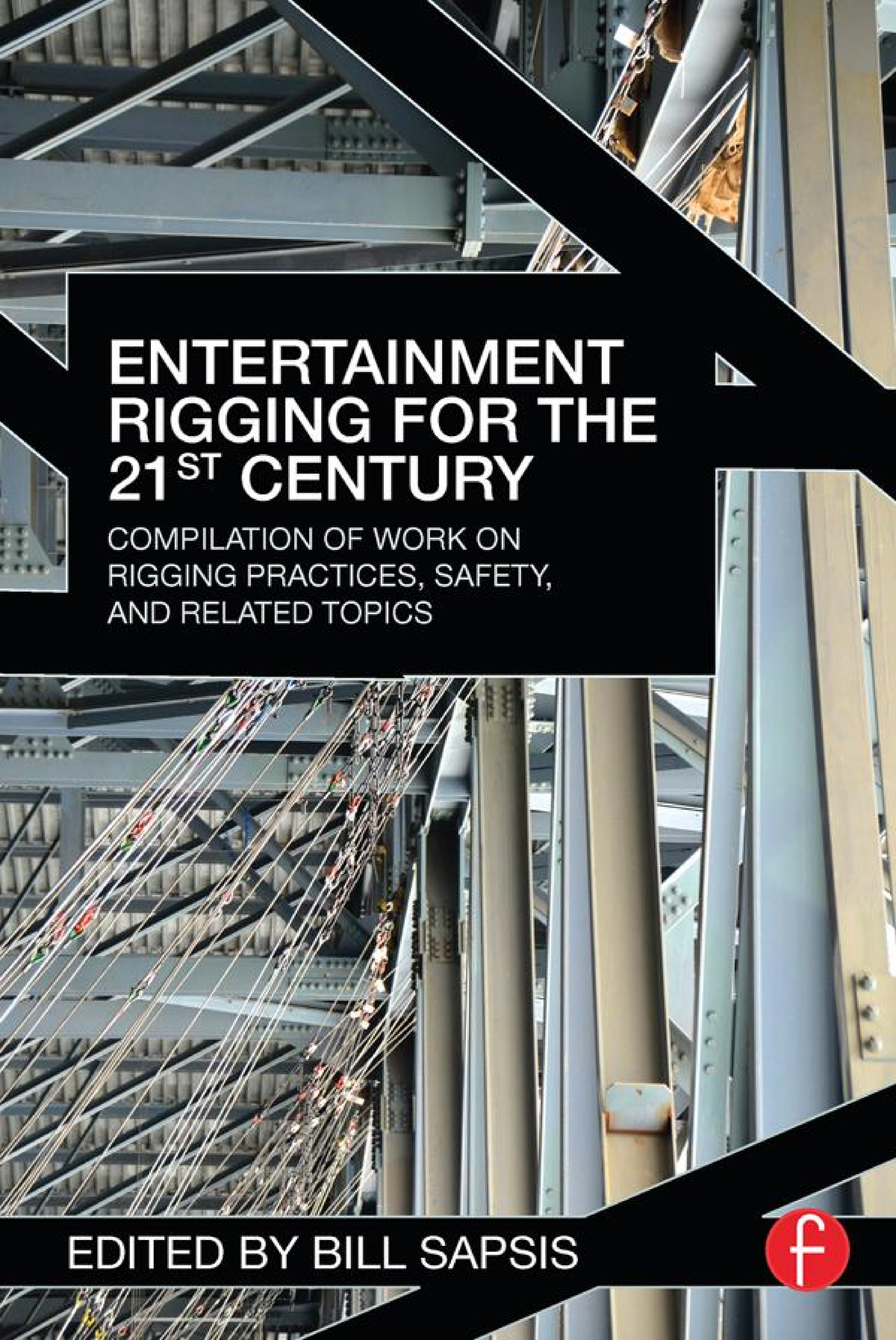


ENTERTAINMENT RIGGING FOR THE 21ST CENTURY

COMPILATION OF WORK ON RIGGING PRACTICES, SAFETY, AND RELATED TOPICS

EDITED BY BILL SAPSIS

Entertainment Rigging for the 21st Century

Entertainment Rigging for the 21st Century

Compilation of Work on Rigging Practices, Safety, and Related Topics

Edited by Bill Sapsis

Focal Press
Taylor & Francis Group
NEW YORK AND LONDON

First published 2015
by Focal Press
70 Blanchard Road, Suite 402, Burlington, MA 01803

and by Focal Press
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

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

Library of Congress Cataloging in Publication Data
21st century: compilation of rigging practices, safety, automation, and related issues / edited by Bill Sapsis.
pages cm
Includes index.
ISBN 978-0-415-70274-4 (pbk) – ISBN 978-0-203-79541-5 (ebk)
1. Hoisting machinery–Rigging. 2. Theaters–Stage-setting and scenery–Safety measures. I. Sapsis, Bill, editor.
TA660.C3E58 2015
790.028′4–dc23 2014018242

ISBN: 978-0-415-70274-4 (pbk)
ISBN: 978-0-203-79541-5 (ebk)

Typeset in Minion
By Keystroke, Station Road, Codsall, Wolverhampton

Contents

List of Contributors

ROCKY PAULSON

Rocky Paulson started rigging in 1969 at the Cow Palace in San Francisco. In 1973 he became a member of IATSE. That same year he went to work for NBC as a rigger for the *Disney on Parade* shows, as well as working as a production rigger on NBC's production of *Peter Pan*. After traveling on several continents with these shows, Rocky did many rock tours. In 1977 he formed the first entertainment rigging production company. Since that time Stage Rigging has maintained its position as one of the most respected rigging companies in the US. At the end of 2005, Rocky retired from Stage Rigging, but has continued teaching activities.

BILL GORLIN

Bill Gorlin serves as McLaren Engineering Group's vice-president of the Entertainment Division. A graduate of Cornell University in engineering, he is registered as a professional engineer in ten states and is a board-certified structural engineer. His more than 27 years of experience include engineering of scenic, entertainment, and amusement structures, staging, rigging, buildings, show action equipment, architectural theming, sculptures, and other frameworks, nationwide and worldwide.

Bill is a member of the PLASA NA Rigging Working Group, the Performer Flying and Temporary Structures Task Groups; American Society of Civil Engineers; Cornell Society of Engineers; and Structural Engineers Association of New York. He has published articles in *Architecture Week* and *Structural Engineering Forum*, and is a frequent lecturer at various universities and industry conventions.

TRAY ALLEN

Tray Allen became involved with theatre while attending David Lipscomb University in Nashville, Tennessee. His first lighting truss hang was at this university and involved 20′ of truss and two crank-up lifts. After graduating with a BSc in Engineering Science he worked for Bradfield Stage Lighting in Nashville, then as a master electrician for Opryland USA. After getting married, Tray moved to Knoxville, Tennessee, and, in 1992, went to work for James Thomas Engineering.

ROY BICKEL

Roy Bickel's career started more than 50 years ago as a circus performer whose skills included trapeze, trampoline, and human cannonball. He started rigging with the circus and then moved on to become the first rigger for *Disney on Parade*. He was also the first large arena tour rigger in the USA and was the first to introduce fixed length wire rope slings and sling color-coding. Roy also worked on a number of Broadway show including *Chicago*, *The Wiz*, and *Truckloads*. Roy introduced to the industry many of the practices still in use by riggers today. After 50 years in the industry, Roy is still rigging for conventions, corporate events, and tours.

KEITH BOHN

Keith Bohn has been in the entertainment industry for more than 25 years. During this time he has been involved in the use, manufacturing, and design of structural rigging solutions ranging from simple truss to complex, permanently installed structures. Keith has also served the industry through PLASA as a principle voting member for the Rigging Working Group since 1998, and has chaired the task group assigned to create and revise ANSI E1.21-2013, Temporary Structures Used for Technical Production of Outdoor Entertainment Events. A founding contributor of the Event Safety Alliance, he has contributed on a number of topics contained in *The Event Safety Guide*. Additionally, he has taught classes on the safe use of truss and outdoor structures worldwide.

KAREN BUTLER

Karen Butler lives in Phoenix, Arizona, and has been working in the entertainment industry since 1983. She has had the opportunity to work in all facets and departments for music, dance, movies, commercials, industrials, trade shows, and—her first love—theatre. In 1986, Karen became a proud member of IATSE Local 336. In 1990 she created Suddenly Scenic and has worked as a scenic artist for 25 years. She is the master scenic for Phoenix Theater and Childsplay Inc.

In 1996, Karen became part of the team to reopen the Orpheum Theater in Phoenix as the house steward and head flyman. It was during this period that Karen became part of the ETCP Theatrical Rigging committee; first as an SME, then as chair.

STU COX

Stu Cox has traveled the planet as a ZFX flying director, rigging and choreographing performer flying effects, along with aerialists, oversized inflatable scenery, 500′ motorized zip lines, and no shortage of flying monkeys, ghosts, angels, and Peter Pans. He received a BFA in Theatre Design and Production from the University of Louisville. He has worked with *Wicked*, the Vancouver Winter Olympics, Green Day's *American Idiot*, Fox Sports, and FIFA. Stu is an ETCP theatre and arena rigger, and is an ETCP recognized trainer. He is a member of USITT, CITT, and PLASA. In his downtime, Stu snowboards and spends time with his family in Ontario, Canada.

JOE MCGEOUGH

Joe McGeough is director of operations for Foy Inventerprises, Inc., based in Las Vegas. Over the years, Joe has worked on the development of new flying systems for productions worldwide, and has collaborated on hundreds of productions for Foy, including shows on Broadway (*American Idiot, The Lion King, Mary Poppins, Tarzan the Musical*), concert tours (The Backstreet Boys' *Into the Millennium World Tour*), television (*The Drew Carey Show, The Grammy Awards*, *The American Music Awards*), international productions (*Wicked* in Tokyo), seasonal shows (*The Flying Angels* at the Crystal Cathedral and Phoenix First Assembly of God, *The Radio City Music Hall Christmas Spectacular, The Shoji Tabuchi Show* in Branson, MO), theme parks (*Finding Nemo* at Disney's Animal Kingdom), industrials (*The Microsoft Global Summit*), special events (*Olympic Torch Relay in Times Square, Super Bowl XLV Halftime Show*) and more than a dozen Royal Caribbean cruise ships.

SCOTT FISHER

Scott Fisher is the founder of Fisher Technical Services and a pioneer in the development of theatrical and rigging automation systems. A 25-year veteran of the entertainment industry, Scott and the Fisher Technical team have provided cutting-edge automation systems to hundreds of theaters, theme parks, motion pictures, and attractions, and the systems and techniques developed at Fisher Technical continue to be used throughout the entertainment world today.

DAN CULHANE

Dan Culhane is currently the technical business development manager at SECOA Inc. Prior to this he spent more than 11 years as SECOA's engineering manager. He is an ETCP-certified rigger for theater and a subject matter expert. Dan has spent 15 years as a technical director working for theatres across the country including the Guthrie Theater and the Children's Theatre Company, in Minneapolis, MN.

He serves on the PLASA Technical Standards Program, Rigging Working Group and chairs the task group revising the standard for fire safety curtains. He is a member of the Stage Lift Working Group. Dan also is on the board of directors for USITT and serves as treasurer. He is a member of the UL Standards Technical Panel for Fire Doors (STP 10), and serves as an alternate committee member to the NFPA Technical Committee on Fire Doors and Windows.

EDDIE RAYMOND

Eddie Raymond is a lifelong San Francisco Bay Area resident, graduating from and attending postgraduate work in education at UC Berkeley. He has been a stagehand with Local 16 of the IATSE since 1975. After graduating the Apprentice Program at Local 16, Eddie became involved as a member of the examining board in 1981 and served as the chair of that committee from 1984 until February of 2014. Since 1981 he has been a leader in the progressive improvement of stagehand training in Local 16 as well as in the International Alliance. Currently he serves the IATSE as a member of their Career Advancement Program, providing training and advising the IA's Exhibition and Entertainment Joint Training Trust.

Eddie was a co-chair of PLASA's ETCP rigging certification program and sits as a member of the ETCP Council. He is the second term chair of PLASA's North American Regional Board and sits on PLASA's governing body.

CHRIS HIGGS

Chris Higgs provided rigging for theatre, corporates, television, and concert touring from the early 1970s to the mid-1990s and is one of the founders of entertainment rigging training in the UK. Total Training started in 1998, as part of the Total Solutions Group, and delivers training courses in the UK and overseas in rigging, work at height, rescue, and inspection, amongst other associated subjects. The Total Training three-day rigging course is unique in the world, being held at least three times monthly throughout the year.

BILL SAPSIS

Bill Sapsis, president of Sapsis Rigging, Inc., has been involved in the entertainment industry since 1972. His work on Broadway includes the original productions of *A Chorus Line* and *The Runner Stumbles*. In 1981, Bill began Sapsis Rigging and has grown the company into a multifaceted installation/ production/service company.

Bill has written and lectured on safety related issues on an international basis. Bill is a member of the ETCP council and chair of the Rigging Subject Matter Experts. He serves on PLASA's Technical Standards Committee and is the chair of the Rigging Working Group. Bill is a member of the ESTA Foundation's board of directors.

Bill is a USITT fellow. He is a founding member of the Long Reach Long Riders, an industry-based charity motorcycle group, and he was the 2010 recipient of the Eva Swan Award, PLASA NA's highest honor.

CARLA D. RICHTERS

Carla Richters is a 30-year member of IATSE TWU local 805. She was a road wardrobe supervisor and received her MFA from the University of Texas at Austin in Theatrical Production Design. She was the costume shop manager and Theatre Department safety officer at Dartmouth College for 24 years. She was an EMT at Upper Valley Ambulance in Fairlee, Vermont from 1995 to 2010, and a paramedic from 2001 to 2010. An ambulance squad training officer, she was the medical director of the Vermont Special Olympics Winter Games. She was twice awarded the Jack Seusse Memorial Stump the Rigger trophy. Her interest in rigging safety happened because, as she puts it, "they hang heavy stuff over our heads. I wanted to know what they were doing and how to help when things went wrong."

FOREWORD BY MONONA ROSSOL

Monona Rossol was born into a theatrical family and began working as a professional entertainer at three years of age. She holds a BS in Chemistry with a Math minor, and MS and MFA degrees in Art. Currently, she is an industrial hygienist, chemist, and the president and founder of Arts, Crafts & Theater Safety, Inc., a nonprofit organization providing health and safety services to the arts. She also is the safety officer for IATSE Local USA829 and for the New York Production Locals.

Foreword

As both a former performer and current safety professional, I can heartily endorse the publication of this book. There have been several good basic rigging texts published. But *Entertainment Rigging for the 21st Century* addresses basic information plus what is happening right now in this field. And a lot is happening right now.

For example, the Occupational Safety and Health Administration finally recognizes that theatre and arena rigging are every bit as complex and potentially life-threatening as rigging on major construction sites. Today, OSHA applies the same Construction and General Industry rules to entertainment workplaces. And if there is some new rigging equipment or process for which there is no written OSHA regulation, OSHA can cite them anyway under their General Duty Clause.

The General Duty Clause allows OSHA to cite or fine an employer for failure to address any "recognized hazard." Well, hitting the deck at a rapid rate of speed, clearly, is a recognized hazard. So the producers of *Spider-Man* were cited under this clause (29 CFR 1910.5(a)(1)) when mistakes made in flying some of the various actors playing bits of the Spider-Man role led to accidents.

Today even the general public is aware of rigging perils when the press covers entertainment and theatrical accidents. In 2013, two rigging accidents resulted in fatalities from falls in the range of 100′ above the stage. On April 5, a rigger fell after a Romeo Santos performance at the AT&T arena in San Antonio, Texas. Then on June 29, a Las Vegas Cirque du Soleil acrobat in harness fell to her death in full view of an audience.

Chapter 13 by Bill Sapsis on fall arrest systems will make clear how riggers should be protected by fall protection gear in order to prevent tragedies. Keith Bohn's Chapter 5 on outdoor structures should help readers understand what is needed to avoid accidents such as the 2011 Indiana State Fair stage collapse that killed seven and injured 58 people. Chapter 3 by Tray Allen on lighting trusses explains how these should be used and should remind us all of the many spectacular photos and videos of arena lighting truss collapses on the Internet where we can watch millions of dollars in damages occurring before our eyes.

While the general public certainly can understand the results of rigging accidents, they are not as likely to understand the technical causes. It is also likely they wouldn't even understand the language used by rigging experts to explain the issues involved. One reason is that riggers have their own language. This language is a collection of terms ranging in origin over centuries of time.

The roots of rigger-speak are found in the colorful words used by the very first riggers who were the crews on ancient sailing ships. More terminology was added to describe developments in rigging gear developed during the Industrial Revolution. And the final confusion arises from the geek-generated language applicable to complex computer-driven rigging systems.

A sampling of these words include: belay, bo'sun, cleat, clew, crew, deck, hitch, lanyard, pinrail, locking rail, purchase, trapeze, trim, trim clamp (or knuckle-buster), fly, motor-assist and dead-haul fly systems, fly loft, fly gallery, grid deck, loading bridge, arbor, standard pipe battens, truss battens, electric battens, light ladder battens, tab battens, lines, line-sets, jack lines, hemp lines, nylon lines, cables (wire ropes), steel bands, proof coil chains, rope locks, swage (compression) fittings or cable clips, trim chain, shackles or turnbuckles (which can be moused), pipe clamps, counterweight systems, electrical hoists (or winches), drum winches, tension blocks, head blocks, loftblocks, mule blocks, and programmable logic controllers (PLCs).

And the term "runaway" does *not* refer to a recalcitrant teenager.

And when this language is used in *Entertainment Rigging for the 21st Century*, each author makes sure that the definitions are clear to us all.

Today's riggers not only need to understand this strange language, they also need to provide proof to employers that they understand and rig competently. In other words, many employers today want to see evidence that the riggers they hire have had some formal training. The simple résumé of past jobs may not be enough in the 21st century.

Theatrical riggers used to learn their trade by the seat of their pants, working with older riggers who also learned by the seat of *their* pants. Today, there are formal training programs, the most important of which is the certified training offered by the Entertainment Technicians Certification Program (ETCP). These programs, originated by the Entertainment Services Technology Association and run now by PLASA, require their candidates to pass a rather tough test. In other words, today's riggers should have professional certifications in addition to experience.

Employers like certification programs because it helps protect their liability after an accident. The human toll and damages caused by major rigging accidents almost always result in lawsuits. If employers can show that they hired people with rigging credentials backed up by certifying agencies, they at least cannot be accused of having hired incompetent labor.

Entertainment Rigging for the 21st Century covers these kinds of training programs in Chapters 11 and 12, by Eddie Raymond and Chris Higgs. They cover training resources and issues in both the USA and the UK. And the fact that there are two chapters, one for North America and the other for our pals across the pond, illustrates that today's entertainment riggers are conforming to, and aware of, both local and international standards.

Standards for various types of equipment and the development of protocols for use of the equipment are now being developed under the watchful eye of PLASA. These standards will be referenced repeatedly by authors of the various chapters in *Entertainment Rigging for the 21st Century*.

In fact, PLASA itself is the result of a merger between UK and USA organizations. And their standards are accredited here and in Europe. In North America, PLASA standards usually receive American National Standards Institute (ANSI) accreditation. In Europe, PLASA works closely with the British Standards Institute in the UK and the European Committee for Electrotechnical Standardization (CENELEC). PLASA is also a major contributor to the development of international standards through the International Standards Organization.

While all this sounds technical, the writers have made it easy to understand by providing definitions of their terms, diagrams and drawings, and formulas. Even non-riggers like myself, can follow these chapters and learn. And to keep our interest, the book is peppered with personal observations and stories of actual incidents experienced on the job by those authors who are also riggers.

Entertainment Rigging for the 21st Century is not just for riggers and rigger wannabes. I personally think it also belongs in the library of theatrical safety professionals, regulatory personnel, theatre administrators, writers who address theatre and entertainment subjects, or anyone who wants to know what's really going on in theatres and arenas to make all those wonderful things happen on stage and above.

Monona Rossol

1

Forces and Formulas

ROCKY PAULSON

Introduction

Most riggers choose their profession because they enjoy working at height, the challenges and responsibilities of the job, and having a job that keeps them in shape. When we head down the road to becoming a rigger, most of us never dream that we would need to hone our math skills along with our climbing and knot-tying skills. However, the most important part of a rigger's job is to make sure that the rigging system, the attachment points, and the support structure as a whole are able to support the forces imposed by the rigging load. In order to know whether or not the rigging system and attachment points (anchorages) can support the loads, the rigger must know the strengths of the support elements and how the rigging load distributes the forces produced by it to these elements. This chapter will give the reader the techniques to do much of the force-estimating required to prevent overloading in the rigging system or anchorages.

Much of the estimating we do requires the use of math formulas. To keep the formulas concise, we abbreviate the forces and distances by creating symbols. The symbol system used in this chapter conforms to a system developed over a few years by several teachers and was first published in 2009. Since all of our formulas use forces and distances, the system uses F to indicate a force and D to indicate a distance. S will be used to indicate span, the distance between support points or anchorages. When there are multiple forces or distances within a formula, which happens in most cases, subscripts are added to the symbol. The subscript will consist of a number or a letter, and in some cases a number followed by a letter. The letters are used to indicate the direction of the force or distance as well as being a designator for the force being analyzed. Table 1.1 below shows many of the symbols and their definitions.

By reviewing the symbols in the table, the reader will become familiar with the meaning of the symbols including the use of the subscripts.

In addition to creating symbols for use in the formulas, it is useful to have symbols to denote the points of analysis in the rigging system. The end points of the span being analyzed or, in the case of bridles, the anchor points of the bridle legs will be labeled A_1, A_2 or A_3 as required. For the point of attachment of the applied force, the symbol P will be used (see Table 1.2).

TABLE 1.1 Common symbols used in formulas

F_A	The force applied to the rigging system
F_1	The force at the near support or anchorage
F_2	The force at the far support or anchorage
D_1	The distance from applied force to the near support
D_2	The distance from applied force to the far support
S	The distance between supports
F_H	The horizontal force
F_L	The force in line with an angled leg
	The vertical force

F_V	
D_H	The horizontal distance from the anchorage to the applied force
D_L	The length of the angled leg
D_V	The vertical distance from the anchorage to the applied force
F_{1H}	The horizontal force associated with leg 1 of a bridle
F_{1L}	The force in leg 1 of a bridle
F_{1V}	The vertical force associated with leg 1 of a bridle
D_{1H}	The horizontal distance from the leg 1 anchorage to the bridle point
D_{1L}	The leg length of leg 1 of a bridle
D_{1V}	The vertical distance from the leg 1 anchorage to the bridle point
F_{2H}	The horizontal force associated with leg 2 of a bridle
F_{2L}	The force in leg 2 of a bridle
F_{2V}	The vertical force associated with leg 2 of a bridle
D_{2H}	The horizontal distance from the leg 2 anchorage to the bridle point
D_{2L}	The leg length of leg 2 of a bridle
D_{2V}	The vertical distance from the leg 2 anchorage to the bridle point

TABLE 1.2 Analysis point symbols

A	An anchorage or support point
A_1	An anchorage for a truss or bridle leg
A_2	An anchorage for a truss or bridle leg
A_3	The third anchorage for a three-leg bridle
P	The point of attachment for the applied force

Force Distribution

Force distribution analysis is arguably the most important activity performed by a production rigger. This analysis must be done in some form to determine the force at each hang point for creating a rig plot and, in addition, many times this analysis must be performed to determine whether or not the support structures are being overloaded. Although the Internet and smartphones have made the process of preplanning much easier, there is no app for force distribution estimation. In many cases, the time required for this activity is a very significant portion of the total preplanning of the show for the rigger. In this section, we will examine the formulas and techniques for estimating the resulting forces at the supports caused by applying loads to a truss or beam.

There are several important concepts that need to be put into context prior to any calculation.

- **Force, weight and load:** *Force* is an action on a body caused by another body that tends to cause motion. It can be direct from physical contact or indirect such as the force of gravity. When a motion causing force is resisted by an equal and opposite force a static force exists. It is these static forces which are the subject of our analysis in this chapter. The US customary unit for force is the pound-force (lb). The SI (metric) unit is the Newton (N). *Weight* is simply a measure of the force of gravity on an object. The word *load*, although widely used by riggers, is more general and less succinct in its definition. In general terms it is the sum of all forces acting on an object.
- **Simply supported span:** A *simply supported span* is a beam or truss supported by two supports where the ends of the beam or truss are free to rotate. Imagine a truss supported by a chain hoist at either end. As the load increases between the hoists, the truss is free to deflect more than if the beam were fixed at the ends to prevent free rotation. See Figure 1.1 for examples of simply supported spans.

- **Cantilever:** In a *cantilever* at least one of the supports is not at the end of the beam and there is loading outside of the two supports such that both supports are on the same side as the load. See Figure 1.1 for an example.
- **Point load (PL):** A *point load* creates a force that is concentrated in a single point or very small area along the length of the beam or truss.
- **Uniformly distributed load (UDL).** As opposed to a point load, a *uniformly distributed load* creates a force that is evenly spread over a significant portion of the length of the beam or truss.
- **Center of Gravity (CG)**. The *center of gravity* is the single point at which, if an object is supported, it will remain in equilibrium. The CG of a UDL, which is located at the center of the UDL, will be used to calculate the forces distributed to the supports resulting from the force applied by the UDL.

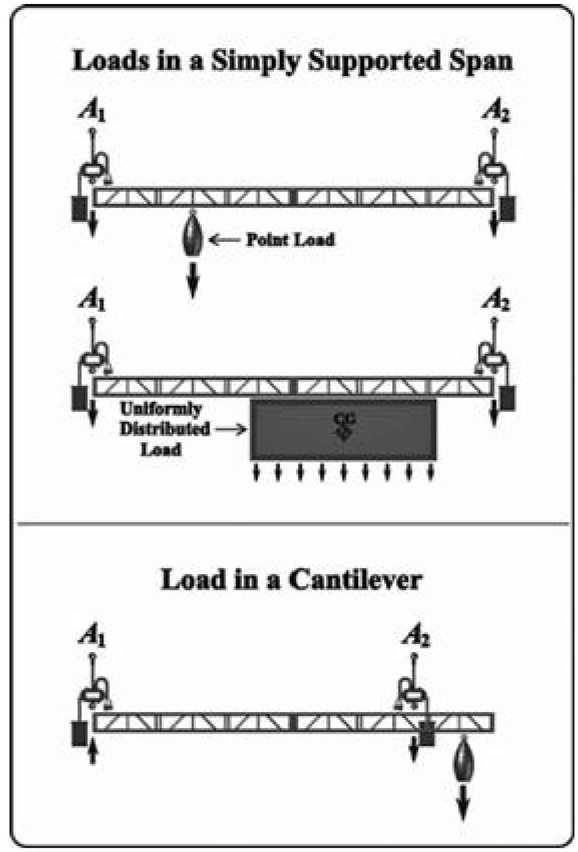


Figure 1.1

Sample Problems

Problem 1: Force Distribution in a Simply Supported Span resulting from a PL

On a 40′ beam supported at each end, a 1,250lb PL is placed 15′ away from the left-hand support. The top portion of Figure 1.2 illustrates the problem to solve.

To solve for forces F_1 and F_2, the following equations will be used:

$$F_1 = \frac{F_A D_2}{S} \text{ and } F_2 = \frac{F_A D_1}{S}$$

These are the basic formulas that form the building blocks for much of the rest of the equations in this chapter. These equations become a part of the rigger's bag of skills and are used as much, or more, than a bowline is used over the career of a production rigger.

Solving math problems accurately requires a combination of organizational skills and math skills. Certainly, those with less of the latter would do well to use as much of the former as possible while the math skills are developed. For this reason, the first steps to all the solutions in this chapter will begin with organizing the data in a fashion that will minimize the chance of making a mathematical error.

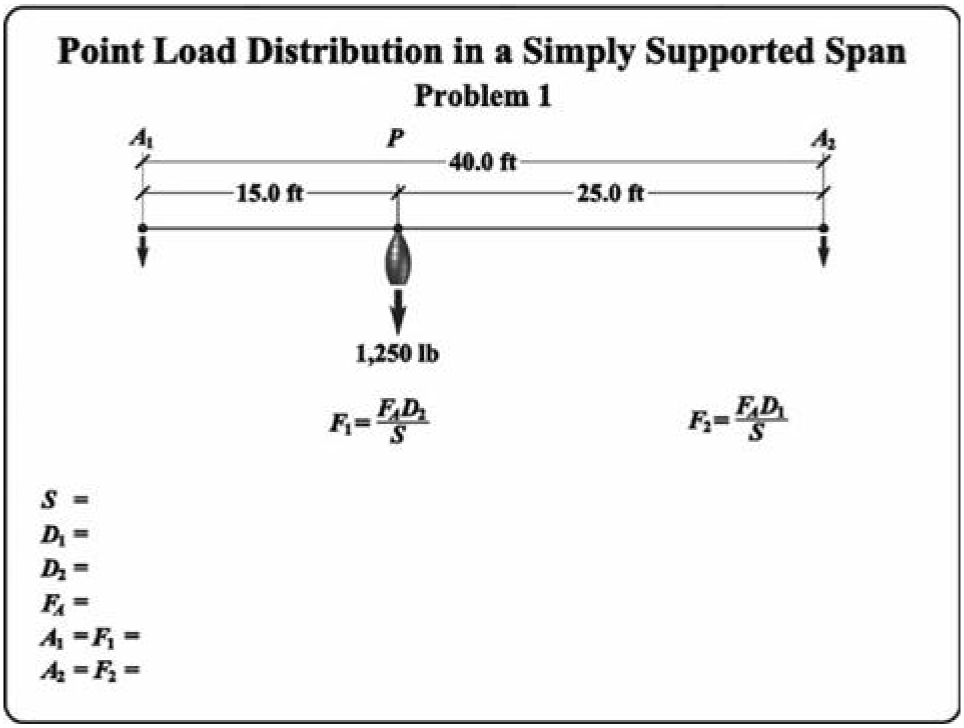


Figure 1.2

The lower half of Figure 1.2 is the structure which will help keep the data organized. It is well worth setting up this structure or a similar one. First, the equations for the unknowns are positioned so that there is room below to perform the required mathematics. On the left side of the figure is an informal table of the known forces and dimensions. Below, the locations A_1 and A_2, of the unknown forces, F_1 and F_2, are listed. For most of this chapter F_1 will be associated with the nearest support or anchorage, so a decision will have to be made initially as to with which supports F_1 and F_2 will be associated.

This and all the following problems will be solved in a step-by-step fashion.

Rounding

Rounding is useful in some cases, but must be done only after evaluating the benefits. For a rigger, a force of 781.25 may convey a false sense of accuracy, since most of our measurements of weight lack precision or are estimates to begin with.

- In this chapter the rounding convention used will be to look to the right of the digit being rounded. If that number is less than five, do nothing to the rounded digit and drop all digits to the right. If the number to the right of the rounding digit is five or greater, increase the rounding digit by one and drop all digits to the right. If changing the rounding digit changes it to zero, then increase the digit to the left by one.
- Be very careful when rounding numbers and then using the rounded numbers for further computations. Rounding a distance to the nearest foot and then using the rounded number to calculate a force can change the force by tens if not hundreds of pounds in some cases. In this chapter, any calculation that results in a number with more than three digits to the right of the decimal will be rounded to three digits. The rounded number will be used in any future calculations.

- If a rounded number is used in a calculation, notice will be given to the reader so that both our calculations will result in the same answer.

SOLUTION

STEP 1: ORGANIZE THE DATA

- Write the equations with space below for solving:

$F_1 = \frac{F_A D_2}{S}$ and $F_2 = \frac{F_A D_1}{S}$

- Make a table or list of the symbols for the known values used in the equations (S, D_1, D_2, F_A).
- Below these, add the anchorage labels, in this case A_1 and A_2. Since P, the location of the PL, is closer to A_1, A_1 will be the location of F_1 and A_2 will be the location of F_2.

STEP 2: INSERT VALUES AND SOLVE

- Using Figure 1.2, insert the values next to the symbols on the list. Until you are familiar with the meaning of the symbols, refer to Table 1.1 for their definitions.
- Substitute the values from your adjacent list into the formulas for F_1 and F_2 and solve for F_1 and F_2.
- Transfer the values for F_1 and F_2 to the appropriate spaces on your table of symbols, rounding as desired once all calculations are complete.

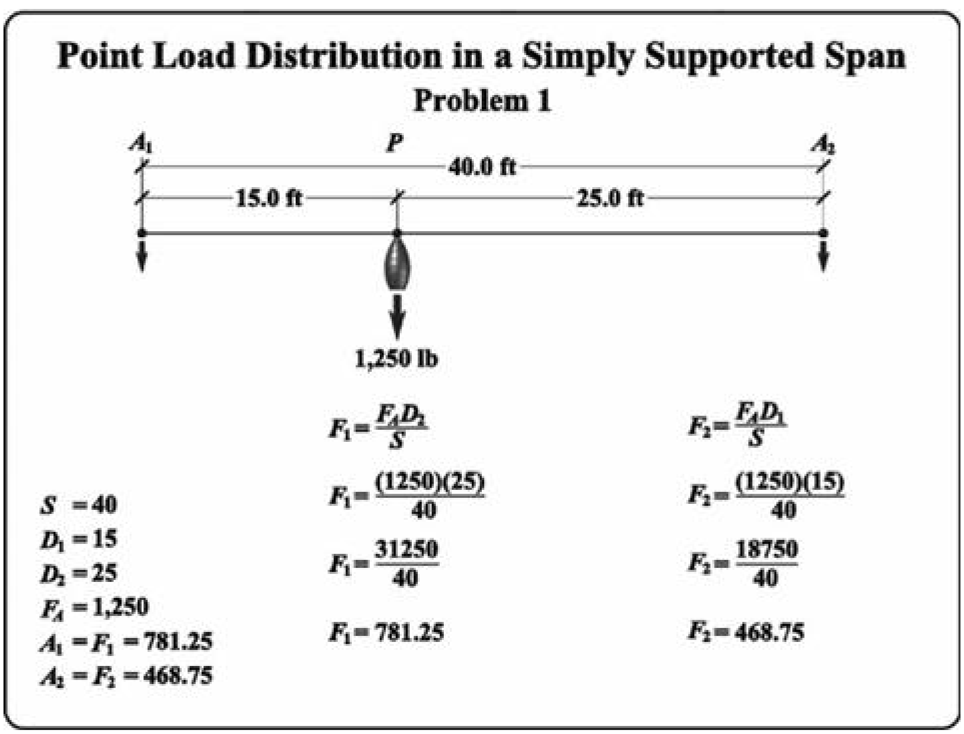


Figure 1.3

Tips

- Double-check your math. $F_1 + F_2 = F_A$
- The value of F_1 should be greater than the value of F_2. The near support will always have more force on it than the far support.

Problem 2

Force Distribution in a Simply Supported Span resulting from multiple PLs, each being the same weight and equally spaced apart. The next problem will illustrate a slightly different way to use these equations. In this case there are four PLs of equal weight and evenly spaced within the span (see Figure 1.4).

SOLUTION

STEP 1: ORGANIZE THE DATA

- Write the equations with space below for solving:

$$F_1 = \frac{F_A D_2}{S} \text{ and } F_2 = \frac{F_A D_1}{S}$$

- Make a table or list of the symbols for the known values used in the equations (S, D_1, D_2, F_A).
- Below add the anchorage labels, in this case A_1 and A_2.

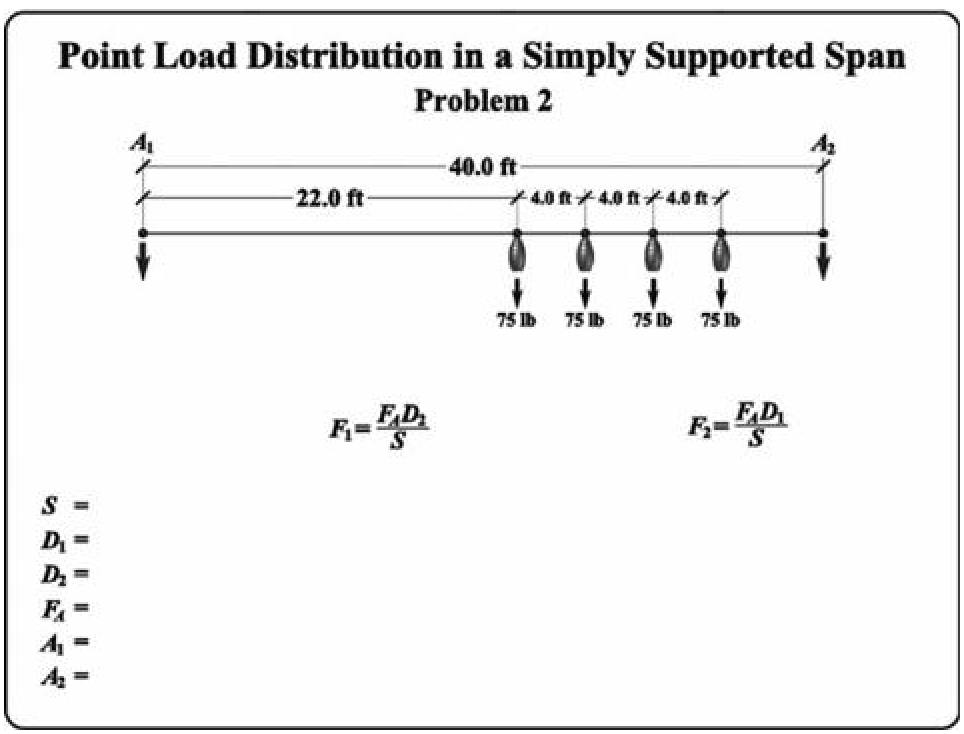


Figure 1.4

STEP 2: FIND P

- In order to solve the problem using our previous equations, we must first locate P, so we can determine the values for D_1 and D_2. When there are multiple PLs supported by the same two support points, and they are of equal weight and spacing, they can be converted into one PL with the weight being the sum of the PLs. The location of P is centered between the two outside PLs (see Figure 1.5).

STEP 3: INSERT VALUES AND SOLVE

- Using Figure 1.5, insert the values next to the symbols on the list.
- Substitute the values from your adjacent list into the formulas for F_1 and F_2 and solve for F_1 and F_2.
- Transfer the values for F_1 and F_2 to the appropriate spaces on your table of symbols, rounding as desired once all calculations are complete (see Figure 1.6).

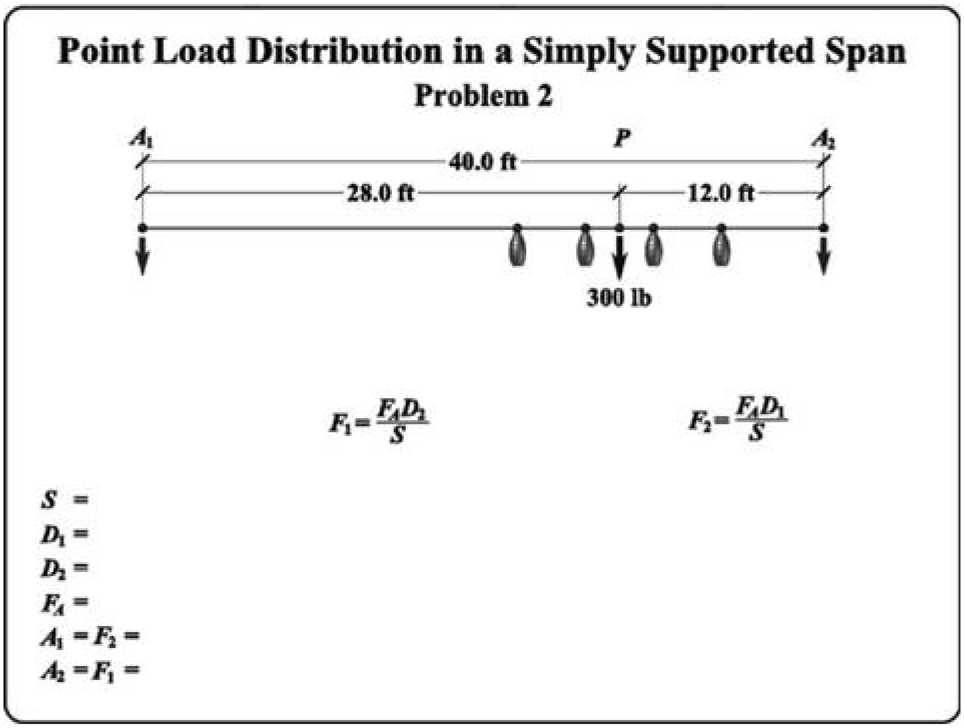


Figure 1.5

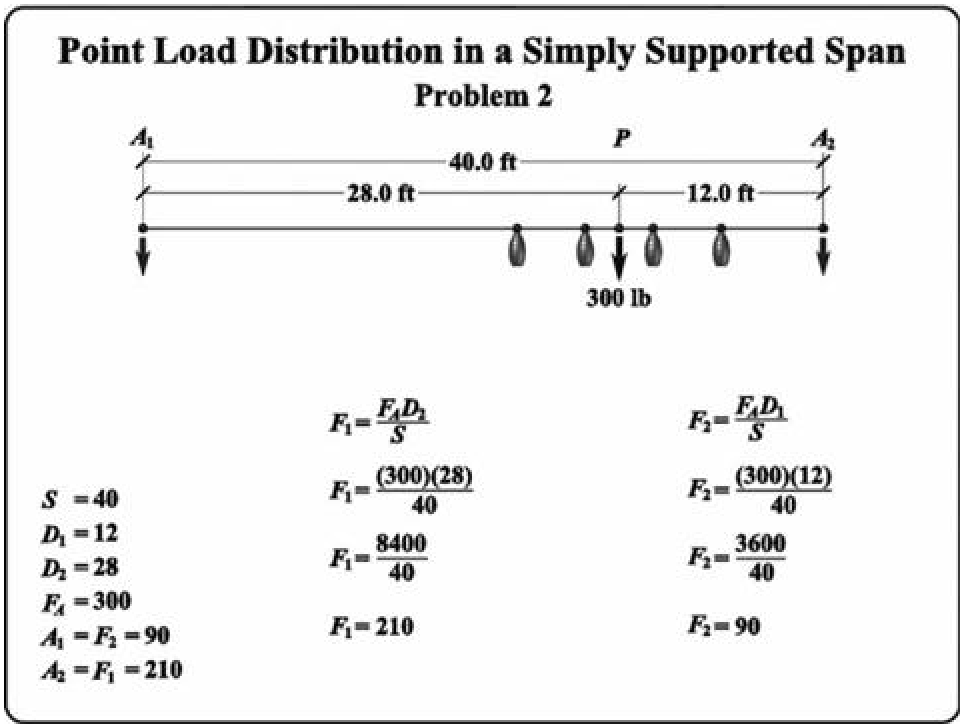


Figure 1.6

Tips

- Note that in this problem P is closer to A_2, so F$_1$ is located at A_2 and F_2 is located at A_1.
- A critical look at the problem would reveal that point P is located three-tenths of the way across the span. Note that the solution for the force at the far support F_1 is 90lb, or three-tenths of the applied force F_A. Had the location of P been one-quarter of the way across the span, then one-quarter of the applied force or 75lb would be at the far support. If the applied force is easily divisible by the fractional distance across the span, the need for solving the equations becomes unnecessary.

Problem 3: Force Distribution in a Cantilever resulting from a PL outside of A_2

For Problem 3, a 40ft beam is supported at the left end by anchorage A_1 and supported 8′ from the right end of the beam by anchorage A_2; 4′ to the right of anchorage A_2 is a PL of 750lb.

SOLUTION

STEP 1: ORGANIZE THE DATA

- Write the equations with space below for solving:

$$F_1 = \frac{F_A D_2}{S} \text{ and } F_2 = -\frac{F_A D_1}{S}$$

Note: these are the same equations as are used in a simply supported span except for the minus sign in the equation for F_2. The reason for the minus sign is that in a cantilever the force on the far support, F_2, is always in the opposite direction to the force on F_1.

- Make a table or list of the symbols for the known values used in the equations (S, D_1, D_2, F_A).
- Below add the anchorage labels, in this case A_1 and A_2. In this case A_1 is the far support, so F_2 will be located at A_1 and F_1 will be located at A_2 (see Figure 1.7).

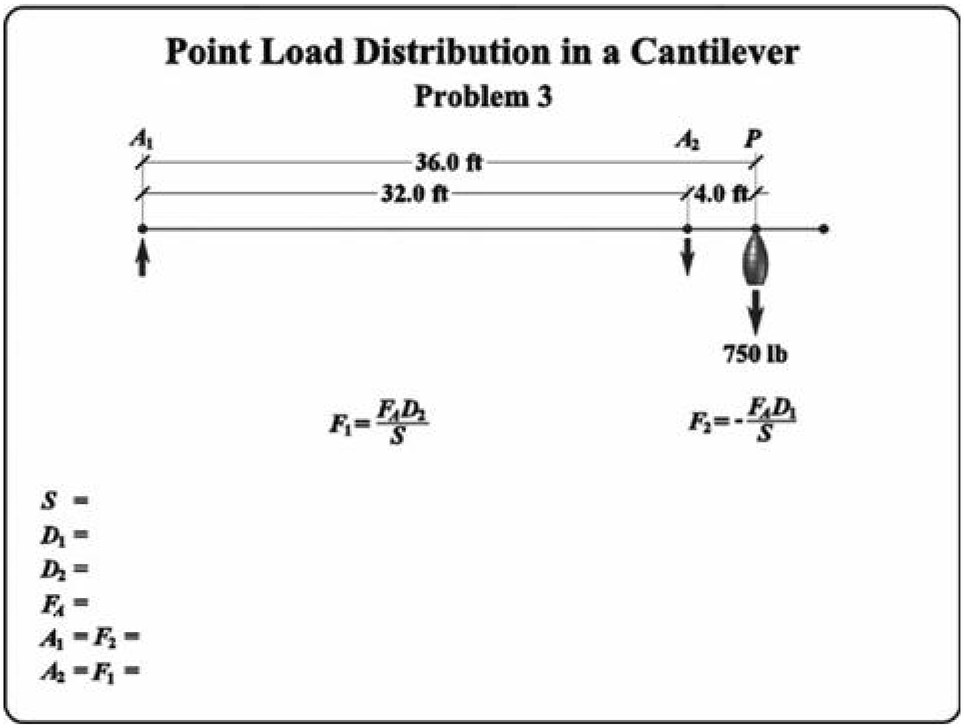


Figure 1.7

STEP 2: INSERT VALUES AND SOLVE

- Using Figure 1.7, insert the values next to the symbols on the list. Until you are familiar with the meaning of the symbols, refer to Table 1.1 for their definitions.
- Substitute the values from your adjacent list into the formulas for F_1 and F_2 and solve for F_1 and F_2.
- Transfer the values for F_1 and F_2 to the appropriate spaces on your table of symbols, rounding as desired once all calculations are complete (see Figure 1.8).

Tips

- The force at the fulcrum, F_1 will always be greater than F_A.
- As in simply supported span problems, the sum of F_1 and F_2 will always equal F_A.

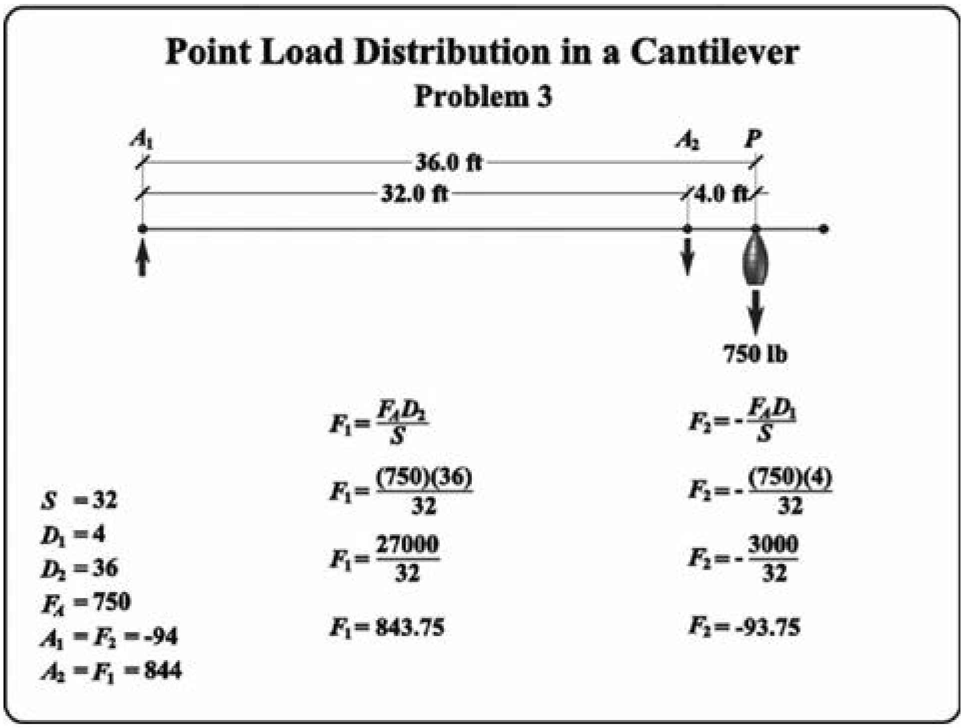


Figure 1.8

Problem 4

Force Distribution in a Cantilever resulting from a PL outside of A_1. For problem 4, a 40′ beam is supported 8′ from the left end and also at the right end of the beam. The PL of 750lb is located at the left end of the beam.

SOLUTION

STEP 1: ORGANIZE THE DATA

- Write the equations with space below for solving:

$$F_1 = \frac{F_A D_2}{S} \text{ and } F_2 = -\frac{F_A D_1}{S}$$

- Make a table or list of the symbols for the known values used in the equations (S, D_1, D_2, F_A).
- Below add the anchorage labels, in this case A_1 and A_2. In this case A_1 is the near support, so F_1 will be located at A_1 and F_2 will be located at A_2. See Figure 1.9 overleaf.

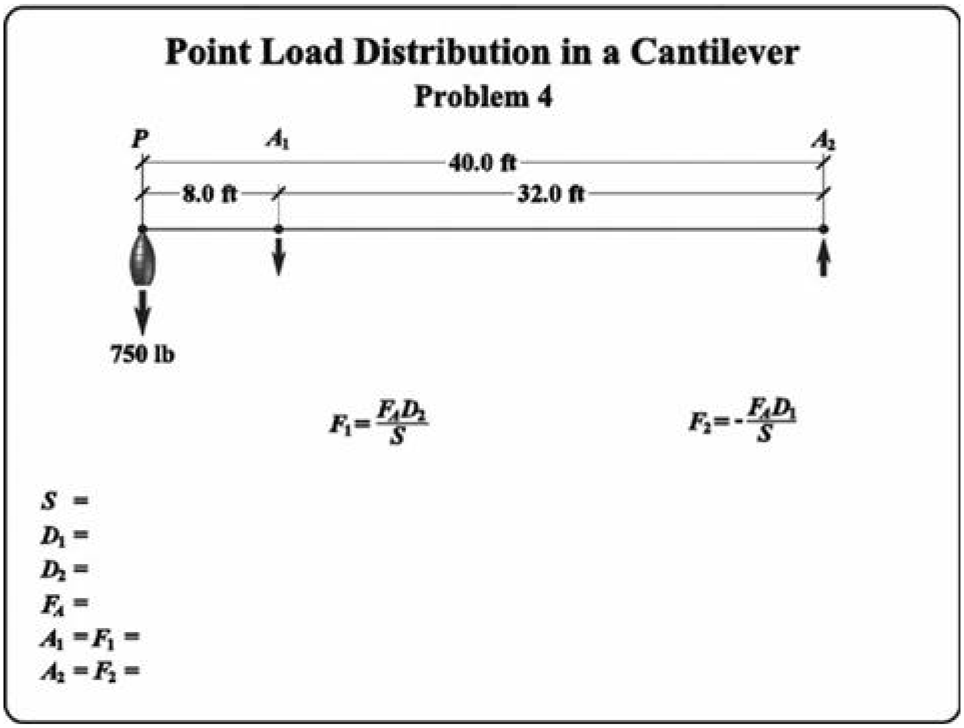


Figure 1.9

STEP 2: INSERT VALUES AND SOLVE

- Using Figure 1.9, insert the values next to the symbols on the list.
- Substitute the values from your adjacent list into the formulas for F_1 and F_2 and solve for F_1 and F_2.
- Transfer the values for F_1 and F_2 to the appropriate spaces on your table of symbols, rounding as desired once all calculations are complete (see Figure 1.10).

