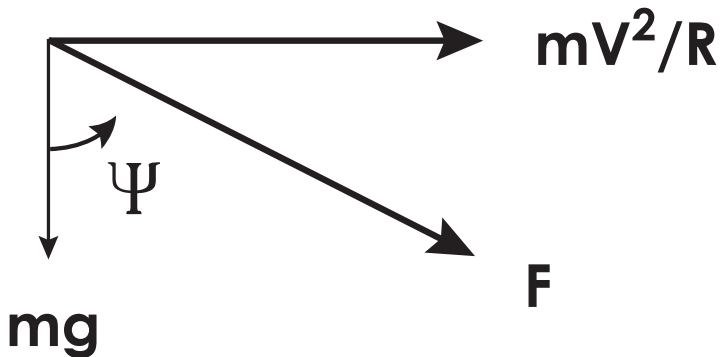
$$\cos \Psi = \cos 76^\circ 50' = .22778$$

$$S = 987.8 \text{ lb}$$

Problem 12-3 Force on the Track

Weight of car plus three riders =

$$800 + 3(225) = 1475 \text{ lb}$$



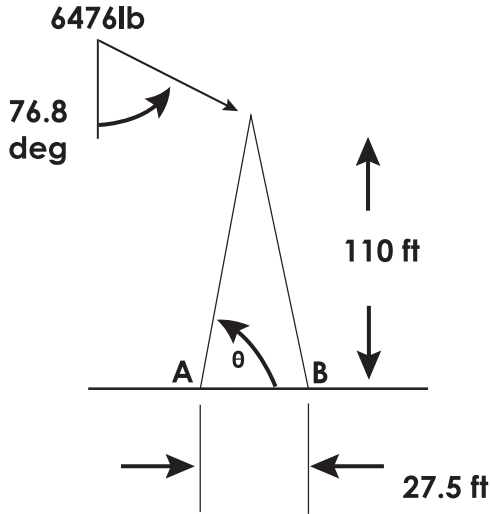
$$mg/F = \cos \psi = W/F$$

$$F = W/\cos \psi$$

$$= 1475/.22778$$

$$F = 6476 \text{ lb}$$

Problem 12-4 Support Loads

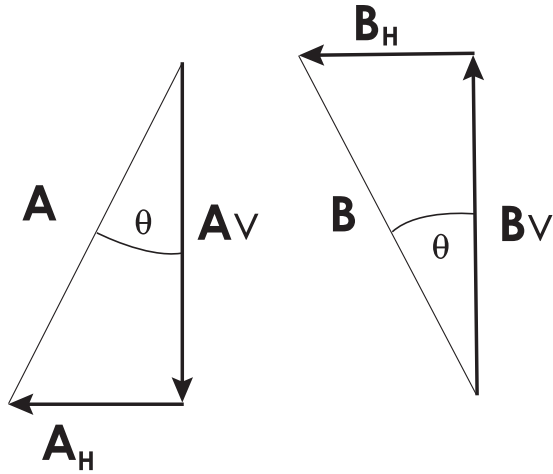


What are the forces at A and B?