Tips

- The force at the fulcrum, F_1 will always be greater than F_A.
- By comparing Figure 1.8 and Figure 1.10, you will see that S and F_A are the same in both figures, but the application point P of F_A was moved away from the fulcrum by 4′ in Problem 3 to 8′ in Problem 4. Note that this change caused nearly a 100lb increase in F_1 in Problem 4. Whenever possible, riggers should attempt to minimize any cantilevered loads by minimizing the weight or by minimizing the distance to the fulcrum D_1.

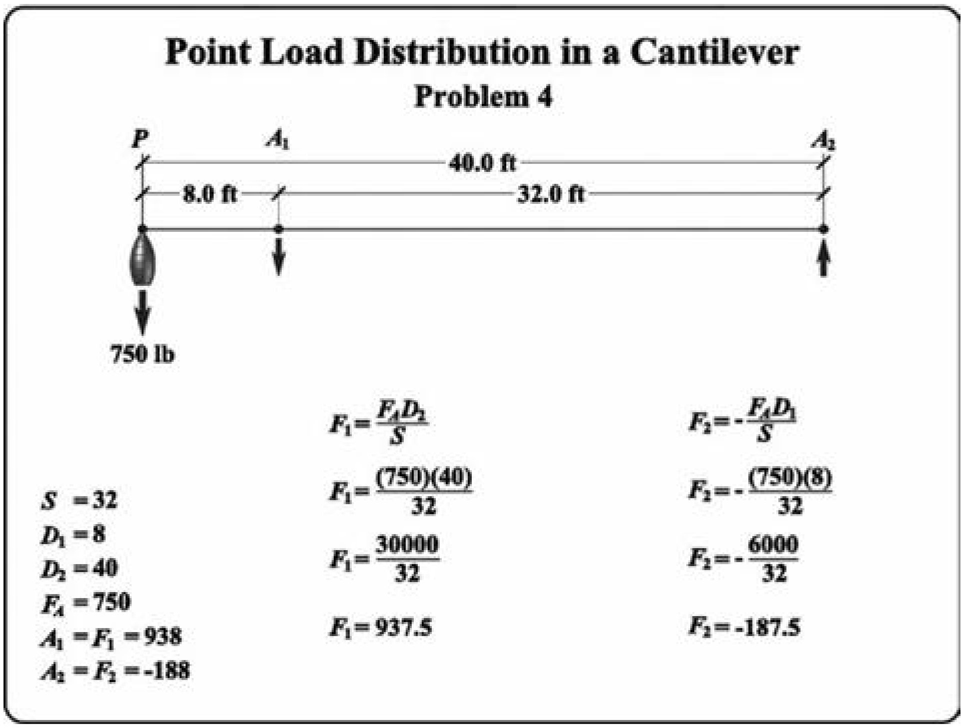


Figure 1.10

Problem 5: Force Distribution in a Simply Supported Span resulting from a UDL

Problem 5 illustrates this issue. In this problem a 16′ wide UDL weighing 1,600lb is attached to a 40′ beam that is supported by anchorages A_1 and A_2 at either end of the beam. The UDL is located such that the right end of it is 22′ from the right-hand support A_2.

SOLUTION

STEP 1: ORGANIZE THE DATA

- Write the equations with space below for solving:

$$F_1 = \frac{F_A D_2}{S} \text{ and } F_2 = \frac{F_A D_1}{S}$$

- Make a table or list of the symbols for the known values used in the equations (S, D_1, D_2, F_A).
- Below add the anchorage labels A_1 and A_2. See Figure 1.11 below.

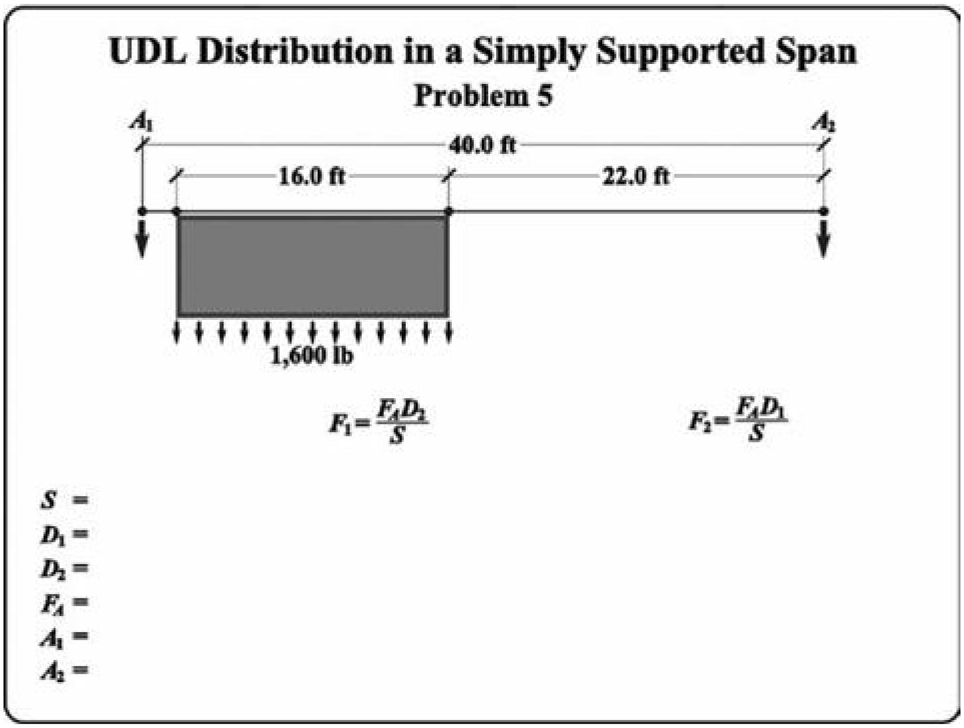


Figure 1.11

STEP 2: FIND P

- In order to fill in values for D_1 and D_2 we must first locate *P*. *P* is located by finding the center of gravity of the UDL, which would be at its center. In this case it is 22′ from A_2 to the edge of the UDL plus half the width of it, or 8′. This places *P* at 30′ to the left of A_2 (see Figure 1.12).

STEP 3: INSERT VALUES AND SOLVE

- Using Figure 1.12, insert the values next to the symbols on the list.
- Substitute the values from your adjacent list into the formulas for F_1 and F_2 and solve for F_1 and F_2.
- Transfer the values for F_1 and F_2 to the appropriate spaces on your table of symbols, rounding as desired once all calculations are complete. In this case A_1 is the closest support to *P*, so F_1 would be located at it and F_2 would be located at A_2 (see Figure 1.13).

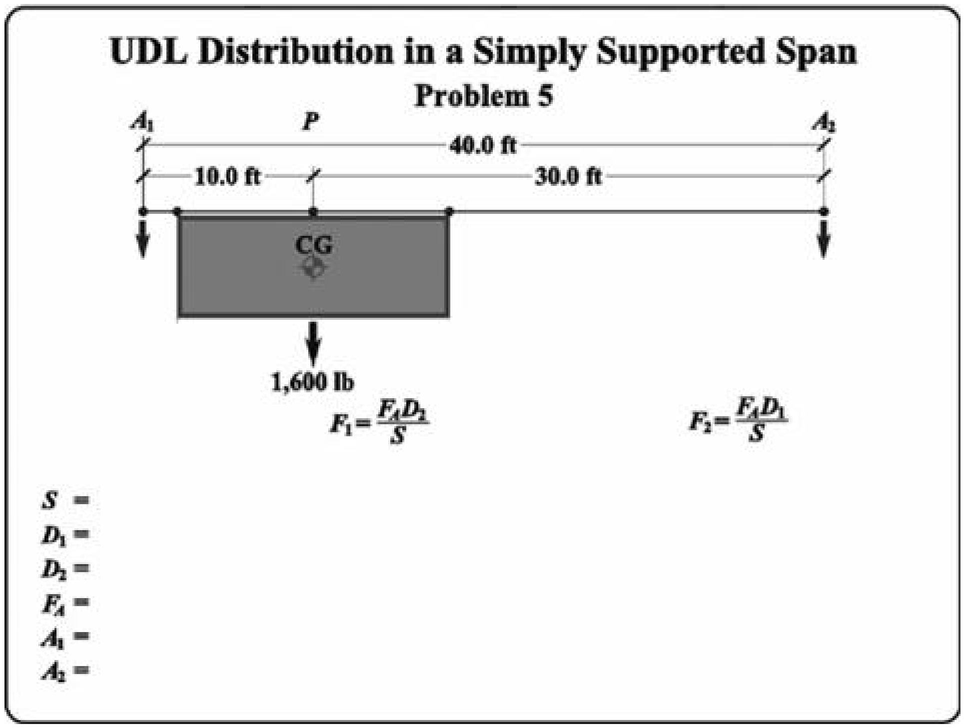


Figure 1.12

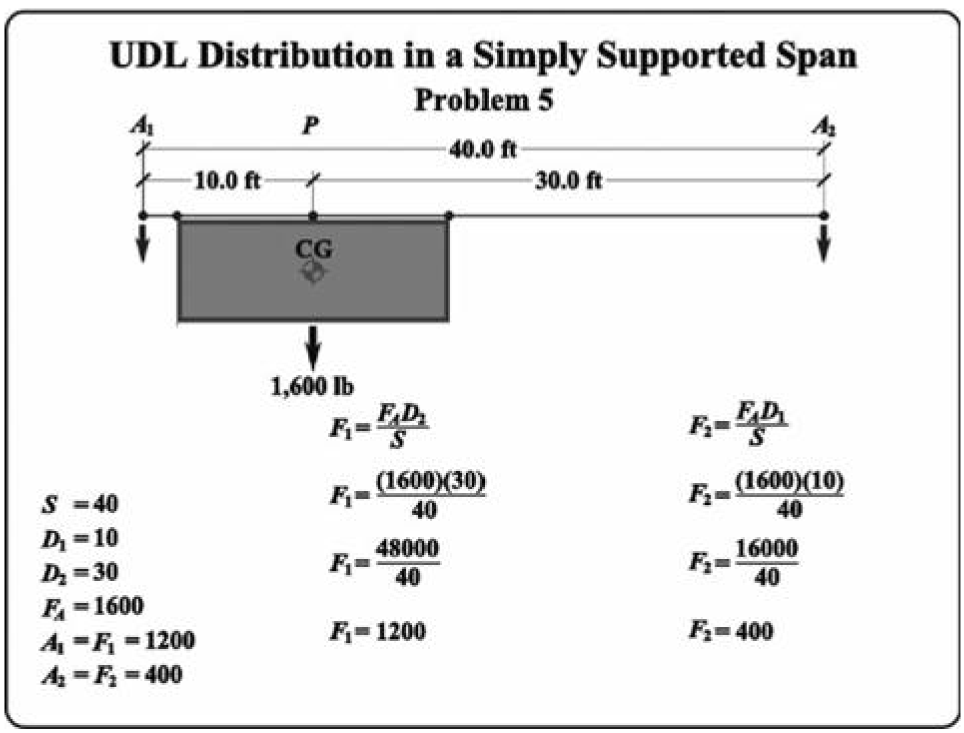


Figure 1.13

Tips

- On all force distribution problems where the applied force is a UDL, P must be located to find D_1 and D_2 by finding the center of the UDL.
- By looking at the values of D_1 and D_2 and comparing them to the value of S in Figure 1.12, P is located at a quarter point along the beam. This means that three-quarters of the force is distributed to the near support A_1 (1,200lb) and one-quarter is distributed to A_2 (400lb). This is the same result as obtained by using the equations.

Problem 6: Force Distribution in a Cantilever resulting from a UDL

Problem 6 consists of a 40′ beam supported by two points: A_1, which is 10′ in from the left end of the beam, and A_2 at the right end of the beam. An 8′ long UDL weighing 1,200lb is attached flush to the left end of the beam.

SOLUTION

STEP 1: ORGANIZE THE DATA

- Write the equations with space below for solving:

$$F_1 = \frac{F_A D_2}{S} \text{ and } F_2 = -\frac{F_A D_1}{S}$$

- Make a table or list of the symbols for the known values used in the equations (S, D_1, D_2, F_A).
- Below add the anchorage labels, in this case A_1 and A_2. In this case A_1 is the near support, so F_1 will be located at A_1 and F_2 will be located at A_2 (see Figure 1.14).

STEP 2: FIND P

- In order to fill in values for D_1 and D_2 we must first locate P. P is located by finding the center of gravity of the UDL, which would be in its center. In this case the distance from A_1 is 2 + 4, or 6′ (see Figure 1.15).

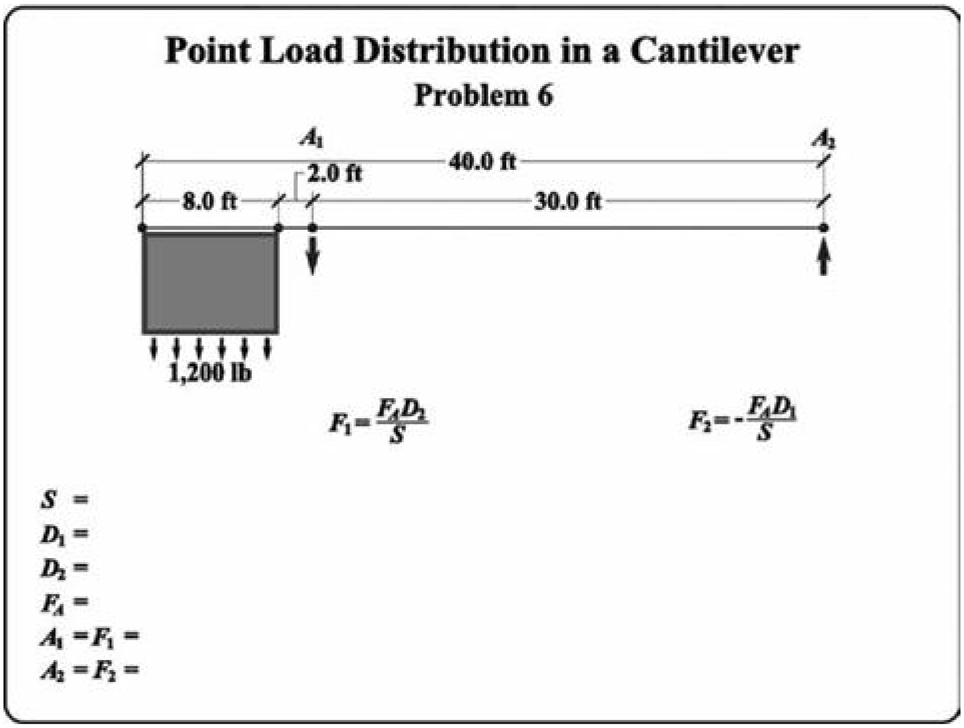


Figure 1.14

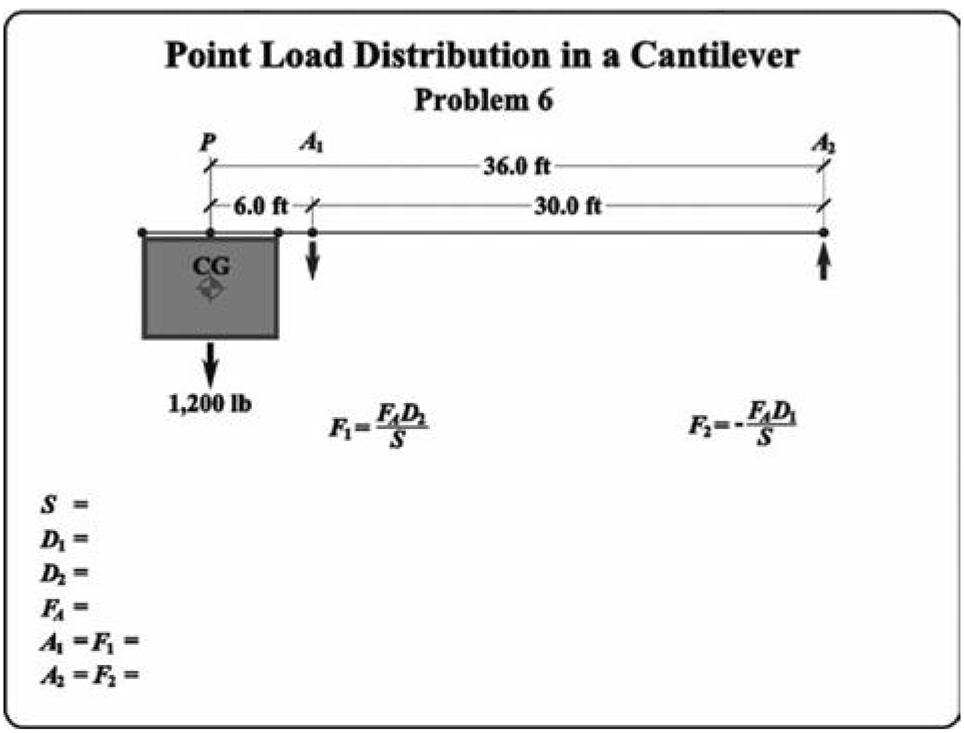


Figure 1.15

Step 3: Insert Values and Solve

- Using Figure 1.15, insert the values next to the symbols on the list.

- Substitute the values from your adjacent list into the formulas for F_1 and F_2 and solve for F_1 and F_2.
- Transfer the values for F_1 and F_2 to the appropriate spaces on your table of symbols, rounding as desired once all calculations are complete. In this case A_1 is the closest support to P, so F_1 would be located at it and F_2 would be located at A_2 (see Figure 1.16).

Tip

- As in all cantilever problems, the force on the far support, in this case A_2, is in the opposite direction of the force on the near support, in this case A_1.

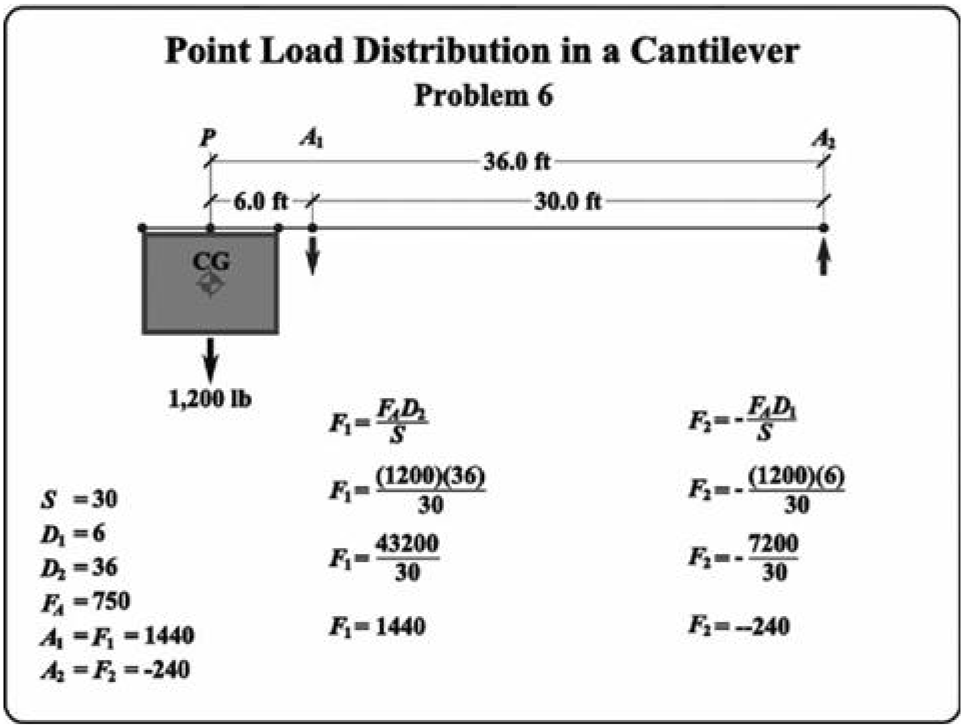


Figure 1.16

Problem 7: Complex Use of Force Distribution Equations

Problem 7 is an example of a 16′ wide UDL that is partially in a simply supported span and partially in a cantilever. For this problem the UDL is attached to a 40′ beam that is supported 6′ from the left end and at the right end of the beam. The 1,350lb UDL is positioned such that its left end is 4′ to the left of anchorage A_1 and extends past A_1 to the right 12′ towards A_2. Figure 1.17 is an illustration of the problem.

Note that the equations can't be laid out until the position of P is located.

SOLUTION

STEP 1: FIND P

- P is located by finding the CG of the UDL which would be 4′ to the right of A_1 (see Figure 1.18).

Step 2: Organize the Data

- Since P is located between A_1 and A_2, the simply supported span equations will be used and written on the worksheet.
- Since P is closer to A_1 than it is to A_2, F_1 will be located at A_1 and F_2 will be located at A_2 and noted on the worksheet.

Step 3: Insert Values and Solve

- From the data on Figure 1.18, fill in the values for the knowns S, D_1, D_2, and F_A on the worksheet.
- Substitute the values from your adjacent list into the formulas for F_1 and F_2 and solve for F_1 and F_2.
- Transfer the values for F_1 and F_2 to the appropriate spaces on your table of symbols, rounding as desired once all calculations are complete (see Figure 1.19).

Tip

- The method used for Problem 7 will also work for solving problems with equally spaced point loads of the same weight when they are located partially in a simply supported span and in a cantilever. As long as the PLs are all being supported by the same two supports, they can be grouped as was done in Problem 2.

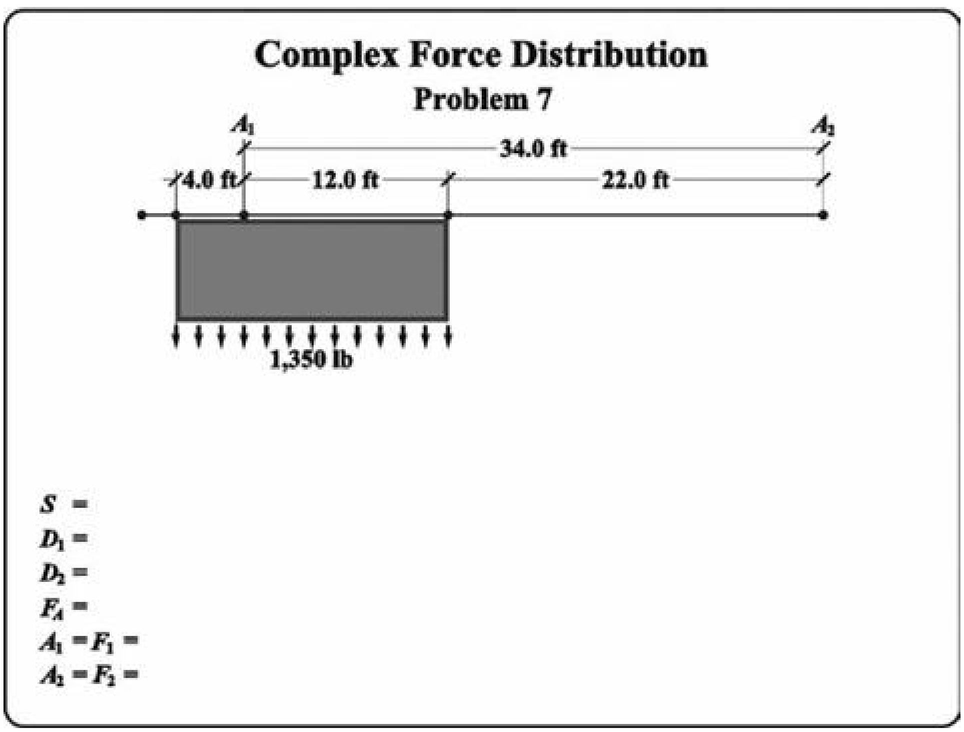


Figure 1.17

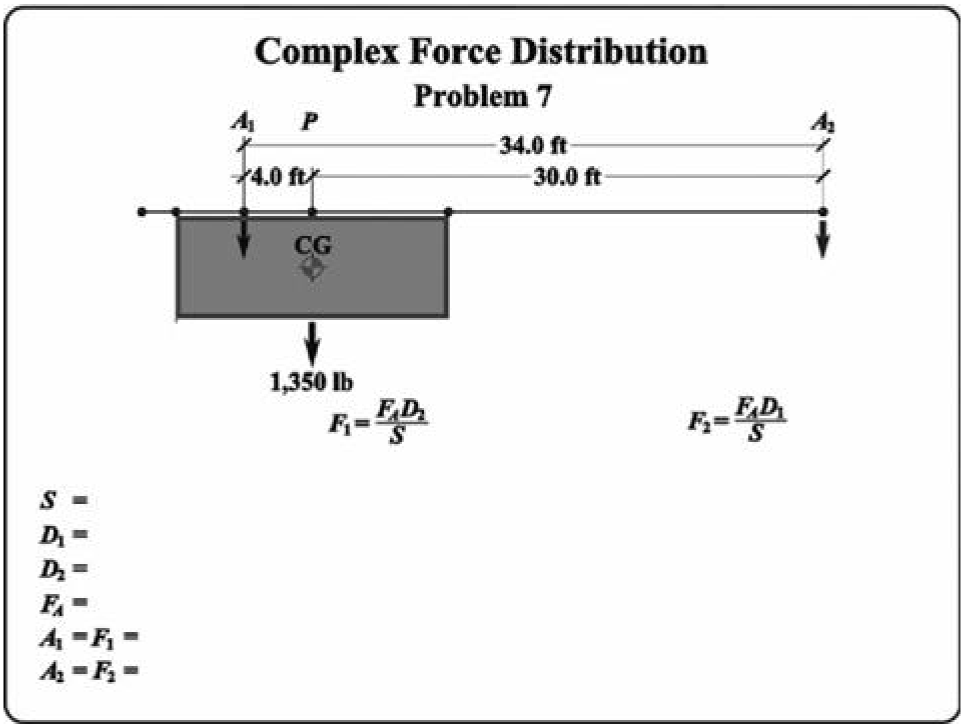


Figure 1.18

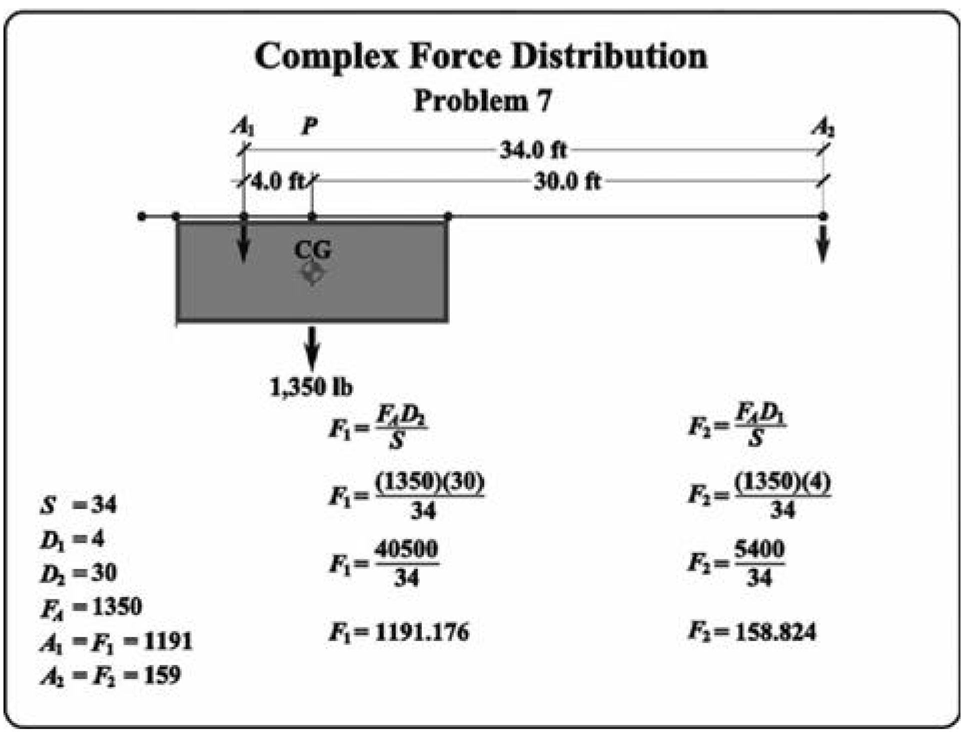


Figure 1.19

In order to determine the total weight transferred to a chain hoist from a particular arrangement of lights or other loads on a truss, the above procedures will have to be repeated for each load or group of loads until all loads have been accounted for.

Another use of the force distribution equations is to determine the load on the trusses or beams we are bridling from on the support structure. This is particularly important on low capacity support structures such as temporary structures or rigging grids, sometimes referred to as mother grids. By superimposing a rig plot onto a structure's beam layout as I have done in Figure 1.20, using the distance between the beams as S and labeling D_1 and D_2 according to the symbol definitions, the weight distribution for each point can be calculated. After the calculations are complete for all four PLs, the distributions for each beam can be summed to arrive at the total imposed load on each beam.

I have discussed many of the uses for the force distribution equations and solved several problems using them. Remember, organization of data is very important to make sure that the correct numbers are entered into the appropriate equations. After solving 15–20 of this type of problem the symbols and equations will probably be committed to your memory.

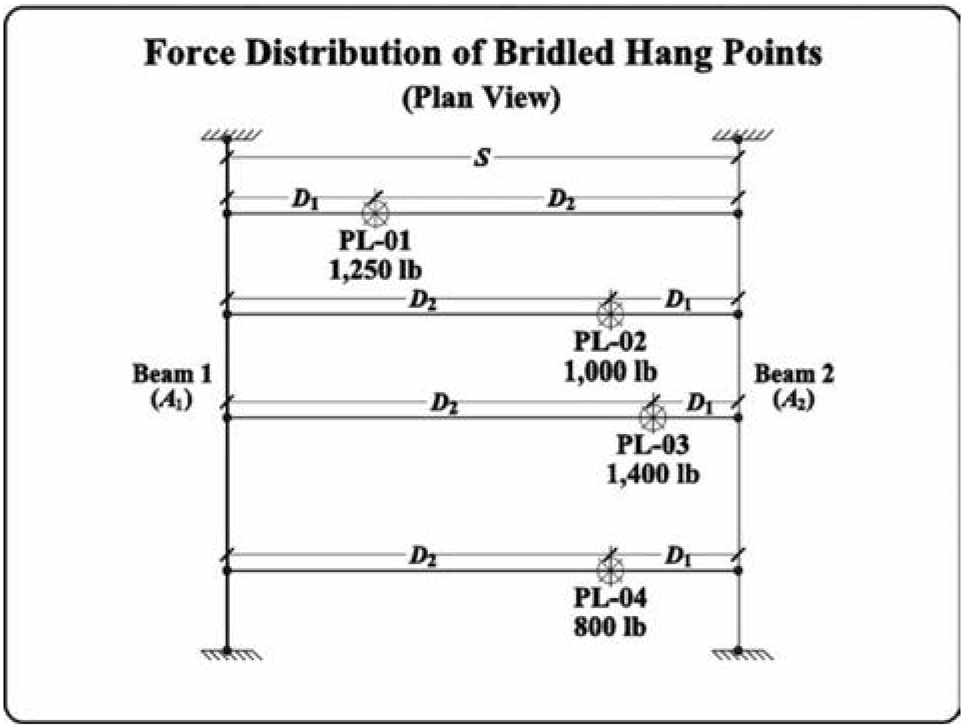


Figure 1.20

Angle Loading

In the previous section, all the forces discussed were vertical forces and could be added together if they were in the same direction or subtracted if they are in the opposite direction. However, what happens when we combine a vertical and a horizontal force, forces that are 90 degrees apart instead of 0 or 180 degrees apart? To visualize angle loading, imagine a point being deadhung and then breasted off to the side a little with a hand line. This situation will not usually make us break out our calculators though, as how much force could we be adding to the system with a hand line? Another common situation that occurs often is of more concern and can cause increases in tension worthy of a quick calculation. This situation occurs when anchorages in the support structure are not directly above their attachment points on the truss being raised. Figure 1.21 is an example of this situation. If the truss was being raised using half-ton hoists, would they be overloaded by the time the truss reached its trim height 10′ below the anchorages?

Our objective will be to calculate the force on the angled support line, but first let's explain some new concepts.

- **Force as a vector quantity:** In order to accurately describe force, it must be stated in terms of both magnitude and direction as well as its origin. When we talk about weight, which is a special case of force, we tend not to describe the direction because gravity always works in the same direction. Force as a vector can best be viewed graphically as an arrow. The beginning of the arrow shaft is the *origin* of the force. The length of the arrow is a scale representation of the *magnitude*. And finally, the point of the arrow indicates the *direction* of the force (see Figure 1.22).

- **Parallelogram rule for combining forces:** We have noted that when forces are not in the same or opposite directions, they cannot be added or subtracted to arrive at a total force. The *parallelogram rule* must be used in cases where addition and subtraction won't work. The rule states that if two forces with the same origin are drawn as sides of a parallelogram, the diagonal of the parallelogram will represent the resultant force. The converse of the rule is also useful when thinking about vertical and horizontal component forces resulting from an angled support or bridle leg (see Figure 1.23).
- **Force triangles:** A *force triangle* is simply one-half of a force parallelogram. Looking at the rectangle at the bottom of Figure 1.23, if the arrow representing the horizontal force, Force B, were moved to the bottom side of the rectangle, a triangle would be formed by Forces A, B, and C.
- **Similar triangles:** *Similar triangles* are triangles that have the same shape, but not necessarily the same size. The unique property of similar triangles is that the ratio of the lengths of all the sides is the same for both triangles. In other words, if side A of triangle 1 is twice the length of side A of triangle 2, then sides B and C of triangle 1 will also be twice the length of sides B and C of triangle 2. This property can be used to solve force problems, since the force in the angled leg forms the same shaped triangle when combined with the vertical and horizontal forces as the triangle formed by the vertical and horizontal distances measuring from *A* to *P*. In fact, since vertical and horizontal form a 90-degree angle, the similar triangles are *right triangles*.
- **Right triangles:** Right triangles are triangles that contain a 90-degree angle as one of the three angles that make up the triangle.
- **Pythagorean Theorem:** If the length of two sides of a right triangle are known, the third length can be found use the *Pythagorean Theorem*. The theorem states that the hypotenuse, the side opposite the 90-degree angle, is the square root of the sum of the squares of the other two sides. Expressed as an equation it is:

$$a^2 + b^2 = c^2 \text{ or } c = \sqrt{a^2 + b^2}$$

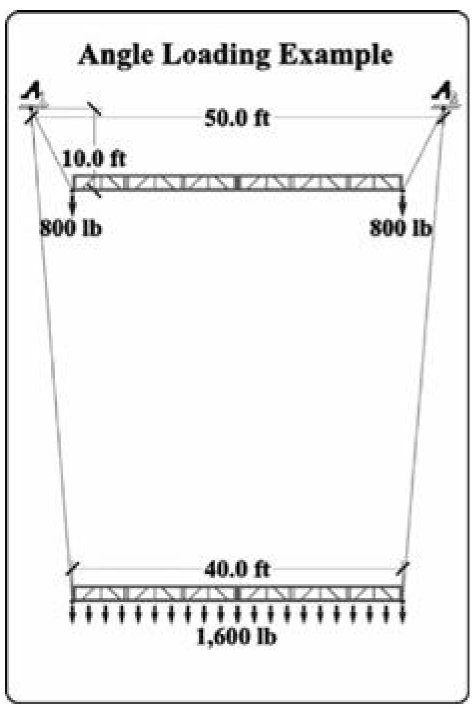


Figure 1.21

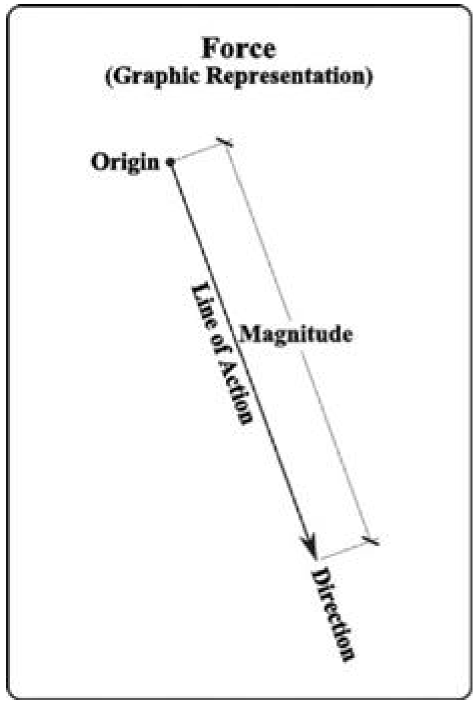


Figure 1.22

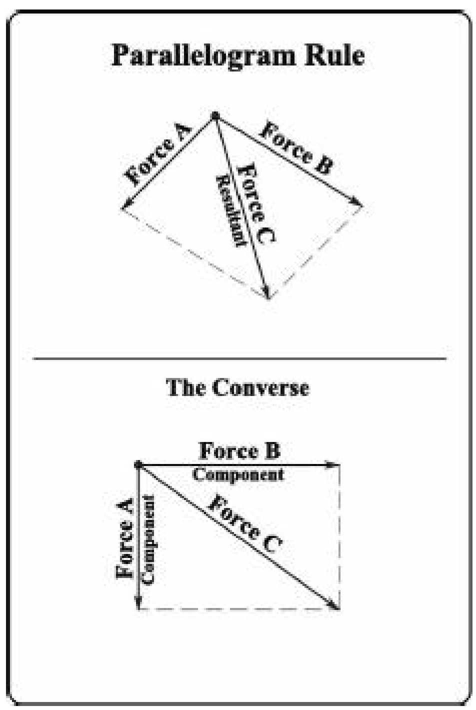


Figure 1.23

Using it with a force triangle and the symbols used in this chapter the equation becomes:

$$F_L^2 = F_H^2 + F_V^2 \text{ or } F_L = \sqrt{F_H^2 + F_V^2}$$

Solving Angled Leg Force Problems

Problem 8

Finding the angled leg force when the vertical force is known, method one. For Problem 8, the example shown in Figure 1.21 will be used. In this case we have an anchorage (A) that is offset 10′ vertically and 5′ horizontally from the point (P), at which the applied force (F_A) is attached. Since the truss is uniformly loaded and weighs 1,600lb, there is an 800lb vertical force (F_V) at each end. We want to know the value of the force in the angled leg (F_L) to determine whether or not we would be overloading the half-ton hoists that are lifting the truss.

SOLUTION

STEP 1: ORGANIZE THE DATA

- To better visualize the problem, we will draw two triangles. The first will represent the distances. Starting at the anchorage a vertical line is drawn representing D_V, the 10′ height difference between A and P. From the bottom of that line we will draw a line horizontally representing D_H, the 5′ offset between A and P. The line connecting A and P represents D_L, the slope and length of the angled leg.
- Adjacent to the triangle, make a table of the three distances and fill in the two that are known.
- Below the distance triangle, draw a similar triangle representing the forces. For this triangle we will start at A and draw a vertical line F_V, representing the 800lb vertical force. We know this triangle is similar to the distance triangle so the angles will be the same, but the forces F_H and F_L are unknown at this point.
- Next to this triangle make a table representing the three forces F_H, F_L, and F_V, filling in the value for F_V.
- Finding F_L will be a two-step process and there is more than one way to come to a solution. We could begin by either finding the length of D_L or by finding F_H. For this problem we wouldn't care what the length of D_L is as there is a chain hoist in line with it. F_H might be more useful, so we will start by finding its value. Since the force and distance triangles are similar, the ratio of F_H to F_V will be the same as the ratio of D_H to D_V. The equation for this is:

$$F_H = F_V \frac{D_H}{D_V}$$

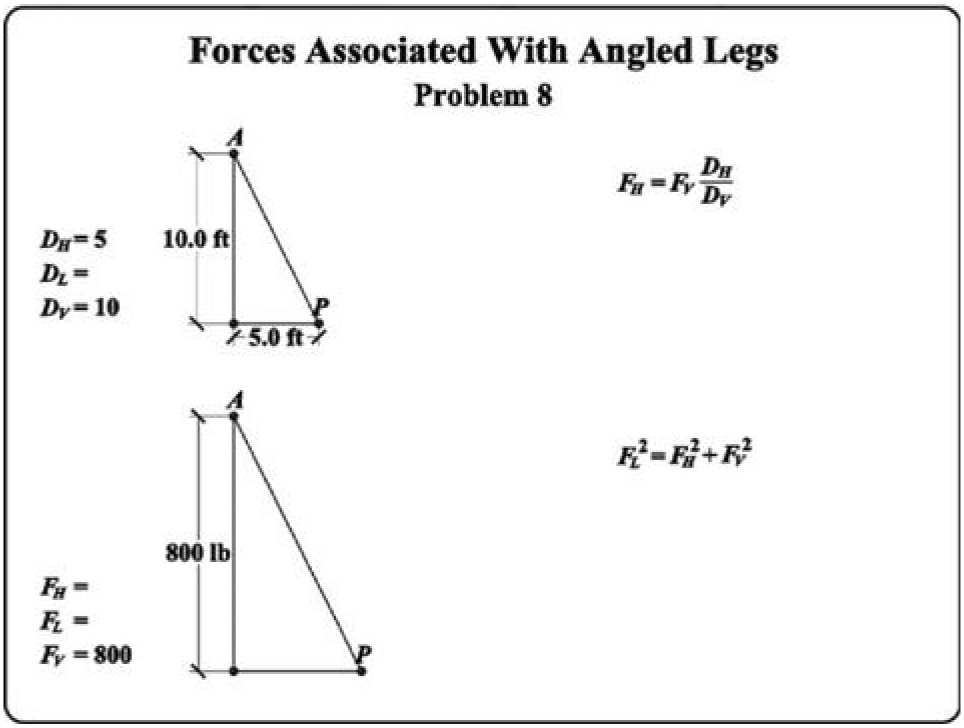


Figure 1.24

This formula is the first of two needed and will be useful to remember for use later in solving bridle problems as well. It should be written down with space below for solving.

Once we have the value for F_H, we can use the Pythagorean Theorem to find F_L, the hypotenuse of the force triangle (see Figure 1.24). For this triangle it would be written down as follows:

$$F_L^2 = F_H^2 + F_V^2$$

STEP 2: INSERT VALUES AND SOLVE

- Solving for F_H first by substituting the values for F_V, D_H, and D_V, we find the value of 400lb for F_H.
- After writing this in the table, we can then substitute the values into our Pythagorean Theorem equation and arrive at an answer of approximately 894.427lb. So, by doing this calculation we see that we would not be overloading the half-ton chain hoists.
- Finally, transfer the value of F_L to the table and round as desired once all calculations are complete (see Figure 1.25).

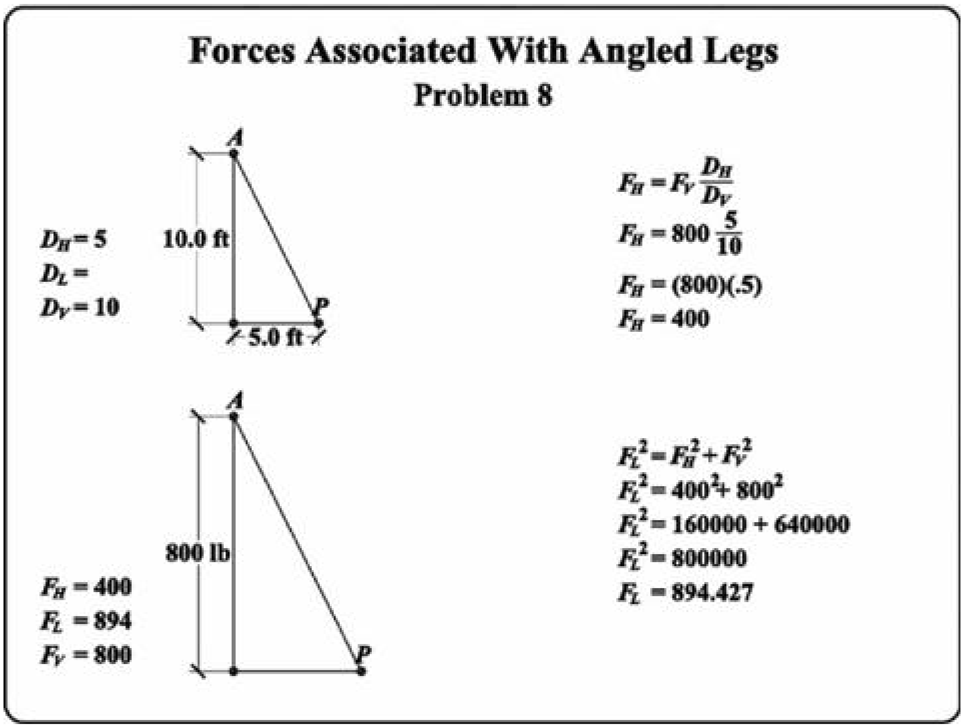


Figure 1.25

Problem 9

Finding the angled leg force when the vertical force is known, method two. For Problem 9, we will create a little more angle loading and solve the problem using the Pythagorean Theorem first and use the similar triangle ratio second. For this problem we will keep D_V and F_V the same as in Problem 8, with values of 10′ and 800lb respectively. We will increase the horizontal offset to 7.59 to see how this affects F_L.

SOLUTION

STEP 1: ORGANIZE THE DATA

- As in Problem 8 we will draw the distance triangle using the dimensions given for Problem 9.
- Create a table of the distances adjacent to the triangle and fill in the known distances.
- Create a force triangle using F_V as the only known side, approximating the angles of the distance triangle.
- Create a table of the forces adjacent to the triangle and fill in the value for F_V.
- This time, to find F_L we will start off by finding the value of D_L using the Pythagorean Theorem using this equation:

  $$D_L^2 = D_H^2 + D_V^2$$

  This equation should be copied with space below for solving.
- Once we have a value for D_L, we can use the ratio of sides in the distance triangle to find F_L in the force triangle (see Figure 1.26). Below is the equation we will use. It should be copied with space for solving:

$$F_L = F_V \frac{D_L}{D_V}$$

Step 2: Insert values and Solve

- In this case we will substitute the values into our Pythagorean Theorem equation to find the value of D_L.
- Once the value of D_L has been found the second equation can be solved to find F_L (see Figure 1.27). Note that F_L has increased from the previous problem by increasing D_H.

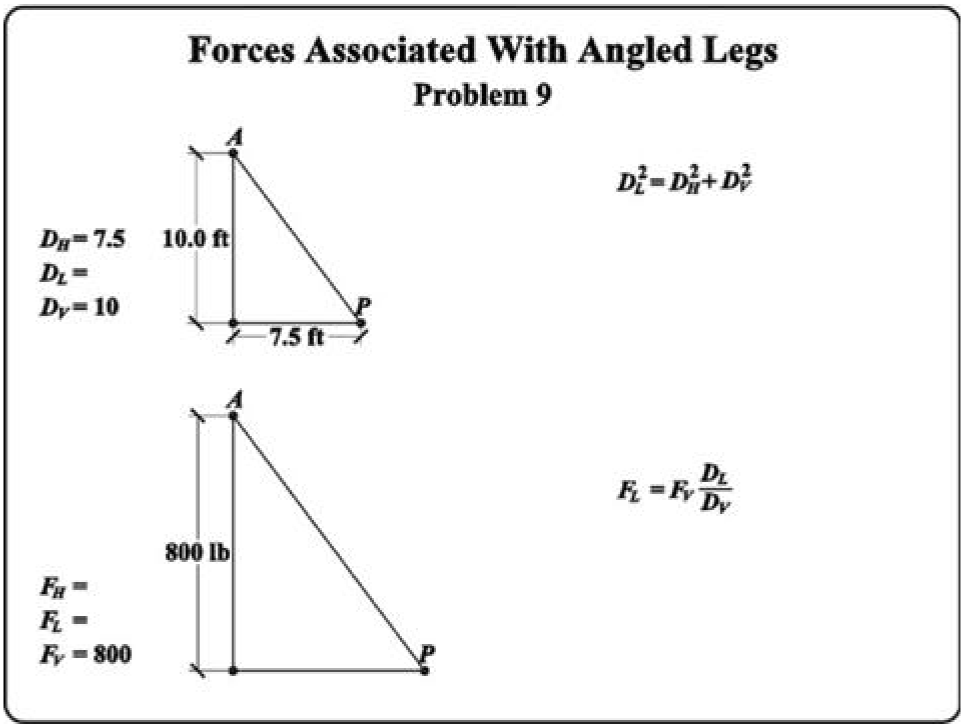


Figure 1.26

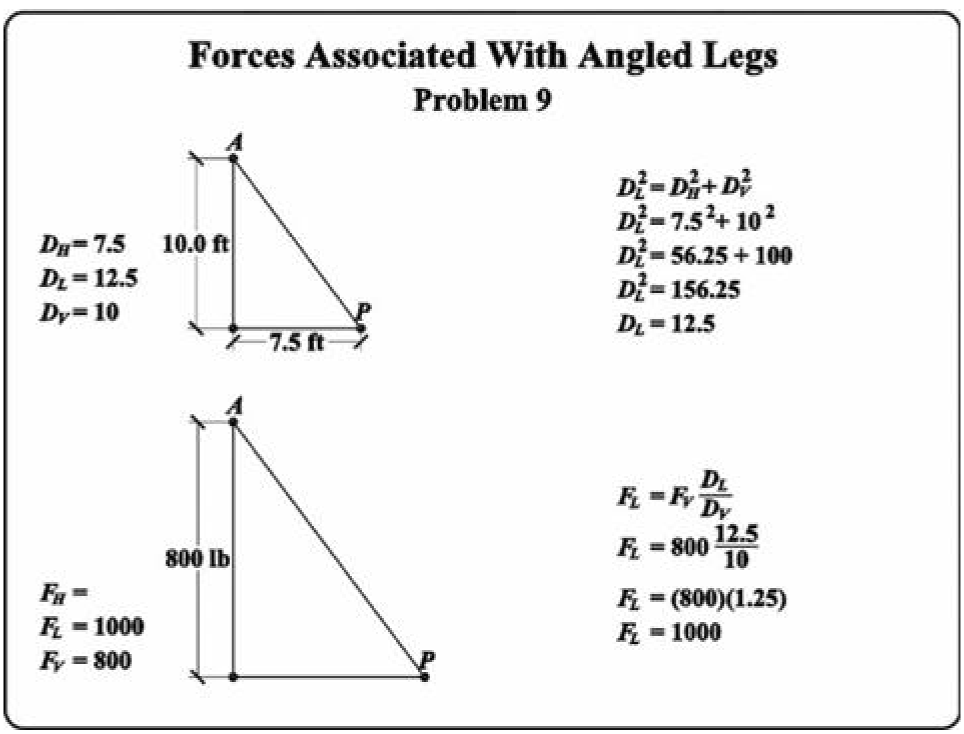


Figure 1.27

Tips

- If you look at both ratio equations side by side, it may make them easier to remember:

$$F_L = F_V \frac{D_L}{D_V} \text{ and } F_H = F_V \frac{D_H}{D_V}$$

  - Whether you are solving for F_H or F_L, the vertical force is multiplied by a fraction.
  - The fraction always has D_V as the denominator.
  - The numerator uses D_H when solving for F_H, and D_L when solving for F_L.
- The distance triangle in Problem 9 is a *3-4-5 triangle*. That means that the short side is a multiple of 3, the long side is a multiple of 4, and the hypotenuse is a multiple of 5. In this case the multiple is 2.5. If this had been recognized, the ratio equation need not have been solved as 2.5 × 5 would have yielded the correct value for D_L of 12.5. Since the force triangle is similar to the distance triangle, it also must be a 3-4-5 triangle with a long side of 800. 4 × 200 equals 800, so F_H = 3 × 200 or 600, and the hypotenuse F_L = 5 × 200 or 1,000. Recognizing things like this will make you a more accurate and more efficient rigger.

The main concern about angle loading is that as the angled leg gets flatter and flatter, F_H and F_L dramatically increase. The angle riggers commonly refer to when talking about bridle or angled legs is the acute angle formed at the anchorage from horizontal down to the angled leg. I will refer to it as *angle-a* (*∠a)* because it is associated with the anchorage *A*. Some of the key approximate relationships to remember are:

$$\text{If } \angle a = 45^\circ\text{, then } F_H = F_V$$
$$\text{If } \angle a = 45^\circ\text{, then } F_L = 1.5F_V$$
$$\text{If } \angle a = 30^\circ\text{, then } F_L = 2F_V$$
$$\text{If } \angle a = 15^\circ\text{, then } F_L = 4F_V$$

See Figure 1.28 for an illustration.

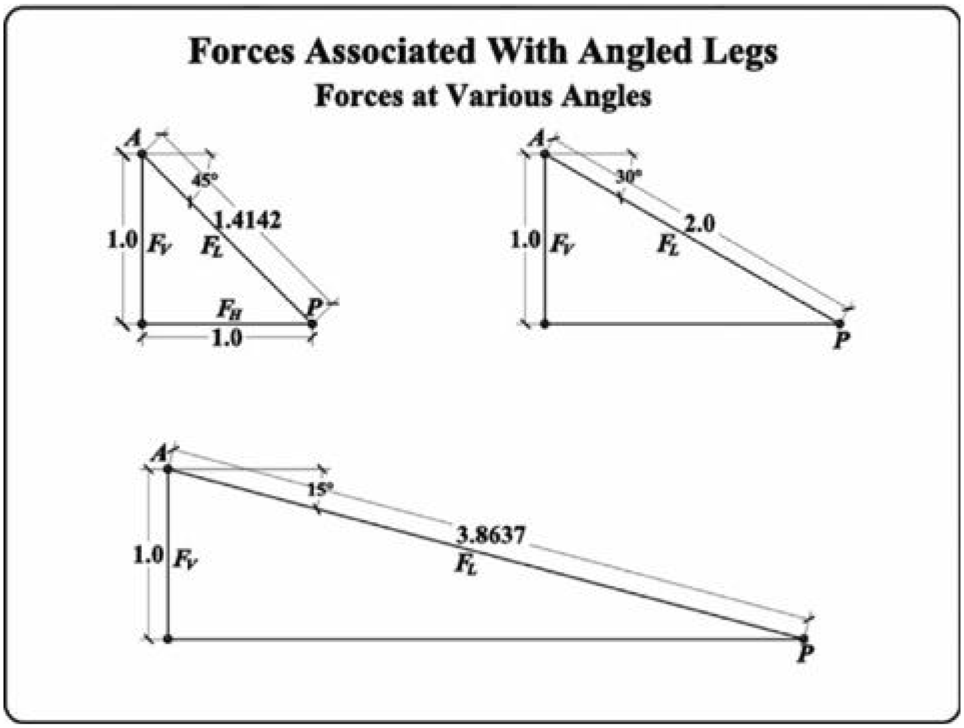


Figure 1.28

Two-Leg Bridles—Equal Height Anchorages

Two-leg, equal height bridles are the most common type of bridle done by entertainment riggers. There are, however, many buildings around the world where the anchorage beams for the bridles are at different heights, as well as a few where three-leg bridles are common. Not only are the two-leg, equal height bridles more common, they are the simplest to install accurately and the simplest to solve mathematically. To differentiate them from the other types I will call them *simple bridles* in this chapter. In this section, I will present methods for determining all the forces associated with simple bridles.

Solving bridle force problems can be accomplished several different ways. When I was first reading about forces in bridle legs, I stumbled upon a chart of “multipliers” used for calculating the force in a bridle leg when the angle-a ($\angle a$) of the leg was known. It was useful, but I didn’t want to carry the chart around with me. The best I could do was to memorize a couple of the key multipliers. One day I discovered that the chart of multipliers was in fact the table of values for a trigonometric function. Since this was long before the days of smartphones and even the Internet, my option was to buy a calculator that had the functions programmed in it. For me back then, it was the equivalent of getting a smartphone and downloading a bridle calculation app. As useful as that was back then, I found it very challenging to teach the use of trigonometry in my rigging classes. Over the years I have found that instead of thinking about angles and trigonometric functions, most riggers found that learning to solve bridle problems by directly applying the ratios involved was easier. However, no discussion of rigging math would be complete without at least the briefest description of the various functions.

Trigonometric Functions

Trigonometric or *trig functions* are the ratios of the various sides that contain the angle being evaluated. With a given angle in a right triangle, the sides have a specific ratio. These ratios are described by three primary and three secondary functions listed below:

- Primary functions

- $Sine\ (sin) = \frac{Opposite\ Side}{Hypotenuse}$
- $Cosine\ (cos) = \frac{Adjacent\ Side}{Hypotenuse}$
- $Tangent\ (tan) = \frac{Opposite\ Side}{Adjacent\ Side}$
- Secondary functions
- $Cosecant\ (csc) = \frac{Hypotenuse}{Opposite\ Side}$
- $Secant\ (sec) = \frac{Hypotenuse}{Adjacent\ Side}$
- $Cotangent\ (cot) = \frac{Adjacent\ Side}{Opposite\ Side}$

The secondary functions are the reciprocal of their primary counterparts. For instance, *csc* is the reciprocal of *sin*. That means that the fractions are reversed. On a calculator the reciprocal can be found by dividing the number into one, or in some cases pressing the "1/x" button.

On a calculator, entering the angle and pressing the function button will yield the value for that function. The reverse can be done although all calculators are not labeled the same. On an iPhone, pressing the "2nd" button, then typing in the ratio, followed by the pressing the desired function button will yield the angle.

The problem with using trig functions is that we either have to know what the angle is to find the appropriate ratio, or we have to find the angle by using a different ratio in order to find the ratio we need. In many ways ratios are easier to understand and measure since we generally have tape measures available but not protractors. Most of us have learned about fleet angles and that, for a smooth drum, the maximum fleet angle is 1.5 degrees. It seems more useful to me to know the ratio of 1:40 instead of the angle. This tells us that for every 40″ of distance away from the drum that the wire rope can be 1″ off-center.

Span to Height Ratio ($S{:}D_V$)

All riggers should be aware that tremendous forces are produced in very flat bridles, and many rigging sources teach different rules of thumb for avoiding potentially dangerous bridles. Most riggers have heard of the 90-degree rule, or the not quite as conservative 120-degree rule, about never exceeding these values for the bridle angle. For us, the bridle is in the middle of space and estimating or measuring it is difficult at best. Instead of thinking about a bridle angle, think about the ratio of bridle height to span. If the S to D_V ratio is 3 to 1 or less you will avoid overloading the rigging slings and hardware as long as they would safely support the load in a dead hang.

Problem 10: Bridle labels

Figure 1.29 illustrates the labels and symbols used for discussion and solving bridle problems. Finding bridle leg forces when the anchorage heights of the legs are equal. In Problem 10 we will be solving for the three forces associated with each leg of the bridle as well as the bridle leg lengths. In order to solve for all six unknown forces we will use the force distribution equations along with the ratio formulas learned in the previous section. The bridle leg lengths will be found using the Pythagorean Theorem. For this problem the distance between the beams is 45′, and the bridle point is 15′ away from the near beam. The point weighs 1,800lb, and the bridle point is 10′ below the beams.

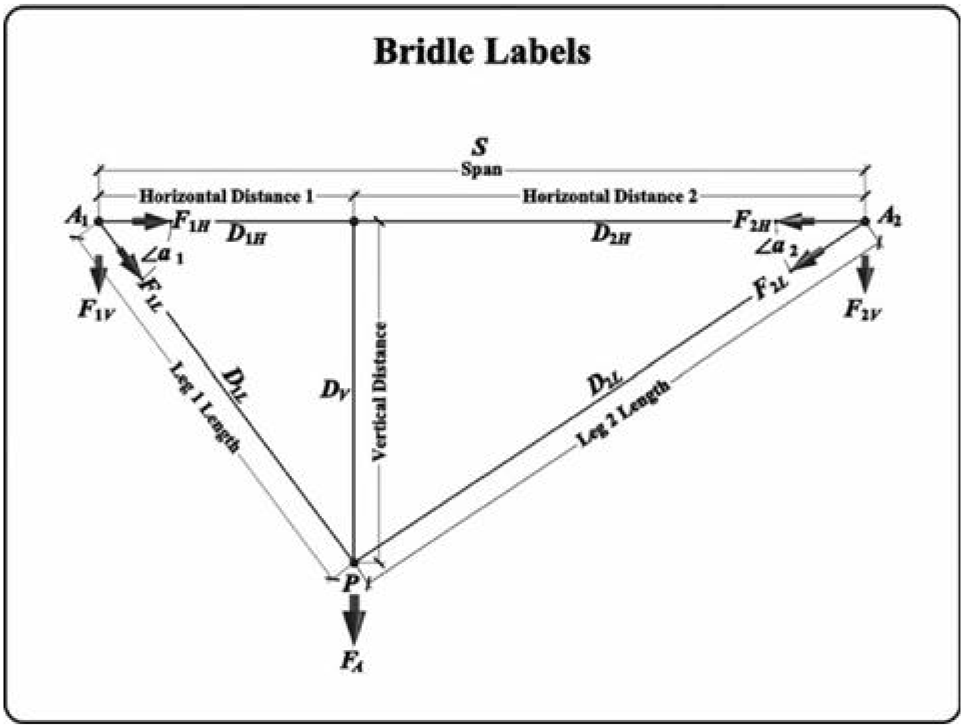


Figure 1.29

SOLUTION

STEP 1: ORGANIZE THE DATA

- Sketch a drawing of the bridle with the dimensions given above, showing the weight applied.
- Below the drawing make a table of the known values and their symbols. Also make a table of the symbols for the eight unknown values (see Figure 1.30).
- On a second sheet of paper, divide it into two columns with a vertical line and then divide the columns into four sections each. The four unknown values for leg 1 will be solved on the left side and the unknowns for leg 2 on the right side.

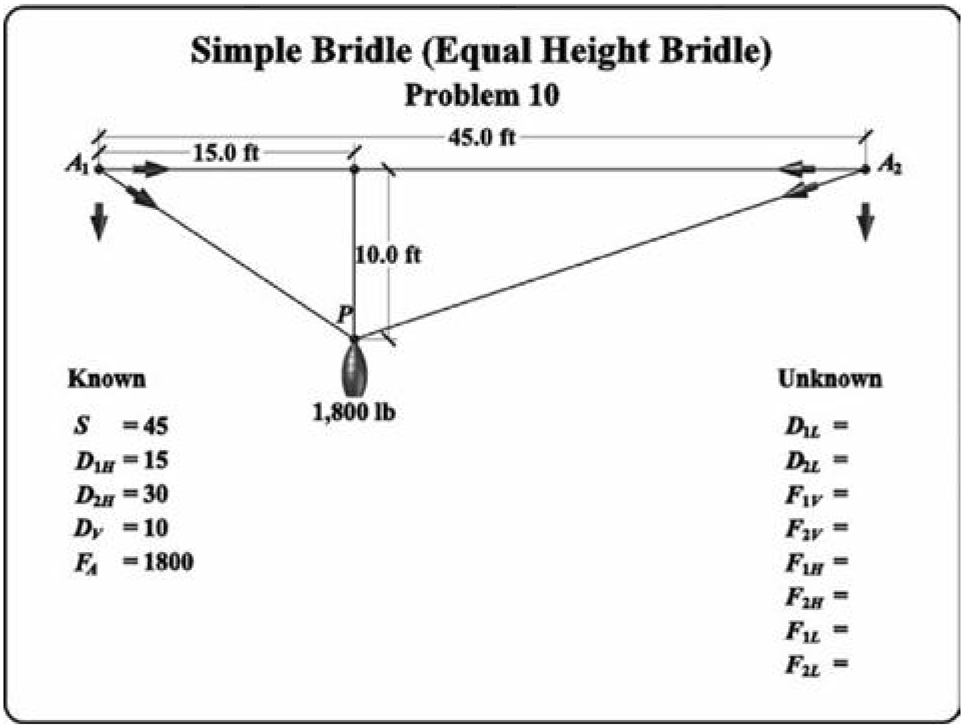


Figure 1.30

STEP 2: SOLVE FOR BRIDLE LEG LENGTH

It may help when solving bridle problems to think of a bridle as two back-to-back angled leg triangles that in this case share a common side. The vertical distance, D_V, is the common side. By looking at Figure 1.30, we know the values for the short sides of both triangles, D_{1H} and D_V for bridle leg 1, and D_{2H} and D_V for bridle leg 2. Using the Pythagorean Theorem, the hypotenuses of both legs, D_{1L} and D_{2L}, can be calculated.

- Using the top sections of the two columns, find the bridle leg lengths D_{1L} and D_{2L}. At the top of the left-hand section write either equation:

$$D_{1L} = \sqrt{D_{1H}^2 + D_{1V}^2} \text{ or } D_{1L}^2 = D_{1H}^2 + D_{1V}^2$$

- At the top of the right-hand upper section write either of the following forms of the Pythagorean Theorem for D_{2L}:

$$D_{2L} = \sqrt{D_{2H}^2 + D_{2V}^2} \text{ or } D_{2L}^2 = D_{2H}^2 + D_{2V}^2$$

- Substitute values into the equations and solve for D_{1L} and D_{2L}. Transfer your answers to the table of unknowns, rounding if desired once all calculations are complete.

Note: The solutions for both D_{1L} and D_{2L} resulted in numbers with many decimal places. The values of D_{1L} and D_{2L} rounded to three places will be used later in this problem.

STEP 3: SOLVE FOR VERTICAL FORCE

We now have values for all three sides of the distance triangles associated with this problem. We need to find the values for the sides of the force triangles. Looking back at the angled leg problem, we were given the vertical force, which we used in finding the horizontal and leg force. So finding the vertical force first is a useful next step. Finding the vertical force is a force distribution problem for which we know the distances S, D_{1H} and D_{2H}, along with F_A.

- At the top of the second section down on the scratch paper, write the force distribution formulas below:

For Leg 1 $F_{1V} = \frac{F_A D_{2H}}{S}$, and for Leg 2, $F_{2V} = \frac{F_A D_{1H}}{S}$

- Substitute the values into the equations and solve, transferring the values for F_{1V} and F_{2V} to the table.

STEP 4: SOLVE FOR HORIZONTAL FORCE

Once we have the values for F_{1V} and F_{2V}, we can solve for the horizontal and bridle leg forces. Starting with the horizontal forces F_{1H} and F_{2H} we can use the ratio formulas we used in the angled leg problems. We will multiply the vertical force by the horizontal distance divided by the vertical distance.

- At the top of the next section down on your worksheet write the formulas below for F_{1H} and F_{2H}:

$F_{1H} = F_{1V} \frac{D_{1H}}{D_{1V}}$ and $F_{2H} = F_{2V} \frac{D_{2H}}{D_{2V}}$

- Substitute the values into the equations and solve, transferring the values for F_{1H} and F_{2H} to the table.

STEP 5: SOLVE FOR BRIDLE LEG FORCE

Finally we can solve for the bridle leg forces. This time the ratio will be D_L over D_V since we are trying to find F_L.

- Write the ratio equations for finding F_{1L} and F_{2L} at the top of the bottom section of the worksheet:

$F_{1L} = F_{1V} \frac{D_{1L}}{D_{1V}}$ and $F_{2L} = F_{2V} \frac{D_{2L}}{D_{2V}}$

- Substitute the values into the equations and solve, transferring the values for F_{1L} and F_{2L} to the table. To obtain the same result as the book does, you must round D_{1L} and D_{2L} to three places to the right of the decimal point in the above equations.

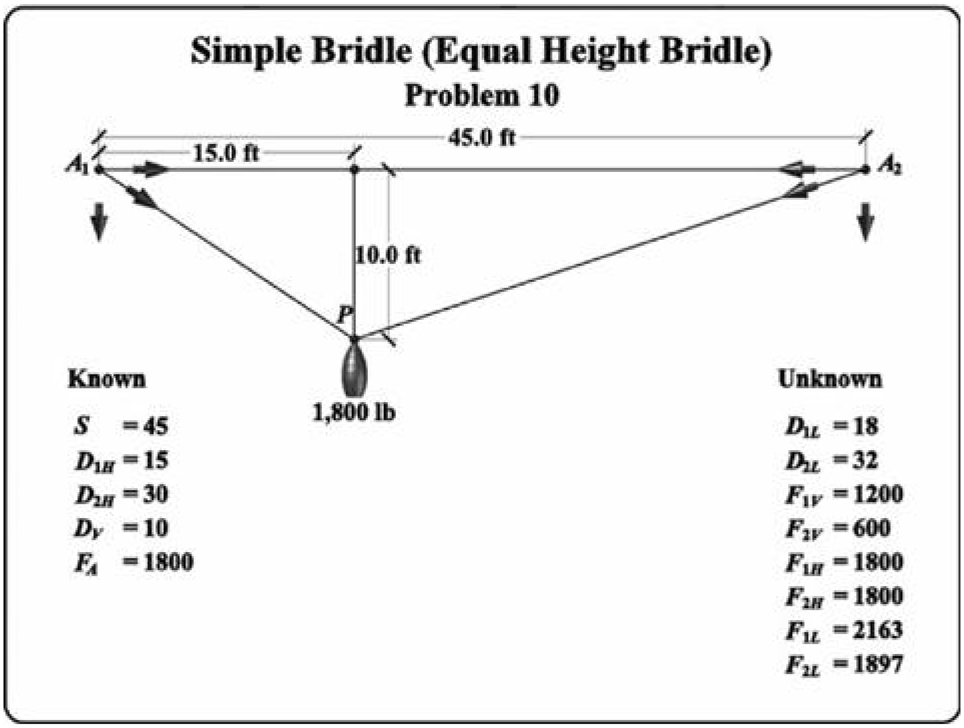


Figure 1.31

Review Figures 1.31 and 1.32 to check your results.

Tips

- When calculating the leg lengths, the square roots yielded many places after the decimal. I only kept three places to the right of the decimal point for future use in equations. When transferring the data to a rig plot, the data needs not be that accurate and can be rounded further.
- Note that *P* is one-third of the way across the span in this problem, therefore two-thirds of the force is transferred to the near support and one-third to the far support. Using this method works on simple bridles, but not on bridles with different height anchorages. They will be discussed later in the chapter.
- When you compare the horizontal force and the bridle leg force equations, the vertical force for the triangle is multiplied by a ratio with the denominator being the vertical distance. The only change to the numerator is that it is the horizontal distance when finding the horizontal force, and the leg length when finding the leg force. By studying these equations, they can be committed to memory.
- In this problem, the bridle leg forces were the last sides of the force triangles that were unknown. Instead of using the ratio equations we could have found them using the Pythagorean Theorem on the force triangles. See the equations below:
  $F_{1L}^2 = F_{1H}^2 + F_{1V}^2$ and $F_{2L}^2 = F_{2H}^2 + F_{2V}^2$
- The forces in both legs are significantly more than 1,800lb, the value of F_A. This is because the S:D_V ratio is 4.5, well above 3. If possible, when S is 45′, D_V should be at least 15′.

Bridle Leg Length

$$D_{1L}^2 = D_{1H}^2 + D_{1V}^2$$
$$D_{1L}^2 = 15^2 + 10^2$$
$$D_{1L}^2 = 225 + 100$$
$$D_{1L}^2 = 325$$
$$D_{1L} = 18.028$$

$$D_{2L}^2 = D_{2H}^2 + D_{2V}^2$$
$$D_{2L}^2 = 30^2 + 10^2$$
$$D_{2L}^2 = 900 + 100$$
$$D_{2L}^2 = 1000$$
$$D_{2L} = 31.623$$

Vertical Force

$$F_{1V} = \frac{F_A\, D_{2H}}{S}$$
$$F_{1V} = \frac{(1800)(30)}{45}$$
$$F_{1V} = \frac{54000}{45}$$
$$F_{1V} = 1200$$

$$F_{2V} = \frac{F_A\, D_{1H}}{S}$$
$$F_{2V} = \frac{(1800)(15)}{45}$$
$$F_{2V} = \frac{27000}{45}$$
$$F_{2V} = 600$$

Horizontal Force

$$F_{1H} = F_{1V}\frac{D_{1H}}{D_V}$$
$$F_{1H} = 1200\,\frac{15}{10}$$
$$F_{1H} = (1200)(1.5)$$
$$F_{1H} = 1800$$

$$F_{2H} = F_{2V}\frac{D_{2H}}{D_V}$$
$$F_{2H} = 600\,\frac{30}{10}$$
$$F_{2H} = (600)(3)$$
$$F_{2H} = 1800$$

Bridle Leg Force

$$F_{1L} = F_{1V}\frac{D_{1L}}{D_V}$$
$$F_{1L} = 1200\,\frac{18.028}{10}$$
$$F_{1L} = (1200)(1.8028)$$
$$F_{1L} = 2163.36$$

$$F_{2L} = F_{2V}\frac{D_{2L}}{D_V}$$
$$F_{2L} = 600\,\frac{31.623}{10}$$
$$F_{2L} = (600)(3.1623)$$
$$F_{2L} = 1897.38$$

Figure 1.32

Two-Leg Bridles—Unequal Height Anchorages

Unequal height bridles cannot be solved exactly the same way as simple bridles because the anchorages are at different heights. However, these problems can be solved using the concepts we have already learned. We just need to apply the concept of similar triangles in a different application when trying to find forces. Using the concept of similar triangles we can convert the bridle into a simple bridle in order to apply the force distribution equation to find the vertical forces.

First, think of the legs in a bridle as representing the lines of actions for the forces in the legs and realize that the force is the same anywhere along the line of action (see Figure 1.33).

One side of the bridle can be changed to a similar triangle with the same D_V as the other side (see Figure 1.34).

Since we are creating a new leg 2 similar triangle with a D_V equal to D_{1V}, the new horizontal distance, $D_{2H\text{new}}$, can be calculated by multiplying D_{2H} by the ratio of D_{1V} divided by D_{2V}. Once we have a value for $D_{2H\text{new}}$, it can be added to D_{1H} to arrive at the new span S_{new}. These values can then be put into the force distribution formulas as follows:

$$F_{1V} = F_A \frac{D_{2H\text{new}}}{S_{\text{new}}} \text{ and } F_{2V} = F_A \frac{D_{1H}}{S_{\text{new}}}$$

Once the vertical forces are obtained, the other forces can be found by the same methods as were done with the simple bridle.

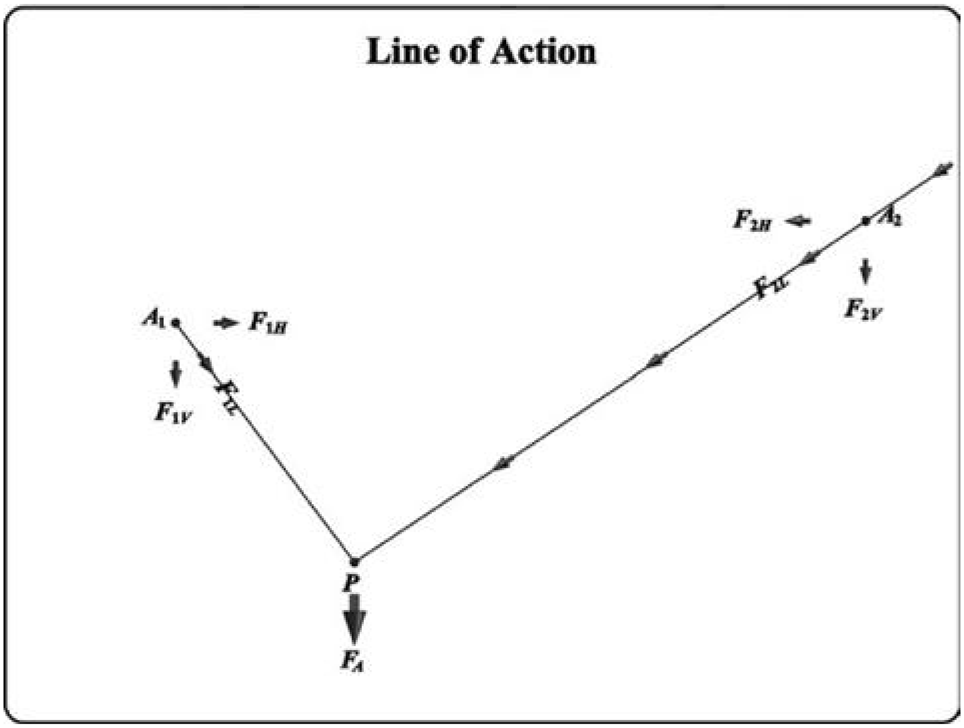


Figure 1.33

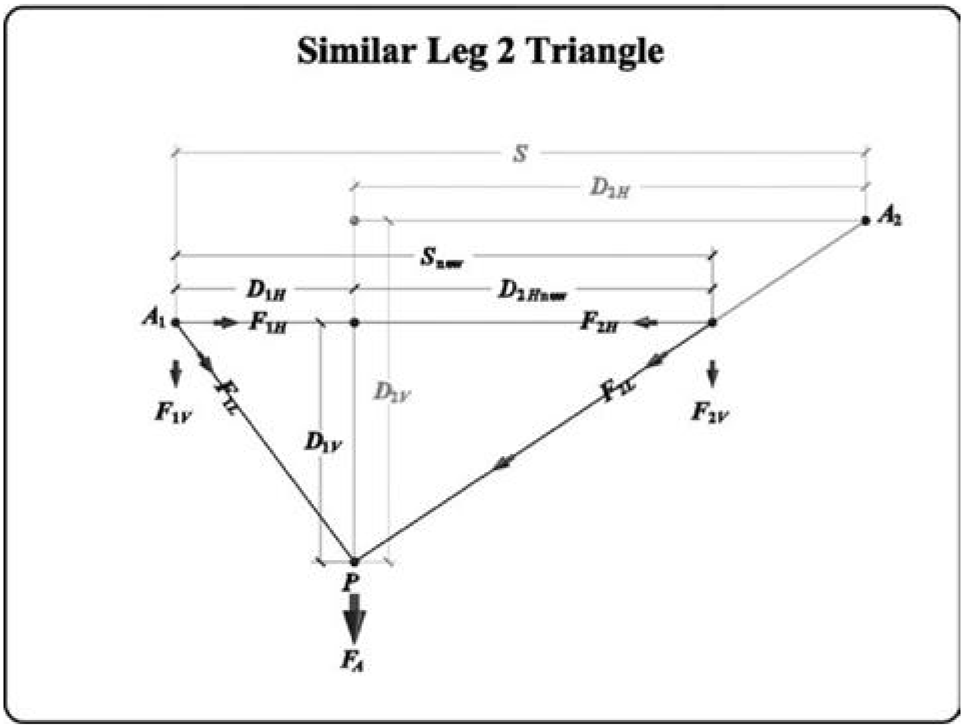


Figure 1.34

Problem 11

Finding bridle leg forces when the anchorage heights of the legs are not equal. For problem 11, the span between the beams is 40.59. The bridle point, P, is 10.59 from anchorage A_1. The vertical distance, D_{1V}, from A_1 to P is 14′, while the vertical distance, D_{2V}, from A_2 to P is 20′. The applied force, F_A is 1,600lb as in the simple bridle problem, Problem 10.

SOLUTION

STEP 1: ORGANIZE THE DATA

- Sketch a drawing of the bridle with the dimensions given above, showing the weight applied.
- Below the drawing make a table of the known values and their symbols. Also make a table of the symbols for the ten unknown values (see Figure 1.35).
- On a second sheet of paper, divide it into two columns with a vertical line and then divide the columns into five sections each. The four unknown values for leg 1 will be solved on the left side and the unknowns for leg 2 on the right side. The fifth section will be used to find the new span by creating a similar triangle for leg 2 with the same height as leg 1.

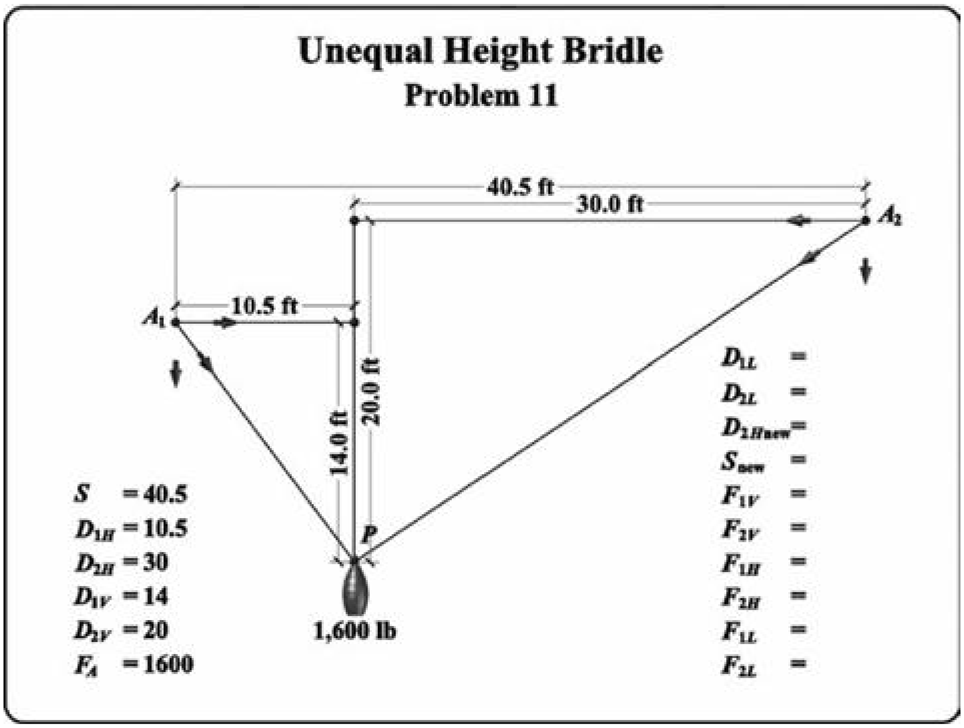


Figure 1.35

STEP 2: SOLVE FOR BRIDLE LEG LENGTH

Since the short sides of both the distance triangles are known, the Pythagorean Theorem can be used to find the bridle leg lengths. The short sides of the triangles would be the heights, D_{1V} and D_{2V}, and the horizontal distances D_{1H} and D_{2H}. The hypotenuse of the leg 1 triangle would be represented by D_{1L}, and for leg 2 the hypotenuse would be D_{2L}.

- Using the top section of your worksheet, in the left side add a form of the Pythagorean Theorem for Leg 1 such as:

$$D_{1L}^2 = D_{1H}^2 + D_{1V}^2$$

- On the right side of the top section add the equation for Leg 2:

$$D_{2L}^2 = D_{2H}^2 + D_{2V}^2$$

- Substitute the known values into the equations and solve for D_{1L} and D_{2L}.
- Transfer the values to the list of unknowns, rounding as desired once all calculations are complete.

STEP 3: FIND THE NEW SPAN

- In the next section down, on the left side, write the ratio equation to find the horizontal distance for a new leg 2 triangle that has the same height as leg1:

$$D_{2Hnew} = D_{2H}\frac{D_{1V}}{D_{2V}}$$

- In the right side of this section write the formula for the new span using the new horizontal distance for leg 2:

$$S_{new} = D_{1H} + D_{2Hnew}$$

- Solve both equations, adding the solutions to the list of unknowns.

STEP 4: FIND THE VERTICAL FORCE

- Using the information from the newly equalized height bridle write the formulas for F_{1V} and F_{2V} in the next section down:

$$F_{1V} = \frac{F_A D_{2Hnew}}{S_{new}} \text{ and } F_{2V} = \frac{F_A D_{1H}}{S_{new}}$$

- Insert the known values into the equations and solve, adding the results to the list of unknowns rounded as desired.

Note: The solutions for F_{1V} and F_{2V} resulted in numbers with many decimal places. I rounded both to three decimal places on the worksheet for use later in the problem.

STEP 5: FIND THE HORIZONTAL FORCE

- In the next section down, write the ratio equations for finding F_{1H} and F_{2H}:

$$F_{1H} = F_{1V} \frac{D_{1H}}{D_{1V}} \text{ and } F_{2H} = F_{2V} \frac{D_{2H}}{D_{2V}}$$

- Insert the known values into the equations and solve, adding the results to the list of unknowns rounded as desired.

Note: The solutions for F_{1H} and F_{2H} resulted in numbers with many decimal places. I rounded both to three decimal places on the worksheet for use later in the problem.

STEP 6: FIND THE BRIDLE LEG FORCE

In Problem 10, we used ratio equations to find the values for F_{1L} and F_{2L}. Instead of doing that, this time we will use the Pythagorean Theorem to find the forces in the bridle legs. Either way will result in similar results.

- In the bottom section, write the Pythagorean Theorems for F_{1L} and F_{2L}:

$$F_{1L}^2 = F_{1H}^2 + F_{1V}^2 \text{ and } F_{2L}^2 = F_{2H}^2 + F_{2V}^2$$

- Insert the known values into the equations and solve, adding the results to the list of unknowns rounded as desired.

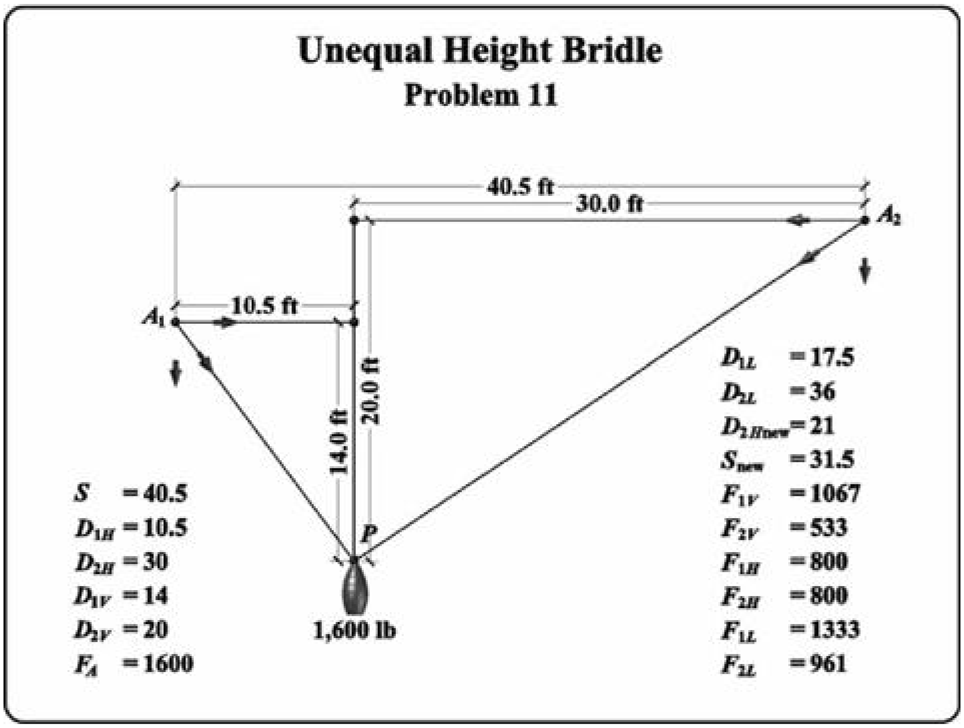

Unequal Height Bridle
Problem 11
40.5 ft
30.0 ft
A_2
A_1
10.5 ft
20.0 ft
14.0 ft
P
1,600 lb
S = 40.5
D_{1H} = 10.5
D_{2H} = 30
D_{1V} = 14
D_{2V} = 20
F_A = 1600
D_{1L} = 17.5
D_{2L} = 36
$D_{2H\text{new}}$ = 21
S_{new} = 31.5
F_{1V} = 1067
F_{2V} = 533
F_{1H} = 800
F_{2H} = 800
F_{1L} = 1333
F_{2L} = 961

Figure 1.38

Bridle Leg Length

$$D_{1L}^2 = D_{1H}^2 + D_{1V}^2$$
$$D_{1L}^2 = 10.5^2 + 14^2$$
$$D_{1L}^2 = 110.25 + 196$$
$$D_{1L}^2 = 306.25$$
$$D_{1L} = 17.5$$

$$D_{2L}^2 = D_{2H}^2 + D_{2V}^2$$
$$D_{2L}^2 = 30^2 + 20^2$$
$$D_{2L}^2 = 900 + 400$$
$$D_{2L}^2 = 1300$$
$$D_{2L} = 36.056$$

Find New Span

$$D_{2Hnew} = D_{2H}\frac{D_{1V}}{D_{2V}}$$
$$D_{2Hnew} = 30\frac{14}{20}$$
$$D_{2Hnew} = (30)(.7)$$
$$D_{2Hnew} = 21$$

$$S_{new} = D_{1H} + D_{2Hnew}$$
$$S_{new} = 10.5 + 21$$
$$S_{new} = 31.5$$

Vertical Force

$$F_{1V} = \frac{F_A D_{2Hnew}}{S_{new}}$$
$$F_{1V} = \frac{(1600)(21)}{31.5}$$
$$F_{1V} = \frac{33600}{31.5}$$
$$F_{1V} = 1066.667$$

$$F_{2V} = \frac{F_A D_{1H}}{S_{new}}$$
$$F_{2V} = \frac{(1600)(10.5)}{31.5}$$
$$F_{2V} = \frac{16800}{31.5}$$
$$F_{2V} = 533.333$$

Horizontal Force

$$F_{1H} = F_{1V}\frac{D_{1H}}{D_{1V}}$$
$$F_{1H} = 1066.667\frac{10.5}{14}$$
$$F_{1H} = (1066.667)(.75)$$
$$F_{1H} = 800$$

$$F_{2H} = F_{2V}\frac{D_{2H}}{D_{2V}}$$
$$F_{2H} = 533.333\frac{30}{20}$$
$$F_{2H} = (533.333)(1.5)$$
$$F_{2H} = 800$$

Bridle Leg Force

$$F_{1L}^2 = F_{1H}^2 + F_{1V}^2$$
$$F_{1L}^2 = 800^2 + 1066.667^2$$
$$F_{1L}^2 = 640000 + 1137778.489$$
$$F_{1L}^2 = 1777778.489$$
$$F_{1L} = 1333.334$$

$$F_{2L}^2 = F_{2H}^2 + F_{2V}^2$$
$$F_{2L}^2 = 800^2 + 533.333^2$$
$$F_{2L}^2 = 640000 + 284444.089$$
$$F_{2L}^2 = 924444.089$$
$$F_{2L} = 961.480$$

Figure 1.37

Note: The solutions for F_{1L} and F_{2L} resulted in numbers with many decimal places during the process of squaring values and taking their square roots. I rounded both to three decimal places on the worksheet each time. To check your results, look at Figures 1.36 and 1.37.

Tip

- In order to find the vertical forces in an unequal height bridle, one side of the bridle must be changed using the principle of similar triangles so that $D_{1V} = D_{2V}$. The newly created D_H is used to find the span of the newly created bridle. The newly created bridle is used only to find F_{1V} and F_{2V}. Once the vertical forces have been determined, the distances of the original bridle are used to find the other forces.

Three-Leg Bridle Geometry

In the last section of this chapter we will learn to calculate the lengths of the legs of three-leg bridles. To solve problems with two-leg bridles all the dimensions are in the same plane, which is some ways simplifies the mathematics, especially when considering the force calculations, which will not be discussed in this chapter. The bridle leg lengths, however, are simple enough to calculate with the addition of two new concepts.

Cartesian Coordinate System

The Cartesian coordinate system was developed by a French philosopher named René Descartes. The system is used to describe unique points in space. On a two-dimensional system there are two axes separated by 90 degrees in the same plane. Generally these axes are labeled *x* and *y*. The point at which the axes cross is called the *origin*. Many people in our business call it the *zero-zero point*. Where they cross is described by the ordered pair (0,0), where the first number is the value of *x* and the second number is the value of *y*. When used on the stage, normally the *x-axis* runs cross stage and the *y-axis* runs up and down stage. See the left side of Figure 1.38 for an illustration of a two-dimensional Cartesian coordinate system.

A three-dimensional system adds an additional axis, perpendicular to the plane of the *x-y* axes. This axis is the *z-axis*, and represents the elevation above the floor or stage. In this system the values are shown as (x,y,z). See the right side of Figure 1.38 for an illustration of a three-dimensional Cartesian coordinate system.

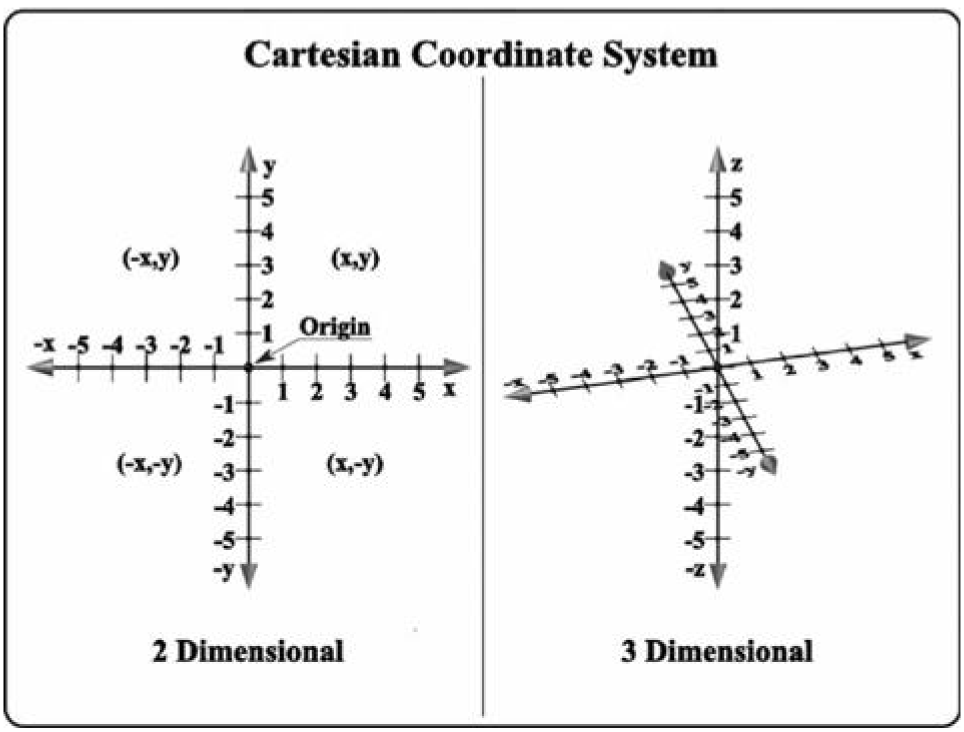


Figure 1.38

Delta (Δ)

In mathematics, the term *delta* (Δ) means change. It is the absolute difference in value and will be used in conjunction with the Cartesian coordinate system to solve for our bridle leg lengths. When thinking about the absolute difference in two values of x, or Δx, it is always a positive value no matter what the signs are of the values we are comparing (see Figure 1.39).

Three-Dimensional Pythagorean Theorem

Previously we have been using the Pythagorean Theorem on a triangle which is a two-dimensional object. We have used it to find D_L, the leg length or hypotenuse of the triangle. Because we are working in three dimensions instead of two when trying to find the leg lengths of a three-leg bridle we need to expand the Pythagorean Theorem to accommodate the change. The new theorem is:

$$D_L^2 = \Delta x^2 + \Delta y^2 + \Delta z^2$$

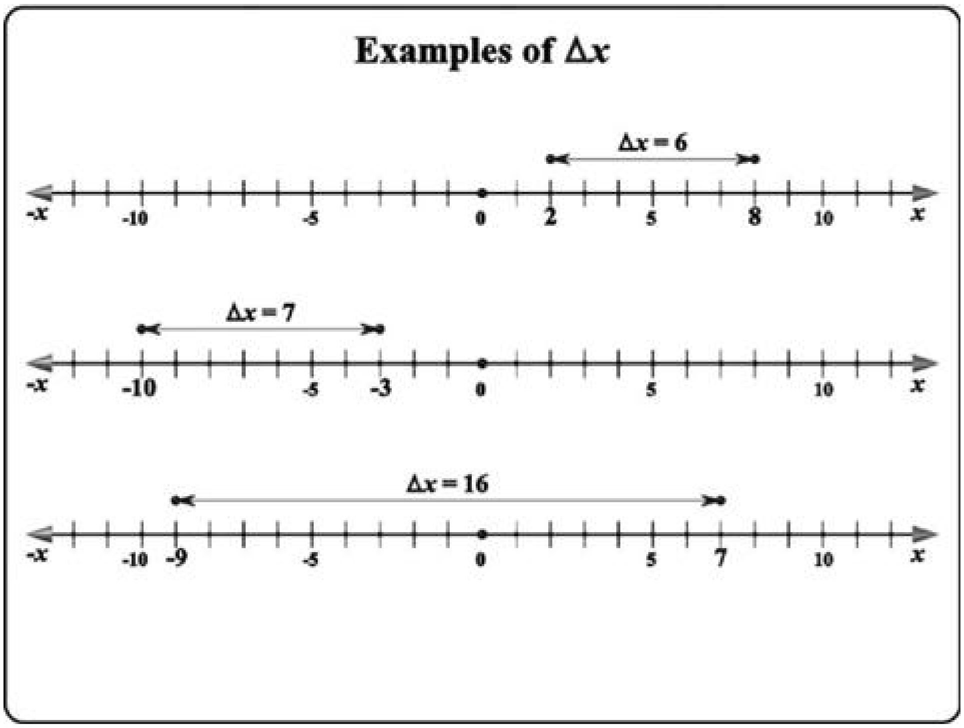


Figure 1.39

The Δ in this case is the difference in the value of the Cartesian coordinate at the anchorage of the leg in question and the respective coordinate at the bridle point P.

Problem 12

Finding the leg lengths of a three-legged bridle. For the final problem, we will use this new version of the Pythagorean Theorem to find the leg lengths of a three-leg bridle. For this problem the point is 28′ left of center stage, 16′ upstage of the downstage edge of the stage, and P needs to be 35′ above the stage. The beams we are anchoring the bridle to are 50′ above the stage, running up and downstage with attachment points every 12′ starting at the downstage edge.

To identify the anchorage points and bridle point using the Cartesian coordinate system we will place the origin at the downstage edge of the stage at center stage. The three anchorage points are: $A_1 = (36, 24, 50)$, $A_2 = (36, 12, 50)$, and $A_3 = (0, 12, 50)$. The bridle point P is at (28, 16, 35).

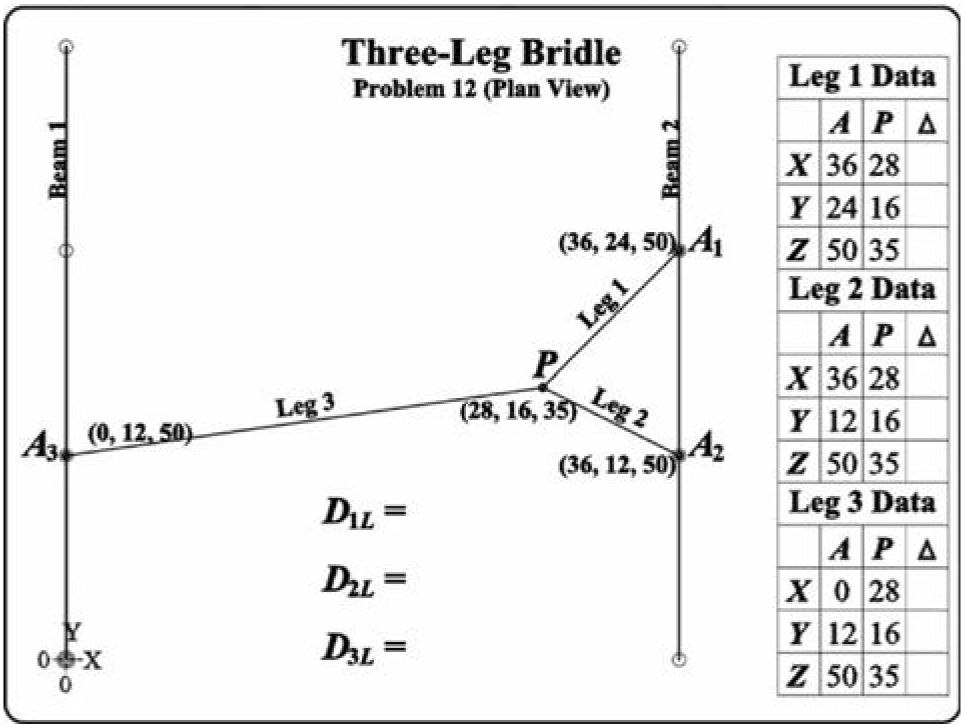


Figure 1.40

SOLUTION

STEP 1: ORGANIZE THE DATA

- Sketch a plan view drawing of the bridle with the dimensions given above, showing the beams, origin, and Cartesian coordinates.
- Make a table of data for each leg with three columns and three rows. Label the columns *A*, *P*, and Δ. Label the rows *X*, *Y*, and *Z*.
- Insert the coordinates in the tables for each leg (see Figure 1.40).
- On a second sheet of paper, write the three-dimensional Pythagorean Theorem for each leg, leaving space between for solving for leg length.

STEP 2: FIND ALL THE DELTAS

On the tables created earlier, fill in the differences between *A* and *P* for the values of *x*, *y*, and *z* for each leg.

STEP 3: SOLVE FOR LEG LENGTH

Insert the delta values into the equations and solve for leg length. Transfer the results to the drawing, rounding as desired once all calculations are complete.