$$\cotan \theta = 1/8; \theta = 82.87^\circ$$

$$\Sigma F_X = 6476 \sin(76.8^\circ) - A_H - B_H = 0$$

$$\Sigma F_Y = 6476 \cos(76.8^\circ) + A_V - B_V = 0$$



$$\Sigma F_x = 6476 \sin(76.8^\circ) - (A + B) \cos\theta = 0$$

$$\Sigma F_y = 6476 \cos(76.8^\circ) + (A - B) \sin\theta = 0$$

$$\sin 76.8^\circ = .9735 \quad \cos 76.8^\circ = .2277$$

$$\Sigma F_x = 6304 - (A+B)(.1248) = 0$$

$$\Sigma F_y = 1475 + (A-B)(.9922)$$

$$B + A = 50,513$$

$$B - A = 1487$$

Adding,

$$2B = 52,000; B = 26,000 \text{ lb compression}$$

$$A = 24,513 \text{ lb tension}$$

And

$$A_H = 3059 \text{ lb} \quad A_Y = 24,322 \text{ lb tension}$$

$$B_H = 3245 \text{ lb} \quad B_Y = 25,792 \text{ lb compression}$$

Problem 12-5 Bunny Hops

$$KE_{\text{BOTTOM}} + PE_{\text{BOTTOM}} = KE_{\text{TOP}} + PE_{\text{TOP}}$$

$$(mV_B^2)/2 + mgh_B = (mV_T^2)/2 + mgh_T$$

“m” cancels out, and we get

$$V_B^2 - V_T^2 = 2g(h_T - h_B)$$

We are given $V_B = 20 \text{ mph} = 29.3 \text{ ft/sec}$
 $\Delta h = 10 \text{ ft}$

Then

$$V_T^2 = V_B^2 - 2g \Delta h$$

$$= 858.49 - 644 = 214.49$$

$$V_T = 14.65 \text{ ft/sec} = 10 \text{ mph} (= 4.47 \text{ m/sec})$$

To find the radius for zero g, use

$$V^2 = gR$$

$$R = V^2/g = (14.65)^2/32.2$$

$$\underline{R = 6.67 \text{ ft}}$$

Problem 12-6 Braking into the Station

Assume uniform deceleration at 1.3 g

$$a = (1.3)(32.2) = 41.86 \text{ ft/sec}^2$$

$$\Sigma F = ma = F_B$$

$$F = (mg)(a/g)$$

$$a/g = \text{desired acceleration} = 1.3$$

$$mg = \text{weight} = 1475 \text{ lb}$$

$$F = (1475)(1.3)$$

$$= 1917.5 \text{ lb}$$

To find the distance,

$$\text{Work} = \text{change in KE} = Fd$$

$$KE_1 - KE_2 = Fd$$

$$KE_2 = 0$$

$$Fd = KE_1 = mV_1^2/2$$

$$d = mV_1^2/2F$$

But

$$F = (mg)(a/g)$$

Then

$$D = (mV_1^2)/[2mg(a/g)] = V_1^2/[2g(a/g)]$$

For $V_1 = 29.5$ ft/sec, $a/g = 1.3$

We calculate

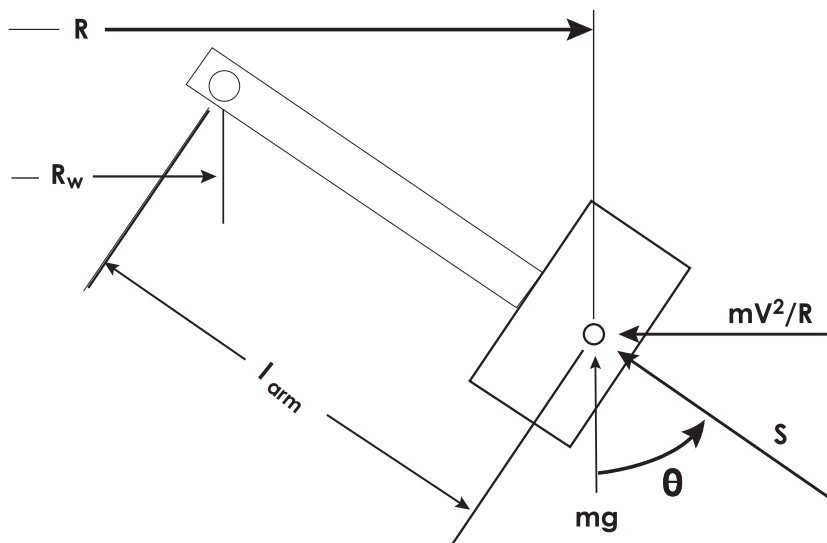
$$\begin{aligned}d &= (29.3)^2/[2(32.2)(1.3)] \\ &= 10.25 \text{ ft}\end{aligned}$$

Chapter 13 Solutions

Thrill Rides: Other Dry Rides

Problem 13-1. When the wheel is horizontal, what is the maximum g force the riders experience? At what tilt angle?