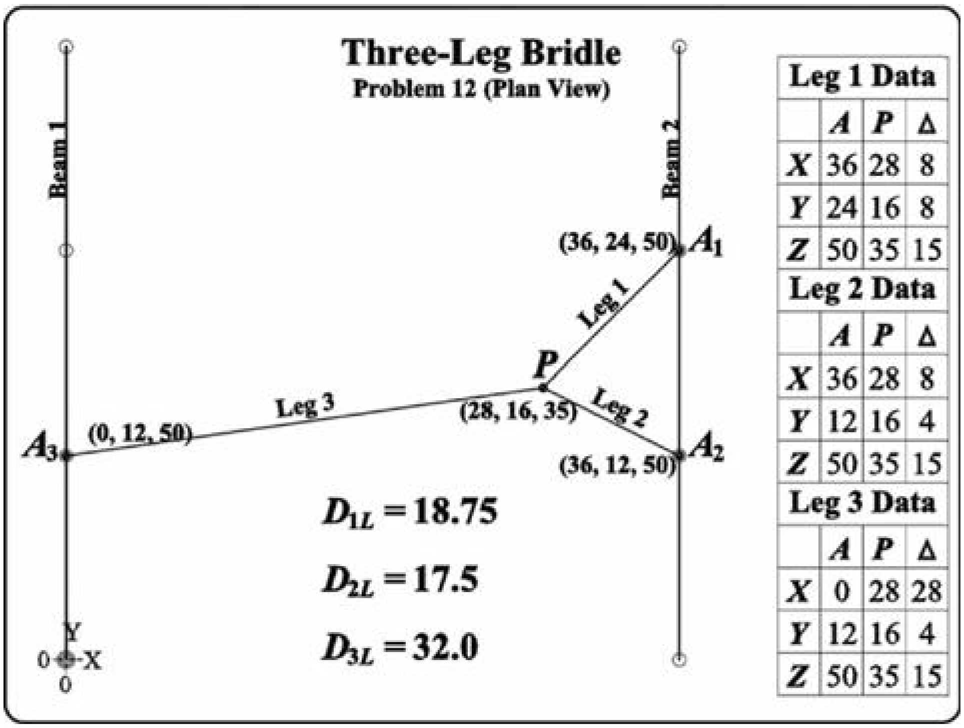


Figure 1.41

Three-Leg Bridle

Problem 12 Worksheet

$$D_{1L}^2 = \Delta x_1^2 + \Delta y_1^2 + \Delta z_1^2$$
$$D_{1L}^2 = 8^2 + 8^2 + 15^2$$
$$D_{1L}^2 = 64 + 64 + 225$$
$$D_{1L}^2 = 353$$
$$D_{1L} = 18.788$$

$$D_{2L}^2 = \Delta x_2^2 + \Delta y_2^2 + \Delta z_2^2$$
$$D_{2L}^2 = 8^2 + 4^2 + 15^2$$
$$D_{2L}^2 = 64 + 16 + 225$$
$$D_{2L}^2 = 305$$
$$D_{2L} = 17.464$$

$$D_{3L}^2 = \Delta x_3^2 + \Delta y_3^2 + \Delta z_3^2$$
$$D_{3L}^2 = 28^2 + 4^2 + 15^2$$
$$D_{3L}^2 = 784 + 16 + 225$$
$$D_{3L}^2 = 1025$$
$$D_{3L} = 32.016$$

Figure 1.42

Tips

- As a practical matter, bridle legs lengths do not need to be exact. A common adjusting method is to use STAC chain, which has approximately 3″ links. For this reason I have rounded the answers to the nearest one-quarter foot, or 3″.
- Once you become familiar with the concepts and the coordinates are known, the Ds can be found and inserted into the equations without drawing the bridle, beams, and tables.

2
Structural Behavior

BILL GORLIN

This chapter is intended to introduce structural behavior to people involved in entertainment rigging, tapping into the experiences and "feel" all of us have gained from looking at structures every day of our lives. Structures are governed by the laws of physics, namely Isaac Newton's Laws, which are all around us: buildings, bridges, box trusses, rope, fences, trees, rock formations, etc. We will explore key basic structural subjects, with the intention of improving the reader's awareness of such behaviors. This is a chapter of concepts, not equations, although I will introduce a couple of those.

Structural engineers can be helpful collaborators with designers, technical directors, riggers, and stagehands when developing entertainment designs. The engineer visualizes the load paths and stability of the system, ensuring safety and hopefully improving the ease of use and cost. It is best to involve the engineer early in the design process in order to best utilize their insights. Alert the engineer to real-world issues that are important to your project, such as the production schedule, preferred equipment and construction methods, and access and handling issues. Share insights back and forth, since the engineer and you may have very different experiences.

It is worthwhile to note that the coveted engineer's stamp on a document is more than patterned ink. To become a professional engineer, a person needs to graduate from an accredited engineering college, work several years as an engineer-in-training, apply for licensure with the state, and then take and pass a rigorous test. Once a person is licensed, he is legally responsible to the state government to comply with engineering laws and to perform engineering to a standard of care expected in the industry. In fact, an engineer is first responsible to the state to protect public safety, and then responsible to his employer and client.

Let's now get into the structural behavior.

Newton's Laws

Newton's Laws of Motion, combined with a lot of math, provide the key to most of structural engineering. These laws are as follows:

1 An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

2 Acceleration is produced when a force acts on a mass. The greater the mass of the object being accelerated the greater the amount of force needed to accelerate the object.

3 For every action there is an equal and opposite reaction.

The First Law relates to stationary versus moving objects, confirming that objects will maintain their current state (moving or not) unless acted upon by an outside force. In rigging, this establishes the basis for understanding static force relationships, and it gives us a basis for understanding rigging dynamics.

The Second Law states that the force needed to move an object is greater for heavier objects.

The Third Law is simple, yet it is the most powerful tool available to a structural engineer. For example, the floor pushes up on a person's feet equal to the person's weight; a winch produces a certain amount of torque and its base must resist that same torque; a guy cable pulls on ballast and the ballast pulls back the same amount using its weight and its frictional resistance on the ground. When you visualize and apply this basic concept, you can undertake many structural systems.

Here are some examples: First, a rigger attaches a static object to a roof truss. In order for the object to remain in place, the truss needs to pull up on the hanger with a force equal to the object's weight. If the object is bridled, then the truss "pull" must resist the bridle forces. These examples utilize all three of the Laws.

How do we apply this to flexural situations, such as beams? Let's consider a playground see-saw in which the people are balancing one another so the see-saw is not moving.

Example 1

Two people of equal weight at the same distance from the fulcrum. The fulcrum supports the weight of two people, satisfying the Third Law. An engineer would say that the sum of the forces in the "Y" direction is equal to zero since there is no movement, i.e., the weight of two equal people directed down plus the reaction of the two people up at the fulcrum.

The see-saw does not rotate because the weight of the two people is balanced. An engineer would say that the sum of the moments (force times distance) about the fulcrum is equal to zero since there is no movement, i.e., weight of Person 1 times her distance to the fulcrum equals the weight of Person 2 times his distance to the fulcrum rotating in the other direction. The engineer would say that the sum of the moments is zero: $0 = (P1)(D) - (P2)(D)$, where D = distance from center, and P1 and P2 = weight of each person. P1 must equal P2 for this equation to work.

Example 2

Person 2 weighs more than Person 1. The fulcrum still resists the combined weight, regardless of location on the see-saw. The engineer would say that the sum of the forces in "Y" direction is zero: $0 = P1 + P2 - R$, where R is the fulcrum reaction acting in the opposite direction from the forces.

The reader can probably visualize that the heavier person needs to be closer to the fulcrum than the lighter person in order to achieve balance, i.e., no movement. The same "sum of the moments" equation used above can be used to find the distances: $0 = (P1)(D1) - (P2)(D2)$, where D1 and D2 are the respective distances.

These relationships exist everywhere an object exists in relation to other objects, such as a cable bridle, supports for a beam, guy cables, a truss, and a group of bolts or welds in a connection.

When an externally applied moment (or force at a distance) is applied to an object, the object is anchored by a resisting moment that must equal the externally applied moment. The resisting moment is often anchored by a "force couple" consisting of equal and opposite forces separated by a distance. For example, a plated box truss connection resists flexure by a force couple consisting of the bottom bolts in tension coupled with the top plates bearing against one another in compression. A group of welds forming a shape can also provide a force couple to resist moments, e.g., a weld all around the interface of an angle and a gusset plate forms a rectangular weld group shape.

Force couples are everywhere—you just have to look for them.

Stress-Strain

Structural members of any material resist externally applied loads by pulling back (Newton's Law). Strain is the amount of movement when the force is applied and stress is the force per unit of material area. Any material will undergo strain when stress occurs, so if someone says there is "no movement" they really mean "negligible movement."

A member subjected to axial force will stretch if tension is applied or shrink if compression is applied. A member subjected to flexure will bend such that it will curve, causing one face to stretch and the other to contract. The amount of stretch/contraction decreases towards the center of the cross section, at which point the direction of stress and strain reverses.

Most common structural materials behave in an elastic fashion under normal use, which means stress and strain is directly correlated, e.g., double the pull to double the stretch. However, when the material reaches its yield stress, further load will make it stretch like putty, unable to rebound fully when the load is removed. Then when stretched too far, the material will fracture. Each material has its own elastic-plastic behavior. For example, steel will more reliably stretch like putty before fracture, whereas aluminum is more vulnerable to sudden fracture. For rigging, always use a material in its elastic behavior range, but it is good to know how it might behave at high load.

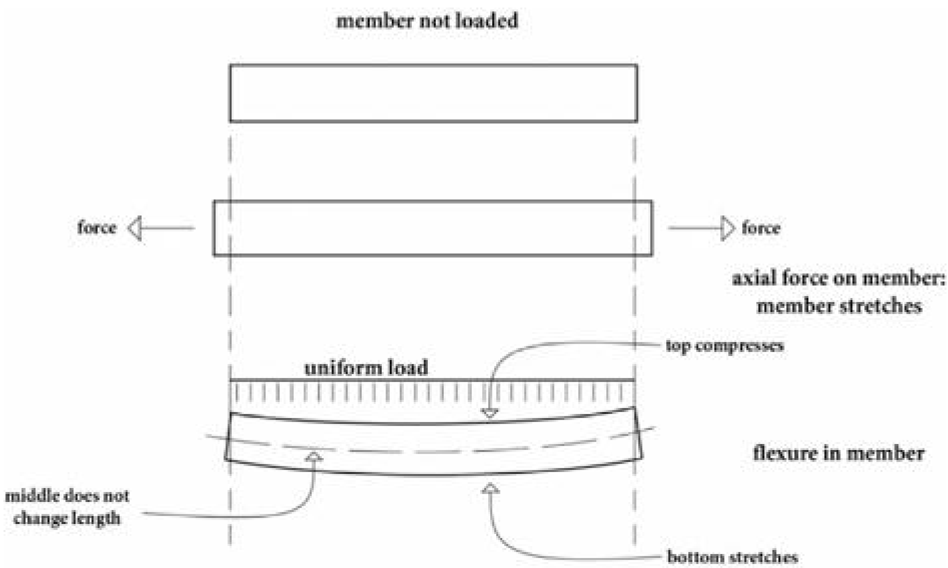


Figure 2.1 Stress – Strain

Each material has a defined minimum yield stress above which the behavior is not elastic, as well as an ultimate stress at which it fractures. In some codes, this is expressed as strength rather than stress, and can get rather complicated.

Material Stiffness

The ratio between stress and strain defines how stiff a material is when stressed, which is called the elastic or "Young's" modulus. The higher the modulus, the stiffer the material. Examples of common Young's modulus are listed below (psi = pounds per square inch):

- Steel: 29,000,000 psi
- Aluminum: 10,000,000 psi
- Lumber (Doug Fir North): 1,600,000 psi
- Engineered lumber: 2,000,000 psi

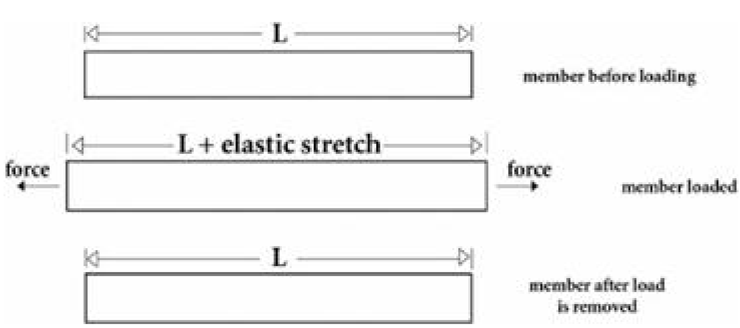


Figure 2.2 Elastic behavior

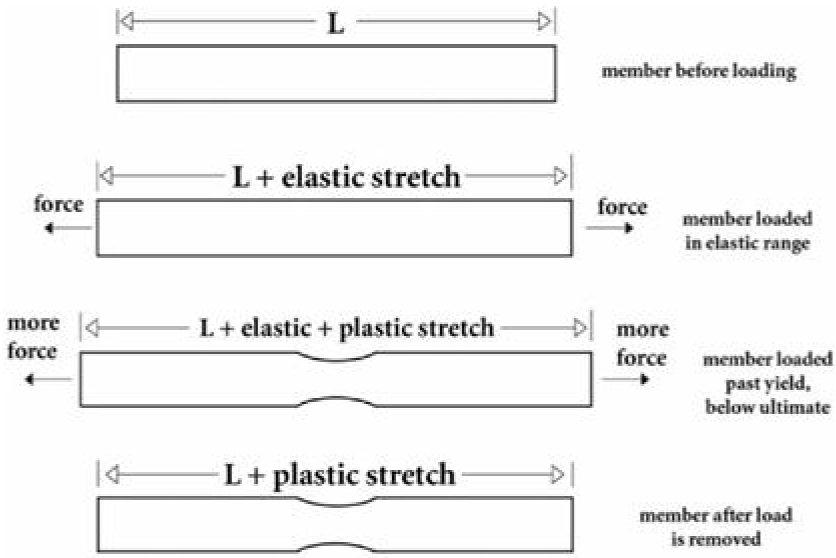


Figure 2.3 Plastic behavior

Member Properties

Member section properties pertain to the geometry of the member and influence allowable stresses and stiffness, and can become complicated quickly. The following is a quick overview.

Axial stiffness is related to cross sectional area. Flexural stiffness is related to moment of inertia of the cross section in the axis subject to bending. (Moment of inertia is a function of location of the material away from the cross section center axis.)

For example, a solid rod has a certain amount of material, or cross sectional area. Let's hollow out the center by stretching the material to create a pipe that is a larger diameter than the original rod, but with the same cross sectional area. This pipe is significantly stiffer in bending than the rod, using the same material. The improvement is related to the square of the distance from the center to the material.

This explains why I-beams are the most cost effective section for common building beams since most of the material in the flanges is spread far apart by the web. Of course, the very same I-beam is much less stiff when bent in the other ("weak") direction.

What if we want a member that is equally stiff when bent vertically or sideways? In this case, a pipe or tube will be a more efficient use of the material for this situation, since the material is distributed relatively uniformly in both directions.

A property listed in common structural section properties is "radius of gyration," which is calculated using moment of inertia and area, so it is solely a function of geometry. This property is the key for selecting members to resist column buckling.

Behavior of Sections Under Load

Tension

Tension is force pulling directly in line with the length of a member, i.e., axially. Members subjected to axial stress will stretch, so behavior is not dependent on length other than the amount of stretch. Pure tension is the most efficient of all load transfer methods. Be mindful that some basic building materials cannot resist much tension, such as unreinforced concrete, unreinforced masonry, and a pile of rocks—all of which can support a lot of compression.

Compression

Compression is force pushing axially on a member. Members subjected to compressive stress are at risk for buckling. This is a vital and often overlooked issue in structural systems, so please take notice. Anything under compression has a tendency to buckle and bow away from a straight line.

Let's first explore axial compression. This commonly occurs in a column or a brace. Let's consider the most basic condition where the force introduces pure axial compression with no eccentricities to complicate matters.

In the 18th century, Euler proved that slender elements will buckle suddenly when subjected to a tiny lateral force when they reach a certain stress. The definition of "slender" relates to the unbraced length of the member compared with the radius of gyration of the cross-section. The critical stress for a member is a function of these values and the Young's modulus of the material. It has no relation to the yield stress or ultimate stress. This means that the exact same size column in mild steel and high strength steel will buckle at the same critical stress.

In common applications, columns are classified as slender, compact, and in between. This means that a slender column will fail in buckling before it fails in a fashion related to cross-section stress, and a compact column will exceed an allowable stress before buckling behavior becomes a factor. Of course, there are slenderness cases that are a combination of the two.

The buckling situation becomes more complicated when considering buckling of the elements of a column failing or buckling before the overall section fails. For example, a box truss in compression needs checks of individual compression members for their own point-to-point lengths, as well as the overall truss for its full, unbraced length between supports and properties.

Let's return to basics for an example of compressive behavior:

- Imagine a common plastic drinking straw that is an inch long; it takes strong fingers to crush it. It never buckles—it just crushes and does not spring back to the original form. This is a compact column.
- Make the same straw 12″ long; this can be made to buckle pretty easily and will spring back to straight when the load is released. However, it will support load after initially buckling. If you continue to compress, it will kink and fail "plastically," i.e., it will deform and be unable to spring back to the original shape. This is a slender column, possibly with some intermediate behavior.
- Now make the same straw 200″ long; it would buckle under its own weight and you would be unable to brace it at the top. You would want to hang it from the top so that it goes into tension, or you would want to brace it laterally in the middle with a pinch of your fingers to reduce its unbraced length so it can be stabilized. This is a super-slender column.

The key to column selection when dealing with slender columns is column section geometry, not area. Considering the same force applied by one's fingers, the 200″ long unbraced straw needs a larger radius of gyration to support the same force as the shorter straws. Likewise, a really short straw could be a smaller diameter and support the same force as the 12″ straw.

The codes for various materials include a maximum slenderness that is allowed for compression members. For example, primary steel members are not permitted to have a slenderness exceeding 200, in which slenderness = (unbraced length)/(radius of gyration). Secondary members can be pushed a bit further, but the author tends to avoid slenderness above 240.

Be mindful that slender member buckling is related to Young's modulus, so a given cross section in aluminum will buckle at nearly a third of the force required to buckle the same cross section in steel.

How might one use this information?

Example 1

Say you have a steel scenic framework subjected to relatively low forces, with vertical members spaced at 6′ on center and horizontal members spaced at 8′ on center, and you want to install corner-to-corner diagonal members in bays to keep the bays square when subjected to in-plane lateral forces. The diagonal by trigonometry is 10′ long.

- Unbraced length of vertical = (8′)(12″/ft) = 96″. Select a steel member with a radius of gyration that generates a slenderness less than 200. R ≤ 96″/200 = 0.48″. A 1.5″ × 1.55″ × 0.0830″ tube has a radius of gyration of 0.580″ and a slenderness of 156, so it is a good trial choice.

- The diagonal is 10′ long, so select a steel member with a radius of gyration that generates a slenderness less than 200. R ≤ 120″/200 = 0.60″. In this case, one might try out the same 1.5″ tube or use the next size up, depending on the anticipated forces and fit-up needed.

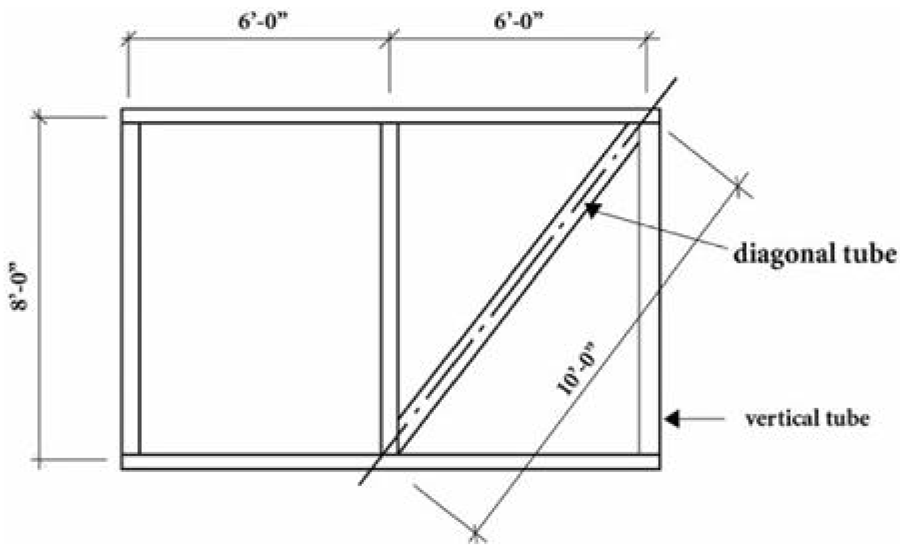


Figure 2.4 Frame braced with single tube

The main point of this example is that we have defined a logical starting point for member sizing. If the designer had proposed 1″ members, this quick calculation would easily identify these as too small regardless of loads.

Example 2

In another twist on the same frame, let's say that you want the lightest weight solution. A designer could specify ⅛″ steel rod for the diagonal acting in tension instead of the heavier tube. This works for load in one direction, but not the other, since the radius of gyration is 0.031″ and the slenderness is 3,840—no good.

The appropriate solution is to install an X-brace consisting of two rods, in which one acts in tension and the other buckles out of the load path. This is a satisfactory approach as long as the taut/un-taut behavior when loads are reversed is acceptable for the frame.

A general understanding of load paths and structural behavior, particularly buckling, can help in creating a successful design. For common elements such as scenic flats or trusses subjected to modest loads, member geometry is often more important than high strength.

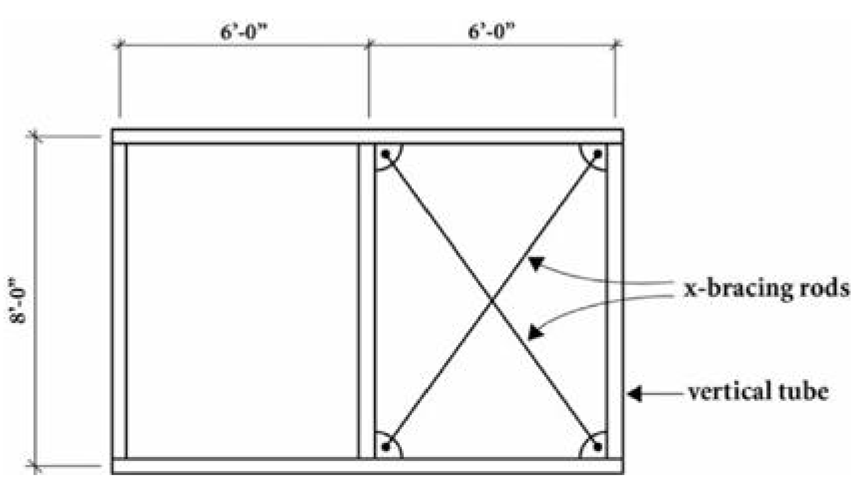


Figure 2.5 Frame braced with X-bracing

Flexure

Flexure combines tensile and compressive behaviors. In a typical simple span beam, the deflected shape is a smile—the bottom stretches and the top compresses. The stress is greatest in the midspan and diminishes to zero at the ends. For a cantilever, the member deflects down, so the top is in tension and the bottom is in compression. The cantilever member stress is greatest at the support and diminishes at the free end. If the cantilever beam has a back span, the back end wants to deflect upwards but is pulled down by the back support.

You can imagine a cantilever beam as a see-saw with the light person at the free end and the heavy person as the "reaction" at the end of the back span, bearing on the ground. Using this image, this explains why the reaction at the first support of a cantilever with a back span is greater than the weight of the object supported on the cantilever (see Figure 2.6; refer to see-saw description above). If the cantilever is rigidly attached to a support without a back span, then there is a moment resisted by the support, rather than resisted by the bending of the back span (see Figure 2.7). Loads on the back span, or different support rigidity, further complicates the math, but the principles are the same.

Let's return to the behavior of the member.

The compressive side of the cross-section presents challenges. As noted previously, anything in compression is vulnerable to buckling. In a building, the floor framing is usually braced by the floor slab, which permits efficient use of members with slender top flanges, such as I-beams, bar joists, and 2x lumber. The exact same members subjected to the same floor loads but without the slab or floor panel bracing the top flange will buckle laterally, or rather flop over as the top buckles and the bottom remains in tension.

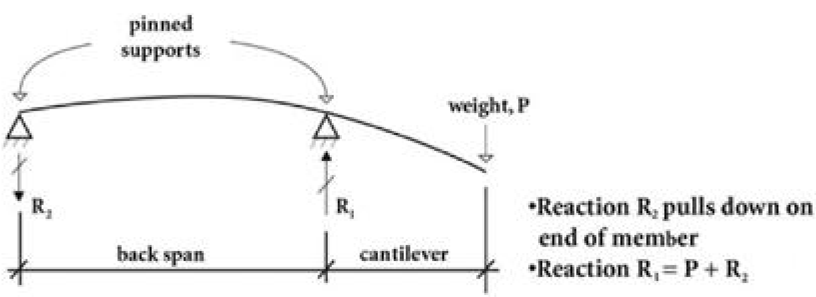


Figure 2.6 Cantilever with back span

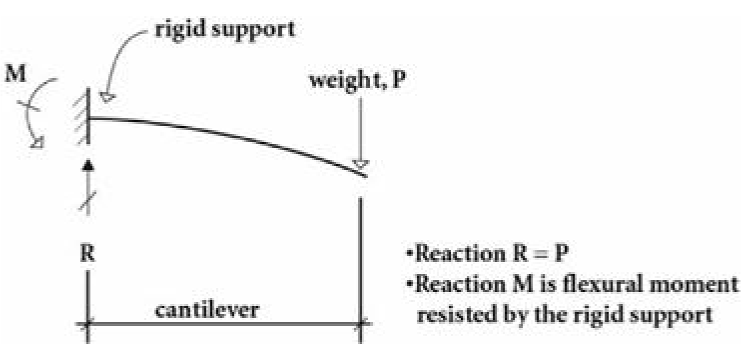


Figure 2.7 Cantilever with rigid support

While a continuous plane like a floor is the ideal system to brace compression flanges, transverse framing can also provide effective bracing, as long as it is capable. Bracing to a stiff element such as a wall, frame or major beam is very effective. Bracing that resists member twist is more effective than purely lateral framing.

Tubes and pipes have excellent resistance to lateral buckling compared with comparable size and weight open sections (I-beams, channels, angles).

Horizontal Shear

What is horizontal shear and why should I care?

Horizontal shear makes beams work. It is the difference in behavior between a stack of paper and a piece of wood the same size and shape as the stack. Support the stack of paper at its ends and subject it to beam flexure under self-weight. The center drops straight down, while the ends of the sheets of paper slip by one another, allowing the stack to deflect a lot. The amount of slip increases from the center to the end.

Now do the same to the solid piece of wood. It deflects so much less and does not exhibit the extreme slippage. What is the difference between the one thick piece of wood and the stack of really thin wood called paper? The wood fibers resist slippage in order to create effective beam behavior. This slip resistance is horizontal shear strength. The shear is the greatest at the ends, and is commonly maximum where the bending is minimum, except for cantilever supports.

The shear happens to be directly related to the reaction that accumulates at the support.

Shear resistance is provided by wood fibers naturally "glued" together or by inherent material shear resistance, for which there are values in the engineering codes.

In a truss, shear can be directly converted to axial force in a web member, and one can envision a virtual truss web occurring in the solid web of an I-beam or 2x.

In spliced or composite members, shear influences how connections are made. Imagine bolting or welding two members—one on top of the other—to create a deep composite that is stronger than the two members in parallel. The increased depth creates a much stiffer moment of inertia, thereby increasing stiffness and strength beyond the doubling of the members. Horizontal shear has to be resisted in order to mobilize this composite behavior. In this example, the bolts or welds along the interface resist the horizontal forces, and the force is greatest approaching the supports. (We will leave out equations here.)

Torsion

Torsion occurs when a member is twisted. Torsion can be evil if not handled correctly.

When twisting a plate or an open section, the resistance to twist is by warping of the shape. The thickness of the element (thickness of a web or flange) contributes much more to torsional resistance than the width. For example, if you double the width of a plate, you double its torsional stiffness. If you double the thickness of the plate, you increase the torsional stiff eight times.

Hollow sections resist torsion by creating a spiraling-type of resistance. Sections increase in torsional stiffness as they become larger. More significantly, hollow sections are orders of magnitude stiffer in torsion than open sections. For example, take a 22-gauge metal wall stud and twist it by hand; this is easy. Then take the same stud and close off the open side with a welded plate; you cannot twist this at all by hand.

When designing members to resist torsion, the supports need to reliably transfer the twist. A box truss subjected to torsion cannot simply rest on a support; it needs twist resistance.

Box trusses at first glance are excellent members to resist torsion. They are deep and wide and behave essentially as hollow sections. But remember that torsional resistance is accomplished by spiraling-type resistance. The two vertical faces have diagonal webs to facilitate the "spiral" forces around the truss centerline. However, the top and bottom are built like ladders in which resistance to parallelograming is what handles torsion; as a result, member connections are subjected to large bending moments. This is a lot less effective than the triangulated faces.

In general, it is advisable to avoid having to rely on torsion when designing structures. It is often better to arrange members so that a pair of members resists twist as a "force couple." This is how most headblock beams in theatres are constructed.

Behavior of Common Sections

The following is a brief description of the basic pros and cons of common structural shapes, meant to give the reader a general understanding of key behaviors. It is by no means an exhaustive listing of all features, and there are exceptions commonly made that may be appropriate given certain conditions.

The most common American material grades are noted in each segment. There are other materials that may be common but are not listed. It is important to note that material supply varies throughout the country. Even more importantly, material grades are quite different in other countries, including our nearest North American neighbors.

I-sections

I-beams include wide flange beams, American standard beams, and other I- or H-shaped sections. As noted previously, these sections are the most economical when bent about the strong axis (flanges top and bottom as a floor beam), because the majority of the material is kept apart by the web. They work very well when the compression flange (often the top for common beams) is braced.

These beams readily facilitate bolted and welded connections, because the flanges and web are readily accessible.

A disadvantage includes the weak axis, which is a relatively inefficient distribution of the material. If a beam has significant bending about both axes, then an I-beam could be a good choice, but not necessarily the best.

Similar to the flexural discrepancy between the strong and weak axes, there is a notable difference when these sections are used in compression. The radius of gyration can be vastly different between the strong and weak axes, so one must be careful orienting the column, providing bracing if needed. Wide flange members are often used as columns because the weak axis inefficiency is offset by the ease of bolted connections.

I-beams are relatively flexible and weak in torsion. While the wider shapes can be used successfully in torsion, one must be very careful to properly analyze the torsion, often in combination with bi-axial bending. Also, it is extremely important that the supports of torsionally loaded I-beams resist the torsion through flange connections. A web connection alone is not sufficient.

In today's market in the US, wide flange members are available in ASTM A992, which has a minimum yield stress of 50,000 psi. Other shapes are commonly available in ASTM A36, which has a minimum yield stress of 36,000 psi.

Channels

Channels have similar disadvantages as I-beams, only worse. The unbraced compression flange issues are worse, the weak axis is weaker, and the torsional behavior is very poor. The flanges are notably tapered, requiring tapered shims and making connection a bit awkward.

To make matters worse, when a channel is loaded in its strong axis, it tends to twist unless it is loaded at this magical location offset from the web.

So why do we use channels? Channels are basic shapes that are easy to use, since they are a simple geometry. They cost less to purchase per pound of steel than most other sections. When used in back-to-back pairs connected to one another, they behave more like I-beams and have some advantages in how they are handled.

Channels are typically available in ASTM A36 material, but can be purchased in ASTM A992.

Angles

The only commonly used section worse than a channel is an angle. The flexural, compressive, and torsional capabilities of angles are very poor. Single angles are almost never used as flexural members because they tend to twist so that the open side is down. Angles are so bad in torsion that they should not be allowed to twist. (Try to twist one by hand – it is not difficult.)

Similar to the channel, when angles are used back-to-back connected to one another, they behave more like tee sections. The back-to-back use allows them to be used easily with gusset plates as braces.

Like channels, angles are inexpensive per pound of steel. They can also be very easy to use in bolted connections. Angles are mostly used where the benefit of their simple shape is useful in joining framing members or for secondary members such as bracing.

Angles are typically available in ASTM A36 material.

Plates

Plates are a totally different member than the three-dimensional sections. They are great for building up a collection of plates to create the unique three dimensional object, or when used as a base or floor plate. Plates can be used alone as tension members not subject to compression.

Plates should generally not be used as beams or columns without compression flange bracing.

Hollow Sections

Hollow sections include pipes, round tubes, square tubes, and rectangular tubes. Hollow sections are much, much stronger and stiffer when twisted than any of the "open" section members, and they are better able to resist buckling. They are also strong when bent in either direction.

Tubes are often more expensive per pound of steel than open sections, whereas pipes are relatively cheap. Pipes have a rougher finish and larger tolerances than round tubes. Square and rectangular tubes in steel have rounded edges that can be of varying radii, even in the same cross-section. Aluminum tubes have either rounded or square corners.

Tubes and pipes are often more challenging than open sections when making bolted connections, since there is not a "plate" element readily available for making the attachment. Hollow sections are used when the benefits of their strength and stiffness in all directions are needed. Hollow sections often have thinner elements than comparable open sections, thereby offering weight savings.

Pipes are typically available in ASTM A53, which has a minimum yield stress of 35,000 psi. Round tubes come in a variety of materials with varying yield points, so pay careful attention to what may be available. Structural square and rectangular tubes include ⅛″ and thicker tubes, and is typically available in ASTM A500 Grade B, which has a minimum yield stress of 46,000 psi. Thin gauge square and rectangular tubing up to 11 gauge is considered mechanical tubing, and is typically available in ASTM A513 Grade 1010, which has a minimum yield stress of 32,000 psi; however, check with suppliers before assuming a grade.

Types of Loads

Dead Loads

Dead loads include the weight of all permanent components of a structure, including trusses, towers, decking, cladding, etc. Such loads can be calculated using the geometry and unit weights of the materials, or they can be weighed. Structural engineers who commonly work on buildings and bridges generally consider dead loads to be more predictable and accurate than other loads.

Live Loads

Live loads include all loads that are directly caused by the weight of occupants, equipment, and other items that can be moved or repositioned. Props, furniture, scenery, soft goods, speakers, lighting, machinery, and dimmer racks are all considered live load. Building Codes have tables of required minimum live loads that are derived from ASCE-7 "Minimum Design Loads for Buildings and Other Structures." Some common live loads are as follows:

- Stage floors: 150 psf (pounds/square feet)
- Public assembly platforms, movable seats, dance halls, bleachers: 100 psf
- Fixed seating areas, fastened to the floor: 60 psf (the seats are in addition to this load)
- Catwalks for maintenance access: 40 psf
- Residential: 40 psf

These live loads are uniform loads applied to the whole area or portions of the area that may produce the maximum effects. In reality, live loads are actually the combination of many concentrated loads that average out to a uniform live load. The intent of a live load rating for a floor is to have sufficient capacity to ensure that normal use with a collection of real loads will not overload the floor, thereby avoiding an engineering reanalysis every time a new load is added.

For some uses or when equipment or other items are particularly heavy, a specific analysis is needed to confirm the structural integrity of the floor.

The building codes allow exceptions to the required minimum live loads for uses that can be managed, as long as the reduced live load is stated on a sign that is permanently posted. For some specialized entertainment structures, the live loads are specified and managed in detail in order to get the most out of a structure. Such use requires proper documentation and controls.

Another important live load that often arises is for guardrails, which is 50 psf horizontal loading along the top of the rail, but not less than a concentrated load of 200lb.

Dynamic Loads

In general terms, dynamic loads include all loads that are directly caused by movements of objects. In the entertainment industry, dynamic loads are associated with intended motions, including controlled emergency stops. Dynamic loads include revolutions of a winch drum, hydraulic cylinder actuation, fall arrest forces, rolling of wheels, mechanical braking, swinging from a rope, and dancing.

The key to a rigger is that dynamic forces are essentially related to time. The shorter the time to change movement, the greater the dynamic effect, which is often expressed in “Gs” of acceleration. For example, a motion creating 2Gs of acceleration on a body results in a force equal to twice the person’s weight.

Mechanical brakes pose interesting challenges. In a typical design, it is desirable to have redundant brakes in the event of loss of one brake, and since you want either one of the brakes to be capable of holding the load, each must be sufficiently robust. Now that there are two brakes acting, there is more braking force, so the load stops more quickly, thereby increasing impact forces (“impact” refers to sudden stop). This situation is made more challenging when those brakes are on a performer flying rig, since you want to be able to reliably stop the performer, yet avoid injuring him/her during the stop.

Shock Loads

Shock loads are a type of dynamic load in which there is a sudden stop, often with a change of direction of the motion, which is typically unintended. Shock loads include chain hoist stops and category “0” uncontrolled stops (caused by the immediate removal of power to a machine causing brakes to fully engage suddenly).

Shock loads can be alleviated by incorporating features that increase the time to stop. Examples include the cushioning in a helmet and the shock absorbing fall protection lanyard. Bumpers in an automobile do the same thing.

Shock loads should not be taken lightly. If there are no components in a load path to decelerate a dropping weight, impact forces can be 20 to 50 (or more) times greater than the weight.

Environmental Loads

Theatres and arenas typically have walls and roofs that keep the environment from being a factor in rigging, with the exception of earthquakes. When you take away weather protection, weather can often be a governing loading condition and an important safety issue. Let’s look at several types of environmental loads.

Temperature Changes

Temperature changes will cause all materials to shrink or stretch as the temperature changes. Steel and concrete move about the same amount as one another (which explains why rebar does not routinely blow out of concrete). Aluminum moves about two times more for each degree of change.

For example, a 40′ long piece of steel subjected to 40°F temperature change will change ⅛″ in length if it is free to move; if the same member is aluminum, the change is ¼″. If it is not free to move, significant stresses can develop. Some structures will adjust shape to accommodate these changes if possible, such as an outdoor amphitheater roof.

Rain

Rain is always a potential load outdoors. The weight of water is related to the ability of a roof drain system to shed water. For the purposes of live event structures, the author generally recommends reserving 5 psf of capacity to handle rain and hail, assuming the roof is appropriately pitched to avoid ponding. Ponding is the situation where the roof deflects under the weight of water, so it collects more water and deflects more, until the roof collapses. Ponding is a serious hazard and must be avoided.

Snow and Ice

Snow and ice are obviously only concerns in cold weather locations and seasons. The design weight of snow as per building codes can depend on many factors, including elevation, terrain, geometry of the structure in relation to neighboring structures (sliding snow and snow drift), and local weather patterns. While snow and ice are not a concern in warm seasons, they can actually provide rigging load opportunities since roofs of permanent buildings are engineered for maximum snow loading conditions. As a result, a clever engineer can utilize the reserve capacity for snow load to allow larger roof rigging loads during warm weather, subject to local roof framing and connection limitations.

Sometimes snow removal operational procedures can be employed to take advantage of some roof snow load capacity, but this should only be done judiciously with realistic operational plans. Be very careful to avoid imbalanced loading that might result from snow removal, which in some situations can be worse than not removing any snow.

Earthquakes

Earthquakes occur without warning; the risk is generally based on probability in which the longer the life of the structure, the greater the probability that it will experience an earthquake. In many locations, earthquake loading is not required for short-term temporary structures. Notwithstanding, the author generally recommends some minimal lateral load to account for earthquakes, such as 2% to 5% of the dead load and attached live load (such as lighting equipment).

The probability of earthquakes occurring and possible magnitudes are dependent on location. Major seismic regions generally occur where there is tectonic activity, such as the US West Coast, Japan, and parts of central Asia. There are other moderate seismic areas worth noting, such as the parts of the Rocky Mountains, New Madrid Fault (central Mississippi River area), South Carolina, and parts of the US Northeast.

Earthquakes produce lateral and vertical motions that go back and forth in cycles, which can last from a second to over a minute. The forces in objects from earthquakes depend on the intensity of the earthquake and the mass (weight) of the object. Heavier objects generate more force. Top-heavy objects behave badly in an earthquake, whereas stocky elements behave well.

Earthquakes tend to impose ground-shaking cycles of a second or less (sometimes much less). Overhead rigged elements that are free to swing often will take a longer time to swing when subjected to seismic forces; for these elements, engineers often neglect the mass of these items when calculating seismic effects.

For live event structures, a rigger should be careful using ballast, which itself will be subjected to seismic forces.

Wind

Wind is the nemesis of all outdoor events. Wind often occurs with some warning, but weather prediction for a very specific location is not an exact science and depends on many variables. Wind loads are influenced by region, local geographic features, local construction, seasonal conditions, temperature changes, and even the geometry of the structure under consideration.

Closed structures such as buildings will attract a lot of lateral force due to the walls. In contrast, open structures with no side walls or partial side walls will have lower lateral forces, but they can have larger roof uplift forces. This means that the amount of ballast needed for an open stage roof structure may be more or less than if the same structure has wind walls all around.

Wind prediction has improved considerably in recent years, and there are many reliable weather information services to aid in forecasting. However, these cannot pinpoint with certainty the wind speed and timing at any site. Forecasting of hurricanes often comes with a day or more of quality warning. Forecasting of tornadoes will only predict the likelihood of them occurring. The same is generally true for summer thunderstorms. In desert locations, sudden microburst wind can occur without warning.

The building codes have complex formulations to determine design forces on structures that are affected by location, structure shape, height, openness, and even the number of people in the structure. Wind on local objects and edges of the structure can be more than on the overall structure. There is different wind pressure on the windward face compared with the leeward face. It gets complicated quickly.

To make matters trickier, wind speeds are reported differently depending on where and who is reporting. US codes calculate wind forces using three-second wind gust. European codes use ten-minute average, which is a lower number than the corresponding three-second gust. News services often report one-minute average speed.

The codes include a design wind speed as shown on a map for buildings and similar structures, from which design wind forces are determined. These forces are intended for permanent structures and represent a statistical probability of that force being exceeded in 50 or 100 years. For a temporary structure, there is a lower probability. For this reason, a reduced design wind speed is often used for temporary structures. How low should the wind be reduced? The probability of the reduced wind occurring in the short time frame should be the same as for the building subjected to its code wind forces in its design lifetime.

For temporary structures, not only is it rational to use a reduced wind speed, but the nature of the wind predictability and the structure itself can help mitigate risks. For example, since hurricanes can be forecast more than a day ahead of time, some temporary structures can be partially or fully dismantled to avoid damage in a hurricane. Some structures are designed to rapidly remove items that could catch a lot of wind, such as fabric wind walls.

Weather patterns may be changing more quickly than in the past, presumably due to global warming, which means that our industry needs to continue to be diligent in addressing weather issues. Improved planning for weather is necessary, including weather monitoring and action plans that get implemented when certain weather conditions arise or become a risk. Temporary live events differ from permanent structures in that you can take advantage of people involved in managing the temporary structures. Operational actions are effective for keeping these events safe, as long as they are planned in advance, confirmed that they work as intended, and then executed when needed.

Deflections

Deflections of structures can affect the appearance, feel, and usefulness of a structure. A staging platform that is very flexible may feel overly bouncy; rolling a stage wagon over this platform may be difficult.

In addition, excessive deflections could affect the structural integrity and stability of a structure. For example, an outdoor stage roof without guys may sway laterally a foot; in doing so, the roof weight now bears on a tower that bent into a slight “S” curve, thereby bending the tower. As a result, the tower shifts over a little bit more. It keeps going like this until the system either stabilizes or falls over.

The building codes provide deflection limits than can be useful for comparison with entertainment systems. (Deflection is compared with the beam span “L” between its supports.)

- Building floor live load: Maximum deflection = L/360
- Building floor total load: Maximum deflection = L/240
- Building roof live load: Maximum deflection = L/180
- Building beam supporting elements that can crack easily (brick, glass block): Maximum deflection = L/600

For some entertainment structures, these limits can be relaxed, but a deflection of more than L/100 is not advisable. In contract, where visual or machinery alignment is needed, more stringent deflection limits may be warranted.

Determinate and Indeterminate Structures

Determinate Structures

A determinate structure is a structure in which load distributions to supports are influenced by load and support locations alone. In terms of entertainment rigging, a determinate structure is a load system supported by multiple hoists in such a fashion that small moves of one hoist do not cause large load shifting to occur between hoists in the lifting system (Section 2.6 of ANSI E1.6-3-2012). A beam is determinate if it has two supports. A rigid curved or triangular truss arrangement is determinate if it has three supports.

Determinate structures are advantageous in that their reactions are very predictable and easy to calculate, they are easy to understand, and control of hoists is rarely a problem. Load shifting does not occur, so they are reliable for entertainment truss arrangements.

A popular opinion among entertainment riggers is that determinate structures are beneficial.

However, what happens if one support fails in a determinate structure? The assembly collapses. In this case, the problem is that a single point can cause system failure.

Indeterminate Structures

An indeterminate structure is a structure in which load distributions to supports are influenced by load and support locations, as well as by structure stiffness. In terms of entertainment rigging in this document, an indeterminate structure is a load system supported by multiple hoists in such a fashion that it is not practical to calculate with accuracy the dynamic load on any one of the hoists due to load shifting (Section 2.11 of ANSI E1.6-3-2012). The structure is indeterminate if a straight line can be drawn through all of the supports carrying the load system and if it is held by more than two supports. If a straight line cannot be drawn between all supports carrying a load system, the structure is indeterminate if it is held by more than three supports.

The main advantage of indeterminate structures is that they mitigate single-point failure concerns. In a critical structure, an important objective is to avoid structure failure or progressive collapse if any one of the structural elements fails. For example, when hanging a ring-shaped structure, it may be advantageous to use at least five hangers or hoists so that if any one fails, the system remains stable. Engineers will commonly design the remaining structural system to remain safe, possibly with lower safety factors. In earthquake design, the goal is to ensure redundancy in the structural system to protect against catastrophic collapse, maximizing the use of indeterminate structures.

Indeterminate structures can also be used to improve stiffness for a given member size and span.

Indeterminate structures require the involvement of a structural engineer in order to accurately determine member forces, deflections, and support reactions. Relatively stiff members and precise construction techniques allow a design to benefit from an indeterminate structure.

When a series of hoists lifts an indeterminate structure, the hoists will run at slightly different speeds with varying start-stop characteristics. This causes the flown structure to distort. A stiff structure will redistribute the loads via its own bending resistance, wreaking havoc with the loads to hoists. In the entertainment rigging industry, flexible aluminum trusses and pipe battens are often used to rig equipment. These flexible structures are very helpful in accommodating the significant inaccuracies resulting from the use of chain hoists, cable baskets and roundslings.

Sometimes this flexibility is also a potential problem. The author is often concerned about these flexible rigging trusses when they support tracking video screens. The loads on the trusses change as the screens travel, yet the screens want to appear to be level throughout travel. This would be a condition that deserves the use of load cells to verify maximum support reactions during the installation at each venue in order to ensure the system behaves safely.

In conclusion, determinate and indeterminate structures each have pros and cons. It is important to understand these when deciding the type of support arrangement for a structure.

Closing Comment

Anyone involved in technical aspects of entertainment can contribute significantly to structural safety and stability by improving awareness of structural behavior, without needing to do any math. These behaviors are open to all to see, and many of us have a great feel for such behaviors simply by having a lifetime of observing our world.

Such awareness will enrich and improve your experience in developing solutions to entertainment technical challenges, and help avert problems. It will also empower you to productively guide your structural engineering advisor.

Now that you are more aware of structural behavior, tap into this insight and use it!

3
Lighting Truss

TRAY ALLEN

The Creation of Truss

In the beginning, there were wooden and steel beams. Steel trusses were eventually designed and of course the Great Production Company of Old took smaller versions of these trusses and started to use them in shows. The people setting up the steel truss said it was heavy and no good. So someone at the Great Production Company of Old said "What about aluminum?" So they tried it and said, "This is good." This is a simplified explanation of what could be described as an explosion and the formation of an industry.

Lighting truss is an assembly of metal, aluminum, or composite materials formed in such a way as to maximize the distance supported (the span), then maximize the amount of weight that can be applied to that assembly (the load), and finally minimize the weight and size of the assembly. In America, the 1960s saw the British invasion, not only with rock 'n' roll but also with their touring gear. The truss was steel and the technology was borrowed from antenna towers. Weight capacity and deflection were not calculated and structural engineering was still off in the future. My earliest experience with truss was at Rock Creek Park in Washington, DC. That truss had a complete mechanical system to extend the truss over the stage area. The main purpose of the steel triangle truss was to hold a curtain to allow it to open and close by parting in the middle.

So why does everyone now use aluminum? Aluminum is the most common metal found on planet Earth. It is lightweight, yet very strong pound for pound. It maintains this strength when used in normal temperatures, from 0 to 120°F. Aluminum oxidizes easily to protect itself from the elements and is also relatively inexpensive. But there are some negatives to using aluminum: it conducts electricity, and it reacts readily to alkaline materials, concrete, steel, mercury, and bromine (just to name a few).

What is Truss?

Let's start to look at a truss structure as an additive structure. Start with a pipe, load it between two points until it scares you to walk under it, or until it fails (Figures 3.1 and 3.2).

What if we took two pipes and added some vertical pipes to help the pipe assembly support more weight? So we take two pipes and add other similar pipes (spreaders) between them (Figure 3.3).

Figure 3.1

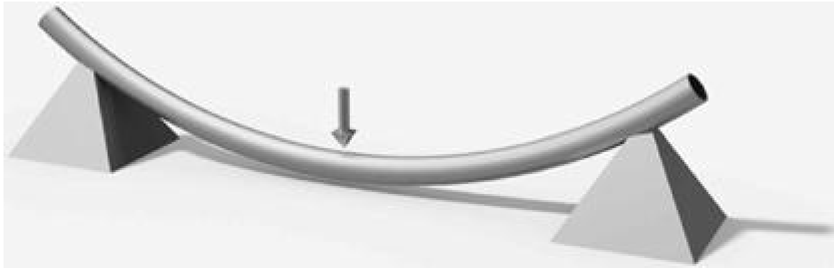


Figure 3.2

Figure 3.3

When we draw lines running through the system to represent forces we find a conundrum. These forces like to take the shortest path to the lifting or supporting device. These right angles are bad in structures. What can we do to improve this? Think Egyptian pyramids or the Eiffel Tower. Triangles are strong. To make truss stronger, add triangles aka diagonals (Figure 3.4).

This is a ladder beam or two dimensional truss. This ladder behaves kind of like a 4′ × 8′ sheet of plywood—when you are holding it vertically it is strong but when you hold it horizontally it starts to bow or deflect. If we were to add a second sheet of plywood with some 2′ × 4′s around the perimeter and through the center we would start to stiffen the structure. The same thing is truss if you add a second ladder beam and place some more spreaders in the top and bottom plane—then you have the start of a three-dimensional truss (Figure 3.5).

Just add end plates and you come up with most of the truss in use today (Figure 3.6).

Figure 3.4

Figure 3.5

Figure 3.6

Figure 3.7

To advance the truss design further, and increase the structural capacity, you need a connection inline with the main members or chords—forks, or eggs (Figure 3.7).

That covers the design of the simple box truss. But truss comes in many forms: ladder (Figure 3.8), two mains with rungs or diagonals, triangle (Figure 3.9), square (Figure 3.10), trapezoid (Figure 3.11), hex (Figure 3.12), octagonal (Figure 3.13), even round (Figure 3.14).

Most manufacturers of truss have around 20 different box truss designs and seven or so triangle truss designs. The reason for this is simple—the customer has created the demand. "I need an inexpensive truss that will span 20′ and support 400lb of weight at the center of the span. What are my options?" The request for these options that come from various constraints given by the customers forces the manufacturers to come up with all these different varieties. I would not want to hang a section of 36″ tall by 36″ wide truss from a low 12′tall ballroom ceiling. The 12″ tall by 12″ wide truss would be much more appropriate. Then you have the need to hang 5,000lb under an existing scoreboard in an arena and the two rigging points I have are 60′ apart. Most 12″ × 12″ truss maximum spans are limited to 40′ or less with a load capacity far less than 5,000lb. The 36″ × 36″ truss might be the truss of choice if it has 3″ main chords and a load capacity to match the requirements. When calling the manufacturer you will need to know the following: size and type of truss used, length of truss between the hanging points, actual weight of "whatever it is you have hanging from the truss," and where the "whatever it is you have hanging from the truss" is actually hanging on the truss. Take special care not to forget the details of where a lighting cable bundle is making its downhill run from the truss to the dimmers or devices that may be dropping, or moving curtains, or other items that you have attached to the truss.