With the ride spinning horizontally (the axis of the ride vertical), this is the geometry:



We are given

$$R_w = 25.3 \text{ ft} \quad \omega = 14.8 \text{ rpm} = 1.55 \text{ rad/sec}$$

$$mg \text{ on riders} = 600 \text{ lbf}$$

$$l_{arm} = 4 \text{ ft}$$

To find the tilt,

$$\tan \theta = (mV^2/R)/mg$$

$$V = R\omega \quad R = R_w + l_{arm} \sin \theta$$

$$\begin{aligned}
g \tan \theta &= V^2/R = R\omega^2 \\
&= (R_w + l_{\text{arm}} \sin \theta) \omega^2 \\
\tan \theta &= R_w \omega^2/g + (l_{\text{arm}} \omega^2/g) \sin \theta \\
&= (25.3)(1.55)^2/(32.2) + [(4)(1.55)^2/(32.2)] \sin \theta \\
&\quad (\text{ft})(1/\text{sec}^2)/(\text{ft}/\text{sec}^2) \\
&= 1.89 + .30 \sin \theta + \text{error}
\end{aligned}$$

To find θ we can try a range of values:

<u>$\theta(\text{deg})$</u>	<u>$\tan \theta$</u>	<u>$\sin \theta$</u>	<u>error</u>
60	1.732	.866	-1.418
65	2.145	.906	-.0168
66	2.246	.914	+.0818
65.5	2.194	.910	+.031
65.25	2.169	.908	+.0066
65°10'	2.161	.9095	-.00125
65°11'	2.1625	.9077	0

Thus the answer is:

$$\theta = \mathbf{65^\circ 11'}$$

The maximum force on a rider is given by

$$F_R = \text{sqrt}[(mV^2/R)^2 + (mg)^2]$$

The “g” force is

$$S = F_R/m = \text{sqrt}[(V^2/R)^2 + g^2]$$

We know that

$$\begin{aligned}
V^2/R &= R\omega^2 \\
&= (R_w + l_{\text{arm}} \sin \theta) \omega^2 \\
&= [(25.3) + (4)(.9077)](1.55)^2 \\
&= (28.93)(2.4025) \\
&= 69.5 \text{ ft}/\text{sec}^2
\end{aligned}$$

Then

$$S = \text{sqrt}[(69.5)^2 + (32.2)^2] = \text{sqrt}(4830.25 + 1036.84) \\ = 76.6 \text{ ft/sec}^2$$

$$S = 2.38 \text{ gs}$$

Problem 13-2. When the wheel is at maximum tilt, what are the maximum and minimum g forces the riders experience?

With the ride nearly vertical (axis of rotation nearly horizontal), we can assume that the plane of the ride is vertical.

For a rider at the top of the ride,



Summing forces

$$\Sigma F = mV^2/R - mg = ma \\ a = V^2/R - g = R\omega^2 - g$$

$$\text{In this case, } R = R_w + l_{\text{arm}} \\ = 25.3 + 4 = 29.3 \text{ ft}$$

Then

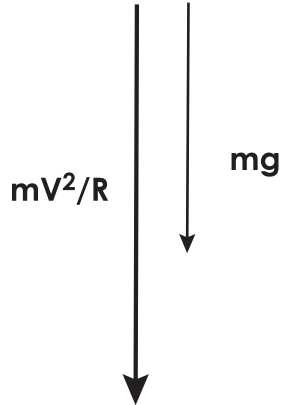
$$R\omega^2 = (2.3)(1.55)^2 = 70.39 \text{ ft/sec}^2$$

And

$$a = 70.39 - 32.2 = 38.19 \text{ ft/sec}^2$$

a = 1.19 gs at the top

For a rider at the bottom,



Using the same data as above,

$$\begin{aligned} a &= R\omega^2 + g \\ &= 70.39 + 32.2 = 102.59 \text{ ft/sec}^2 \end{aligned}$$

a = 3.19 gs at the bottom

(The data says 0.9 gs and 2.9 gs. This uses $R = R_w$)

Problem 13-3. What power motor is required to accelerate the wheel?