Figure 3.8

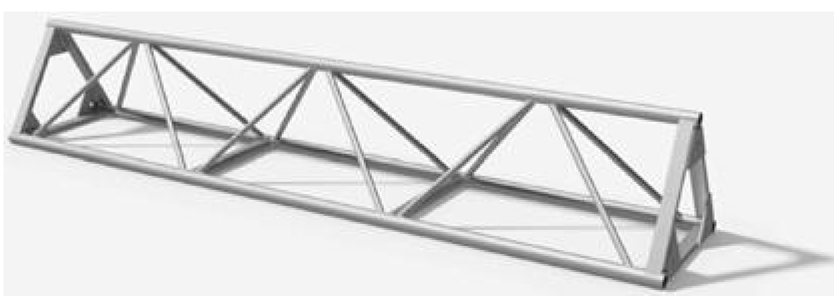


Figure 3.9

Figure 3.10

Figure 3.11

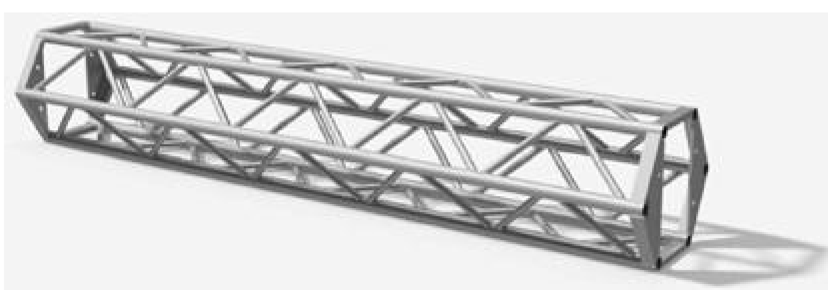


Figure 3.12

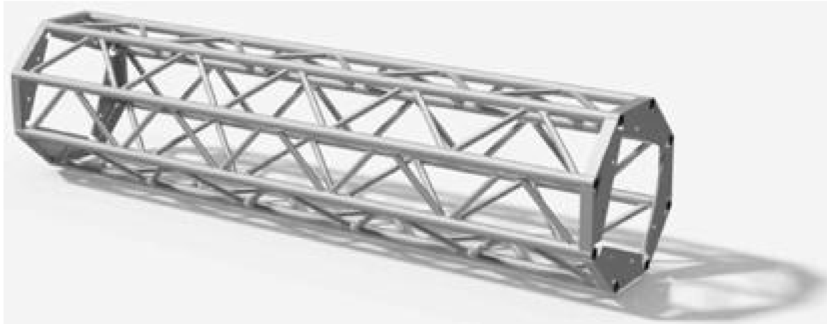


Figure 3.13

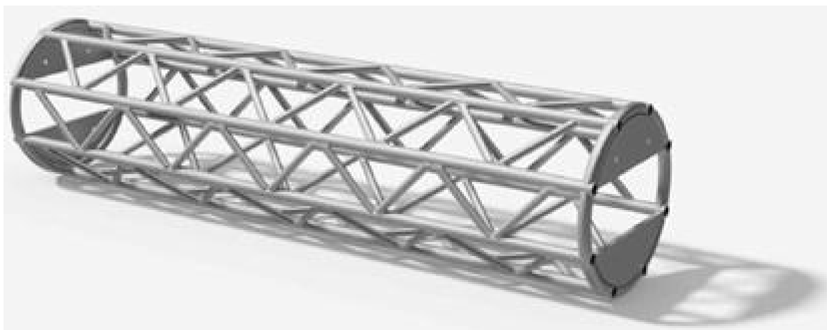


Figure 3.14

What is the best truss to use? The short answer is the truss that best fits your needs of span and loading. Why do people buy box truss over other trusses? Box truss is like the multipurpose tool of the industry—it does a lot of things well but it does not specialize or have a thing that makes it outstanding.

What is the advantage of a triangle truss over a box truss and vice versa? A triangle truss is great for hanging a curtain or a single run of lighting fixtures. But it does not have the same strength as a box truss does over the same length. Box truss is stronger but this truss has a problem if you do not balance the load on both sets of bottom chords. Box truss tends to try and form a diamond shape if those loads are not balanced. The heavy portion of the load is on the lower set of the bottom chords of the diamond. You can correct this by hanging lighting fixtures or even ballast on the higher bottom chords. Even this diamond shape might be allowable if you consult with the manufacturer.

Making the Truss

In project design you have the triple constraint triangle with cost, scope, and schedule at the three points of the triangle and quality in the center. In truss design, the triple constraint triangle would include weight of the material, strength of the material, and quality of the material. The quality of the aluminum and thickness of the aluminum must be balanced with weight minimization. If you decrease any of these three points too much you will find that your quality (the stuff at the center) has dropped out of sight.

Figure 3.15 shows the typical bolted truss and all the members that make this truss.

The primary material in the American-made entertainment truss business is aluminum 6061-T6. The Aluminum Association describes 6061-T6 as “a system of four-digit numerical designations is used to identify wrought aluminum and wrought aluminum alloys. The 6XXX series refers to the content of magnesium and silicon present in the alloy. The last two digits identify the aluminum alloy or indicate the aluminum purity.” The T6 nomenclature means the aluminum is solution heat-treated and then artificially aged. The original truss from the UK was mostly 6082-T6. While the 6082 has better machinability and base properties than 6061, most manufacturers now go for a higher quality 6061, which has a better yield and percentage of elongation. Yield is the point at which the material begins to deform plastically. Percentage elongation is the specific amount of stretch that a pipe or tube will tolerate before it fails.

The aluminum shapes used are pipes or tubes. When it comes to selecting the strongest tube, the thicker the area occupied by the aluminum, the stronger it will be. The tube could be solid aluminum, but that would be a lot of additional weight. The designer of truss tries to find the right strength-to-weight ratio.

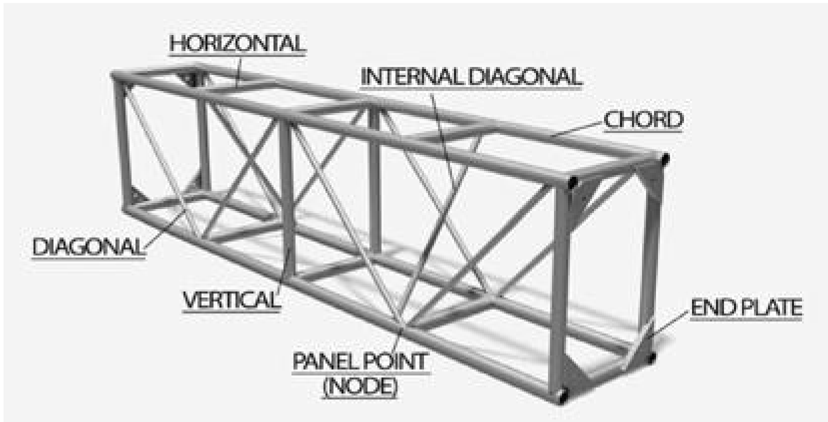


Figure 3.15

All of this tubing gets connected with two basic types of welding: TIG and MIG. TIG (Tungsten Inert Gas) is better known in the welding world as GTAW (Gas Tungsten Arc Welding). MIG (Metal Inert Gas) is better known in the welding world as GMAW (Gas Metal Arc Welding). TIG is used for holding the diagonals and other large members together. MIG is used to attach end plates to the truss and generally filling larger gaps. MIG is a faster process, but generally requires cleaning of the welded area after the fact. Currently, hybrid welds are being used with and without robotic welding. The hybrid gives the speed of MIG welding with the look and finish of the TIG welding. Even better than that, some of the welds are starting to rival that of the Friction Stir method of welding. The Friction Stir method uses great pressure and speed to mix the materials together to where the finished process has a molecular structure better than the base materials. The Friction Stir method is generally used for joining plates of aluminum together. This method has a long way to go before it breaks into the world of aluminum truss. The bad news about welding (except for the Friction Stir method) is that it weakens the strength of the base materials. Currently, for 6061-T6 weld-affected regions, the Aluminum Design Code 2010 has an allowable tension stress of 9.1ksi. This represents a 27.2% reduction from Aluminum Design Code in 2005 that had an allowable tension stress of 12.5ksi (ksi is a measure of 1,000lb per square inch). This is important to know when looking at standards, engineering, and tables from different manufacturers. When was this engineering done for the truss?

And what do you do when you want something different than the gray industrial look? Powder-coating is a process in which the powder is electrostatically charged, then the powder is sprayed on to the grounded truss, then the truss baked. This is probably the best method for changing the color of your truss. There is a limit to the number of times you can powder-coat the truss. Anodizing is a chemical and electrical etching process that changes the color of the truss, but it does have some drawbacks. There is a problem keeping the color the same throughout the piece since the welds are a different alloy. Also, during the welding process holes are drilled to allow heated gases to escape to keep from blowing the weld back out of the joint. So anodizing may result in salt wandering around in the tubes or, even worse, the salt acid combination leaking out, causing grey and white streaks on the finished product.

Towers

What led to the development of tower truss? Production companies started using the truss as a tower. In some limited cases this worked OK. However, as the engineers started to look into it, they made some vital and necessary changes. First, if we take some of the same truss sections and add more diagonals and cross-members to the section then we can then use this truss vertically. By adding internal cross-braces we help keep the truss in its box shape.

Next, if we increase the size of the main chords then these towers can support some substantial loads. (Example 12″ × 12″ towers 30′ tall supporting two tons of weight.) If we change those main chords to a 3″ diameter chord with a ¼″ wall thickness we can build towers to heights of at ranging up to 80″ supporting around 20,000lb. When towers are used outdoors they need guy wires, ballast and/or earth anchors. Ballast is generally in the form of concrete barriers. If you are attaching guy wires to these barriers they will need to be kept from sliding across the ground. As you get the barriers closer to the tower the amount and weight of the barriers will need to increase. When I use the term "earth anchors" I am not referring to tent stakes (a long solid cylinder of steel with a point at the end). I am referring to a system that is driven, pushed, or screwed into the ground. Tent stakes might keep something like a concrete barrier from sliding but they are not a solution to guying (attaching a guy wire) to a tower. These tent stakes can become ineffective if the condition of the ground changes. When it rains and is windy is a perfect example of this condition. The mainstay for outdoor use is solid ground, a solid base design, and attention to the weather when using towers. Don't forget that aluminum conducts electricity, so use proper grounding techniques if outdoors where lightning might occur. Also, keep in mind the location of power lines and other obstacles at height when erecting towers.

When indoors or even in a stadium it might give the illusion of safety and the temptation to not use guy wires or ballast will be great. Do not give in or make this mistake, if you are indoors, make sure it is not subject to the open loading door where the wind blows in and knocks your towers down. That said, the popular sizes of towers start at a cross section of 12″ × 120, 15″ × 15″, 16″ × 16″, 20.5″ × 20.5″ and move up from there. Tower heights vary they start at 20′ and move up to around 80′ tall. The soil and base detail constraints are significantly different between these heights of towers and there weight capacities. The 80′ tower will probably require a footer detail composed of concrete and rebar and a base of solid steel or aluminum to match. The 20′ to 50′ towers may require only one to four sets of guy wires per tower (depending upon the configuration). Towers taller than 50′ may require up to eight guy wires with four of these being a mid-set of guy wires. When planning to set up towers, make sure you know who the authority with jurisdiction is in the area you plan on using these towers. Engineering reports, permits, soil engineering, and other items may be required.

Setting Standards

When the rigging working group was formed back in the late 1990s under what was known as the ESTA (Entertainment Standards and Technical Association), the first two issues that were pushed to the forefront were a wire rope ladder standard and the need for truss standards. So the battle over trying to come up with consistency, and making an effort to bring sense out of the chaos of loading figures, safety factors, and design factor began. The main battle cries of 5 to 1 design factors, 10 to 1 design factors, 300%, and 500% still ring in my ears. A factor of design, or a design ratio, is how many times the maximum allowable load the manufacturer expects will be bearable before the structure will fail or become unsafe or unusable.

This factor is sometimes given as a percentage; i.e., 300% means the design should hold three times the recommended load. At least that's what the term *should* mean. But then you start digging into what the manufacturers and engineers really meant by these numbers. Given a choice you would go for a piece with a 500% rating over a piece with a 300% rating, right? But one manufacturer's 300% rating might have meant you would have a structure with a permanent smile or bow in it if you loaded it to three times its recommended weight. The permanent smile or bow means you have permanent deflection. The permanent deflection means that you have probably turned this truss into a recycler's dream. The other manufacturer's 500% rating might have meant that would be the point where you needed to call the recycling company. The main point of this section is that if you have these figures dancing around, make sure you know what they mean.

Several ratios are used by engineers to give these loading figures a margin of safety: deflection shall not be greater than the length of span of the truss measured in inches divided by 160. What does that mean? Well, let's crank some numbers into the equation using a 40′ span of truss: 40′ is equal to 4800 So the measured deflection at the center should be no more than 480/160 = 3″.

This is fairly easy to check and does not require anything more than a calculator and tape measure. Say we have a uniformly distributed load on a 40′ span of truss. The end chords of the truss are both at 36″ off the floor. When we measure the center of the truss we find it is 32″ off the ground. Is this truss okay? No, that is a deflection of 4″ and it is higher than the ratio given. What should you do? Hang more points? Bridle the points? Remove weight from the truss? Correct answer: d) all of the above, or a combination of the above until you get the deflection to 3″ or less.

More recently we have added the repetitive use of the truss into consideration. For example, a truss may be rented from your local production company for a show, which means that truss will be considered as being used repetitively.

The loading from this truss will be multiplied by a factor of 0.85. If the truss catalog sheet says 1,000lb uniformly distributed load, this will be reduced to a load of 850lb. The loading will be 1,000lb uniformly distributed load if that same truss is purchased from the manufacturer and permanently installed in a building.

I get asked the following questions a lot: What can we do to protect our truss? What causes damage to truss? Surprisingly, the most common damage is not the overloading of truss but the old theatrical c-clamp. When this clamp is used without a piece of PVC tube to protect the aluminum, a ½″ gouge is generally formed by the screw. This damage is then aggravated by a lighting designer that says "I need you to lift that whole fixture up when you focus it." This action starts to saw the main chords in half. To solve this damaging practice, use a half coupler or triggered coupler to locate lighting fixtures or other devices to the truss.

What else damages truss? Forklifts bending or chewing the internal diagonals or the diagonals in the side of the truss are probably the second largest cause of damage. Use care when using a forklift to pick up and place truss. Take care of the truss and it will take care of you. The third cause is allowing someone to drag the truss across the floor by one end. The solution to this problem is always use two people to pick up the truss sections. Invest in truss dollies to help move the truss around. Next is improper rigging from the truss using slings to hold another load underneath the truss without anything like a pipe or tube either in the truss or attached with swivel couplers to keep the sides of the truss from being pulled in towards each other.

Finally, the truss loaded into the truck improperly, allowing objects to rub against the truss or smash into the truss. All of these cause more damage than overloading of the truss.

To prevent the overloading of the truss: follow the loading tables, take a class on rigging, hire professional riggers.

Hanging or Suspending the Truss

How do we get this truss into the air? We use two slings of the appropriate length; from both sides of the truss we choke the bottom chords wrapping the top chords forming a triangle at the top, placing the loose loop of the sling into a shackle. This is done at panel or node points where two or more structural pieces meet. These panel points keep the slings from sliding.

Follow the manufacturer's guidelines when suspending truss from the top or bottom chords. For the bottom chords: choke the bottom chords at a panel point on either side of the truss forming a triangle and attach a shackle at the peak of this triangle.

For the top chords: choke the top chords at a panel point on either side of the truss forming a triangle and attach a shackle at the peak of this triangle. Use the chart below to help you determine the appropriate sling length for the angle to be less than 30 degrees. Notice how the force versus the angle of the sling changes.

Yes, it is possible to pull the top or bottom chords towards each other if you do not keep this in mind.

Picking up a box grid of truss from the bottom chords is not a problem for the center of gravity. Picking up a single span of truss from the bottom chords is not recommended due to it moving the center of gravity of the load, thereby making the load unstable.

You could use a lifting point a device designed to connect both top or bottom chords of the truss and attach to the lifting device. Most lifting points are designed for use on either two top chords or the two bottom chords of a truss span. If you were in a box grid, four trusses connected with corner blocks attaching lifting points to the two bottom chords is possible and good practice. On a single span of truss, however, if you locate the lifting points on the bottom chords you will have a truss trying to do a balancing act. You have moved into a less stable lifting system. Do you move the lifting points to the top chords? Always follow both the truss and lifting point manufacturer's guidelines when you use them.

Innovations in Design

In the 1970s, truss spot operators began being flown from trusses. In the 1980s, moving lights started coming. The first moving lights were huge and placed a moment back into the truss that caused an interesting ride for some of the truss spot operators. A moment would be like a pendulum swinging on the truss, causing it to move in a circular motion or back and forth depending on the lighting cues. And with the addition of these lights came more cables. Control cables to move the fixture around, make the light coming out of it change color, move patterns in and out, change focus, and even rotate the patterns.

To explain my love-hate relationship with cables, let me go back a little bit (cue the dream sequence …). The rig I cut my teeth on was 120K pars in Pre-Rigged Truss (PRT), 91″ long, 26″ tall, and 30″ wide. The front of house truss: five sections of PRT with ten Socapex 19-pin connector cables in various lengths taped together in a bundle powering the ten lighting bars, each with six parcans. That meant 6″ parcans, each with 1,000-watt lamps. The cables we used were only 1.5mm, or 16awg/18-conductor cable. This cable would generally swag to the rear truss. The rear truss was also five sections of PRT with its own bundle of ten cables. These cables would drop to the dimmers located either upstage left or upstage right depending on where the main power feed was located. I apologize now for my carbon footprint. But back to moving lights, each cable added more and more weight. For a time, I figured with more moving lights the parcans would completely go away. Nope, the rigs just got heavier with a combined weight of moving lights and pars.

Why the size and the width and depth? The pars were on 15″ centers, so when you do the math the lighting bar length worked out to be 900. The 91″ truss allowed you to contain 90″ lighting bars without bumping into each other.

Another clever development for the lighting truss was the octagonal color frame. This allowed for a tighter focus between instruments than you could have with a square color frame while still making it possible to cut gels into shape with a paper cutter. Has anyone else cut themselves with a razor knife while trying to cut gels for a followspot? Octagonal was a glorious innovation. This frame allows 12 lighting fixtures that are in this pre-rig truss to be focused in many different areas across a stage.

The next innovation in the world of the lighting truss was the LED. The first versions of these looked like a million tiny indicator lights such as the kind you find in a science fiction movie from the 1970s. The first fixtures to use LEDs were box-like contraptions, or simply a par can that had the LEDs shoved in them to replace the lamp. As these fixtures progressed, they became brighter and heavier and developed a fan noise like their moving light kin. But they needed a lot less power: 90–300 watts with similar or greater output than the 1,000-watt pars. This innovation may finally be the death of the parcan. The interesting thing is that now the rigs with the LEDs use less power, but they weigh more than the parcan rigs. And now there are moving LEDs, so they have gained even more weight.

It’s a bird! It’s a plane! No, it’s a video wall! With the move for image magnification came various attempts at masking and using projectors outdoors or in brightly lit convention centers. That worked OK, but to really make a statement you needed huge walls of video monitors to show how important you were. Somewhere back in the 1980s we had a tube-type video display. We commonly called these video walls. Now the LEDs are multicolored and allow resolution limited only by the client’s wallet. The current ones are not as heavy as their cathode ray tube (CRT) predecessors, but they occupy huge spaces across the truss. This brings a new set of problems: how do you hang them, and where do you hang them? A bumper or interface from the truss to the LED wall is generally provided. Why some people that own the walls and the bumpers still don’t know how much these things weigh is one of the great mysteries of life similar to whether the light in the refrigerator stays on when the door is closed. I have had numerous phone calls similar to the following:

> The truss seems to be deflecting or smiling a lot.
>
> Really, what is hanging from the truss?
>
> Well, we have this video wall hanging from five hoists.
>
> OK, what kind of hoists?
>
> One ton or two ton. Hang on and let me ask the rigger … He says they are two ton.
>
> Really, so are you saying to me that you are hanging ten tons or around 20,000lb. from this single truss?
>
> No, the touring group’s rider said that it was only 5,000lb.

Before you hang it know how much it weighs. We will all sleep better.

The Future of Truss

So, what is the future of lighting truss? What material will it be made of? Will it continue to be aluminum, or maybe carbon fiber?

Bolted truss connections appear to be here to stay despite the better loading efficiency of a spigot, forked connection, dual forked connection, or the egg connection. In the future will we just have five connections to make? Four of these connections would be the actual chords themselves, and the fifth connection would be a ring circuit connection for the electricity. The control for all our other lights, gadgets, and even the motors would either be wireless or would be controlled by a signal sent down the hot leg of the power input. Is it possible for five simple connections per truss to become reality?

The appropriate question is: when will the next quantum leap in truss design occur? Will it come from new materials or from new customer needs? Whatever it is and whenever it happens, I hope to be around to see it and I hope the end users will say “This is good.”

Sources and Credits

ANSI E1.2-2012 Entertainment Technology Design, Manufacture and Use of Aluminum Trusses and Tower.

Chart: Safetysling.com.

Drawings: Angel Hicks and Isaac Cogdill with James Thomas Engineering, Inc.

The Aluminum Design Code 2010.

4
Arena Rigging

ROY BICKEL

Introduction

While it's a bit difficult to pinpoint exactly when arena rigging began, it's a pretty safe bet it started with the touring ice shows somewhere in the early to mid-1960s. By today's standards, the methods used at the time were pretty crude. There was very little truss. Most of the hanging pieces were made of steel pipe and the methods used to hang the pipe, block and tackle, as well as manual chain falls were cumbersome at best. As rock 'n' roll shows became more sophisticated, their crews took this technology and began adapting it for their own use. Instead of block and tackle they started using electric chain hoists. Rudimentary truss replaced pipe to hang lighting and sound equipment. Almost overnight, it seemed, an industry was born.

In those early days the chain hoists were attached directly to the roof beams. This meant that the hoists didn't move and their chains ran up and down. The biggest problem with this arrangement was the hoist weighed at least 130lb and it was no fun to haul 80′ or 90′ in the air. The other problem was controlling the chain, which was gathered into a bucket up at the hoist. If there was a problem with the chain—and there usually was—then it was up at the ceiling and very hard to reach. The solution to both problems was to turn the hoist upside-down. This meant that the hook end of the chain was raised to the building steel and the hoist was at the floor where it was free to ride up and down on the chain. This solved both the hauling problem and most of the chain issues.

It's been pretty much that way ever since. This is not to say that there have been no technological advances in arena rigging; there have, but the fundamental way we hang a show remains surprisingly the same. The big differences between then and now lie in the size and complexity of the shows. But to understand these differences we should first look at the basics.

The Equipment

A chain hoist is an electrically operated material handling device that is designed to raise and lower objects. It's a not terribly sophisticated machine that, at least in the basic models, has very few bells and whistles. Standard chain hoists* come in load ratings ranging from ⅛-ton to 3-ton. Larger capacity hoists are available but seldom used in the entertainment industry. How high a hoist can lift an object depends on the make and model of the hoist, the amount of travel between the upper and lower limit switches, and other factors inside the hoist, but it is usually around 130′.

Figure 4.1 Electric chain hoist

The hoist has a hook at the end of the load chain to connect to the building steel and one on the bottom of its housing to connect to the load being lifted. A chain bag is hung from the hoist to collect the chain as it passes through the hoist.

The hoist load chain is most often attached to the building steel by means of a wire rope sling and screw-pin anchor shackles. The sling is typically wrapped over the steel beam leaving both ends of the sling hanging below the beam. When used in this manner, the wire rope sling is called a basket.

Sometimes, when the building is particularly high and the trim height of the hoist is relatively low, a wire rope sling called a stinger or downtail is placed between the basket and the chain hook. This is done to reduce the amount of chain weight the rigger has to pull.

Figure 4.2 Roundsling with synthetic core

The load rating of the hoist will determine what size wire rope and shackles to use. For all sizes up to and including 1-ton, a ⅜″ diameter wire rope sling and ⅝″ diameter shackles are used. For 2-ton loads we typically use a ½″ diameter wire rope sling and ¾″ diameter shackles, while 3-ton and higher rigs are custom-designed to meet the specifics of the situation.

The connection of the hoist to the load is normally accomplished with a roundsling. These slings come in two varieties: synthetic core and wire rope core.

The synthetic core sling is made of 100% polyester. The core has filament polyester laid in a circle, creating many loops of the fiber. Polyester is then woven into a shell that fits over the core and protects the core from damage. In the commercial world, the color of the shell identifies its load rating. Not so in the entertainment industry, where the shell color is usually black. For us the load rating is on the label, both in the printed information found there and in the color of the label. A green-rated roundsling is typically used for a 1-ton or smaller rig. Yellow is used for 2-ton.

The wire rope core roundsling is a relatively recent development. It came about when fire marshals began expressing a concern about the relatively low melting point of the polyester in a synthetic sling. (A polyester sling will begin to suffer permanent damage at approximately 200° F.) To resolve this problem, one of the roundsling manufacturers came up with a roundsling made of wire rope. They replaced the polyester core with two lengths of 1⁄16" diameter wire rope that are long enough to create approximately 50 loops. The core was then encased in a polyester cover to hold everything together. The result is a roundsling that is just about as flexible as a synthetic roundsling and has a load rating equal to that of a green polyester roundsling. The label comes with a Velcro attachment that allows you to open the sling without damaging it to show the fire marshal the steel wire rope inside.

Figure 4.3
(a) Roundsling with wire rope core;
(b) Wire rope core exposed

The roundsling, regardless of what core material is used, is then connected to the hoist with the ubiquitous screw-pin anchor shackle.

Figure 4.4 Screw-pin anchor shackle

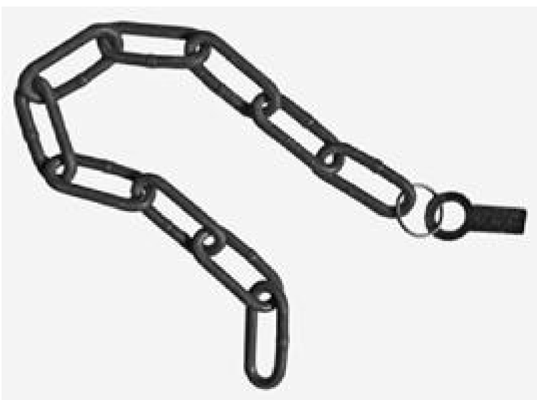


Figure 4.5 Long link (STAC) chain

Figure 4.6 (a) Oval ring; (b) Pear ring

Long link chain, sometimes referred to by its brand name STAC, is often used in a hanging point to allow for more precise positioning of the downtail.

There are other hardware devices that are used in this assembly, all of which are used to connect slings and shackles in a hanging point. The most common of these devices are oval and pear rings.

The Riggers

When hanging a show, the most important component are the riggers. Their job requires that they be keenly focused on their work, making sure everything is in order at all times. Failure on their part to properly complete their work can have serious consequences for everyone involved in the show. One need only look at the photos of rig collapses over the past 20 years to get a clear understanding of how serious this work is.

The up-rigger or high-steel rigger has a singular and very specific job to do. They must connect the hanging hardware to the building in such a manner as to ensure that a) it's in the right location, b) it won't fall down, and c) it can be safely removed once the show is over. The fact that this work is usually done 100′ in the air while sitting on a 12″ wide I-beam makes it that much more fun. To be an up-rigger requires steady hands and a patient demeanor. Hurrying through a job may cause something to go wrong; a shackle gets turned the wrong way or, worse yet, a shackle pin could be dropped. Good up-riggers understand that a steady pace and a religious attention to detail make for a safe and fun work day.

The down-rigger, or ground-rigger as they are also called, is responsible for just about everything else. It's their job to make sure the hanging hardware (the "point") has been built properly on the deck before the up-rigger pulls it up to the I-beam. It's also their job to make sure the chain hoist has been set up properly: the chain is running freely through the hoist and the chain bag has been attached to the hoist in the correctly. The down-rigger is also in charge of attaching the load to the hoist.

One recurring problem worth mentioning at this point is chain running out of the chain bag. It happens fairly frequently and is a serious problem. Imagine the damage the end of a ¼″ diameter chain can do as it comes whipping down from 70′ in the air. It will take a chunk out of the floor or your shoulder. It will level a drum kit with wanton abandon. It's the ground-rigger's job to make sure the chain stays in the bag. Chain runs out of the bag for several reasons. First, you need to use the right size bag. A bag that's designed to hold 60′ of ½-ton chain will not hold 75′ of 1-ton chain. While it's not very common, it would be a big help if the chain bags were all color-coded. That would make it easier to match the right size bag with the chain length and hoist capacity. The other cause of chain running out is that the chain isn't seated in the bag properly. When the hoist is floating just off the deck and the rig is set to be raised up to its trim height, the load chain hanging below the hoist should be inside the bag and touching the bottom of that bag. Or, at the very least, it should be hanging two-thirds of the way down into the bag. The weight of the chain will then help keep the chain in the bag when the hoists start up. If the chain isn't far enough into the bag at the beginning, raise the rig only 2′ and stop. Then check all of the bags in the rig to make sure the chain is running properly into the bag. This only takes a few extra minutes. This might annoy those who are worrying about the schedule, but it takes less time to check chain bags then it does to lower the rig to refill a bag.

Ground-riggers don't get much credit but they're the ones who do the lion's share of the work and can make or break a load-in.

Now that we've identified who is doing the work and what they have to work with, we should take a look at how they do it.

The Action

Before any actual rigging starts, the floor must first be marked to show where all the hoists are supposed to go. If it's a touring production then this is usually the job for the venue head rigger and the road rigger. They will measure out the venue and either use chalk to mark the floor or large printed stickers to show where the rigging points are located. The markings not only tell the ground-rigger where to put the hanging point but also what hardware to use when making the hanging point. For example, Figure 4.7 tells the ground-rigger that they are supposed to make up a deadhang (vertical) point that, starting from the top, has a 5′ basket, a 20′ downtail and uses a ½-ton hoist. The C3 refers to the control channel that's been assigned to it.

How the rigging point is made up on the floor is critical to ensuring it is attached properly and safely on the overhead steel. Figure 4.8 shows the proper location of the basket, work and load shackles, downtail and the rope that is used to pull the point up to the steel. The burlap in the eye of the basket is used to pad the beam and protect the basket from damage.

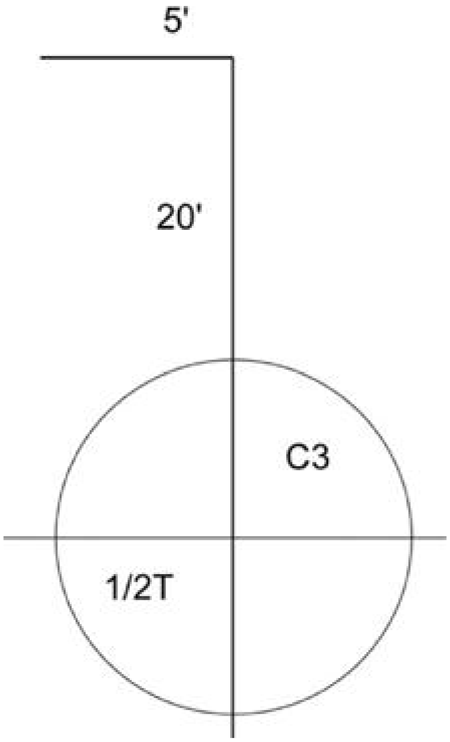


Figure 4.7

Figure 4.8

The up-rigger, once they've pulled the hanging point hardware up to the beam, must now go about the business of attaching it to the beam. The steps involved typically look like this:

1 Place the burlap on the beam
2 Lay the basket over the beam on top of the burlap.

3 Take the pin out of the work shackle, connect the work shackle to the loose end of the basket, and put the pin back in to the work shackle.

4 Lower the point until the basket is taking weight around the beam.

5 Make sure all shackles, basket sling eyes, and any other hardware involved in this point are hanging straight. A shackle that is twisted, for example, will become a problem when the rig is loaded and could cause a failure.

Once the point has been put into place it should look like Figure 4.9.

Sometimes a basket is not possible. It may be that the location of the hanging point is critical and the beam flange too wide to use a basket and still have the point hanging in the right location. In this case a choke point is used. A choke point has only one vertical leg that runs down the side of the beam. Care must be taken when using a choke point because there's only one vertical leg and so the capacity of the choke is determined by the diameter of the wire rope sling and the damage created by the beam around which the sling is wrapped. It's also important to remember that a choke point can twist a beam if that beam doesn't have the proper lateral support.

Figure 4.9

The hardware in a choke point is basically the same except the work shackle is used not to connect the two ends of the basket but to connect one end of the basket to an in-line spot on the other side of the basket. When making up a choke point it's important to make sure the vertical leg isn't deflected or pulled over by the work shackle. If this does happen, the in-line spot on the basket leg will take a significant side load that can cause significant damage to the wire rope.

Then there are those times when the building refuses to cooperate. As you stand on the arena flooring marking out the points you look up and realize that for many of the points you just marked out there's no steel directly overhead. A normal deadhang won't work and so a different way of making the point needs to be found. This is where a bridle is used.

A bridle is an assembly of rigging hardware very similar to a deadhang but instead of having a vertical leg, it has two or more legs at the tip that form a Y shape. Figure 4.11 shows a bridle as it's drawn on the floor for the ground rigger to assemble. The assembly has a 5′ basket and a 20′ sling on each leg.

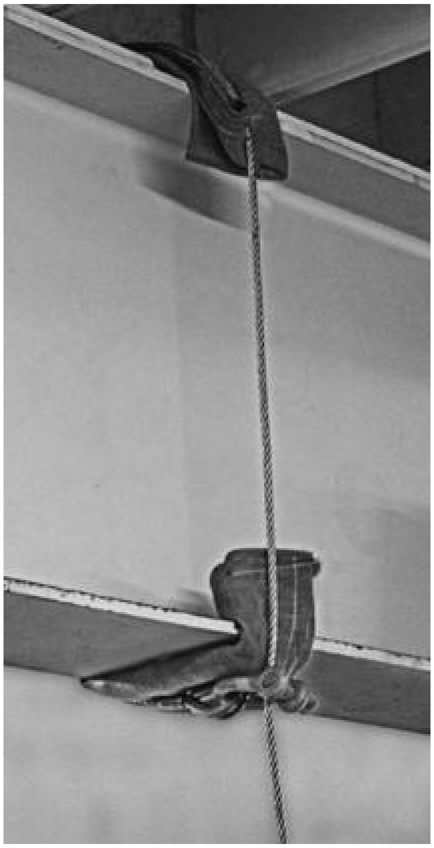


Figure 4.10 Choke style point

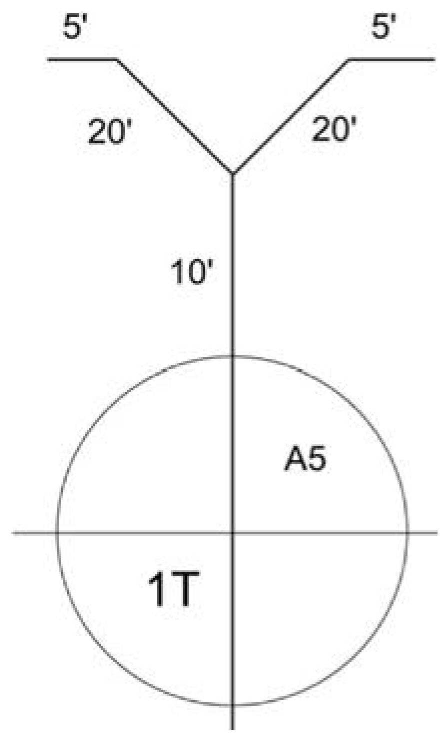


Figure 4.11 Bridle diagram

The purpose of the bridle is to connect the hanging point to the nearest available rigging beam and place the hanging point in the right location. To do this, the length of the bridle legs is adjusted until the point falls where you want it.

Let's assume that the distance between rigging steel overhead is 40′. The point you want to hang needs to be located midway between two rigging beams or, to put it another way, 20′ away from any rigging steel. To achieve this, each bridle leg should be approximately equal. The exact length of the bridle is determined by not only the distance between the rigging beams but also the height of the beam and the height of the junction of the bridle legs. To sort this out mathematically you should check out Rocky's chapter in this book (Chapter 1).

You may be asking yourself at this point, why do we rig this way? Why do we wrap wire rope around I-beams with only a bit of burlap padding? The answer is, because it works. The reason it works is because of the size and load rating of the components of a hanging point relative to the loads applied to the hanging point. For example, a 1-ton hanging point uses a ⅜″ diameter wire rope sling for the basket. That sling has, in a vertical "pull-to pull" application, a working load limit (WLL) of 1.2 tons. When used as a basket, however, each leg of the sling hangs over the beam, one on each side. Used in this way, each leg will have a WLL of 1.2 tons resulting in a WLL of the basket assembly at 2.4 tons. Considering that we would only ever use a ⅜″ diameter basket for a 1-ton point, there is ample capacity in the configuration to compensate for the abuse the wire rope receives when wrapped around the edges of an I-beam. (The burlap padding does help a bit, but not nearly as much as some people hope.)

A 2-ton point has the same geometry but with ½″ diameter wire rope. The ½″ diameter wire rope sling has a WLL of 2.5, so the basket rating is 5 tons.

When asked why they rig this way, most people respond with "this is the way we've always done it." While true, the reality is that we've rigged this way because the equipment has load capacities considerably higher than the loads they carry. This provides a generally acceptable margin of safety when lifting and moving loads over people's heads. But that margin is shrinking.

There was a time when all chain hoists were simple and uncomplicated. They ran at a single speed, had pushbutton controllers and moved pretty slowly. We used them to lift lighting truss and audio gear into position and hold them there. Little, if anything, moved during the show and the hoists weren't used again until the show was over. A 50–75 hoist show was considered a big show. Well, those days are long gone. Modern day fixed speed hoists run at speeds ranging from 16fpm up to 64fpm. Variable speed hoists may run up to 100fpm. A 200-hoist show is not uncommon. Hoists are no longer used to simply raise equipment into position and hold it there. They now move scenery, lights, video wall—pretty much anything you can imagine—on cue, during the show. Performers are sometimes flown on chain hoists, much to the dismay of the hoist manufacturers. Shows are now complicated enough to require computer control systems to manage hoist operations and rigging cues.

Shows are getting heavier too. Much heavier. The current roof load record for a touring show is right around 240,000lb. It's a safe bet that that record will be history by the time this book is published. Load cells and other load-monitoring devices are frequently used to ensure these loads on complex structures are distributed properly.

In short, it's gotten a bit crazy out there.

The rigging equipment we've been using for the past 50–6″ years has proven itself over and over to be safe and reliable. The newer gear coming into the market does so with a higher degree of research and testing and scrutiny. So where is the weakest link in the load path of modern arena rigging? The accidents over the past five years all point to the same thing. People. It's the human component that provides the potential for disaster.

Given the size and complexity of the shows on the road these days, the cavalier attitudes of the past are no longer acceptable. When you consider the sheer quantity of equipment hanging overhead, its weight, and the speed at which it moves, the risks are too high to tolerate any sort of arrogant or careless behavior. It's also become clear that on-the-job training is no longer enough to provide the skills to work as an up- or ground-rigger.

Proper training is now of paramount importance if you wish to reach a higher level of employment. Having a thorough understanding of the equipment's capabilities and limitations along with the manufacturer's specifications and restrictions are the road to a safe, efficient and enjoyable theatre experience, not to mention a better paying career. Fortunately, training has become popular over the past ten years.

We can debate until the cows come home when the number of serious training options in the US began to increase. It seems clear, however, that the rise in interest in training coincided with the introduction of the Entertainment Technician Certification Program (ETCP) in 2005. Whether it was an awakening of an awareness that skill levels had to grow, a fear of being left behind, or a combination of the two, riggers began to understand that the status quo was no longer sufficient.

The ETCP mandate and charter does not allow the organization to conduct training—private individuals and organizations provide that service. What the ETCP has done, through the certification exams, is provide the means to measure the skill level required to be a member of the top level of riggers in North America. This is no small feat and should not be taken lightly. Until the ETCP came along a rigger had only their wits and their résumé to show the world how good they really were. The ETCP has added another layer and the industry is all the better for it.

The arena rigging industry had its beginnings in the circus and the road to the present day has been more than a little interesting. The industry has had its share of successes and failures, but that's to be expected when the way forward leads into unchartered territory. As the industry continues to grow, it also continues to mature. The level of safety awareness today is rising to meet the level of technology found in modern-day shows. One can only hope that this relationship will continue to grow, providing safe and wonderful experiences for all for many years to come.

---

*The common practice in the entertainment industry of calling these devices chain motors is inaccurate. A chain motor is the electric device inside the hoist that turns the shaft allowing the hoist to lift the chain. The hoist is the entire machine.

5
Outdoor Roof Structures

KEITH BOHN

Intro

Welcome to the oldest venue for entertainment, the great outdoors. People have enjoyed the wonderful venue of Mother Nature since they first learned how to dance and tell stories around the campfire. Maybe it is something primitive, but there is some draw and appeal in going to a big festival out in a field, with no one around, limited security, PSAs coming from the stage, inadequate bathrooms, no food, lots of mud, and … well, we still like outdoor gigs for some reason.

OK, so less recent than Woodstock and not as far back as the ancients at Stonehenge, Shakespeare's Globe Theatre was open-air and "outdoors" by some definition. But, even in the 17th century they had trouble with the venue not being suitable for the performance, or blunders in the show, when misfired cannon in a performance of *Henry VIII* burned the place down. Let's hope that we have learned from that little trinket of history.

So, what are we talking about here?

There are a lot of different structures used to produce shows and events outdoors. These structures can serve many different purposes and use a variety of designs, materials, and technologies. Things like PA towers, spotlight platforms, mix positions (FOH platforms), freestanding video walls, and the roof covering the stage are all examples of some of the structures you might see in an outdoor show site. These could be made from aluminum, steel, or synthetic materials, or a combination. They might require scaffolding, vertical towers, hydraulics, electric motors, or even cranes to erect.

There are other types of structures used to complete an outdoor event safely that might include portable water closets, tents, and trailers. For the purposes of this chapter, we are going to differentiate between these two categories by identifying that the first list of structures is utilized in the technical production of the show. This isn't to say that those other operational structures are less important, or are not subjected to Mother Nature, it is simply that most trailers or port-o-johns might not present the life safety or structural ambiguities that can exist with a customized temporary structure supporting tens of thousands of pounds overhead.

Throughout the next few pages, the primary focus will be on the over-stage roof structures. However, it is important to realize that most of the same rules apply to PA towers, video walls, etc. Despite all of the different forms and functions of these structures, once they are utilized outdoors, they all are subjected to similar forces and conditions. The challenge is identifying, understanding, and minimizing the risks associated with those conditions.

Inside, Outside—What's the Difference?

Many of the same technology required to produce a show outdoors is also utilized indoors. There are some extraordinary differences, besides the obvious weather. For example, when rigging a show in an indoor venue, most of the time the loads hang from a separate and independent superstructure such as a building. When loads are hanging, the supporting components such as wire rope or hoists are in tension. In most cases, this tensile load is relatively quantifiable with clear direction. In other words, we can identify how much something weighs and we know that the force is in the direction of gravity's pull. The other end of the supporting mechanism simply needs to resist this simple pull.

The complication to this clear direction of gravity indoors is when lateral forces are induced into the hanging objects. (As an aside, there are regularly lateral forces imposed on local components of the superstructure when the rigging configuration requires the use of bridles, but for this discussion, we are focusing on the hanging loads.) Lateral loads on the hanging objects can be created by automation elements, such as tracking video walls and performer flying, or even wind or air movement indoors when loading doors are open, for example. Most times, this lateral force can be resolved with some type of additional rigging specifically designed to resist the direction of this motion. However, since the supporting assemblies are in tension, a lateral load-imposed hanging object may cause the tension cables to be pulled out of vertical, or create a swinging or pendulum effect. And, while this may not be desirable from the perspective of the show, it could be perfectly safe (considering that the anchorage in the superstructure is suitable) in regards to the hanging structure itself. In other words, a tension cable going out of vertical by a few, or even many degrees, may not create an extraordinarily unsafe condition.

In contrast to this, an outdoor structure almost always depends on the main supporting devices to be put into compression. This means that instead of trying to pull something apart, like a cable or chain, the load is trying to press things together. In this situation it is absolutely critical that the direction of compression and how much it is out of perfect alignment is clearly controlled. A tower that is out of vertical by only a couple of degrees can be completely unstable.

You can use a simple drinking straw to further understand this critical tension versus compression concept. To test tension, simply grab on each end and try to pull apart. Odds are pretty good that your fingers are going to slip off long before you pull the straw apart. Now, if you put the straw between your fingers and press together, compressing the straw, it will take very little to get the straw to buckle. This is precisely what we see in hanging (tension) loads, versus ground (compression) supported loads. It also relates to a concept called slenderness, which will dictate size and height limits on towers, but we are getting ahead of ourselves a little.

For now, it is important to understand this key, tensile versus compression concept. If you then toss in the added aspects of wind, rain, and snow that take place outdoors, you can clearly see how different the considerations need to be for outdoors over indoor applications.

This is Easy, Right?

So before we get much further, let’s put the complexity of these structures in perspective by comparing the expectation of a temporary outdoor roof structure to that of a brick and mortar permanent building. In the process of erecting a permanent building, an architect completes a design. Then, an engineer validates that design to be suitable for the location and what is required. This includes understanding the soil and foundation, the environment (i.e., wind, snow), and the addition of the live loads, which in most cases are occupancy loads.

Many of the loads the engineer will use are dictated by codes and standards. For example, certain soil types have established bearing capacity, occupancy loads are typically based on available square area, and wind, snow, and seismic are based on the statistical likelihood of occurrence in a given locale. Once these calculations and values are completed, the materials and construction methods can be determined and construction can begin.

During construction, the contractor must ensure that the end result is consistent with the design and engineering documents. If anything is done incorrectly, then the building process could be delayed until the appropriate corrections can be made or modifications are approved. With a permanent building such as this, the entire process could range from six months to a few years to complete. It is also important to note that we haven’t talked about building and an electrical inspections that have to take place that are driven by the local municipality and usually required at multiple stages of completion. These inspections throughout the construction process are intended to ensure compliance and safety.

Now let’s look at a temporary roof structure. A designer will be involved and an engineer. However, in this case, quite a few of the fixed or known factors in a permanent building are now variable factors for a temporary structure. For example, a roof system may move every few days or weeks. Now the structure must be able to accommodate different soil types, different weather conditions, and a variety of load scenarios (not all shows are the same). Aside from that, the structure must be erected in a fraction of the time of a brick and mortar structure. The allowable setup and dismantle period many times is quantified in hours rather than days or weeks. This means that there is little, if any, time to make corrections or modifications if something isn’t exactly right. Despite those differences and variables, the general expectation is that these structures, which can be set up in a very short period of time, are going to be no less safe than the permanent building.

Further to the perception of these structures, let's consider the potential number of players involved in this complex system. Including the aforementioned designer and engineer, a list of who could be involved with a structure might include: designer, engineer, manufacturer, system owner, setup manager, labor provider/supervisor, operator, security, and, in some cases, the promoter. Each entity has a role, in some cases a critical and complex role, that could monumentally affect the reliability of the structure. The long and short of it is that there are lots of people involved, each with a specific job to do, and each likely to be reliant on others to complete their tasks safely. At one time there was the notion that you shouldn't buy a car that was built on a Monday or Friday. But, temporary structures aren't mass-produced machines, and even the slightest misstep along the way at any stage can have catastrophic consequences.

The trap that many people fall into is that they want the temporary structure to be as safe as a building, but they don't consider exactly what is required to achieve those levels of safety. There are different perspectives at play here.

- Attendees and concert goers, i.e., the punter
- Employers/hirers, i.e., promoter
- Providers, i.e., the production company

The attendees assume that the responsible parties producing the event have considered patron safety. And while some common sense should prevail in the case of extreme weather, it typically isn't in the purview of the patron to consider that they are ever in any peril.

Employers and promoters want the safety, and assume that their provider is an "expert" (if they weren't an expert, why would they say they are qualified to do this kind of work?), but may let competitive cost and economics play an important role in their choice of provider. Many times the employer or promoter doesn't know the difference between a qualified provider and unqualified provider. They might put a project or show out for bid and receive a varied response. And, while economics seem to always be part of the equation, employers have to take the time to understand whether the entity they are hiring is truly demonstrating the ability to provide the appropriate equipment and personnel. In other words, you might get what you pay for, and the cheaper provider just might not be the correct decision.

With regard to these production companies or providers, it is expected that they are the experts and have considered all aspects of safety and structural integrity of the structures. However, as mentioned before, they are regularly forced into competitive bid situations. These bid situations can pit a qualified provider against an unqualified provider, creating an uneven competitive advantage to the unqualified provider and forcing the overall quality of the structure to be diminished. At this point, it is not only incumbent upon the previously mentioned employer/promoter to be diligent in their decision, it is also key for the provider to clearly outline all of their qualifications and exactly how their structure is suitable for the show in question.

This suitability is one of the key considerations for these structures and requires careful consideration by all parties involved (other than the punters). What usually happens is a promoter is given a set of requirements from the act or show they have hired. This could include rigging plots, lighting equipment, audio needs, video, etc. It is imperative that, when assembling a bid, the potential provider compares these requirements with the limitations of the structure they intend to use for the show. There must be a clear understanding of all of these loads and requirements and documentation that definitively supports this suitability. Furthermore, the employer/promoter must be diligent enough to ask for this compliance.

Keep the complex nature of temporary structures, as well as the differences to permanent buildings, in mind as you consider these types of structures and, as you read on, note that caution and understanding will provide a better chance for success than a cavalier approach. The amount of respect needed for these types of structures cannot be overstated. The instant you think this is as easy as setting up your tent at Lake Too-Many-Bugs is the precise instant that you invite the potential for disasters and all the lawyers that tend to accompany them.

You Want to Build This Where?

So the real appeal for temporary outdoor structures is that you can produce an event almost anywhere. That is a vast oversimplification, however. The suitability of a site for a temporary outdoor structure is as critical as the structure itself. As discussed previously, there are a number of variables that must be considered to determine this suitability.

Some of the more commonly used locations range from farmland (maybe in upstate NY?) to parking lots and stadium venues. Wherever you might choose to hold an event, careful planning must take place far in advance.

One of the most critical, if not *the* most critical, factors in determining site suitability is the foundation on which the structure will be erected. This particular factor involves the foundations on which the towers or support system might rest as well as the anchorage system and guy cables that might be needed. So we have to consider the load-bearing (compression) capacity of the foundations under the supports as well as its tensile suitability for the type of anchors that might be employed on guy cables or other tension components.

For example, looser soils might further compact during the event if there is enough pressure—this can cause towers or supports to sink. Depending on the design of the structure, this can cause myriad negative effects to the integrity and stability of the structure. This might cause the towers to go beyond their acceptable levels of verticality, or could cause the system to shift out of a desired horizontally level condition. In extreme cases, where towers might be in close proximity to each other, a compaction of bearing soils could effectively negate the function of the tower itself. In many systems that employ multiple towers on each side of the stage, the interior towers are supporting the most weight. Effectively losing reliable foundations under these towers can be catastrophic for the entire system.

Further to this are the effects of moisture on the foundations. Some sites are chosen for their naturally occurring amphitheater characteristics. However, this usually means that the stage area is located in an area that is a naturally occurring drainage path (muddy mosh pit anyone?). Certain types of soil, particularly some types of clay, expand and contract based on moisture content. This reaction may not be discernible in very short periods of time, but certainly during a few weeks it is quite possible that simple moisture changes will cause the structure to shift according to the soil reactions.

Solutions for this bearing pressure usually involve spreading the foundation-bearing loads over the appropriate square area. For example, if you know that the maximum load potential down a tower in your particular system is 8,000lb, and the area of the base that is in direct contact with the foundation is 2′ square, then you need bearing capacity of at least 2,000lb per square foot (2′ × 2′ = 4′, 8,000lb ÷ 4 = 2,000lb). If your particular soil type is limited to 1,000lb per square foot, then your base area needs to be a minimum of 8’ square.

Aside from simply considering different soils, sports venues may have limitations on ground-bearing pressures not related to soils, but related to infrastructure. Some natural turf venues might have irrigation systems beneath the surface that must be considered. There are also synthetic turf systems that are actually built on modular panels. These conditions might necessitate that the maximum load at the base of the tower or support be limited.

Similar instability that is created by soil compaction can also occur with a foundation that simply disappears due to erosion. Once again, the type of soil has a direct impact on this possibility, as could any vegetation. A thick grass with a hardy root system might be less prone to erosion than loose soil in a field.

But wait! What about tensile components like guy cables? This certainly has to be another consideration when reviewing the ground suitability at a site. If guy cables are required, then what type of anchorage is to be used? If earth anchors are used, then the type of anchor must be selected based on the resistance required by the system as well as the type of soil. This will usually dictate the depth and angle of the anchor to sufficiently perform at the required level. In other words, banging a car axle into the ground isn’t usually quantifiable enough to answer these questions; Beamer or Buick, doesn’t matter.

In the situation that reliable earth anchors cannot be installed, as is regularly the case in sports venues where the ground surface cannot be broken, a ballasting system is likely to be the solution. Ballast will be discussed more a little later, but suffice it to say that you have to consider the interaction of the different surfaces in both the ground and the ballast type to identify a coefficient of friction that can be used to calculate the required mass. Regardless of the type of anchorage for tensile components, whether it is earth anchors or a ballast system, the notion of erosion potential must also be included in their evaluation.

Additionally, guy cables present another factor related to site suitability. Operationally, where are guy cable and anchors located? External guy cable positions might have an impact on audience areas, production access, emergency egress, or other key operational functions required at an outdoor event. Is security required at each guy cable anchor to prevent someone from trying to climb? Does the guy cable path cross any key areas? Loading dock? Truck or bus access? This starts to touch on the more global planning and communication coordination that is required between all of the key players in the event. Operational planning has to start at site selection.

Wait, Wait, Wait. There’s Math Involved?

I suppose the answer to the math question was already revealed in the previous section since we started calculating bearing pressures for foundations. This precise math and calculation must occur on every component throughout the system. Regardless of the type of design, materials or methods of manufacture, every part of an outdoor roof system must be mathematically verified to be appropriate for its function.

In a sense, there are two directions to approach the design and mathematical verification of a structure. The first would be to simply validate the capacity of a system based on the components intended to be used. For example, you own a certain type of truss or structure which you plan to integrate to other components to create the system. For this, you would want to know what it is capable of supporting and in what conditions. This approach should be used on any system that might have been put together with components not designed for this specific purpose. Basically, this approach is used when the question is "how much can this support?"

The second direction to approach the design and verification of the structure is to start with the target objectives that are desired. This would include load capacity in specific places in the system (i.e., PA wings or video walls), as well as operating conditions or locations that might have different wind or environmental requirements. In other words, this is the design approach when the question is "what would it take to accomplish this?"

Regardless of the direction required in your situation, the fact remains that a design professional, usually a licensed professional engineer (PE), must complete the necessary calculations to validate the strength of the system and the components within the system. It is also important to note that, whatever PE you use, it is likely preferred that they are licensed in the location you are building your structure and holding your event.

So, specifically what kind of math are we talking about here? Well, for example, we know that a 1-ton rated hoist is good to support 2,000lb. We know that if we use prefabricated truss components, those items also should have a rated capacity (albeit most of the published ratings are for highly controlled conditions that do *not* include outdoor applications). We also know that commonly used rigging components like shackles, wire rope, and roundslings have rated capacities as well. We even know the capacity of single- and double-wrapped zip ties and gaff tape … oh wait, ignore those last two examples. Anyway, many components used in outdoor structures are items that are adapted from existing technology. But, in many cases, as pointed out with the truss, those items haven't been evaluated for outdoor use. So when we get to these outdoor applications, we have to apply the appropriate loads and directions of force to ensure that these components work in this application as well.

Before we get into the specific outdoor loads, let's quickly look at the overhead grid in an outdoor roof structure. Typically, there is a grid that is supported on vertical towers to provide the overhead roof. Since all of the load must ultimately transfer back to the ground, the most efficient path for the load to travel is in a straight line to the closest tower. Using this principle, many outdoor structures utilize main spans of structure between towers on opposite sides of the stage. It is these main spans that must carry all of the load, and their size is dictated by the length of the span and the necessary load capacity.

In the case of a simple four-tower type of system, the structure or truss on the perimeter of the grid effectively carries the load to the towers. Any loads that are placed on intermediate structures within the interior of the grid will have to transfer to these perimeter trusses before getting to the towers. Therefore, it is typically the capacity of these perimeter trusses that dictates the overall capacity of the grid.

However, even within this simple perimeter type of example, the layout of any interior structure and where it intersects with the perimeter structure will have a very direct impact on the usability of the system. For example, if the desire is to simply have some lights on the downstage and upstage spans, and nothing on the interior or sides, then the largest structural spans will simply be those that are carrying that weight. On the other hand, if there is a center span truss running left to right that is carrying weight, not only does that truss have to be sufficient to support the intended load, now the side trusses that are supporting it must be sufficiently sized to carry the intended load and the self-weight of the center truss span. On top of that, this side perimeter truss has to be able to support it in the worst possible location, the center.

So, the easy solution to the above scenario is to add towers to the middle of the side perimeter spans. This would result in that center truss span having a direct load path to the towers. And this indeed, is more efficient and favorable over the simple four-tower perimeter system. It is this same concept that applies to most major cross stage truss spans within an outdoor structure. If you see a system that has three or more towers on each side of the stage, you are likely to see a larger main cross-stage truss connecting directly in line with these towers to provide the greatest and most efficient capacity.

So far we have been talking about "loads" in a very generic sense, but you need to make sure you understand that any evaluation of a system must include all possible loads that the system will have to support. In addition to the presumably easily quantified gravity loads, lateral, dynamic, and environmental loads must also be quantified and evaluated.

Lateral loads are going to be any loads that are trying to pull the system, or a component of the system, sideways. The most obvious of these would be guy cables that might be attached to the system, but you can't forget that any rigging done by way of a bridle is also going to create a lateral load. In fact, most outdoor roof structures prohibit the use of bridles since they could put a lateral load on a component that is insufficient to support it. Furthermore, the use of bridles in an outdoor structure is usually impractical since the structure is already relatively low compared to an indoor arena, so using a bridle for rigging hurts trim height for anything under the structure even more.

One way to get around the use of bridles in an outdoor roof structure is to utilize load beams or intermediate structures that can span between the main support spans of the system. This provides an infinite number of support points that can be rigged as deadhangs rather than bridles, and thereby maximizing the available trim height in the system.

Dynamic loads that are placed on the system must also be evaluated. These would include any automation or acrobatic performance that the system might be supporting. Yes, jumping out of the grid on bungees creates some dynamic force into the structure. Additionally, any simple rigging movements during the load-in must be considered. These conditions of dynamic amplification could range anywhere from a 1.1 to 2.0 increase of the moving load depending on how fast it starts and how fast it stops.

For example, if a truss supporting 1,000lb of lighting is hanging from the outdoor structure on 1-ton hoists that lift at 16fpm, the simple operation of lifting the truss into position will likely result in a higher load than what it weighs statically, or as a non-moving load. The best way to talk about dynamic loads is to put them in terms of a statically equivalent load, which would be the load multiplied by its dynamic amplification factor. One prevalent chain hoist manufacturer has stated that their 16fpm, 1-ton hoist will induce a dynamic amplification factor of 1.25. This means that a 1,000lb load will actually create a 1,250lb reaction into whatever it is supporting it. This 1,250lb would be the static equivalent load just for the lighting. But, in our example we can't forget the weight of the truss (let's say 500lb) and the hoists and rigging (200lb at each end, so 400lb). This equates to a total static load of 1,900lb, and a static equivalent load of 2,375lb. This is a far cry from simply considering 1,000lb of lighting.

Finally, we have to consider the environmental loads that are present on an outdoor structure. This can easily be the most under-estimated of all the loads. For the longest time, a wind speed of 40mph was considered a minimum wind force that a structure must be able to withstand. However, this is a load that has historically been applied to the use of lightweight tents and non-load-bearing systems. Recently, the required values for these types of system have necessarily been increased. The current ANSI E1.21-2013 minimum wind force that a structure must be capable of resisting is 67.5mph based on a three-second gust. This 67.5mph is essentially a 25% reduction of the basic design wind speed in the US of 90mph, and is derived from the applicable code ASCE 37, which covers buildings under construction. It is important to note that this reduced wind speed can only be applied if the structure is intended to be in place less than six weeks, which is the definition of "temporary" according to ANSI E1.21-2013.

Before we look at what that wind load might be at 67.5mph, let's circle back to the support layout of our structure. For that basic four-tower system, we can easily recognize (as a simplification) that each of the towers is likely to carry equal amounts of the load from wind. This considers that the wind load is based upon the square area of surface that will resist the force of wind, such as the entire covered area overhead. Now, when we step up to the six-tower system that utilizes mid-towers on the sides, we have a different scenario. In this configuration, a simplification would be to assume that each of the towers carries equal parts of the load, but this would be incorrect. In this situation, the center truss span, and therefore the mid-stage towers, are carrying not just the center third of the covering, but a full half of that total load. This is because that center span must support everything halfway between itself and the upstage and downstage spans. We call this total area to be supported, the tributary area, as the area that can be attributed to that span. The point in bringing attention to this is simply to ensure that it is understood that any towers or mid-stage spans of truss really could be the weakest link in the system and must be evaluated with the consideration of their location in the system.

OK. Wind. It blows. Wind is calculated as a force against an exposed area of the structure. Most commonly considered is the area that covers the stage, but you can't forget the area of any towers or support structure, as well as equipment like video walls, scenery and audio, and certainly you can't forget backdrops, side walls, and banners (that always seem to show up at the last minute). So how do you know how much force a specific wind speed puts on the structure? Well, there is math for that. The basic formula is simply velocity squared times 0.00256. This gives you a product of pounds per square foot (psf). So, for the “old” and misapplied wind speed of 40mph, the force equivalent is 4.096lb psf ($40^2 \times .00256$). Compare that to the current 67.5mph requirement, which results in a force equivalent of 11.664lb psf ($67.5^2 \times .00256$). Obviously, this is an increase of almost 300% of force with an increase of only 68.75% of wind speed. Figure 5.1 shows this relationship between wind speed and force.

When calculating this wind force, like anything else, it has to be calculated from the worst possible position, so basically the entire wind load is calculated with wind coming from any direction. The charts below, Figures 5.2 through 5.4, are simple grids showing the generalized total wind area for different sized outdoor structures. You can see the force and loads at the various wind speeds that would be present for each sized system. Make a quick note regarding the dramatic difference between the “old” 40mph thinking and the more recent 67.5mph. Also keep in mind that the wind load on the side and back walls is entirely lateral and must be resolved into the towers, grid, or through guy cables; essentially anywhere that these walls are attached, the anchoring structure must be capable of resisting that portion of the lateral load.

There is an allowance in ANSI E1.21-2013 for items that can be removed from a structure within five minutes. This allowance reduces the wind load requirement on these components down to the aforementioned 40mph, but *only* if they can be removed in the five minutes. Many have said that it isn’t practical to move anything in five minutes, and the response to that is simple. If it can’t be removed in time, then analyze and design for the full required wind speed. Easy.

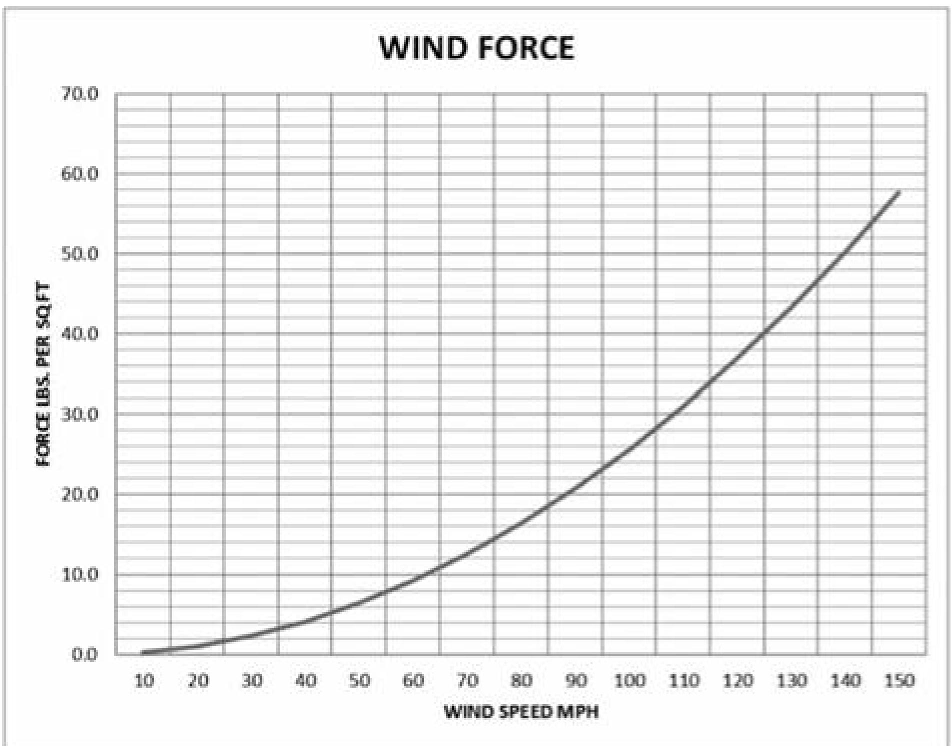


Figure 5.1

For a 40'x40'x30'H structure							
		Overhead		Back Wall		Side Wall	
MPH	PSF	Area (sq. ft.)	Force (lbs.)	Area (sq. ft.)	Force (lbs.)	Area (sq. ft.)	Force (lbs.)
40	4.1	1600	6,554	1200	4,915	1200	4,915
67.5	**11.7**	**1600**	**18,662**	**1200**	**13,997**	**1200**	**13,997**
90	**20.7**	**1600**	**33,178**	**1200**	**24,883**	**1200**	**24,883**
120	36.9	1600	58,982	1200	44,237	1200	44,237

Figure 5.2

For a 60'x40'x40'H structure							
		Overhead		Back Wall		Side Wall	
MPH	PSF	Area (sq. ft.)	Force (lbs.)	Area (sq. ft.)	Force (lbs.)	Area (sq. ft.)	Force (lbs.)
40	4.1	2400	9,830	2400	9,830	1600	6,554
67.5	**11.7**	**2400**	**27,994**	**2400**	**27,994**	**1600**	**18,662**
90	**20.7**	**2400**	**49,766**	**2400**	**49,766**	**1600**	**33,178**
120	36.9	2400	88,474	2400	88,474	1600	58,982

Figure 5.3

For an 80'x60'x50'H structure							
		Overhead		Back Wall		Side Wall	
MPH	PSF	Area (sq. ft.)	Force (lbs.)	Area (sq. ft.)	Force (lbs.)	Area (sq. ft.)	Force (lbs.)
40	4.1	4800	19,661	4000	16,384	3000	12,288
67.5	**11.7**	**4800**	**55,987**	**4000**	**46,656**	**3000**	**34,992**
90	**20.7**	**4800**	**99,533**	**4000**	**82,944**	**3000**	**62,208**
120	36.9	4800	176,947	4000	147,456	3000	110,592

Figure 5.4

Lastly regarding wind and wind area, there have been a couple of myths out there that should be dispelled. First the use of “blow through” materials for side or back walls is a misnomer. Any reasonable engineer will consider these areas as solid surfaces rather than the 70% (or whatever it is) that supposedly “passes through.” Part of the reason for this, is that even with a 70% pass-through, what is there will likely billow when wind hits it. Once it billows, the effective openings in the material begin to get smaller as the overall shape of the surface begins to become concave. At a certain point, the material won’t be realistically passing anything through it because all of the openings will essentially be closed to the direction of the wind; benefit negated. The other myth is that truss or open towers and structure don’t provide as much wind resistance as a solid surface. While this seems to make good sense, the reality is that truss, and truss with round members in particular, can actually be more difficult to quantify for wind than a solid surface. The reason for this is that the round members are going to deflect the wind in a multitude of directions within the truss or tower. This is nearly unquantifiable in realistic terms. So, most engineers default to the 100% solid surface approach in all directions to help compensate for this phenomenon.

Once the capacity and limitations of the structure are known, it is important to now make sure it is suitable for the use. In the case that the structure was designed to the parameters of a particular show, you would hope that this review of suitability wouldn’t be too extensive. However, in the case of an existing structure that is used for a variety of events and shows, it is imperative that someone is looking at the requirements of the show and ensuring that they fit within the limitations of the structure to be used.

So, yes. There is a lot of math involved. We haven’t even gotten into weld tensile capacity, member buckling, seismic consideration, connection analysis, and so on. It is absolutely imperative that a licensed design professional who is familiar with these types of structures performs a thorough analysis and does all of the math for you.

Badges? We Don’t Need No Stinkin’ Badges!

Back in the “old” days, no one really worried about making sure that a structure was suitable for its purpose. There was also no clear idea on who would approve the use of a structure or what codes it had to comply with. Thus, 40mph wind became a common benchmark, and it was simply assumed by, well, everybody that if you had the wherewithal to own and build the structure, you must be able to do it safely. This led to the proliferation of many substandard systems being used for the wrong purpose and beyond the purview of any oversight. Sadly, many of those structures still get used, but slowly the industry is becoming more safety conscious.

One of the things that has been a repeated theme throughout this chapter is the need for professional engineering involvement. This input from the licensed smart guys is at multiple stages, including design and suitability. But one more area that is needed is confirmation of compliance with the local codes in the area the structure is being used. Part of the reason for a temporary structure is that it can operate in different locations from one week to the next. However, these different locales are likely to have different prevailing codes and requirements and someone has to make sure the structure meets them all, or that the structure is modified to meet those requirements.

So, where do you find out what these requirements are? Well, that is a pretty complicated question that is without a consistent answer. Part of the reason for this is that the United States is a republic of 50 states, each with their own ability to adopt codes that might be different than another. For example, there are separate building codes for New York and Chicago among others, some states adopt the International Building Code (IBC), or even different years of the IBC. But that is only scratching the surface.

Depending on where you are holding your event, you may not fit into a clear governing authority's jurisdiction, so who do you need to check with to ensure you comply? For example, if you are on city property, or in city limits, you might need to file for a permit with the city building department. However, if you are out of a city and on county property, it might be the county parks and recreation department that is in charge. It is possible that the fire department needs to verify that your structure is safe. These are only a few of the possibilities.

However, regardless of who has to inspect or approve the structure, it is quite likely that they will have little idea of what a temporary entertainment structure like roof system is designed to do. This is where a good relationship with your engineer and some proactive research for your local authority can prove to be very beneficial. The authority having jurisdiction (AHJ) where you are to set up your system needs to be your ally, and the best way to be their ally is to make sure they know that you have covered all the bases. This is most easily done with input from a good engineer who is familiar with the local requirements and can help you convey your compliance to these requirements. The last thing you need is for the AHJ to show up on your show site the day of the event, and be so unfamiliar with the structure and what it does that they are intimidated by it to the point of shutting you down. Take the time to identify who the AHJ is and what you need to do to make them happy, and you will have a better day.

I Have Been Doing This for Years. Doesn't That Count?

There are a lot of myths in the entertainment industry. Many of these are perpetuated with good intentions, but end up being taken out of context over time and pretty soon the original intent has been lost. The notion that just because you have been doing something for years equates to some level of expertise isn't really logical. Maybe you were taught the wrong lessons, but have never been in a situation where the weaknesses in your technique have been exposed.

As an example, it was once argued that aluminum truss rated for a certain load had a great amount of empirical, real-world evidence to show that it was suitable, or even underrated, based on the limited number of incidents that had occurred. But what this argument fails to point out, is that on many of the occasions on which this truss is used it is seldom actually pressed to its limits. In other words, if it was never tested and used to its capacity, then how do you have any real empirical evidence? The same goes for techniques and personal qualifications; if you never learned correctly, but the conditions that you operated within were always relatively safe and controlled, then you have never truly been tested. Many system failures that have occurred were in systems that had been set up the same way for many years, so the operators falsely assumed that what they were doing was fine. But when the time came for the system to be really challenged, it didn't hold up.

Someone claiming to have years of experience as the extent of their qualifications may or may not have a sufficient or clear understanding of the limits of the system they are operating. Once again, this leads to the need for a partnership with a registered design professional to help understand the limits of the structure and understand what can and cannot be done safely. It is important to further understand that what could be done in one configuration may not be completed safely in a different configuration, even under the same structure. This can be due to wind exposure, use of scenery as ballast, different loads in different locations or a variety of other factors. If you think you already know everything, you are already out of your league.

We Are All Set Up. Now We Party Until Load-Out, Right?

Getting the structure set up and the show ready to go underneath it is only part of the process. Managing the structure during use is absolutely critical for a safe event. In 2011, there was an incident at the Indiana State Fair that resulted in quite a few deaths and injuries. One of the follow-up reports to that accident clearly outlined deficiencies in managing the structure and the decisions, or lack of decisions, made to ensure the safety of the event.

An Operations Management Plan (OMP) needs to be created and followed throughout each stage of the use of an outdoor structure. This plan needs to be shared and explained to every single stakeholder in the production of an outdoor event, as each party can have an effect on the performance and outcome of the event. For example, all the parties need to know who the final decision-maker would be in the event of extreme weather, and what the security staff need to do when a weather plan is implemented. These things all need to be clear and objective, which is what a good OMP will provide. If you are trying to decide what to do in an unexpected situation when it happens, then your OMP isn't good enough, and you are likely already in a very tough position.

Some of the things that need to be outlined in the OMP might include:

- daily or hourly system inspections
- shifting conditions to the site
- performance thresholds
- weather plan—what changes need to happen at what weather conditions
- training requirements
- public safety considerations (storm shelter areas)
- venue configuration (access and egress issues)
- venue impact on structure

All of the previously mentioned precautions to ensure the structure is designed and built correctly and meets the proper codes are completely wasted if the structure isn't managed appropriately on site. One thing that is particularly important, and should be clarified at the time the structure is hired or contracted, is a clear understanding on which entity (promoter, structure owner, etc.) is responsible for decisions regarding the structure at any given moment. Someone always has to have clear and unquestioned authority, and it must be very clear on how that authority is to communicate critical decisions at critical times to everyone involved. The real point of an OMP is to make all of these decisions as objective as possible rather than subjective or based on someone's opinion.

Summary

What should be clear and simple at this point is that these types of structures are anything but clear and simple. These are all complex undertakings from start to finish and they deserve the appropriate attention to all details at every step along the way. There are a number of qualified resources available for you to learn more, and if you are in a situation using an outdoor temporary structure where you or the person you are working with doesn't know "why" something is the way it is, seek out an answer that makes sense and ensure that you and your event operate safely.

6
Counterweight Rigging

KAREN BUTLER

History

As near as can be told, theatrical rigging (the suspension of scenery and actors above the performance area) started in Greece. In their plays about gods and heroes, they wanted more spectacle. They searched for better and bigger staging effects to entice the audience and engage them in the tragedy and drama in front of them.

In the "modern" theatre, stagehands utilized the technology of the day to rig scenery. Relying on the rope crafts of the tall-ship sailor, theatre technicians used belaying pins, Manila hemp, wooden grids, and sandbags to counterbalance scenery and lights. Every new show required a skilled crew to spot loft blocks on the grid specific to the incoming show, and to reeve hemp through the loft blocks and head blocks. The load was tied to the hemp, and a crew of stagehands, using block and falls, wire rope sundays, and lots of effort, raised the loads to a working height. Sandbags were attached to the line-sets by means of wire rope sundays or clamps to balance the load, and the scenery was raised and lowered using the line-set and auxiliary lines called haul-downs. It was a poetic but labor-intense way to hang a show.

This continued up into the early 20th century when J.R. Clancy introduced the first counterweight system.

> In 1924, the company took counterweight rigging to the next step, introducing a system Clancy called Manual Counterbalance Rigging, "a method by which scenery could be easily raised and lowered with the least effort and in a way that would, in necessity, be rapid but always sure."
>
> *Theatre Design & Technology*, 2010, p. 61

J.R. Clancy began offering the components to the manual counterweight system in its 1925 catalogue and theatres began installing them. While there are still a few operating hemp houses tucked away, the majority of theatres in North America use counterweight systems evolved from these origins.

Manual Counterweight Rigging

Manually operated counterweight systems are the standard for proscenium fly houses in much of the world. Next to those that utilize rope and sandbags, they are the oldest form of theatrical rigging systems. Simple and direct, they are the backbone of most theatres. While the use of motorized line-set systems has become more common, manual counterweight rigging systems continue to be the essential driving force in theatrical productions; they yield magic via trained people, ropes, sheaves, and sweat.

Counterweight rigging systems are where most theatrical riggers and flymen get their start. They are the classrooms where these individuals are introduced to all the basics of proper operation, applied forces, standards, and to the immense responsibility they hold in their hands. Nothing drives home better the inherent dangers and responsibilities in theatrical rigging than having to wrestle with an out of weight line-set.

In this chapter we are going to look at a brief history of manual counterweight rigging systems, define the components and how they work with each other to create a reliable system, relate the safe operation procedures, and point out some of the warning signs of wear and tear that should never be ignored.

Parts of the System

Blocks and Sheaves

HEAD BLOCK

Figure 6.1 Head block

The head block is located above the arbor guide tracks. It is a stationary, multiline sheave that changes the direction of the wire rope lift lines from horizontal coming from the loft blocks, to vertical where they attach to the top of the arbor. It is also grooved in the center for the hand line, also known as the operating line, allowing for operation and control.

The head blocks are installed on substantial I-beams oriented along the side wall of the theatre perpendicular to the proscenium. These beams must be able to withstand vertical, horizontal, and resultant forces. In a single purchase system, the beams and block must be able to withstand the weight of the arbor, the maximum force of the load on the batten, plus the dead load of the head block. In a double purchase system, the beam and block must stand up to twice the vertical load in addition to the maximum lateral load of the batten.

The resultant load is the summation of the batten load and the arbor load, going around the head block. This creates a force on the beam relative to the angle between the lines coming from the loft blocks and the lines going to the arbor. If the angle were zero, the load would be 100%. At 180 degrees it would be 200%. If the angle is close to 90 degrees, the load is 1.41 times the sum of the two loads. This can be calculated using the Law of Sines, or by using multipliers based on the angle between the two lines.

$$\frac{F_R = P \times sine \leq}{\frac{sine <}{2}}$$

LOFTBLOCK

Figure 6.2 Underhung loftblock

Figure 6.3 Upright loftblock

Loftblocks are the individual sheave blocks used to change the direction of the lift-lines between the head block and the batten. They are grooved for the number of lift-lines passing through them. They can be mounted to the grid itself, either overhung or underhung, or they can be mounted to overhead loftblock beams that are often part of a building's roof structure.

IDLER BLOCKS

Figure 6.4 Loftblock with idlers

Idler blocks are small non-weight-bearing sheaves that attach to the side of the loftblocks to keep the longer lift-lines supported on their way to the head block.

TENSION BLOCKS

The tension block, also known as the floor block, is located at the bottom of the T-track below the arbor. It is an adjustable assembly that can be raised to put slack into the operating line for some purposes, and lowered to take slack out of the operating line. When operating the system, it is important to keep the line in tension to prevent twisting of the line and to avoid friction between the operating line and the arbor and other structural parts of the system.

Figure 6.5 Up-floor block

MULE BLOCKS

A mule block is a sheave block used to reroute wire rope lift lines from positions not in line with the head blocks into alignment with the head block. Typically used for offstage side battens oriented up to downstage.

Figure 6.6 Mule block

The Lines

Wire Rope

The battens in a counterweight system are suspended on steel wire rope that is threaded through the loftblocks and head blocks on the way to the counterweight arbor. There are terminations at both ends. Wire rope is a machine in itself. The way it is constructed, the lay pattern, the core types, and the configuration all play a part in its efficiency. There are three basic components to the machine, wires, strands, and the core.

It is the main artery of strength and support in the system. Just with regular everyday use, with everything in perfect working order, it takes a beating by way of friction, breasting lines, bending and moving back and forth through sheaves.

There are many grades, sizes and classifications of wire rope, and each one is constructed with a purpose in mind; none are constructed specifically for theatre. In counterweight rigging, we first need both flexibility and durability. Most theatrical system applications use a 7 × 19 GAC construction because it has both of these qualities. The GAC stands for "Galvanized Aircraft Cable," the "7 × 19" denotes the construction. There are six bundles of wire rope strands wrapped around a center bundle, with 19 individual steel wire strands in each bundle.

Hand-Line

The hand-line, also known as an operating line, is a fibrous rope used to control the movement of the counterweight arbor. Until the early 1990s the hand-line was made exclusively from organic material, usually manila. Since then synthetic ropes have been designed specifically for this use. The synthetic ropes are typically made of polyester and, in some cases, a secondary fiber called polyolefin. Most theatres use synthetic operating lines, although there are still some using manila.

When operating the system, the flyman pulls on the line closest to the stage to lower the batten and the suspended load. Conversely, the back-line, farthest from the stage is pulled to raise the batten.

The lifeline of the system, the analog control panel if you will, the operating line transmits to the flyman information about the system. The operator might not always be able to see what is happening on stage or in the fly tower, but the feel of the hand-line will tell the operator if something is amiss. There is no motherboard, no RAM, no circuits, no operating program to do the calculations. The system doesn't have a brain of its own; the flymen must use their own.

Other Parts

Lock Rail

Figure 6.7 Lock rail

The lock rail is a heavy steel frame to which the rope locks for each line-set are attached. It is securely attached to the floor of the stage to prevent lifting, and contains some facility for marking each line-set with a changeable identifier.

Rope Lock

A rope lock is a positioning device located on the lock rail. It’s meant to be used as a method of maintaining the operating line in a set location. It has a pair of jaws that compress the hand-line to hold it in place. There is a lock ring that is threaded around the hand-line such that when the handle is up (in the locked position), the ring slips over the handle and secures it in the locked position

This is one of the more abused parts of the system. Rope locks are designed as a means of controlling or slowing down an out of balance load; they are not intended to be used as a brake, or to hold a heavily out-of-balance line-set. Rope locks are generally designed to hold no more than 50lb of out-of-balance load; misuse of the rope lock greatly reduce its life span, adversely affect its strength and can lead to a catastrophic failure.

Figure 6.8 Rope lock

Guide System

The guide system is a series of vertical tracks or, in some cases, wire ropes, from stage deck to just under the head block used to guide the arbor and keep its travel smooth and quiet. They also restrict the lateral movement of the counterweight arbors to prevent them from running into one another as they pass. Wire guide systems are generally not used for line-sets that require more than 30′ of travel. They tend to be a little noisier than the other guide systems because the wires allow for movement in the arbor even under normal conditions. T-bar and J-bar systems are the most prominent. They are usually constructed out of $1\frac{1}{2} \times 1\frac{1}{2} \times \frac{3}{16}$ steel or aluminum that is rigidly fastened to the support wall at regular intervals.

Arbor

An arbor is a rack or carriage used to hold the counterweight. The lift-lines terminate at the top of the arbor, as does the operating line in a single purchase system. Steel rods connect the bottom and top plates of the arbor. The arbors are constructed so as to facilitate the loading and unloading of the weights. They must be constructed to retain the weights even in the case of an unexpected impact. The lift-lines are normally attached to the arbor with a single termination for each line, and then reeved through the head block in a way that keeps the lines untwisted and free from one another and allows for easy inspection and maintenance.

Figure 6.9 Arbor

There are spreader plates located in the arbor, designed to prevent the arbor rods from bending and accidentally releasing the weights in the event of an out-of-balance accident. There should be one spreader plate for every two vertical feet of arbor rod.

Locking collars placed on each arbor rod above the last spreader plate are designed to help prevent the counterweight from being forced out of the arbor in the event of an out of balance accident. There should be one locking collar on each arbor rod.

Batten

Battens, also known as system pipes, are the other side of the balance scale. Battens are attached to the lift lines and suspend scenic pieces, electrics or other equipment above the stage. They can be as simple as pieces of 1½″ Schedule 40 pipe, or they can be an engineered ladder batten or a truss.

Materials used to construct battens must be able to hold at least 30lb per foot of uniformly distributed load and 100lb point loads between two lift-lines. Splicing is a normal method of joining batten sections, but the materials used must be of the same standard as the batten. Threaded couplers should never be used.

Battens, whatever their construction, are beams. They are subject to the same forces as those applied to other beams. As such they are not indestructible. If forces are applied to the battens that compromise their structure then they will fail. It is not uncommon to find battens that are noodle-shaped from abuse. These need to be retired from service.

Once a material has been strained past its yield point and does not return to its original shape, physical and chemical changes render it permanently altered; an alchemy of sorts. Not the transmutation of base metals into gold, but the transformation of a material to a weakened state. It will never have the load bearing properties it did before. Schedule 40 pipe is used in so many different places around the stage house, it seems people believe it to have magical properties—able to be bent, overloaded, and abused and still be in service. Not so.

Terminations and Hardware

Terminations and hardware are the connective tissue that hold the system together. They are comprised of an assortment of hardware elements. They are used to terminate the wire rope lift-lines at both ends in such a way that they can then be attached to the arbors and battens.

Wire rope can be terminated using compression sleeves designed for that use, wire rope clips, or fist grips. There are other pieces of termination hardware used with wire rope, but not in this application.

The terminated ends of the wire rope can be attached to the batten directly or with trim chain and shackles, allowing height adjustments to be made easily. At the arbor the ends are attached to the top of the arbor with shackles or, in some cases, turnbuckles.

A word on hardware; not all hardware is equal—always use hardware designed for the application. There are many pieces on the market at your local big box hardware store that look very similar to the hardware designed for the purpose but rated hardware will be marked as such either on the piece or on the packaging. As the system is only as strong as its weakest link, and as the hardware can be that link, don't jeopardize your safety or the safety of others by using unrated hardware.

Operation

Our industry is unique in that we are allowed to have moving loads over people's heads. The fact that we do so in the dark and in a matter of seconds adds to the potential that something can go wrong. Because of this we must adhere to a higher set of standards, use higher design factors, have stringent rules, and be unwavering in our attention to inspection and maintenance.

There are a number of roles that are filled in the operation of these systems. While there are variations on the specifics due to the circumstance of any individual venue, the responsibilities of each role still need to be fulfilled. The safe and efficient operation of any fly system requires specialized skills. While there is a longstanding tradition of on-the-job training, there is a need for formalized training as well. It is important that no worker be sent to fulfill any task listed below without proper training and oversight to assure that the job is done correctly and safely.

Personnel and Responsibilities

The head flyman is in charge of directing the loading and unloading of the arbors as well as the attachment or removal of loads from the battens. It is important that these activities be under the leadership of one individual in order to prevent accidents due to out-of-balance line-sets.

Know Your System

A flyman may work in a variety of houses with different systems, and must know the general properties of each system. It is important to know the kind of system (single, double purchase, or a combination), the weight limits for each line-set, the heights of the grids, and the vertical travel distance of the line-sets. A flyman needs to be familiar with the counterweight available (full, half, and/or quarter bricks), the position(s) for arbor loading, and the lengths of the battens. Often there is a manufacturer's plate from the installer near the lock rail and/or in the loading gallery area where this information can be found.

Line-Set Schedule

Prior to (but sometimes during) a load-in, one of the first things the flyman receives is a line-set schedule. This denotes which scenic elements or lighting design elements will be hung on specific line-sets for the incoming show. It should also indicate what each element weighs, its dimensions, whether or not it is tailed down from the system pipe, and where in the house plot it is to be hung. Exactly when this comes to the flyman is often a function of how the space is programmed—some venues allow for preplanning and some must deal with shows with very little to no time for preparation.

Labeling

Labeling the rail and keeping a log book are essential parts of a well-run system. Proper labeling includes a description of what is on the batten, what it weighs, and whether or not the line-set moves during a show. Usually there is a place for a 3 × 5 card to label the line-set on the locking rail. As the only consistent fact about our business is that "things will change," it is necessary to verify the position and weight of each element after the load is hung and balanced. The log book is an important record of system usage as well as a place to memorialize each show's hanging plot.

Loading

The loading and unloading of arbors is one with great potential hazard. Dropping a counterweight brick can set off a dramatic and very dangerous chain of events.

The flyman must assure that the deck crew and loading crew are aware when arbors are being loaded and unloaded. Clear, concise, and consistent communications from the rail are very important.

The steps to safely hang a load on a batten are as follows:

1. Warn the deck crew that a pipe is moving in.
2. Warn all personnel on the loading bridge and grid that the pipe is moving.
3. Bring pipe in to the lowest limit for loading.
4. Secure the hand-line.
5. Attach scenery or electrics.
6. Load arbor with appropriate counterweights; as the entire weight of the elements hung may not immediately transfer to the batten—as in the case of tall flats or heavy drapes—arrangements must be made to control the arbor heavy line-set until all of the weight is suspended from the batten; do not use the rope lock to try and control an out-of-balance line-set!
7. Using snub knots and/or twisting the rear line around the front line four or five times, allow the operator to control an out-of-balance line-set until balance is achieved.
8. Check the weight with the hand-line and adjust accordingly

Calculating and Loading Counterweight

Counterweight can vary in size and weight from house to house. Knowing the weights of the house bricks makes the procedure safer and more efficient. Refer to the line-set schedule for preliminary loading calculations. Once the load is suspended, the weight can be adjusted so as to achieve the desired balance. There are occasions where line-sets that move during a performance may want to be slightly batten- or arbor-heavy.

Setting Trim

The low trim or "in trim" is the position relative to the stage where an element needs to be during performance situations. For an electric pipe, this is usually a static position. For a moving piece of scenery this can vary from the stage (as a scenic wall element) or at a prescribed height from the stage (as a chandelier). This position is marked on the operating line with a trim indicator. When using twisted line, the common practice is to use a trim indicator in the form of a piece of colored string, ribbon, or twill tape. Each system will have their own color system, but red for low trim and white for high trim are common. Intermediate and warning trims of different colors may be used when necessary.

The high trim or "out trim" is the highest position the element will travel. This is often the storage position. It is important to mark this with a trim indicator to prevent battens from reaching their ultimate height, which can potentially damage parts of the line-set if not eased into that position.

Showtime Operation

During the operation of a performance it is important that all personnel operating the fly system be familiar with the cue sheets, the cue lights, or other cue warning devices as well as the characteristics of the element they are moving. Operators must keep their concentration during these moments and be aware of what is going on not only onstage, but in the line-set itself. An experienced flyman can feel when there is something amiss with the line-set and will know what to do if that occurs.

Unloading

The unloading operation is the reverse of the loading operation. Unloading tall pieces that create out-of-balance situations must be planned carefully and executed exactly to the plan. The arbor can be partially unloaded at an intermediate position and the out-of-balance line-set controlled as in the loading process. The deck crew can also assist in bringing the batten to the deck by means of bull-lines thrown over the batten. Capstan winches may also be employed to control unbalanced loads.

Weight-Loaders

Under the direction of the head flyman, the weight-loaders add and remove the counterweight. Often this job is given to younger, less experienced stagehands. It is vital that they understand the process and the gravity of what they are doing—the safety of the entire crew depends on the proper execution of this task.

Handling 30lb bricks 50′ to 90′ above the heads of your fellow workers, is not to be approached casually. Clear communication from the flyman to the loaders is essential, and the flyman's instructions must be followed to the letter.

The first thing to be aware of is the pipe weight. This is the weight of the system pipe itself and keeps the empty battens in balance when nothing is hung from them. In many houses the pipe weight is marked by painting these bricks red or yellow. These bricks are never to be removed during normal situations.

The next part of the arbor system to understand is the spreader plates. They are a very important safety feature of the arbor as they to ensure that the rods connecting the top and bottom plates of the arbor cannot spread enough to let a brick fall out. This is especially true if there is an unexpected impact, as can occur with a runaway line-set.

There should be enough spreader plates permanently installed to place them every two feet of counterweight. When loading the arbor, the plates must be held up and out of the way. There are a variety of ways this can be achieved: sometimes spring clamps are used, sometimes automotive battery terminal clamps, which grip the arbor rod much better, and sometimes tie-line, as it also poses no overhead danger. When using any kind of clamp, the device must be secured with a line that is tied off to prevent the clamp from being dropped. The spreader plates are set onto the counterweight after every two feet of weight is added to the arbor.

The top spreader plate may have lock screw collars mounted to it. When balance is achieved, these spreaders should be lowered onto the last brick and secured in place with the thumb screws.

Deck Crew

Under the supervision of the head carpenter and/or head electrician, the deck crew is responsible for securing the elements to the battens. In a departmental venue, the carpenters will secure scenic elements and the electricians will hang lights, accessories and cables. The head carpenter oversees the operation of the system as the fly system is ultimately under that department. The head electrician and carpenter must coordinate their efforts to assure that everything suspended on or from the batten is safely secured and within the parameters of the system. Both must assure that the elements are placed in their proper orientation and in accordance with the show's needs.

Taildowns, pipes suspended below the batten, are sometimes used to accommodate unusual loads or trim difficulties. Rigging these would be done by the carpenters. In interdepartmental venues, the work of the department heads is increased as the deck crew is being asked to understand a wider variety of equipment and proper installation procedures and oversight by the department heads is essential.

Inspection and Maintenance

Keeping the system in good working order is of the highest priority. There are simple inspections that should occur with every use, more thorough inspections after every load-out, as well as comprehensive scheduled yearly inspections. Usually very little thought is given to a counterweight system, but as it is a very complicated assembly of parts, inspections must include all pieces of the system. If no one at the venue is trained to inspect the system, then an outside contractor should be brought in once a year to do the annual inspection. In many cases bringing in an outside contractor is a good way to have fresh eyes look at the system. Often this catches things overlooked by the in-house staff who are used to what they see every day and don't always recognize the problem.

Log Book

Keeping a good log book is one of the most important things a flyman can do to assure the system is kept in good working order. Keeping track of what has been loaded and when, and of any problems or accidents that might have occurred, helps to pinpoint problems that need to be addressed either immediately or during yearly maintenance. The entries must be legible and specific in order to direct the maintenance and ensure the system is in good working order. The log book also details the frequency and results of all inspections.

Wire Rope

The wire rope in the system does the lion's share of the work and, as this is a heavy-duty job, it is very important to make a close inspection of the wire rope. Inspecting the terminations and wear points around loftblocks and head blocks are good regular inspection tasks.

There are things that will extend the life span of wire rope. First is to be sure the fleet angles are within tolerance. The general recommendation on fleet angles is no more than 1.5 degrees from zero. An easy rule of thumb is that you are allowed one unit of offset for every 40 units of distance.

The formula to find the fleet angle is:

$$\text{angle} = \text{arctangent of } \left(\frac{\text{offset distance}}{\text{measurement distance}} \right)$$

Second is the D:d ratio. This is the ratio between the sheave tread diameter and the diameter of the rope, wire, or fiber. This must be addressed during the initial installation process and is a time-consuming chore to do afterward. Choosing the proper wire rope for the job and the right diameter sheave assures the rope a longer life. The smaller the diameter of the sheave, the sharper the bend; the shaper the bend, the more wear and tear on the wire rope; the more wear and tear, the shorter the lifespan. All reputable manufactures of wire rope and sheaves list a minimum D:d ratio for their products.

During inspections, look for broken strands in the wire rope. While there are some industrial applications that allow for some broken strands on the outer surface, this is never acceptable in theatrical applications. We should also look for bends and kinks in the wire rope. These can indicate a number of problems and require the wire rope be replaced.

Within a counterweight system many things can happen to the wire rope. Shock loads from runaway arbors or suddenly released snags on other line-sets are among the worst. When this occurs the wire rope will "birdcage," looking like it has come unraveled. This symptom is serious and warrants inspection of the entire line-set, not just replacement of the wire rope.

Closer to the batten connection, deformations in the lift-lines can occur because of bridling or the application of stiffeners to keep the batten from rolling. Damage can also occur when line-sets are diverted instead of relocating the loft blocks to position the lift-lines in a desired location.

Operation of Sheaves

As previously stated, an experienced operator can feel if there is something wrong with a line-set. If there is resistance in the line beyond the normal then inspection is required. An experienced flyman can also hear when there is a problem. Grinding noises or rubbing and chafing sounds are all reasons to inspect the line-set immediately. Generally, the sheaves at the loftblock and head block are a good place to begin when these signs present themselves.

There are times when loftblocks must be moved to create room for other sets to pass or to align with a specific mark on the stage. "Kicking sheaves" is a common practice and these blocks are usually accessible and movable. This changes the fleet angle to the head block and must always be taken into consideration. Excessive fleet angles greatly reduce the life of the wire rope and the sheaves.

Idler blocks are small non-weight-bearing sheaves that attach to the side of the loftblocks that support the longer lines as they traverse the grid on their way to the next block and eventually to the head block.

Condition of Terminations and Connections

Terminations and connections must be inspected for deformation and proper use. Shackles and turnbuckles should be moused in a way that prevents them from loosening. Thimbles should be inspected to be sure they are not elongated or twisted—one is a sign of overloading or shock, the other is a sign of side-load for which they are not designed. Eyebolts and other threaded devices that have a specified torque rating must be checked occasionally to be sure they have not loosened.

Hand-Line

The system's hand-lines must be inspected for frayed or broken strands, indicating misuse or excessive wear, and abrasions. If there are signs of abrasion, the point of rubbing must be discovered and eliminated.

Deformed lines or overly compressed sections can occur with heavy loading and misuse or maladjustment of the rope locks. Where possible the problem needs to be addressed and the line replaced.

Ropes with an outer jacket and inner core are subject to inner core slippage. This results in "lumpy" rope and gathering of the outer jacket. When this occurs the lines need replacement.

Rope Locks

Rope locks must be properly adjusted so the jaws hold the operating line, but do not subject it to over-compression. The lock must be adjusted so that, when lifted nearly to the locked position, it stays put, but not so tight that a great effort is required to lock it. The keeper rings must be in place and easily placed on and taken off the rope lock handle

Food for Thought

We rely on the good condition of our systems, so they must be maintained in safe working order. Regrettably, the more experience we have with these systems, the easier it is to become complacent about them. It is very easy to start taking shortcuts and skipping steps. Confidence in our own expertise can work against the best interest of the system. Assuming that something out of the ordinary will be noticed because experts operate it is hubris. The more familiar things become, the less they are noticed.

Always remember that as the operator of a manual rigging system you are the finesse; you are the motor control and the speed settings; you are the E-stop and the limit switch; you are the safety measures and the precautions. Never forget that the most important component of any manual rigging system is *you*.

7

Aerialist Rigging

STU COX

Introduction

Aerial arts are some of the most popular elements in live performance today. They can be seen in all aspects of entertainment, ranging from live theatre and special events to tradeshows, corporate events, and even biblical productions in houses of worship. They are fast becoming a form of fitness and recreation much like dance or martial arts. Originating in the circus, aerial arts have evolved into a spectacular art form that amazes, frightens, and mesmerizes an audience.

As the number of aerialists increases, so too does the need for experienced riggers who can combine their rigging skills from other parts of the entertainment industry with an understanding of the dynamic forces involved with this art form.

Aerial Arts

The aerial arts are as varied as they are spectacular. For aerialists, these involve differing degrees of strength and flexibility, as well as specialized aerial equipment. For riggers, it is important to have a working knowledge of the various aerial arts to be able to create safe and appropriate rigging.

Silks

One of the most recognizable acts, aerial silks, also known as fabrics or tissues, involve a long piece of fabric, doubled and suspended at its center, thus giving the performer two long lengths of fabric typically reaching to the ground. Fabrics range in width, thickness, and stretch depending on the performer's experience, size, and routine. Performers use a variety of climbs, wrapped poses, and drops to create routines of striking fixed images and dynamic action. Routines may involve swinging and spinning, as well as dramatic unrolling drops that can create sizeable shock loads. These shock loads create a dynamic "bounce" that can cause system components to move, possibly resulting in side-loaded attachment hardware, such as a carabiner or shackle. The point should be stabilized to avoid this.

Figure 7.1 Silks

Sling

A sling, or hammock, is a suspended loop, most often of fabric, that the performer uses for various sits, hangs, and contortions. These usually involve swinging and spinning at a fixed height, making them good for venues with low rigging height. Slings can also be made of chain, rope, or net.

Figure 7.2 Sling

Corde Lisse

Figure 7.3 Corde lisse

Corde lisse or rope acts utilize a vertically hanging rope. It may be a braided or twisted rope, sometimes with a fabric sheath. Typically the rope diameter is between 1″ and 1½″ with a spliced eye at the top for rigging. Performers create routines with combinations of wrapped poses and drops.

Spanish Web

Similar to corde lisse, Spanish web takes the rope and adds hand or foot loops. These loops increase the types of grabs, and therefore the number of poses, that the performer can create. Aside from variety, the loops add a more secure hold, enabling the performer to create very dramatic rope spins, often incorporating a second performer at the bottom of the rope, adding tension or spin to the rope as needed.

Figure 7.4 Spanish web

Lyra

The lyra, or aerial hoop, is a circular steel ring suspended in a way that looks like a vertical hula hoop. It can be rigged using one or two points. Performers sit, hang, contort, and spin on lyras—typically solo, but sometimes as a duo. Routines do not require much height, but can be raised or lowered before or during the performance to add variety, visibility, or effect.

Figure 7.5 Lyra

Trapeze

Trapeze covers an entire family of traditional to modern aerial work. The basic trapeze is a horizontal bar suspended at each end by vertical ropes. Trapeze bars can be metal or wood, and vary in size by performer and routine. Performers use various sits, hangs, poses, and swings in the many styles of trapeze: static, swinging, dance, flying, and the list continues. Some of these involve more than one trapeze bar, and multiple performers. Rigging heights can vary from 12′ to 18′ for static trapeze, and to circus heights for flying trapeze.

Figure 7.6 Trapeze

Straps

Figure 7.7 Straps

The straps, or sometimes known as aerial ribbon, are a pair of straps, typically cotton or nylon, hanging from a spinning point. They may, or may not, have looped ends. Routines most often involve two partners, with a variety of grabs, poses, and spins. Different moves may involve both performers on the ground, one in the air being spun or manipulated by the ground partner, or both spinning in the air at the same time. The height of the straps is often raised and lowered during the act.

There are many other forms of aerial work, often derivations of the ones listed above. These include, but are not limited to: cradle, window, cloud swing, cube, hair hangs, and mouth hangs. Some even involve using body piercings as the attachment points on the performers.

Aerialist Rigging Hardware

The hardware used in aerialist rigging comes mostly out of the rescue and entertainment rigging industries. There are many other types that can be used, but listed here are the most common ones. In all cases, make sure that you are selecting hardware with appropriate load ratings and design factors. Even better is to have hardware with ratings stamped on them, and spec sheets from the manufacturer.

Remember, the hardware used in aerialist rigging is only as good as it is maintained. Proper inspection, maintenance, and removal from service when required are vital safety points.

Beam clamps are available in various styles, and create strong, non-sliding attachment points to the bottom flange of I-beams. Of these different types, only a couple are suitable for aerialist rigging, as they securely capture both sides of the I-beam's lower flange, and have ratings suited to the loads present in aerial acts.

Adjustable Beam Clamps

The jaw-style clamp acts like a vise. When screwed tight, it captures both edges of the I-beam's lower flange. These should only be used for aerial acts that create a downward force, as they are not designed for a dynamic gimbaling motion.