Summing torques,

$$\Sigma T = I\alpha$$

The moment of inertia is

$$I = m(r_1^2 + r_2^2)/2$$

We need to consider two parts, the wheel and the cars with their riders. For the wheel,

$$r_1 = 0, \quad r_2 = R_w$$

$$m = m_T - m_{\text{cars + riders}}$$

For the cars and riders,

$$r_1 = r_2 = R$$

$$\begin{aligned} w &= 21 \text{ cars @ } 600 \text{ lb} \\ &= 12,600 \text{ lb} \end{aligned}$$

For the loaded cars,

$$\text{At } t = 0, R = R_w = 25.3 \text{ ft}$$

$$\text{At } t = 30 \text{ sec, } R = R_w + l_{\text{arm}} \sin \theta \text{ ft}$$

Thus I_{cars} ranges between

$$I_{c1} = (12,600)(25.3)^2/(32.2) = 250,470 \text{ lbftsec}^2$$

$$I_{c2} = (12,600)(28.93)^2/(32.2) = 327,500 \text{ lbftsec}^2$$

For the wheel,

$$\begin{aligned} I_w &= mR_w^2/2 = [(83,780 - 12,600)/(2)(32.2)](25.3)^2 \\ &= (1,105.3)(640.09) \\ &= 707,478 \text{ lbftsec}^2 \end{aligned}$$

Thus the total moment of inertia is in the range

$$957,948 \leq I \leq 1,034,978 \text{ lbftsec}^2$$

At full speed, the wheel is turning 14.8 rpm. This is

$$4.05 \text{ sec/rev}$$

This equals

$$2\pi \text{ radians/rev}/4.06 \text{ sec/rev} = 1.55 \text{ rad/sec}$$

Assuming constant acceleration for 30 sec,

$$\alpha = (V_2 - V_1)/t = V_2/t = 1.55/30 = 0.0517 \text{ rad/sec}^2$$

Then using

$$\Sigma T = I\alpha$$

$$49,514 \leq T \leq 53,595 \text{ ftlb}$$

To find the needed power,

$$W = T * \text{radius}$$

$$P = W/t = T \omega \quad (\text{where } \omega = 1.55 \text{ rad/sec})$$

or,

$$76,747 \leq P \leq 82,917 \text{ ftlb/sec}$$

Dividing by 550 hp/(ftlb/sec)

we get

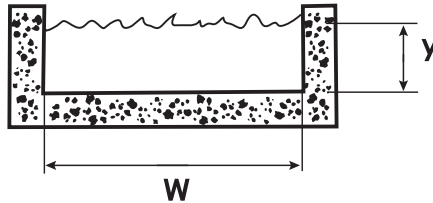
$$\mathbf{139.5 \leq P \leq 151 \text{ hp}}$$

Chapter 14 Problems

Open Channel Flow

A 100-foot long section of a flume ride is to be designed, using a 5-foot wide rectangular flume section. It is to be constructed of smooth trowel finished concrete. The design water velocity is 4 ft/sec, and the design depth is 2.5 ft.

1. What is the required water flow rate?



$$\begin{aligned} Q &= VA = Vwy \\ &= (4)(5)(2.5) = 50 \text{ ft}^3/\text{sec} \end{aligned}$$

2. What is the *specific energy* of the water?

$$\begin{aligned} E &= y + V^2/2g \\ &= 2.5 + (4^2)/(2)(32.2) = \underline{2.748 \text{ ft}} \end{aligned}$$

3. What is the required elevation drop over the length of the flume section?

Using the Manning formula:

$$S = \{(Vn)/(1.486 R^{2/3})\}^2$$

Where:

$$n = 0.011$$

$$R = A/P = (wy)/(w + 2y)$$

$$= (5)(2.5)/[5 + (2)(2.5)] = 1.25$$

Then

$$S = (4)(0.011)/\{(1.486)(1.25)^{2/3}\}^2 = 0.000651 \text{ ft/ft}$$

$$\text{Drop} = (0.000651)(100) = 0.065 \text{ ft.}$$

4. Determine if the flow is supercritical or subcritical.

$$Y_{CR} = \sqrt[9]{\frac{(Q/w)^2}{9}}$$

$$Y_{CR} = \sqrt[3]{\frac{(50/5)^2}{32.2}} = 1.459 \text{ ft}$$

Since the depth of 2.5 ft $>$ Y_{cr} , examining the specific energy curve (Fig. 14-1) indicates that the flow is subcritical.

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