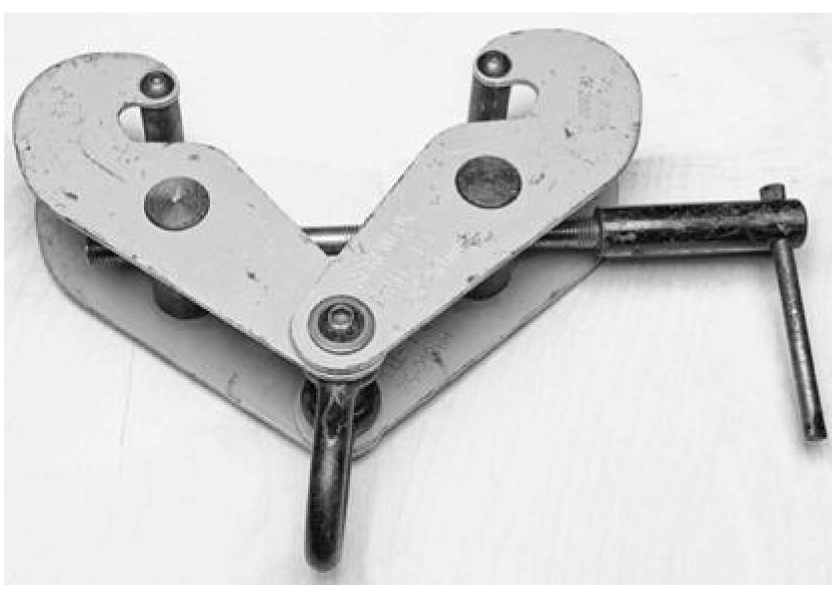


Figure 7.8 Adjustable beam clamp

Cleat Beam Clamps

The other style of clamp places cleats on top of each of the I-beam’s lower flanges, that bolt to a piece of channel steel running perpendicular under the beam. A swiveling eye-bolt for rigging attachment is centered on the underside of the channel steel.

Figure 7.9 Cleat beam clamp

Riggers beware: Many other types of hardware and devices fall under the name “beam clamp.” These are used for hanging electrical conduit, lighting, threaded rod, or other construction materials, and some only clamp to one edge of the bottom flange. They are not appropriate for aerialist acts.

Synthetic Roundslings

These slings come with and without an internal wire rope core, are incredibly strong, and work well in numerous applications for wrapping beams and trusses of all shapes, sizes, and materials. Care should be taken that they are installed in a way that minimizes the chance of them sliding.

Figure 7.10 Synthetic roundsling

Carabiners

Figure 7.11 Carabiners

Carabiners are connectors commonly used in aerialist rigging. They can be manipulated with one hand and do not have separate pieces that can be dropped or lost. They are manufactured in many styles, with the variations focusing mainly on the gate, shape, and material.

Choose carabiners with appropriate ratings and “auto-locking” gates. The motions involved in aerial performances can easily cause an unlocked gate to open, or a “screw-lock” gate to spin itself into an unlocked position. The shape of the carabiner chosen is determined by how this connection will be used and loaded. Ovals and Ds are for connecting straight-line loads, while the pear-shaped ones give more room for attaching aerial fabric or apparatus on the larger side, but can also function like a shackle, connecting three lines or loads together. The choice of steel versus aluminum is up to the educated user.

Swivels

Swivels are essential in aerialist rigging and performance. These allow the aerialists to safely spin at high speeds, and continue to do so over long periods of time. They also keep the rope and cables used in the rigging and aerial apparatus from becoming overly twisted or unwound during the routines. Make sure the swivels you have chosen have appropriate ratings and are designed for spinning, not simply for rotating gear into alignment.

Figure 7.12 Swivels

Blocks or Pulleys

Blocks and pulleys are used in moveable point rigging, or any time the aerial apparatus is going to be raised or lowered. Whether this is happening before and after the routine or during, blocks should be appropriately chosen for not only their design factor, but also for the size of cable or rope that will travel through them.

Figure 7.13 Blocks and pulleys

Clew Plates

Figure 7.14 Clew plates

Clew plates are used for connecting multiple lines or loads together. They are the rigging equivalent to the stage electrician’s twofers or threefers. Typically cut from plate metal, they have multiple holes that give the rigger options for attaching carabiners or other connecting hardware in an organized distribution.

Clew plates are commonly used in straps routines. The two separate straps are attached to the lower outside points of a clew plate, with the top of the clew plate being connected to a swivel.

Rescue 8

Rescue and figure 8s are used for creating the attachment point on an aerial silk. The midpoint of the silk is passed through the large eye and choked over itself making the two hanging lengths used by aerialists. The small eye of the 8 is then connected to a swivel.

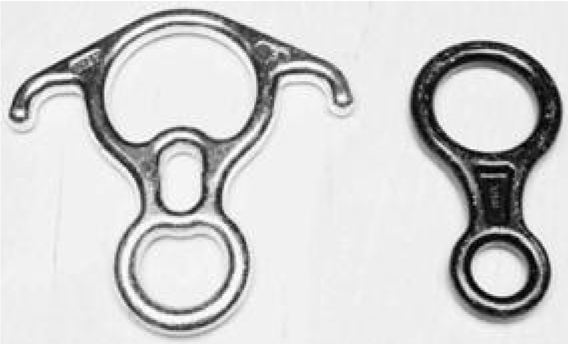


Figure 7.15 Rescue 8

Load Cells

Figure 7.16 Load cell

Load cells are a newer technology entering aerialist rigging circles. Strategically placed between the rigging equipment and the load, the electronic load cell monitors the force created by that load. They are available with various ranges and features including digital readouts, recording of peak loads, and wireless connectivity. Some load cell systems can be networked together to monitor entire rigging systems (placed at every chain hoist of a truss grid, for example), transmitting their data to a single computer that can monitor and record the constant changes in force, and even signaling alerts when programmed thresholds are exceeded.

In aerialist rigging, a load cell would typically be placed above the performer to monitor the changes in force, as well as the peaks throughout a routine. Data that have been collected from load cells used in this way have put hard numbers onto the dynamic, and sometimes confusing, forces created during aerial performances.

Anchorage Points and Rigging Points

In order to rig anything in a venue, there must first be some structure capable of supporting the load. This is an anchorage point. Riggers attach the load to a rigging point that ultimately transfers that load to the anchorage point. In some cases these are the same thing and in others there can be multiple layers of rigging or structure that separate them. How direct this load transfer is depends on the venue.

Entertainment venues are designed to offer multiple accessible rigging points that distribute the loads back to various anchorage points within the venue's structure. In arenas, these rigging points take the form of high and low rigging steel, often I-beams and catwalks, but can also include mother trusses—entire truss grids that can be lowered for ground-level rigging, then raised into show positions. Theatres can have counterweight systems and networks of grids and catwalks, providing not only rigging options, but also the ability to easily fly scenery and equipment during a show.

In venues that do not have these conventions, or do not have them in the desired performance location, the rigger must find the anchorage points and create rigging points from those. These could be accessible I-beams, architectural elements, or any number of things. Just because a beam is the only one in the room or "we've used it before" does not mean it is the only rigging option. Get a building manager or engineer involved if ratings are not known or not readily discernible.

In some cases it might be necessary to build from the ground up, literally using ground support truss or stage scaffolding. Location work for events and film often utilize cranes for overhead rigging, and ballast in the form of water containers, large concrete blocks, or even sea containers for anchorage points.

Aerialist Rigging

Aerialist rigging can be divided into two main categories: fixed point, where the aerial apparatus is suspended at height; or moveable point, where the aerial apparatus is attached to a line running through blocks so it can be raised and lowered. Both of these can be broken down into further variations.

Fixed point, in its simplest form, is where the rigging height meets the aerialist's need, and the aerial apparatus connects directly to a single anchorage point. Where more than one rigging point is needed for load distribution or performance placement, a bridled point, or a suspended section of box truss can be used. When the rigging point is too high for the aerialist, the apparatus attachment must be lowered to the desired aerial height. This can be accomplished by adding an extension between the rigging point and the aerial apparatus or, in a more conventionally outfitted venue, by lowering the rigging point. This might be flying in the batten, or lowering the truss.

A typical fixed point aerialist rig would be as follows: starting at the rigging point, a carabiner is connected to the roundsling, beam clamp, mounted eye, or batten clamp. That hanging carabiner is then connected to a swivel, with another carabiner below, making the final connection of the swivel to the aerial apparatus.

Moveable point is when the connection point for the aerial apparatus is attached to the end of a retractable line instead of a rigging point. The line is routed through blocks to some type of lift control. The blocks are attached to the rigging points. The lift control, either a person manually pulling a rope or a mechanical device such as an electric drum hoist, should be placed safely away from the aerialist's performance area, and offstage if during a show. Being able to lift and lower the aerial apparatus can be necessary in many situations.

The aerial performance may involve changes in height as part of the choreography, including raising the aerialist to a specific height, lifting or lowering them during the performance, and returning them to the stage at the end of the act. Moveable point rigging can also be used for safe storage between studio uses or scenes in a show. The convenience of easy access to the connection point for inspecting, swapping, or removing the apparatus cannot be overstated in situations where the use of ladders or lifts is limited by production obstacles such as scenery. It may also be unreasonable for a non-performance venue to have ready access to ladders or lifts at all times.

A simple moveable point aerialist rig would be as follows: starting from the aerial apparatus, its connecting hardware is attached to a line that routes up through a block attached to a rigging point directly over the aerialist. The line continues across through another block and down, attaching to the lift control. This final block functions as a head block and should be attached to a rigging point located directly above what will be controlling the raising and lowering.

Point Stabilization

Whether fixed or moveable point rigging is used, point stabilization should be considered anytime the aerialist rigging involves more than the apparatus connecting directly to an anchorage point. During an aerial performance, the movements of the aerialist may shock the system or cause it to sway. In all but the simplest of fixed point rigging scenarios, these forces are transferred to the entire rigging system, creating a swing that can make it difficult for the performer to maintain balance and control. In some cases the aerialist might collide with other performers or set pieces. The rigging supporting the aerialist may bump into other truss, line-sets, or equipment.

The aerialist rigger's solution to this problem is point stabilization. Stabilizing lines, sometimes referred to as guy lines, are used to immobilize the rigging point from moving with the performer. The number of lines used will depend on the truss, batten, or point you are trying to stabilize. Tensioned wire rope, ratcheting load straps, or metal pipe with cheeseboroughs connect the aerialist rigging to points or structure in the venue.

Venues

Aerial arts are being practiced and performed in just about every type of venue imaginable. From theatre to stadium to outdoor festivals, the aerialist's requirements are relatively simple: a fixed or movable point at a specific height. Aerialist rigging strategies differ depending on the venue and the aerial act. It is the job of the aerialist rigger to create a safe and efficient rigging plan utilizing the venue's advantages, while avoiding elements less conducive to the aerial performance or its rigging.

Arenas

These venues usually have a vast expanse of open space, allowing for rigging access with less chance of structural obstructions and point placement limitations. Arenas often have steel beams as anchorage points that can support substantial loads. These beams are almost always too high for just a simple fixed point to suffice, and in terms of a plan view, they are rarely located above the desired performance position. To get the proper point placement in an arena, oftentimes it is necessary to bridle between two or more beams.

Consideration must also be given to how the aerialist rigging and performance will interact with the rest of the production's rigging for lighting, sound, video, etc. Lighting designers tend to be less than pleased to see their lighting instruments swinging along with the aerialists.

Installing the aerialist rigging on separate points or truss from all other production elements of the show will eliminate this interference. Complete moveable point systems, including their control hoists, can be attached to their own trusses. These independent systems can be easily adjusted or inspected without affecting a show's entire truss network.

Point stabilization in arenas can be a challenge due to the long distances, and the often limited options for sturdy points below the overhead beams used for rigging. Consulting the arena's head rigger or engineer can be very helpful in these instances, making sure the stabilizing lines are rigged to suitable points, and will not cause visibility concerns for the production design. Aerialist rigging that blocks audience line of sight or casts shadows on projection screens can be as bad as swinging lighting instruments.

Theatres

Aerialist rigging in a theatre depends on where in the theatre the aerialist will perform, and what the theatre has to offer in terms of rigging points and conventional fly systems. Knowing the aerialist's needs will enable the aerialist rigger to create a rigging plan that complements the show's other production elements and takes best advantage of the theatre's technical capabilities.

Counterweight and motorized batten fly systems can be utilized for aerialist rigging. The aerialist rigger should check with the technical staff for those systems' ratings, and obtain the venue's permission to use them for aerialist rigging. Both fixed and moveable points can be rigged to battens, as long as care is taken to avoid imposing point loads that will bend a batten.

The rigged batten can be flown out to the desired height and secured, so the batten cannot move during the aerial routine. Immobilizing the arbor with safeties to the counterweight system's anchorage points, appropriately locking out the hoist controlling the batten, or attaching the batten to the grid or overhead anchorage points with dead tie lines of chain or wire rope will work.

If the fly system is not in the right location for the aerial performance, or if using a fly system is not an option, the aerialist rigging methods mentioned in the arena section can be used. Most theatres have beams or structural rigging points that can be used as anchorage points.

Many options exist for mounting and securing hoists for moveable point rigging. Catwalks, mid rails, and pin rails are some of the typical theatre structures positioned in places that align neatly with the aerialist rigging. These are very useful for point stabilizing, which is almost always needed in a theatre venue to give the aerialist a solid point at the desired height, and also to keep the aerial act's motion from disturbing the adjacent line-sets that may contain everything from electrics to band shells to projection screens.

Cruise Ships

Aerial acts are very popular on cruise ships. They tend to be permanent, or at least long-running, parts of the shows. The venues for these shows are, like most other places on ships, efficient and economical with their usage of space. The motion of the ship can also be an issue. Everything from scenery to sound equipment is designed and installed in ways that have them organized to fit in among everything else, and to allow them to move only as needed for the show, but not to be swinging or rolling loose as the ship is at sea.

Aerialist rigging is no exception, and is installed in ways that would be considered permanent in other venues. Rigging points are made with eyebolts mounted to the anchorage points. Hoists are mounted to beams and catwalks with bolts.

The lower heights available in most of the compact cruise ship venues are typically well-suited for most aerial work, although many of them are too low for some of the bigger silk routines. Lower height, coupled with the more permanent style of mounting and rigging the equipment, means point stabilizing is rarely needed.

Ballrooms

Ballrooms and their cousins, convention meeting rooms, generally provide good heights for aerial acts, 15′ to 20′ being common; however, they often have some form of ceiling below the anchorage points. Occasionally rigging grids have been installed above the ceiling to accommodate the more common production needs, such as lighting trusses or projection screens, but usually rigging is limited to the main beams located above the ceiling. These beams can be spread out and, with the low ceiling height, bridling options are limited. The rigging points are often quite a bit above the ceiling, with all sorts of electrical, mechanical, and HVAC in between

In addition, the main beams are usually sprayed with a fireproofing insulation that, when disturbed, breaks away from the beams. A truss section can underhang the ceiling by rigging from two or more main beams, coming down through removed ceiling tiles. Stabilizing lines are necessary to limit sway. Pipe and cheeseboroughs work well if they can be connected from the truss back up to the beams or other solid structure above the ceiling. This will stop insulation from raining down during the performance, and also protect the ceiling from damage.

Ground supported structures can also be used. These boxed-in structures provide a stabilized point and eliminate the need for roof attachments. (They can be supported with grid assists from above, if worried about load limitations.) They provide a rigging option when beams are poorly located, inaccessible, or not rated for the application.

Non-Traditional Venues

Aerialists are performing just about everywhere. While the previous entertainment venues all have their own advantages and disadvantages, they are set up with facilities, staff, and ratings ready for rigging. But many aerial performances are happening in locations just as visually interesting as the acts themselves.

These venues can range from large atriums to studios to outdoor architecture. Aerialist riggers must do extra legwork or consultation to ensure safe rigging options in these circumstances. Engineered drawings and meeting with the engineer may be required to assess and discuss viable load-bearing options. Furnishing the engineer with information as to the type of loads and forces created by the proposed aerial act will help ensure usable rigging specifications.

Smart Aerialist Rigging

Risk assessment and inspections are the “before and after” of smart aerialist rigging. They are the first tools for preventing accidents. Hazards that can be understood before the aerialist rigging plan is developed can be minimized. Inspecting in a planned and routine manner ensures that everything functions as it should, while at the same time making it easier to identify potentially unsafe scenarios that might develop over time.

For any aerialist rigging show or project, identify the why, who, what, when, and how for both the risk assessment and the inspections. The results from this preparedness and follow-through reduce accidents and instill confidence in the aerialist rigger and rigging. Smart aerialist rigging is better aerialist rigging.

Risk Assessment

WHY

Thorough risk assessment will identify hazards in the aerial routine and rigging. Once known, those risks can be eliminated or minimized. Weak links in the rigging plan can be fixed. If needed, rescue plans can be developed that will respond accordingly and efficiently.

WHO

The aerialist rigger should spearhead the risk assessment process. Involve the aerialist—no one will know the aerial apparatus and routine better. Depending on the complexity of the show, get someone from production involved too. By including these individuals, you may learn of new hazards. They may also be able to provide solutions from their end that are simpler than ones on the aerialist rigging side of things.

WHAT

Include the entire aerial project. Rigging should take into account the aerialist rigging and the venue rigging. Consider the aerial apparatus in general, and the specific piece of equipment being used. For the actual performance, look at the routine, the aerialist, and any operators. Remember show factors, such as apparatus storage, cueing procedures, and communication.

Rescue options are ways of minimizing hazards too, but those rescue procedures should be assessed for risks to the rescue team.

WHEN

Do the first risk assessment before rigging even starts. Consider doing follow-up risk assessments as changes happen. Were substitutions made to the rigging plan during the install? Has there been a change in the show, cast, or crew? Have the needs of the aerialist changed? Is there any proposed new hardware or apparatus?

HOW

Be thorough. Go in deep, get specific, but leave egos and biases out of it. Get expert help or input when it is needed. Once the risk assessment is complete, get it looked over for a second opinion.

Inspections

WHY

Inspections catch things before they cause accidents. Aerialist rigging utilizes many types of hardware and equipment. They all wear over time. Some are complex, and require a sophisticated maintenance regime to retain necessary specifications for safe operation. Mistakes can happen during install or servicing.

The overall production may have elements that require consideration during inspection. Use of haze, fog, and pyro can leave residue on rigging components. Poorly preset scenery can obstruct line of sight, or create a dangerous interference.

A comprehensive and well-planned inspection, performed routinely, is one of the most effective ways for an aerialist rigger to reduce risks and prevent accidents during the show run or for the lifetime of the aerialist rigging.

What

Automatically included on the inspection checklist will be the aerial apparatus, the aerialist rigging components, and any venue rigging affected or utilized for the rigging plan or aerial act. Power sources and any mechanical or automated equipment should be checked.

Refer to the risk assessment. Include the aerialist and any operators. Communication lines should be checked. Special cues should have their test runs. Any parts of the rescue plan—equipment, lifts, or personnel—get inspected too.

Who

The aerialist should always check their apparatus, and be encouraged to inspect the aerialist rigging at least after the completion of install. The aerialist rigger should perform the inspections or train a designated inspector.

When

The aerial apparatus should be inspected before and after every use. The aerialist rigging is inspected at the end of install, then on a scheduled basis depending on the risk assessment. If the aerialist rigging is for a long-running show, or a permanent install, there might be service inspections that involve changing out parts of the rigging.

How

Once the inspection checklist has been agreed upon, organize the inspections so they can be performed expeditiously. Is there a necessary order to steps for the inspection? Consider the accessibility to the rigging. Are lifts needed, or is there an easier way to complete that part of the inspection? Could binoculars be used? Is there a portion that requires video monitoring?

Use checklists during the inspections, and be ready to photograph and document any findings. If any repairs or service are performed, document these as well. All of this is recorded in a logbook. Include the dates, checklists, and inspectors' names.

Thinking Ahead

Aerial arts continue to grow in popularity. Aerialists are taking advantage of the increasing resources for training and practice. Aerialist riggers are now finding opportunities for workshops and education in actual aerialist rigging. New performers and riggers are being drawn to this art form. People on both ends of the rigging are expanding the possibilities. As the world of aerial arts grows and expands, is there a place for aerialist rigging to evolve alongside aerial performances?

Yes. By increasing the understanding of what is physically happening to the rigging during aerial routines, aerialist riggers can devise new methods of rigging, search for alternative equipment options (and even create the need) and contribute to the development of gear designed specifically for aerialist rigging. Comparing data from load cells with video (especially high speed) of aerial routines shows how much force is being created, how it changes throughout the aerial performance, and how it affects the different components in an aerialist rigging system.

The increasing availability of load cells over recent years has enabled aerialists and riggers alike, to see in actual numbers, what is happening. Readings can be taken throughout an entire routine and, when cross-referenced with the routine's video, can create true working explanations of the changing forces and loads in an aerial act. These experiments are being done, and, as the volume of data increases, it will benefit aerial artists and aerialist riggers alike.

Finally

Being an aerialist rigger means being part of the team bringing an aerial act to an audience. The aerialist rigger brings skills and experience to create a safe rigging environment for the aerialist, other production professionals, and the audience. At the same time the aerialist rigger provides the aerialist with a secure and stable point at the height they are prepared to confidently perform.

In aerialist rigging especially, the rigger also brings an attitude that promotes understanding and collaboration between the aerialist, the venue, and the production, while providing professional rigging solutions. In all of this diplomacy, the aerialist rigger must still be ready to confidently say “no” when necessary and back up their decision with knowledge and experience.

Aerialist rigging is combining a rigger’s knowledge and experience with a sense of professional responsibility to safely support aerial work while, at the same time, understanding it as a form of art.

8
Performer Flying

JOE MCGEOUGH

Foreword

The field of entertainment technology fascinated me at an early age. I worked on my first show in high school; it was a production of *Fiddler on the Roof* (no performer flying) and I was assigned to the carpenter crew building sets and marveled at the fact that there was a group of wizards known as scenic painters and lighting technicians who could make my crude construction look good. I can remember watching the show and thinking to myself "this is something I would really love to be involved with."

Fortunately I knew the right people in the business and before long I was building stages for rock concerts, setting up lights and loading trucks locally in Portland, Maine. The team aspects of the crew were engaging and before long I was venturing up to the catwalk to assist the tour riggers hanging chain hoists from the roof with steel slings and shackles. The confusion and hectic pace of the work below did not follow me up to the rafters; I found the level of concentration required for high rigging to be very peaceful and calming, and I've never looked back.

Performer flying came when I met Peter Foy in the Ice Capades back in 1978. Like many people who met Peter, I was immediately drawn to both what he did and to the man himself; I knew nothing about his craft but he was very willing to teach me countless things in many areas over the decades that followed. The following is a direct result of that relationship.

History

Stage flying dates back to the time of ancient Greece. Back then the god-like characters such as Hercules would be performing in a drama and find themselves in a near-death predicament when suddenly a device similar to a large crane would appear on stage and lift the performer to safety. It was called "deus ex machina," a Latin term that translates to "god from the machine," and the effect was fitting for the characters portrayed in the shows. The methods are considered primitive by today's standards; however, the ingenuity behind this machine places performer flying alongside the trapdoor as one of the oldest special effects in the history of theatre. There was not much innovation in the art of stage flying for centuries until the opening of *Peter Pan* in London, and then—beginning in the 1950s—Peter Foy not only changed the way stage flying was done but introduced many new products and techniques to accomplish the effects.

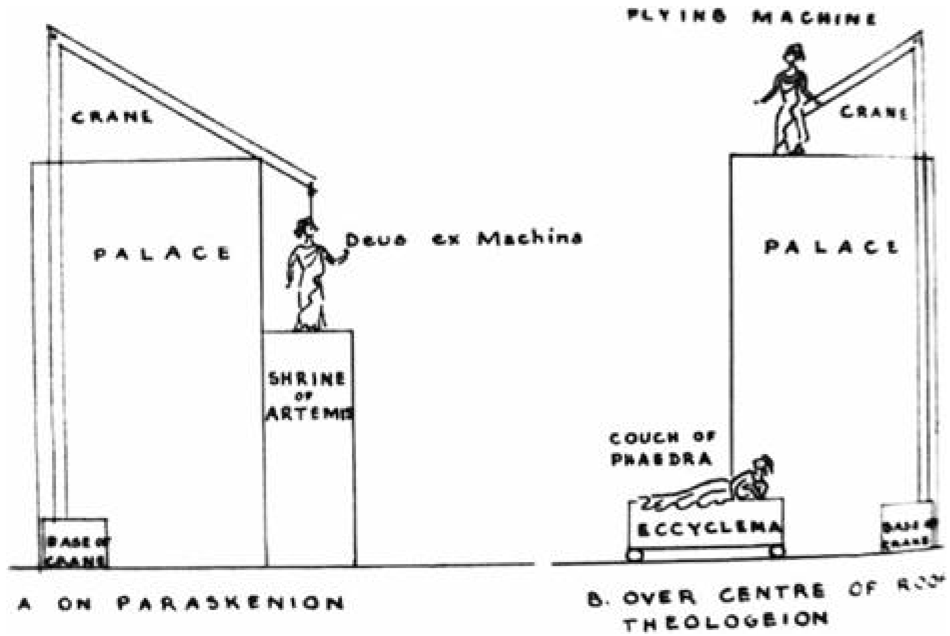


Figure 8.1

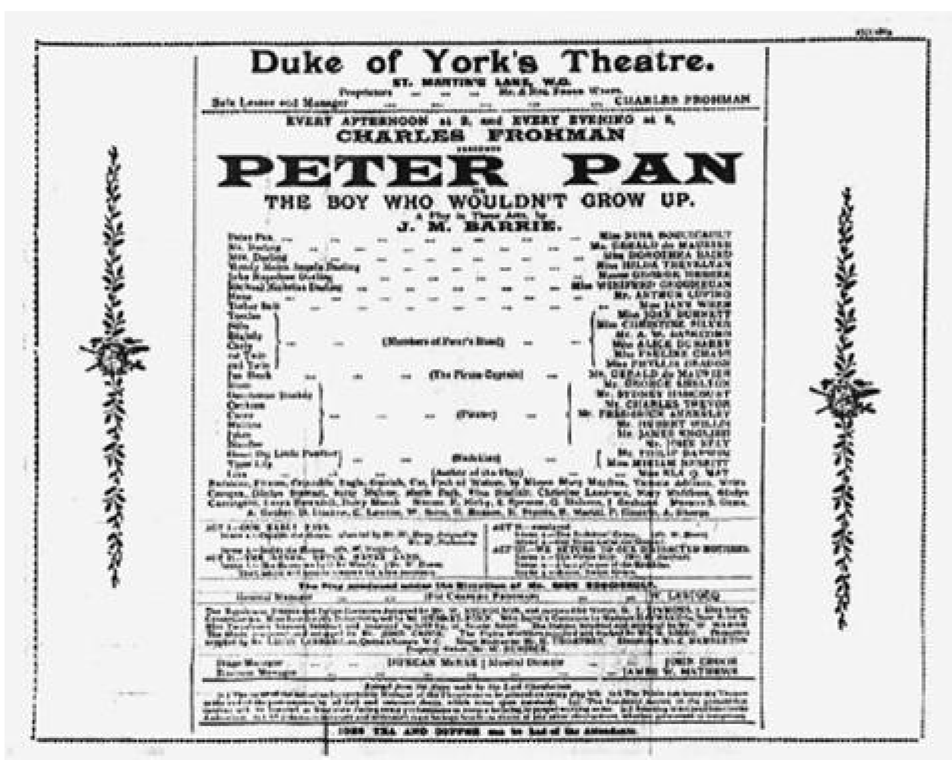


Figure 8.2

With the introduction of J.M. Barrie's play *Peter Pan* at the Duke of York Theatre in London in 1904, performer flying took a giant leap. The show was very successful, with much of the excitement generated by Peter Pan and the Darling children flying from their nursery to Neverland and subsequently back to their home in London. The flying effects as staged in the production were so realistic that the show's producers actually had to post warnings for children attending the play that they should not attempt to fly from their bedroom windows; a sort of "we are professionals here, do not try this at home."

Manual Systems

With the success of the show in 1904, thousands of productions of *Peter Pan* (and many other productions that contain performer flying effects, such as *Wizard of Oz* and *Fiddler on the Roof*) have been produced by amateur and professional groups all over the world, often utilizing manually operated systems. When vertical movement occurs, the simplest form of performer flying available is a manually operated pendulum system consisting of ropes, wires, pulleys, and a harness. The simple pendulum is a 1:1 system, which means that there is no mechanical advantage to the lifting medium; either the operator pulling on the rope is very strong, there is more than one operator, or the performer who is flying is very light, allowing free, flowing movement up and down. The movement can be vertical; ascending or descending into a space from or to a platform, behind a wall, or out of a trapdoor in the stage. It can also be swinging side to side or a circular pattern in a cone shape; given certain parameters such as available height, width, floor space, and some creative minds working on a routine, wonderful flying effects can be created with the simple pendulum system.

If more than vertical motion is required, the pendulum motion is created by establishing a center point for the system and then moving the takeoff position for the performer away from the center point by a fixed distance. The total travel distance of the flight should never exceed two-thirds of the height of the fixed point above the performer, otherwise the speed and action of the move will not be safe. If two pendulum systems are used to fly two people, the performers can be moved away from their center takeoff marks so they are within 2′ of each other; in this position they could be facing one another or virtually back-to-back. If both performers are lifted together, at the same pace and distance, without providing additional motivation then they will swing away from each other then back toward one another. If the movement back and forth is not too dynamic, they can join hands and stop in mid-air during the move; they could then be landed together or release and swing, then land.

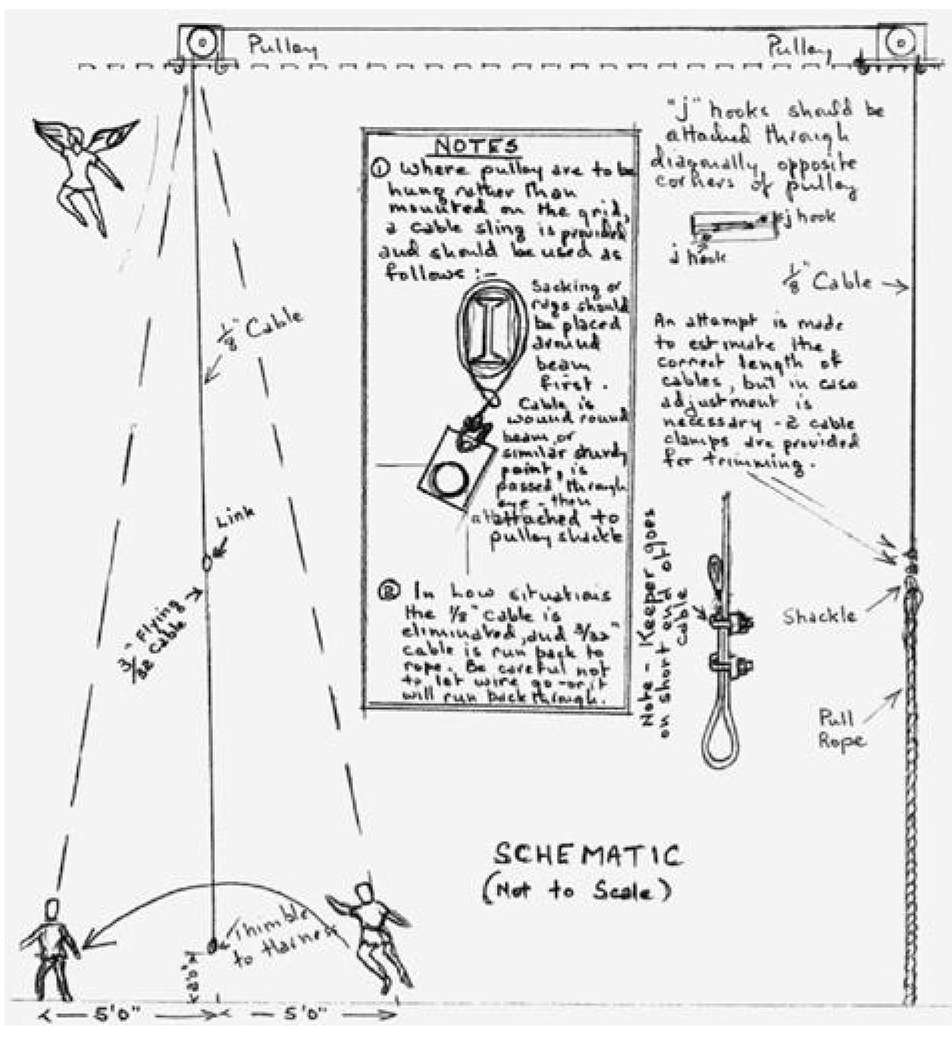


Figure 8.3 A performer’s movement is governed by his starting position. If he starts 5′0″ to one side of a mark placed directly beneath pulley and is lifted then he will fly to a point 5′0″ on the other side of the mark, always passing over

that mark. If he is landed at the end of the swing, he will have completed a flight of 10’0’. If he is not landed then he will continue to swing to and fro over that path until he is landed. He must always be landed at the end of a swing, trying to catch that moment when he is stationary, before he changes direction. Once this technique has been mastered, the flights can be extended one foot at a time until the maximum desired length of flight is achieved. Note that *total* flight length must not exceed two-thirds of the height the pulley is suspended.

In addition to the swing patterns in and out, circular movement can be accomplished. This is done by having the performer walk, glide, or move in a circular motion around the fixed center point. Once they have established the movement, they can be lifted and a conical shape to the flight will be created. If the costume has flowing fabric or large wings then this kind of movement can be breathtaking.

Manual compound lift systems are also available and can be used to lift heavier performers. The compounding can be accomplished with multiple pulleys using a mechanical advantage, counterweights, or via a drum system with different diameter wheels. All of the lifting that is done in the simple pendulum system can be performed by the operator of a compound system. The advantage of the compound is the operator is lifting less weight; however, the operator must move more rope in the compound system in order to move the same distance in a simple pendulum system. If a compound system with a 2:1 mechanical advantage is used the operator must lift 20′ of rope in order to lift the performer 10′. Most times this is not an issue; however, if there is limited height in the venue then other means may be required to do the effect.

Innovations

When side-to-side movement of the system is not able to be done by the performer once they are lifted in the air, other equipment can be provided to make this motion. The interrelated pendulum or bridled system is one such method that can be used. This process takes two pendulum lines that are spaced apart a certain distance (depending upon the available height) and joined together above the performer; then there is typically another wire that is run down to the harness. Most times the interrelated pendulum system utilizes compound drums with a mechanical advantage of 2:1 or 3:2 allowing the operators to lift and slack their ropes without too much resistance to the load. The distance of the points above, together with the height of the structure and the pace at which the operators pull and slack the operating ropes, will dictate the amount of side-to-side motion available.

The operators of the system are typically close by one another so they can determine who is lifting and who is slacking at just the right moment. (In Figure 8.4 they are placed at opposite sides of the stage for clarity in the diagram.) With both operators lifting together, the performer will lift straight up above the stage; if one operator lifts and the other slacks the line then the performer will move in one direction over the stage. To move the performer in the opposite direction, the operators switch the direction they are pulling or slacking the ropes and the performer will swing in the other direction. To control the swing, one rope is pulled as the other is slacked quickly, which moves the bridle point over the head of the performer stabilizing the swing. Operating this type of system is similar to watching a bell ringer in a church tower; as the line is slackened then suddenly stopped the operator is sometimes lifted off the ground due to the speed and swing pattern of the performer. Peter Foy utilized this type of system to fly Mary Martin on Broadway in the production of *Peter Pan* in the early 1950s. The flying he did with Mary was—and still is—considered state of the art and extremely dynamic, generating swoops and swings speeds of up to 25mph over the stage. The technique for this system requires a fair amount of experience but, once mastered, can generate fluid and graceful flying effects. It is often referred to as the most difficult but most enjoyable system to operate by technicians.

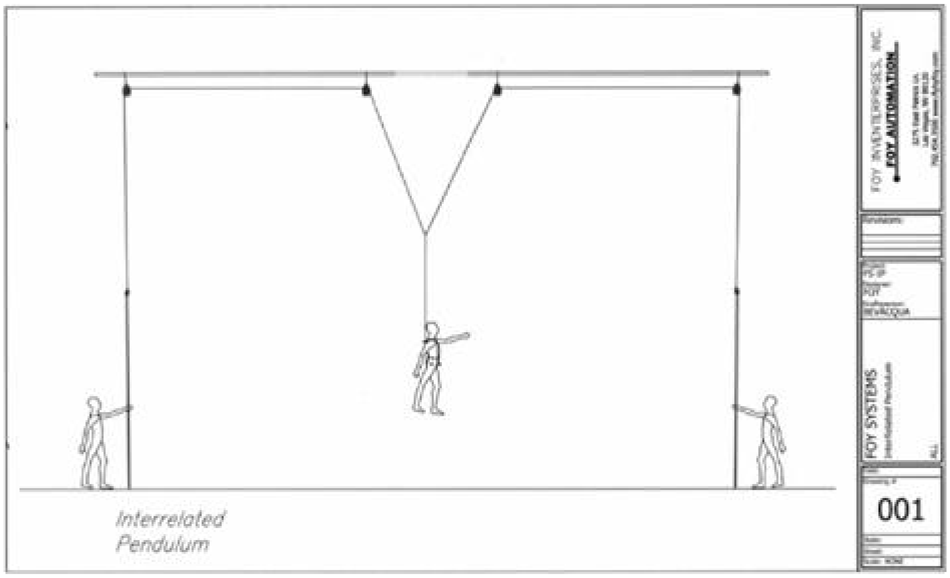


Figure 8.4

When the side-to-side movement with an interrelated pendulum system is required but not possible due to height restrictions, a tracking method needs to be employed. The simplest way of lifting and tracking a performer is to use a floating pulley track system. This is a track that has an upper and lower traveling carrier; the upper carrier houses pulleys that allow the lift cable to run over and through to a lower pulley system that "floats" up and down. The upper carrier also contains the termination for the traversing cables or ropes that pull the carrier along the length of the track. The floating pulley track is very similar to a tower crane that is normally operating on the side of a high-rise building; you can see the upper carrier that travels along the arm of the crane and the hook that attaches to the load being hoisted up and down the side of the building. With the lower pulley rigged to the upper carrier with a single run of cable or rope you get a 2:1 advantage, which reduces the lifting load by half. Manually operated floating pulley tracks are very straightforward to set up and operate, the only drawback to them is the lower floating pulley can be in view in extremely low height venues, causing a distraction to the effect. When in view of the audience, the mechanism is like watching a marionette crossbar during a show and is not easily hidden with masking or lighting.

A groundbreaking development by Peter Foy in 1962 was the Track on Track® system. Peter rigged the floating pulley or compensating pulley and placed it inside a separate short carrier track mounted horizontally below a main support long track. Now the pulley that gives you the 2:1 advantage is moving left to right to lift the performer and not up and down, making it much easier to conceal in low height situations. The Track on Track revolutionized performer flying and made it available to all sorts of venues such as multipurpose rooms in schools, tents, outdoor amphitheaters, theatres without grids, and even parade floats! The limiting factor with the Track on Track system is the length of the horizontal carrier; in manual systems this carrier is furnished with a 2:2 compensating pulley system and a 2:1 compound drum, giving you a 2:1 lifting advantage but limiting your amount of distance to raise the performer to the movement of the travel on the 2:2 compensating pulley. In most cases this would be 8′ of movement on the pulley or 16′ of actual lift.

There are many ways to mount the devices mentioned above and they can be manipulated with human or automated power; all of these systems require precise planning and a good creative outline to be used effectively. It is also important to install the flying equipment in such a way that the audience has a difficult time seeing or hearing it, which gives the element of surprise when the effect actually occurs.

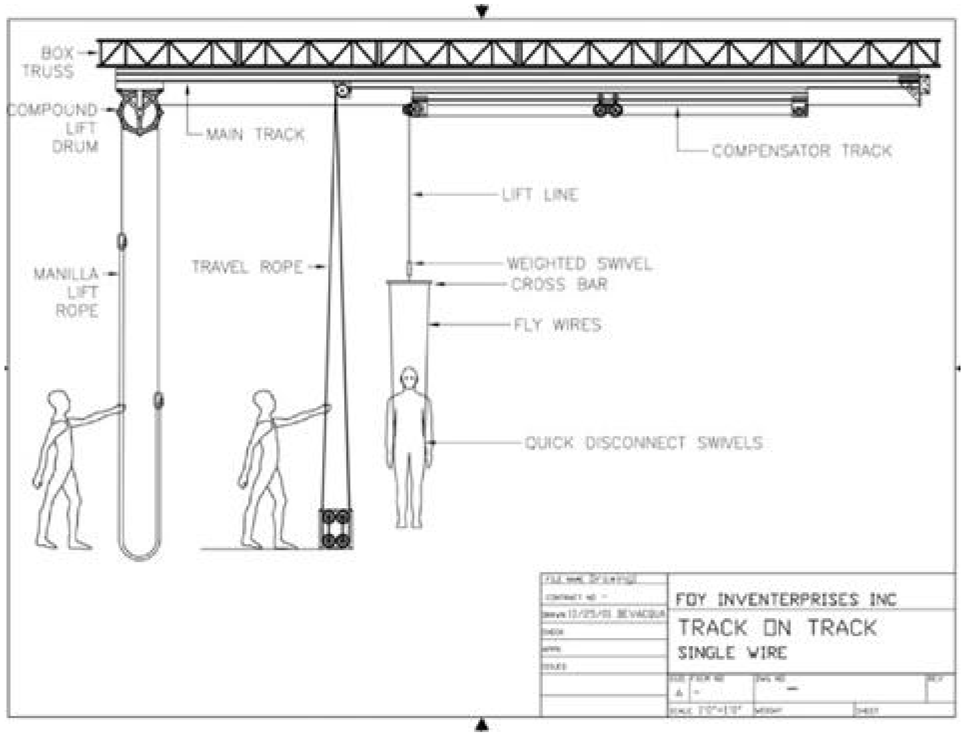


Figure 8.5

Two-dimensional flying systems

The majority of the flying effects that take place in theatre are two-dimensional in nature. Most lighting and scenery used in stage productions is hung or mounted left to right above the stage; this limits the amount of space needed for performer flying and can be quite difficult to secure. In *Peter Pan*, the entrance for Peter is one of the most dramatic in all of entertainment. In order to achieve the upstage to downstage movement (flying toward the audience) there must be an area from 6′ to 8′ kept clear for the path of the flying wire to move through the window and toward the audience. This is accomplished many times by bargaining with the scenic and lighting designers for that highly desired real estate center stage.

Tinker Bell enters the Darling nursery as a ball of light, first flitting about looking for Peter Pan’s shadow; then the windows burst open and Peter shoots through the room, flying high above the window seat and landing softly downstage near the mantle. Even though the audience is expecting Pan’s entrance they are quite often taken completely by surprise by the magnitude of it and applaud instantly. This is two-dimensional movement achieved by a very rapid lift and pendulum action that thrusts the performer into the air and toward the audience. This same method is often used for the curtain call, during which Peter is flown over the audience. The pendulum point is fixed over the orchestra pit or first few rows of the audience, the performer walks on stage to take a bow, and in a split second is lifted, rapidly swinging over the audience. The pendulum action swings back and the operator lowers the performer to the stage. In situations where there is low height above the audience, a track system is used to maximize the effect.

The Impact of Hollywood

The next major event that would have an impact on performer flying came with the release of the *Star Wars* movie in 1977. The spectacular visual effects and battle scenes showing actors flying as they wielded their light sabers created countless ideas for the creation of people moving through space in all areas of live entertainment. It seemed as though live events had to compete with cinema in order to give their audiences a “wow factor” that would keep them coming back for more. Corporate events had their CEOs making entrances flying over the audience as if they were astronauts, James Bond, or agents like Tom Cruise from the *Mission: Impossible* movies to the wild applause of their employees; it was as if everyone was sitting in an IMAX theatre waiting for the next big moment to occur, and it was being delivered.

Today it is very likely that if you watch a televised event—be it a commercial, reality or serial program, or live awards show—there is a good chance a performer will be seen flying. This could not be said 25 to 30 years ago; the influx of special effects into the entertainment industry is progressing at a staggering rate. What used to be done with wires, ropes, and pulleys is now being accomplished with sophisticated winches being controlled by high tech control systems. Let's take a look at the evolution of flying equipment and harnesses over the years.

Harnesses

Regardless of what mechanical system is used to fly a performer, the most personal element of the equation is the harness. It's hard to imagine what types of harnesses were used back in the days of ancient Greece. They probably resembled a corset that contained a few bones from animals (like a girdle), but thanks to modern high tech materials such as webbing, synthetic threads, high-density foam padding, and connection hardware, today's harnesses are lightweight, form fitting, and comfortable. The performer must have the correct fit in the harness, almost becoming one with it in order to avoid discomfort when in the air; loose straps or buckles will only cause problems as the rehearsal and run of the show continues. A prime example of "becoming one" with your harness occurred back in September 1984 in San Francisco at the Davies Symphony Hall with a legend of musical theatre.

Peter Foy was sitting in his office back in the summer of 1984 when the phone rang. He picked it up, and before he could say a word a voice came over the line asking, "Peter Foy? This is Peter Pan." Peter Foy hesitated for a minute, then asked, "Mary … it this you?"

Although it had been more than 20 years since they'd spoken, it was indeed Mary Martin and she had called to ask Peter to fly her again as Peter Pan at Davies Symphony Hall in San Francisco at a benefit for the Trauma Center where, two years earlier, she and Janet Gaynor had been treated for severe injuries suffered in a car accident. Once Peter got his composure he politely asked if Mary was alright; not from the injuries she had suffered in the accident, but for the request to fly as Peter Pan again at the age of 70! She told him she was determined to do it as long as he was there to make it happen, and so it was that Mary Martin flew over an audience filled with black ties and evening gowns wearing her original costume from Peter Pan on Broadway … and that harness. Mary requested the harness be sent to her one month before the show; she wore it diligently for four hours every day to get accustomed to it again, "becoming one" with it. That persistence paid off; she flew magnificently 50′ in the air and 100′ out over the audience to open *Mary and Friends* in September of 1984; the fairy dust and Peter Foy were there to make sure it all happened perfectly.

Single-wire harnesses that used to be made from leather and roller buckles are now made with the webbing and high tech materials mentioned above and can be set up to pick up the performer in a variety of different positions. The harness can be constructed to lift in a front seated position, leaning backward, side hanging, back vertical, or upside-down. Proper fitting of the harness must include that all buckles are secure, straps and waistbands snug, and any costume must allow for free and clear attachment of the lifting media.

Double-wire harnesses allow the performer to be connected at both hips and, if properly fitted, will give them the ability to fly in the horizontal position, flip somersaults through the suspension media, or assume any position in between. Many performers prefer to hang upside down when in the air waiting for a cue because it relieves the pressure on the waist and between the legs.

While working on the Oscar-winning film *Fantastic Voyage* in the 1960s, Peter Foy developed the multi-position attachment for the double-wire harness. The film called for the actors played by Stephen Boyd and Raquel Welch to save the life of scientist Jan Benes (played by Jean Del Val), who was left comatose with a blood clot in his brain caused by an assassination attempt. They are placed into a submarine and miniaturized to microscopic proportion and injected into the body of Mr. Benes with the task of removing the blood clot. Several obstacles change the course of the mission, but in the end the characters eject from the submarine and swim to the blood clot, remove it and exit Mr. Benes' body via a teardrop in his eye just before they returned to normal size.

The challenge for Peter Foy in *Fantastic Voyage* was to create effects that made the actors appear to be scuba diving. The film's producers were concerned about creating actual scuba scenes due to the costly water tanks or location shots required that were outside the budget for the film. Wires were blended into the background of scenic veins (like vines or seaweed) and the multi-position harness allowed for perfect balance for the actors. This balance enabled the actors to fly horizontally or flip effortlessly as if swimming through water. Peter was able to work with the cast to position them in virtually any direction as they interacted with the set and each other (due to the physique of Ms. Welch, the multi-position harness came in very handy). The end result was a perfect underwater sequence causing one director outside of the project to ask Peter how he staged the swimming sequences in the water. Peter took great pride in the fact that most people who saw the film thought the actors were really swimming; other directors approached him to ask how big the tank of water was to create the effects, and he would just smile and tell them it was all accomplished with wires and harnesses.

Figure 8.6

Sometimes rapid movement is required, such as actors being ejected from vehicles or blown up in a battle scene. When this type of movement is needed then jerk vests are worn, which create a multitude of hanging options with multiple loops of webbing sewn into the body of the suit. This type of harness allows for higher impact movement due to the fact that harness covers more of the body and the material spreads the load imparted on the body throughout the chest, shoulders, hips, legs, and crotch.

There are also twisting belts or halo harnesses available. These are harnesses that provide the performer with a third axis of motion; they have the ability to twist between the wires like a corkscrew. There are waist, shoulder, and leg straps just like the other harnesses; however, there is also a solid ring around the exterior of the harness that has a bearing surface allowing the twisting action that is generated by the performer. This type of harness requires more rehearsal time with the performer; very subtle body movements are needed in order to make the twisting appear smooth and effortless.

Custom harnesses for special applications are common; the most common harness for special application is the hanging harness. Many productions require a hanging to take place and to make it appear authentic most times a harness is used. These harnesses have a pick point near the top of the shoulder behind the neck; most are somewhat adjustable to allow for perfect placement of the pick point. The noose is cosmetic only and has the support cable or wire run through or just outside of it. The termination on the noose must not be complete. The noose must fall apart if loaded; only the wire must support the performer.

Other custom harnesses can be used for illusions where the performer is lying on a rigid frame and strapped in; this projects the illusion that the performer is in a trance but completely prone or horizontal in space.

The webbing in all harnesses can be padded to allow the performer to hang for several minutes provided the limbs are kept moving and circulation is continuous. Any numbing of the limbs or noticeable discomfort of the performer requires that they are lowered to the ground and disconnected from the system. Before staging any flying sequences, the operator of the flying equipment will always work out a distress signal with the aerial performer. When that signal is given by the aerialist then the operator knows there is a problem and that the performer needs to be lowered to the ground right away.

Costume Interface

The costume and the harness have to be designed together for any production. Many times the harness is integrated directly into the costume and in some instances it is partially attached to the costume. A typical instance of this is on a double wire harness when the performer is carrying out multiple somersaults and the costume has snaps or Velcro to attach it to the harness around the hip area. This is the same location that the lifting media is attached to the harness and by joining the costume in this area it prevents the two from getting snagged in the rotating hardware on the harness.

Flying without harnesses is prevalent today in many circuses and aerial shows; this is seen as flying with apparatus such as silk or tissue acts, straps or webbing acts, and cube or hoop acts. Many times the apparatus is hung in a static position and the acrobat climbs up to it or is lowered to it to perform the act. These acrobats have years of strength training and many times do not wear safety belts. There are of course situations where safety belts are used; it is mandated that performers wear safety belts when performing over other people, both audience and actors.

Automated and 3D Flying

Automated flying systems have their advantages and have become more prevalent in the past 10–15 years. The main reasons for choosing automation over manually operated systems are safety, labor, and repeatability. Winches can be designed to lift much heavier loads and move them safely and efficiently at speeds not possible with manual systems. In a manually operated system the operators have more feel should problems occur; for instance, if a cable jams in a scenic unit while flying a performer the operators are more likely to be stopped then if it were automated. Thresholds for position errors or over-current can be set in an automated system that would fault or trip if a cable jams; however, if the output current is lowered to this threshold it may not be sufficient to lift or swing the performer. In most safety situations when an automated flying system is installed for a show there are spotters put in place with a clear line of sight to the flying performer; the spotters have immediate access to emergency stop stations that can stop all movement if a problem occurs. It is also extremely important the operator of any automated performer flying system have line of sight to the performers being flown; reaction time to a problem is often a key to protecting the aerialist.

Most people have seen TV cameras being flown over an arena or football stadium during a live sporting event; the same type of setup is used for the flying of performers. Computer programs are now available to control multiple winches that operate together to fly performers in three dimensions. These systems are designed to move the performer up, down, left, right, and in circular motions with extreme accuracy. The manual operation of a system such as this would be virtually impossible given most setup and rehearsal times. Now, with the advanced technology, enabling the operator of a flying console the three-dimensional movement described above can be pre-visualized in simulation on a computer then played back in real time once the winches and rigging have been put in place in a specific venue. The savings on rehearsal time using this type of technology are invaluable.

In a recent production of *Aladdin* at an outdoor amphitheater, the director required a magic carpet to fly from the stage over the audience with the two stars of the show performing on the carpet. The dimensions of the amphitheater, scenery, winches, and the rigging were preprogrammed into the control system and the entire flight sequence was run in a pre-visualization program before the system was installed. The show required four winches to lift and move the carpet over the stage and then out over the audience; a wireless revolving unit rotated the carpet as it flew over the house, making the carpet come to life. Pulleys were strategically placed on towers at the borders of the flight path allowing the carpet to move totally over the seating area giving all patrons a close up view of the stars of the show. The wireless rotate winch was located just below the connection point of the four lines that lifted and moved the carpet and was powered by 12-volt batteries that required charging overnight. Its revolve was programmed in the computer to give the audience the best view of the performers as they flew overhead. The performers were tethered to the system wearing harnesses that would not allow them to reach the side of the carpet. As an added layer of safety there were wireless load cells mounted at the connection point above the carpet; these were tied into the E-stop loop of the control system.

Three-dimensional flying requires clear space in order for the wires or ropes to move about the performance area without contact above the performer being flown. This is not always possible in theatres or studios due to the lighting and scenic elements that are installed for most productions. If there is enough space then the result can be magnificent. On Broadway the *Mary Poppins* curtain call totally surprised the audience when she traveled over the stage then proceeded over the orchestra pit toward the balcony; she then lifted 50’ up to the ceiling, passing both balconies and nearly touching the people in the front row. It was truly amazing how the roar from the crowd got louder the further she went out toward them then up out of sight. Lighting was a key element to this flying effect as the wires were preset over the audience for the entire show but they were never seen, even when lifting up into the ceiling at the end of the show. This three-dimensional flying effect was accomplished with a two-axis track located over the stage and a pendulum winch located out over the audience; the two systems were connected to create the third dimension of flying out into the auditorium.

Creative Process

About 30 years ago, Peter Foy provided the flying effects for Seattle Operas Ring Cycle segment *Die Walküre*; the set designer placed a mobile tower about 30′ tall on the stage, which housed the female lead in the show, a character named Brünnhilde. She controlled all aspects of the tower, which produced the army of Valkyries as it was moved all around the stage by the many minions below. The director wanted her to fly up and down from the tower showing her prowess as the mighty Valkyrie. We were able to install an electric winch system within the tower structure and with a series of pulleys diverted the lift cables to the top of platform allowing the female lead to be flown up and down the tower. "The Ride of the Valkyries" was truly a spectacular scene for this production and the tower was very similar in design to the crane machine used by the ancient Greeks, albeit a motorized system compared to manual operation.

The director for this production of *Die Walküre* also wanted to do something that had not been done before—he wanted to fly five of the Valkyries on horseback. Peter Foy came up with a brilliant manual system that incorporated the house fly battens and custom revolving carriers designed specifically for the show. The horses were made of fiberglass but were very lifelike both in appearance and size … and the female opera singers were very real.

The Valkyries rode their horses high above the stage, floating and turning ever so gracefully. This routine lasted more than 20 minutes and was choreographed with the five horses and female opera singers riding along, they flew together in a complex aerial scene with the stage covered in fog as if flying in the heavens … truly a magnificent image during the show.

Figure 8.7

The creative process is what drives the choice of equipment and harnesses for any flying effect. An example of this is a production in Japan called *Nina and the Twelve Months*, a story of a young girl who tragically dies in an accident but when she awakes she is in a magical place with the 12 months of the year as her mentors. As the story progresses, the 12 months of the year take a liking to the young lady and gather to find a way to return her to her parents. They decide the only way to accomplish this is to turn back time: enter the carousel that will fly 13 people. It is a winter scene and the 12 months of the year are placed in a half circle; they will be suspended in single-wire harnesses by 12 cables that will eventually form a 16′ diameter circle. The characters are lifted by a single winch with a tapered drum (each character has its own wheel with a slightly different diameter so they can lift at different times but eventually level off at a height of 25′). January lifts first and so on till December is in the air. They level off, all holding hands, then January begins to revolve towards December, who is static until January meets him. Then the 12 months of the year all revolve in a counterclockwise direction, which represents the turning back of time. As they revolve, a center two-wire system lowers cables into a trapdoor; the young girl is hooked and she rises revolving in the opposite direction of the 12 months of the year. This was designed as a self-contained flying carousel system through the creative need described above; it had to fit in an 8' space center stage, which is why the 12 months begin in a half circle. The system had the ability to fan open or closed; when open it was an 8′ half circle; when closed it became a 16′ diameter carousel with five moving axis. Lift 12 performers, fan open/closed, revolve 12 performers, lift one performer, and revolve one performer.

Equipment Selection/Engineering

Once the creative process is complete, it is time to select the equipment needed to produce the flying effect and have the system and building structure engineered. This can be a short or a very long time period depending upon what is involved. In most theatre environments the building structure has been designed to accommodate a wide variety of equipment, so it is normally a short engineering phase. Other facilities can be more challenging; stadiums, outdoor venues, cruise ships, and multipurpose rooms sometimes require additional research. The end result has to be that all equipment and personnel are safe and that the equipment can be inspected and maintained on a regular basis.

Today there are many safety, engineering, and rehearsal procedures in place to protect the aerialist, operator, and—in some instances—the audience from any danger that could be introduced by a performer flying system.

All of the flying equipment must be tested prior to shipping and commissioned once it is installed in the venue. This means that not only does the equipment function but it must do so reliably under all conditions. On cruise lines the equipment has to operate under different conditions due to salt air, constant rocking and flexing of the structure, and—in many instances—unstable power.

Risk Assessments

Risk assessments and method statements need to be supplied, pointing out potential hazards and indicating methods to reduce risk. These documents are to be prepared by qualified personnel with full knowledge of the flying effects and the system used to accomplish the flying effects. The fly system installation must also include a rescue scenario for equipment failure up to and including loss of power or catastrophic failure of the system. Training for these types of scenarios is essential and personnel must be signed off. Any new hires must be trained by qualified persons in all aspects of inspections, maintenance, and rescue.

Operator Training

It is best for operator training to take place as the equipment is being installed and during performer training and technical rehearsals. Fitting harnesses on the performers and checking with the performers on the correct fit of the harness must be done prior to any flying effect. All maintenance procedures are covered during installation so the operator will have hands-on experience in trimming cables, making flying wires, attaching ropes and pulleys, assembling track systems, running winches, operating consoles or pendants. During rehearsals the operators of the manual systems are shown the techniques of pulling the ropes, watching the performers on the ground and in the air. If it is not possible to get these procedures in place during installation or technical rehearsals then a proper handover from the systems operator and qualified person must take place for new operators. The timeframe for this is established by the complexity of the flying effects and equipment used to accomplish the flying effects.

For the manual systems, the operator is trained to make long consistent pulls of both the lift rope and the travel rope. Hand-over-hand action is best with the extension of the arm high and finishing at the low waist. The lift rope should be operated so the performer is not exhibiting any stops or jerky movement in the up or down direction. The travel operator must work within the two ropes, feeling for the line to change direction as the performer nears the end of each travel swing. Once the performer is swinging then the operator is trained to cancel the swing by moving the carrier over the performer's head, stopping, slowing down, or controlling the side-to-side movement. The lift and travel operators are trained to communicate with each other so they do not cause any dangerous movements for the performer.

An example of bad fly operator communication occurred during a run of Liberace's show in Las Vegas many years ago. As he was being flown on a manual track system, the lift operator did not pull the rope as the travel operator moved on cue; the travel operator did not notice the lift operator's mistake and kept right on pulling the rope. When this action happened the operators dragged Liberace out of his Rolls-Royce, across the trunk, and onto the stage. After he exited on foot he was heard to say "I don't think that was supposed to happen, and it won't happen again, will it?"

It is essential that the two operators of a manual system communicate constantly so the correct movements occur during the aerial segment.

The programming of the consoles is done exclusively by qualified personnel; operators are trained to make only minor adjustments and to troubleshoot potential issues. Navigation of the system, setup of the equipment on the console, copying and saving files are also provided to the operator. The programming process during rehearsals is the best education for a new operator; observation during this period is the key to learning how to run a console. Cue navigation, fault signaling information, manual jog operation, and study of log files showing how the system logs cue sequences show the operator what to look for in case of system malfunction. Running cues and making sure the operator is aware of when it is essential to stop a cue is a primary function of the training.

Performer training begins with the fitting of the harness and is the most important part of the performer training segment. The harness is fitted first for safety and comfort, then for the functionality when the performer is lifted into the air; a second person must check the harness and the final approval has to be from the performer. As in most things in life, anything can happen—I was involved in a production in San Francisco and an aerialist actually came to the stage during a show to be hooked up … without a harness on. Unfortunately it was too late to go back to the dressing room to get the harness; the operator checking them was completely dumbfounded.

Performer Training

Once the harness is fitted; the performer will be hooked up and flown approximately 2′ in the air—this is done out of sight of the audience—in order to make sure the harness is properly fitted. If a single-wire harness is used the performer will be instructed to keep their head up, arch their back, and to utilize their body, arms, and legs to control their rotation. They are also informed to flex their knees when landing so they are not injured. When getting attached to the lifting media, the performer is also taught to receive a tap or physical signal from the person hooking them up to ensure they are actually coupled to the fly system.

For the double-wire harness, the performer is fitted so the harness is snug and comfortable. The pick points on the side of the harness need to be close to the balance point on that particular person's body. Everyone has a slightly different build, so it is important to make sure the balance point is correct; this may require several repositioning fittings on the performer.

Once the double-wire harness is fitted, the performer is hooked up to the system and flown approximately 2′ in the air and taught the correct way to fly horizontally and to generate somersaults. This is done by keeping the back straight and manipulating the arms and legs to distribute the weight of the body on either side of the pick points. A good balance point will allow the performer to make these motions with ease.

Finally, the operator and the performer must have a safety signal that is displayed by the performer while in the air. This signal indicates to the operator that there is a problem with the performer and they need to land immediately.

When executed properly in the context of a show, performer flying can be breathtaking and significantly enhance the telling of the story. It can also be very dangerous if not done by professionals. A good rule of thumb is to always possess the awareness of what is happening at the moment and never fear stopping if something goes wrong; this holds true for the operator or the aerialist (and the author), full stop.

9
Stage Automation

SCOTT FISHER

The What and Why of Automation

What is Automation?

Automation is the mechanization and control of motion tasks or operations that require precision, safety, and repeatability, or are difficult or impossible to accomplish by direct human operation, or all of the above. Automation involves the connection of machinery to the object being moved, controlling that machinery via motion-control computers and safety devices, and providing operators and programmers with the means to alter the parameters of that motion as well as the timing of execution and the coordination with other motions.

Why Automate?

There are several compelling reasons to automate the stage and rigging machinery in a theatre or production. These include:

- **Safety:** Automating machinery provides precisely controlled and highly repeatable motion as well as the ability to stop that motion quickly and safely either by direct operator action or by automatic safety control systems.
- **Manpower:** A production may be operated by fewer stage personnel using automation equipment, allowing smaller theatres and venues the ability to stage larger and more complex productions.
- **Force amplification:** Heavier loads and larger scenery may be manipulated using automation equipment than can be moved by human power and counterweight alone, allowing for the safe application of larger scenery and rigging systems.
- **Consistency:** Regardless of the personnel operating the equipment, the scenic and rigging systems will move in the exact same manner for each performance, providing a more consistent and higher quality experience for both the performers and the audience.

Different Systems

Automation is used worldwide in many venues and applications and, as such, the nomenclature for different aspects of the systems can vary in different locales and countries. For this chapter, we will be using terms common to applications in the United States.

Basics of Motion

Types of Motion

There are two types of motion typically achievable with an automated system. These are linear motion and rotary motion.

LINEAR MOTION

This refers to motion in a straight line, typically horizontal or vertical only. The most common linear motion in most rigging automation systems is vertical, moving a suspended load up and down.

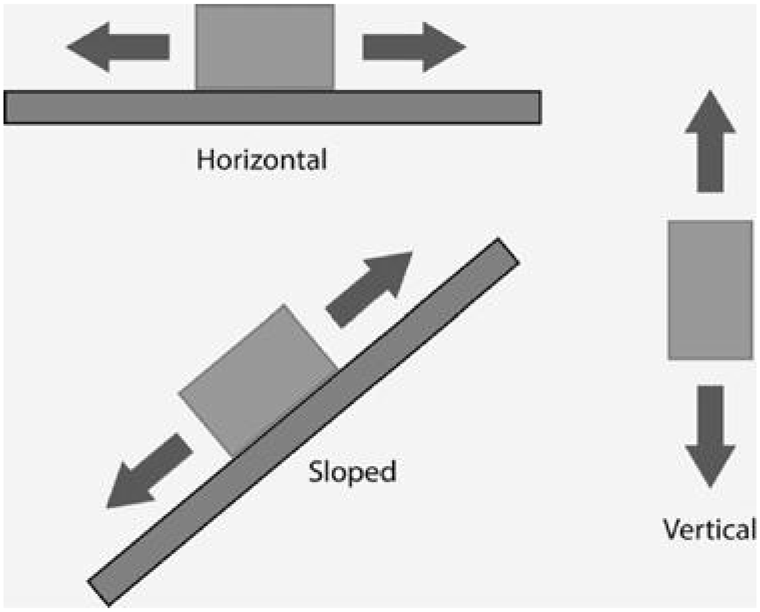


Figure 9.1 Linear motion

Rotary Motion

Rotary motion is motion where an object is set to spin either clockwise or counterclockwise, generally around a vertical axis. The most common rotary motion in stage automation systems is for a stage turntable used to move and present different scenes in a show.

It is also possible to achieve three-dimensional motion of an object through the coordinated use of several automated machines.

Figure 9.2 Rotary motion

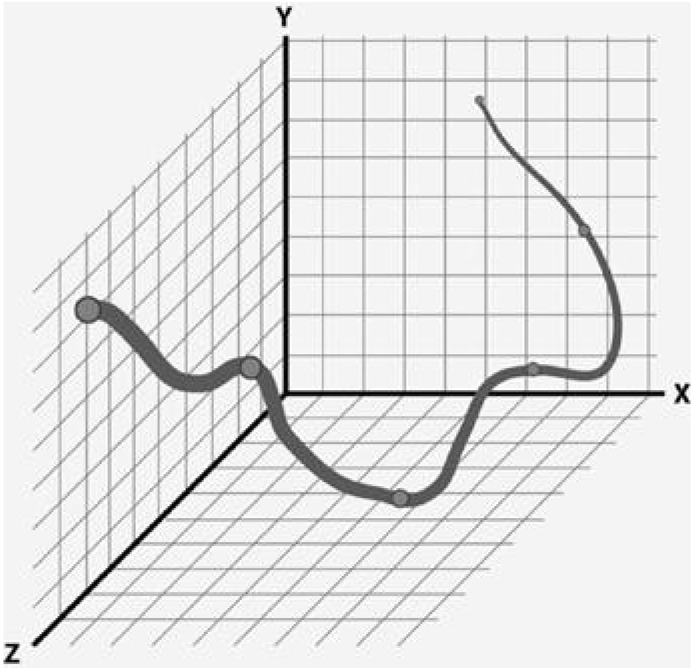


Figure 9.3 Three-dimensional motion

Motion Parameters

The motion of an object is typically defined by several parameters that describe its speed, desired target position, and characteristics of the way it achieves those targets. With these parameters defined by the operator or programmer, an object will move in the desired fashion and its motion can be tailored exactly to the needs of the scene or production. The typical parameters used in defining motion are outlined below:

POSITION

This refers to the location of the object in space. Position can describe its location at any point in the motion profile, although the most common positions used are its position at the start of the move, and its position at the end of the move (the "target" position). Position can be defined using any unit system desired (feet, meters, inches, etc.).

VELOCITY

This refers to the speed at which the object is moving, and is defined by its position over time.

The units for velocity are related to units chosen for position and the timescale required. For example, if you chose meters as your position units and seconds as your time units, your velocity would be expressed in meters per second.

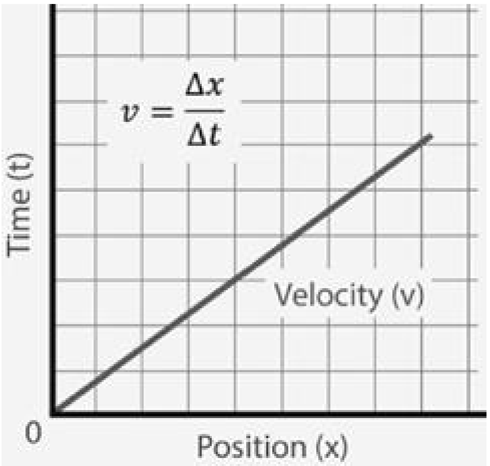


Figure 9.4 Velocity equation and graph

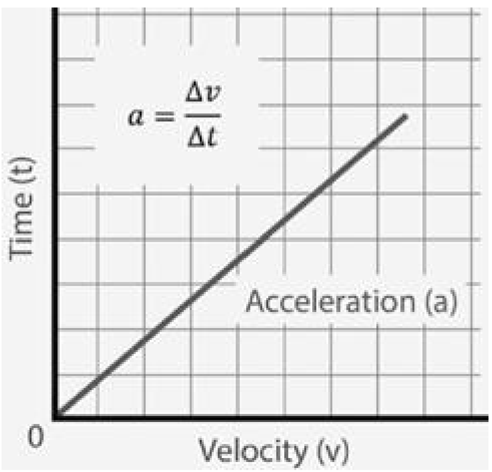


Figure 9.5 Acceleration equation and graph

ACCELERATION

Acceleration is the rate at which the object achieves the target velocity. A higher acceleration rate results in the achievement of the target velocity in a shorter period of time, and a lower rate means the object takes longer to achieve its target speed.

Like velocity, acceleration is a time-based parameter, except in this case it's the rate in the change in velocity over time. Because velocity is expressed in "position units per time unit" (x/t) and acceleration is expressed in "velocity units per time unit" (v/t), the units for acceleration are in "distance unit per time unit^2" ((x/t)/t). If you had chosen the same units as in the previous example, your acceleration would be expressed in m/sec^2.

DECELERATION

Deceleration is the same as acceleration, except instead of moving from a lower speed to a higher speed, the object is moving from a higher speed to a lower speed. Units and definitions remain the same as for acceleration.

JERK

This refers to the rate at which the acceleration or deceleration of an object changes. This is sometimes referred to as the “smoothness” of the acceleration, as it controls the characteristics of how the object changes from one constant velocity to another.

Jerk is also expressed with respect to time, in this case “acceleration units per time unit.” Since we’ve added another “layer” of time for jerk, the units are “distance unit per time unit^3.” Using the meters per second example again, the units for jerk would be expressed as m/sec^3.

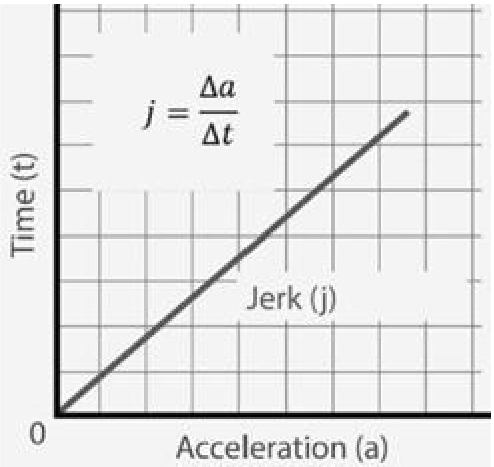


Figure 9.6 Jerk equation and graph

While this is all useful information for any automation operator or programmer to have, it is not usually necessary to know each of the derivatives with respect to time for motion parameters, as modern automation systems will put these in much simpler terms, often just providing a “0–100%” control for these parameters rather than the absolute numbers. However, when building motion profiles, having a basic understanding of where the numbers come from and what effect a higher or lower value will have on the motion can be invaluable.

Motion Profiles

Application of the parameters described in the previous section will result in a few typical types of motion profiles. Motion profiles are usually described by the shape produced by a graph of the velocity of the motion with respect to time. These profiles are described below:

TRAPEZOIDAL PROFILE

A “trapezoidal” profile is the most common type of profile used for motion control in stage and rigging automation. It consists of the acceleration phase, the constant velocity phase, and the deceleration phase. This is what’s most commonly utilized for point-to-point motion commands of the “start here, go this fast, end here” variety.

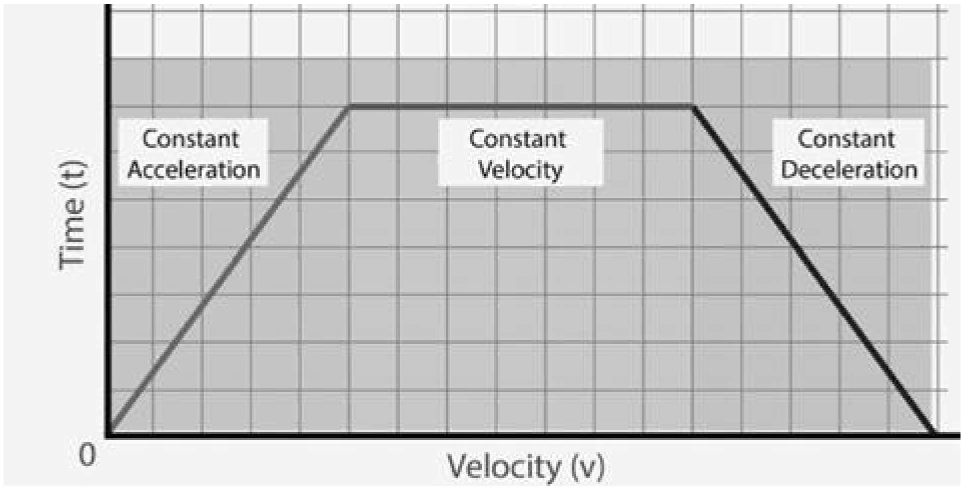


Figure 9.7 Basic trapezoidal motion profile

S-CURVE PROFILE

An S-curve profile is what is produced when more gentle parameters for Jerk are introduced. This basically "rounds off" the corners of a trapezoidal profile, making for more gentle transitions and considerably smoother motion.

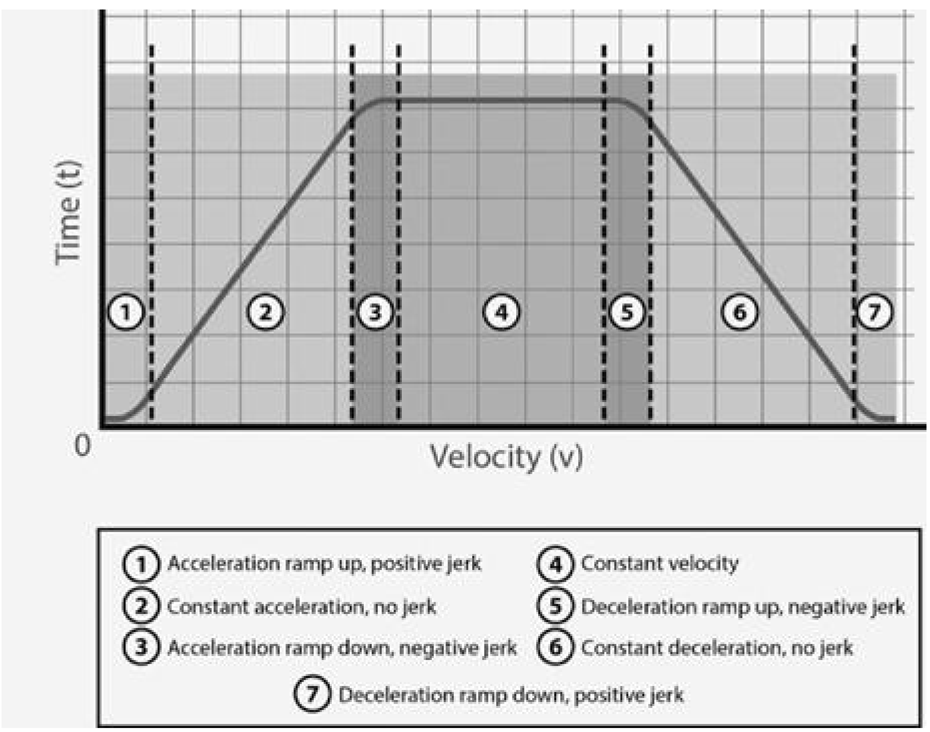


Figure 9.8 Trapezoidal profile with jerk ("S-curve")

In reality, operators who are programming trapezoidal profiles are most likely programming S-curve profiles, as the limitations of the machinery or the built-in parameters of the system will automatically "round off" the corners of the motion without the operator needing to define a specific jerk value. In most applications, the default parameters of the equipment are sufficient and they produce very smooth and precise motion. In higher speed or other unusual applications, the ability for the operator to define the motion parameters more precisely can be critical to the safe and smooth operation of the machinery, and many automation systems provide this ability when necessary.

“Stacked” Profiles

In many modern automation systems, it is possible to “stack” profiles by providing multiple velocities between the start position and the target position. For example, if you were programming a move that went from a position of zero to 100, you could provide a motion profile like this:

- Accelerate to a velocity of “2.5” and travel to “20”
- At “20,” accelerate again to a velocity of “5.1”
- At “50,” accelerate up to a velocity of “6.8”
- At “70,” decelerate to a velocity of “2.8”
- Decelerate to a stop at “100.”

This would produce a motion profile that looks like Figure 9.9

All of the basic aspects of a trapezoidal or S-curve profile still apply to the individual “sections” of the profile, but the programming environment provides the ability to include multiple profiles within a single move, allowing the operator to program more complex motions for the production or application.

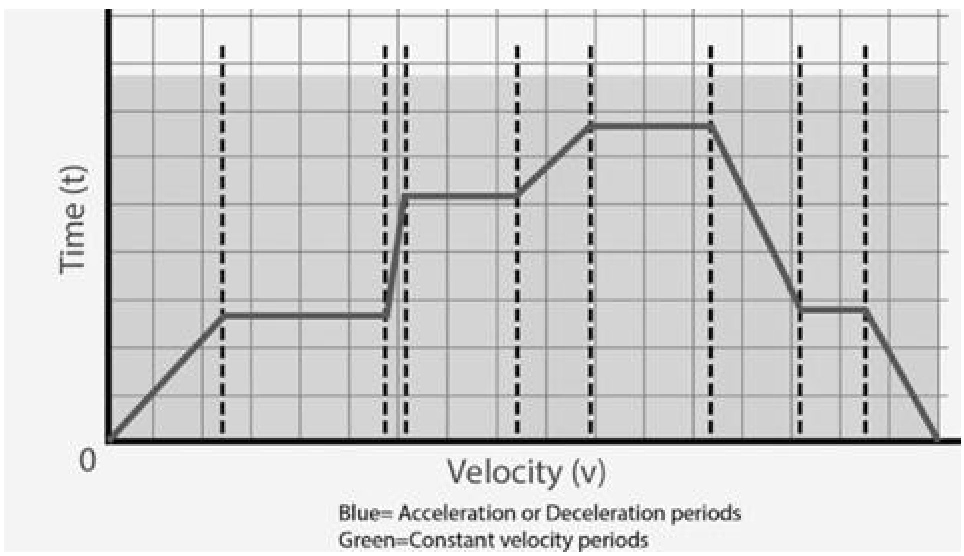


Figure 9.9 Multiple speed profile

Controlling Motion

While automation systems can perform many tasks, the core functionality of stage and rigging automation is the control of the motion of objects, performers, and machinery. Unlike industrial automation, the stage automation environment is typically more fluid and adaptable in order to accommodate the needs of the productions, and modern automation systems provide a variety of methods to initiate and control motion to service those needs.

Manual Control

Manual control is the most basic form of motion control in an automation system. It provides the operator with the means to directly move an object or group of objects, and is most analogous to flymen pulling on ropes in a counterweight system to directly move scenic elements. Typically little or no programming is involved, and the direct physical input of the operator to input devices such as joysticks or pushbuttons is translated directly into object motion through the automation system.

Jogging

The process of moving an object by changing its speed and direction through direct operator input is known as "jogging." This method of motion control is generally used for ad hoc slow speed movement of objects, usually during setup or maintenance procedures. High speed jogging is sometimes used for manually controlled performances or "teach and learn" programming procedures, but as programming tools improve in modern automation systems, these methods are gradually being used less often to improve safety and consistency.

Jogging is typically initiated via an "enable" action that activates the machinery (usually a joystick trigger or similar device) and, once initiated, the speed and motion direction of the machinery is controlled by varying the level of operator input on the control device. The means of level variation can be different depending on the type of device being used—for a joystick input, the angle of stick deflection from center determines speed and direction, while for a wheel or button input, the speed or number of rotations or actuations can serve a similar function. The machinery is stopped by releasing the "enable" function and returning it to its "parked" status.

Control Loops

The "control loop" is the mathematical model and means by which the speed and position of an object is controlled in an automation system. There are typically two types of control loops utilized: "open loop" control, and "closed loop" control.

Open Loop Control

An "open loop" control system is a control system in which the results of applying the command input are not monitored by the system to assure that the desired result is achieved. Open loop systems are very simple and robust, and are useful for basic controllers where precise performance is not necessarily required. An example of an open loop system would be a fan speed controller. A variable voltage is fed to the fan motor controller in order to change its speed, but there is no speed sensor on the motor output to verify that speed has been achieved. If the load on the fan increases or decreases, the speed may also change, as there is no means for the controller to adjust its output to compensate.

In a stage or rigging motion control system, an example of an open loop positioning system would be a chain hoist or winch with a simple position feedback device like a potentiometer and a circuit that shuts off the motion when a certain value is reached. As soon as that circuit sees the targeted position value, it would shut off the motion command, and the machine would come to a stop. However, if the motor continued to "coast" past the position (or "overshoot"), the control loop would have no way to correct for this and assure that it stops at exactly the correct position without overshooting. In many applications, especially those where the machines are moving at slow speeds and the mechanism is constructed such that it's physically unable to overshoot very far, this method of position is good enough, and indeed open loop control can be found in many older motion control systems. However, newer technology and better control methods are available in modern systems, and it is rare that open loop is utilized on these systems.

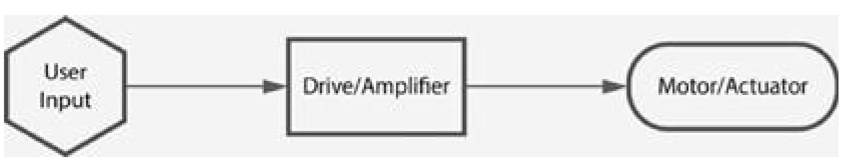


Figure 9.10 Basic open loop diagram

Closed Loop Control

A "closed loop" control system is one in which the process feedback signal (position, speed, force, etc.) is used to modify the motion control command signal and thereby allow the system to compensate for varying loads and to provide much more accurate motion control under a wide variety of conditions. Closed loop systems require more components than open loop to provide feedback, and the circuitry or computing engine is necessarily more complex than an open loop system to provide the precision control characteristics of this method. An everyday example of a closed loop control system is the cruise control in an automobile. The feedback data to the loop is the speed of the car, and the variable motion control signal is the amount of throttle applied to the engine. On level ground, the system will maintain a steady throttle to maintain the preset speed, but if the car encounters a hill or headwind, the system will automatically apply more throttle as necessary to maintain the preset speed. This action will continue on a second-by-second basis as long as the closed loop cruise control system is engaged.

In a stage or rigging control system, the variable that is usually used as the feedback input is the position of the device. If you remember from earlier in this chapter, position is the basis for the basic parameters of motion: Position over time is velocity, velocity over time is acceleration, and so on. Therefore, if you have position information, you can calculate just about everything else you need to move a machine as desired. Position information is generally monitored by the control loop on a schedule in the tens or hundreds of milliseconds; that is, the system checks the position and modifies the output signal that often while the device is in motion. This allows smooth and rapid changes to the motion command signal to compensate for any changes. For example, if a winch is lifting a piece of scenery and six performers step on to it during the motion, this would cause it to slow down in an open loop system due to the additional load. In a closed loop system, the system would detect that additional load within milliseconds and apply a higher control signal level to the machine, causing it to produce more force to counteract the load and thereby produce smooth and steady motion that places the scenery exactly where it's supposed to be throughout the entire range of motion.

For obvious reasons, the performance of a closed loop system is vastly superior to that of an open loop system, and practically all modern stage and rigging automation systems utilize closed loop control.

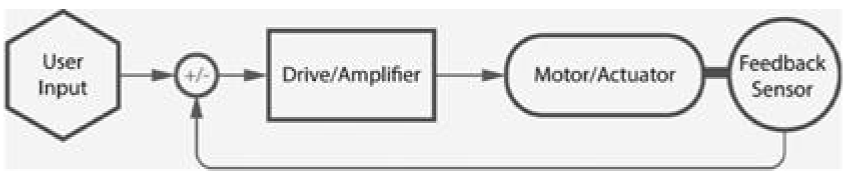


Figure 9.11 Basic closed loop diagram

Variable versus Fixed Speed

With regard to speed control, stage and rigging devices typically fall into one of two categories: fixed speed or variable speed.

FIXED SPEED DEVICES

Fixed speed devices are those where the speed of the machine is set to a fixed value, either by the mechanical characteristics of the device itself, or by the settings of the control system. A common fixed speed device in stage and rigging automation is the chain hoist, where the motor in the hoist simply runs at full speed as soon as the "up" or "down" control is engaged.

The advantage of fixed speed devices is that they're very simple, and typically inexpensive, as they don't require a lot of complex controls to operate. The disadvantage is that they can be difficult to position accurately, as there is no acceleration or deceleration function available to smoothly approach the target position. However, for low-speed applications or applications where either position accuracy or visually appealing motion is not necessary, a fixed speed device can be a great solution, as can be seen by the proliferation of chain hoists throughout the entertainment industry.

VARIABLE SPEED DEVICES

Variable speed devices are those that include controls and mechanisms that allow the speed of the device to be varied between zero (or a very low "creep" speed in the case of some devices) and the full speed that the device is mechanically capable of. Variable speed devices work best with closed loop control systems, and this pairing is the basis for all modern stage and rigging automation systems. A variable speed device on a closed loop control system produces very smooth and visually appealing motion and extremely accurate positioning, which in turn provide for a safer and better-looking show.

The most common example of a variable speed device in stage and rigging automation is the cable drum winch, although there are also variable speed chain hoists available as well as a wide range of hydraulic devices that are provided with variable speed capabilities through the use of proportional or servo controlled hydraulic valves.

Position, Velocity, Torque, Load, and Force

This section provides an overview of some of the key variables that are used in modern stage and rigging automation systems. We will discuss the nature of the parameters themselves, and introduce some of the most common means of measuring those parameters and incorporating them into the control system.

Position

"Position" is the physical position of the actuating part of the machine being controlled. For a winch, this is usually the rotational position of the cable drum, which can be extrapolated into how much cable is reeled out, which in turn tells the system where the suspended piece of scenery is located in space. For a hydraulic lift, it would be the amount that the hydraulic cylinder is extended, which would indicate the position of the lift platform. There are many ways to determine position, and many devices and locations for those devices to obtain position information.

Feedback Devices

There are two types of position feedback devices typically used in stage and rigging automation: incremental and absolute. An incremental position device only indicates a change in position when it is moving and the increment of that change. Once the system "knows" the starting position, it can use this incremental information to count up or down from there and determine the actual position, but from a "power up" state, the system does need to be provided with a current "real" position. An absolute position device maintains its position information at all times, even without power being applied to the system, and can reliably provide that position information to the system at any time. There are many position devices in use in motion control systems, and several of these are common in stage and rigging automation systems. These include:

- **Limit switches:** A limit switch is an electromechanical on/off switch that engages at a specific and known location. Limit switches are typically actuated either by direct contact with the object being moved by the machine, or by the normal action of the machine or actuator itself. Limit switches are very commonly used for positioning in open loop systems, but are usually used only as 'benchmark' position checks or limit-of-motion indicators on closed loop and variable speed machines.
- **Potentiometers:** Potentiometers are analog variable electrical resistance devices that produce a variable voltage throughout their range of motion when a reference voltage is applied to them. For example, if a reference voltage of 10V is applied to the potentiometer, its output would read 5V at the halfway point of its full motion. When a potentiometer is attached to a machine or a load in such a way that its full travel corresponds to the full travel of the machine itself, it can be used as a reliable positioning device. As analog devices, potentiometers can be subject to electrical noise and other interference, which can in turn provide inaccurate position information, but properly applied, they can be very robust and reliable position feedback devices. A potentiometer is an absolute position feedback device.
- **Encoders:** An encoder is a device that provides an incremental on/off pulse output to the system based on the motion applied to its actuating input, which is usually either a rotary shaft or a linear scale. If the information for the encoder scale is known by the control system (i.e., how many pulses it should expect to receive in one turn of a rotary encoder or a specific length of a linear encoder), that information can be extrapolated into actual distance moved as well as current position. Encoders can also be provided with absolute position output, and these devices output a very accurate data that represents a discrete number indicating the position of the encoder shaft or scale. Absolute encoders provide their position from a power-up condition.
- **Other devices:** There are many other position feedback devices that are less commonly utilized in stage and rigging automation, but that you may occasionally encounter. These include laser and sonar rangefinders that

bounce a laser or ultrasonic source off of the target object and provide a position number for that object, magnetostrictive devices that report the position of a magnet moving along their length (most commonly seen in hydraulic cylinder positioning), and resolvers or linear variable differential transformers (LVDTs) that provide a variable voltage output through inductive coupling (or basically a transformer with a moveable core). These types of devices are much less common in the entertainment industry, and are usually employed for very specific applications or environments.

Figure 9.12 Limit Switches

Figure 9.13 Potentiometer

Figure 9.14 Potentiometer

Figure 9.15 Encoder

Figure 9.16 Encoder

Figure 9.17 Linear Variable Differential Transformer

Figure 9.18 Linear Variable Differential Transformer

Using a Position Control Loop

As previously noted, the position control loop is the most common type of closed loop control loop utilized in stage and rigging automation. A position signal is obtained from the position transducer being utilized, fed to the control circuit, and then used to monitor and control speed, acceleration, and jerk as necessary to achieve the desired position of the object being moved.

Velocity

Direct velocity control is not as commonly utilized in motion control applications as position control, although it's always there just "under the hood" in most variable speed control systems. Velocity control is generally utilized for devices where velocity is their defining characteristic, such as fans or pumps. For stage automation, devices such as treadmills or turntables sometimes use velocity control rather than position control, but that is typically dependent on the application.

Velocity Feedback Devices

Velocity feedback devices are typically the same as position feedback devices, but the control circuit receiving the information from the feedback device simply evaluates the signal with respect to time rather than utilizing the signal value directly. For example, if an incremental encoder is used as a velocity feedback device, the circuit will "count" pulses per second, and if the distance a "pulse" represents is known, then the velocity is known and can be used as a control value.

Using a Velocity Control Loop

Our previous example of the cruise control system in a car is an example of a velocity control loop. The speed of travel is the controlling variable, and the amount of throttle is the command variable. A velocity control loop in a stage automation application would work in a similar fashion. For example, if you needed a turntable to move at 1 RPM during a scene, you would set your velocity target to that value. If the turntable load changed due to performers or scenery moving on or off of it, a closed loop velocity control system would detect that change and then alter the control signal to the drive motor to maintain a speed of 1 RPM.

Torque

Controlling torque is one of the options available if a rotational actuator is being used, such as a winch motor. Torque relates directly to force in this case—the harder you twist the winch drum, the harder it pulls on the cable. There are a few special applications where torque control can be important, and these typically fall into one of two categories: constant force control and force limitation. Constant force control is useful for applications where you want to maintain constant pressure or tension on an object, such as stretching fabric or maintaining a steady pressure in a cable. If the load increases on the object, the winch or device will allow the position to change in order to maintain a constant level of force. Force limitation works in a similar fashion, but where variable position and force is available up to a certain limit, after which the actuator will not provide additional force, or will allow position change to avoid exceeding a set torque value.

Torque Feedback Devices

Dedicated torque feedback transducers are specialized devices that are installed in line with the shaft producing the torque. In the case of a winch device, this would typically be in between the gearbox output shaft and the winch drum. These devices provide an absolute value for torque that can be monitored and scaled as necessary by the control system. There are other means of controlling torque through indirect measurement, such as monitoring the amount of electrical current being used by a motor, or by mounting the entire rotating assembly on a plate that can rotate against a load transducer at the end of a fixed-length arm. Any of these methods can provide the necessary data to a closed loop control system that can then control the torque levels.

Using a Torque Control Loop

To utilize a torque control loop, you must first decide if you are using the torque feedback as a maximum limit control or a constant torque control, as these methods utilize different loop variables in the controller. Once the method has been selected, the transducer or other data source output is connected to the control circuit and scaled appropriately. Once these steps have been completed, the machine can be turned on and it will produce or limit torque as appropriate.

Many modern variable speed motor controllers or motion controllers have built-in torque control circuits and control algorithms, so it is unnecessary to build one up from scratch. These are typically well-matched to the devices being utilized, and provide a very accurate and reliable means of torque control.

Load and Force

Load and force control are very similar to torque control, and they utilize almost identical devices and methodologies. In fact, in many cases the two can be used interchangeably, especially if rotating equipment is being used. In the case of a winch, knowing the torque on the drum shaft is the same thing as knowing the force at the end of the cable, so either is applicable and useful for force or torque control. In the case of a hydraulic cylinder, load and force are the parameters being measured, as there is no rotational component to the motion.

Like torque control, load and force control are typically used to either maintain a constant level of force, or to provide a maximum limit for force. Load and force control can also be used to simply provide an “overload” alarm level for the operators or riggers to respond to, rather than causing the control system to respond directly.

Load and Force Feedback

There are a few common means of measuring and reporting the load on, or force applied by, a machine or actuator. These include:

- **Load cells:** A load cell is a transducer that converts an amount of force on the transducer into a directly proportional electrical output. The strain placed on the device changes the electrical resistance of small wires inside, causing a change in its output voltage. This voltage can be used to produce a very accurate measurement of the load on the device.
- **Motor current:** In motorized systems, the amount of current used by the motor is directly related to the amount of load on it. If the load-per-amp value is known, the current value can be scaled into an actual load value. The drawback to this method is that the motor has to be supporting the load at the time of measurement, which can be problematic for static load measurements where the system is actually in an overload condition, or in situations where it is impractical or undesirable to put the load to be measured on the active machinery.
- **Hydraulic pressure:** In a system utilizing a hydraulic cylinder, the force on the cylinder rod is equal to the pressure per unit surface area. In US units, this would be psi or pounds per square inch. If the area of the cylinder piston is known and the pressure is measured, then it's a simple matter of division to come up with the pounds of force on the rod. There are also commercially available load cells that use this method rather than the electrical strain gauge method, where the device is essentially a very small inline hydraulic cylinder equipped with a pressure gauge or transducer.

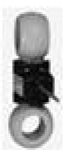


Figure 9.19 Load Cell

Figure 9.20 Load Cell

In all process measurement sensors, it is important to know that your sampling rate is of sufficient frequency to allow the system to react to changes in a timely manner. The sampling rate is the rate at which the sensor acquires and reports the data back to the control system. For example, a sensor with a 100ms sampling rate would return a value to the system ten times per second. Your sampling rate should be a multiple of the amount of time in which a significant change can occur in your system. If you have a piece of machinery that moves at 20′ per second and you are sampling your position five times per second, then that means that you could cover four feet in the time between samples, which is a very significant distance. System and sensor sampling rates are most often set by the manufacturer of your selected system, but in general the sampling rate should be taken into consideration and well-matched to the process and system that you are controlling.

Using a Load Control Loop

Utilizing a load control loop is essentially identical to utilizing a torque control loop. You must first decide if you are using the load feedback as a maximum limit control or a constant load control, as these methods utilize different loop variables in the controller. Once the method has been selected, the transducer or other data source output is connected to the control circuit and scaled appropriately. Once these steps have been completed, the machine can be turned on and it will produce or limit load as appropriate.

Many modern variable speed motor controllers or motion controllers have built-in torque control circuits and control algorithms, so it is unnecessary to build one up from scratch. These are typically well-matched to the devices being utilized, and provide a very accurate and reliable means of torque control.

Synchronized Motion

In many cases, it's necessary to coordinate or synchronize the motion of several machines in a stage or rigging automation system. Sometimes this is just for the visual effect of a scene change or other stage motion, and sometimes it is out of mechanical necessity, where the force of several machines is required to lift a large object or a heavy load. This is one of the trickier problems in automation, and it's important to know the challenges involved and methods for addressing solutions.

SYNCHRONIZATION VERSUS COORDINATION

While both synchronization and coordination can appear to be similar methods, they are in fact very different. The primary differences between the two are as follows:

- Coordination is a method of controlling multiple machines and objects where command signals are sent to those machines at coordinated times (usually simultaneously), but there is no inter-machine checking or feedback to assure that they stay in coordination with each other. This method simply counts on the accuracy of the control signal timing in reaching the machines and the individual accuracy of the machines to run their motion profiles correctly to maintain coordinated motion. This method is fine for motions where it's not critical that the machines all stay perfectly aligned and timed, and where there are no non-compliant physical links between the machines or loads themselves.
- Synchronization is a method where multiple machines are set in motion and where there is inter-machine communication and control to assure that those machines start, move, and stop as if they were a single device. A typical application of synchronization would be to lift a large rigid structure using several winches or hoists where the failure or uncoordinated motion of one or more of those machines could cause structural issues or failures.

MEANS OF SYNCHRONIZATION

There are several different ways to synchronize the motion of multiple machines, as this is a common application in industrial systems. Some methods involve additional wiring and connections between devices in order to directly coordinate their position feedback signals among one another, and others rely on real time high-speed network communication between the devices to achieve tight synchronization.

While it is beyond the scope of this chapter to go into great detail on the methodologies for synchronization, it is important for the reader to understand the differences between coordination and synchronization, as misapplication of these methods can lead to errors and accidents. First, it is important to be able to recognize when an application requires full synchronization, or if simple coordination is acceptable. Second, you must be able to recognize when you are actually using a synchronized system and when you are not, as some controllers can appear to be synchronized when they are actually just coordinated. A common example is suspending a large truss structure from a number of chain hoists. All of the hoists are set into motion at roughly the same time with a single button push, but there's no guarantee that they're all running at the same rate of speed or all supporting an equal amount of the load. This is simple coordination, not synchronization. Likewise, sending a "go" command simultaneously to a number of machines in a closed loop variable speed control system does not necessarily guarantee that they are all starting, stopping, and moving synchronously. Be sure to familiarize yourself with both the system being utilized and the object(s) being lifted or moved, and be sure you know how the system will react on the failure of a single device in the group or in an emergency stop.

MITIGATION OF FAILURES OR ERRORS

As complex systems, it is inevitable that one or more machines will fail or stop at some point during a coordinated or synchronized move. The system and structures must be prepared to handle this eventuality without compromising safety or the integrity of the machinery and structures. There are a number of ways to go about doing this, both from the physical and mechanical side and from the controls side.

- **Physical mitigation:** Make sure that the structure being lifted or moved can handle a certain amount of localized bending or deflection without compromising its structural integrity. Do not build or lift anything that requires absolutely perfect synchronization. Lifting or pulling devices can also be equipped with slip clutches or other physical load controlling devices that prevent the equipment from being overloaded to the point of failure.
- **Control system mitigation:** The synchronizing control system should have the means of assuring that if one device stops, they all stop well within the physical "comfort zone" of the object being lifted or moved. Likewise, motion starts should be coordinated across all devices to assure that they move together as a single machine. Load monitoring and control should be employed to assure that no single device takes on more load than it is designed for or that should be applied to any one point on the structure.

Keep in mind that there is always the potential scenario of complete power failure during motion due to lightning strike, infrastructure failure, or other reasons. In this case, it does not matter how capable your control system is, as it can be instantly taken out of the picture. Machines and structures need to be designed to handle this eventuality and stop the move safely, and the control system needs to be able to recover from a power loss situation without causing uncommanded motion or other issues with the system.

Means of Motion

All of the previous information in this chapter dealt largely with the theories and practices behind motion control, but eventually these theories have to be turned into real-world devices and machines in order to make things happen. The following sections describe some of the most common machines and devices in use in stage and rigging motion control today.

Electrical

Electricity is by far the most common means of powering automation devices for stage and rigging. It's clean, easily transmitted, readily available, and there is a wide range of devices available to run on it. Some of the most common are as follows:

- **Chain hoists:** A chain hoist is typically a low-speed lifting device that uses a highly geared motor and chain wheel in an enclosed case to take up or let out chain and lift objects and structures. Chain hoists are commercially available from a number of manufacturers, and they are the workhorses of the touring segment of the entertainment industry.
- **Cable winches:** Cable winches are available from many manufacturers in a large range of speeds, capacities, and configurations. Cable winches are typically much quieter than chain hoists, and are also considerably faster and more accurate in positioning. Most cable winches are used with variable speed closed loop automation systems for control.
- **Linear actuators:** Linear actuators are also known as "electric cylinders," and they are used to produce large amounts of short-distance linear force. The typical arrangement uses a motor to drive a screw assembly, which causes a rod to extend or retract within a housing. These are often seen on trapdoors, platforms, panels, and other applications where high force and short throws are required.

Figure 9.21 Chain Hoist

Figure 9.22 Chain Hoist

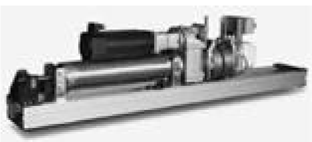


Figure 9.23 Cable Winch

Figure 9.24 Linear Actuator

Fluid Power

Many stage and rigging applications utilize fluid power as a motivation means for the machinery. “Fluid power” includes both hydraulic (oil) and pneumatic (air) powered devices. The main advantage of fluid power is “power density,” which is the amount of force that can be produced by a device of a certain size. In the case of hydraulics, the power density is extremely high. A relatively small hydraulic cylinder can produce an enormous amount of force compared to its electrical counterpart.

The tradeoff for this high power density is the amount of infrastructure required to support and operate a fluid power system. Pumps, reservoirs, compressors, piping, valves, accumulators, and other devices are necessary for a complete hydraulic or pneumatic system, and this amount of equipment and the space it requires can sometimes outweigh the advantages of a fluid power system. However, there are cases where nothing else will do, and in those cases fluid power performs very effectively and reliably.

Some fluid power devices commonly seen in stage and rigging automation applications include:

- **Hydraulic cylinders:** Typically used to move or support stage lifts, but also used in many props and specialty scenic pieces.
- **Hydraulic motors and winches:** Hydraulic motors and winches are used in the same stage applications as electrical motors, and several manufacturers have produced hydraulic winch and powered batten systems. While the space savings can be considerable, the disadvantages of potential oil leaks and the large infrastructure requirements for piping and pump systems can outweigh the space and power density benefits.

Motion Commands and Controls: Cueing Systems

In order to be useful in a stage environment, automation devices require a control system to provide an interface for users to program and operate the machinery. Control systems can be as simple as a set of pushbuttons or as advanced as a completely integrated computer-controlled automation system. At a minimum, a modern stage and rigging automation system consists of a networked series of motion controlled machines and a programmable user interface to construct motion sequences for playback and editing. For the purposes of this chapter, we will concentrate on a basic system of this type.

Cueing and Playback Systems

A cueing and playback system communicates with the various machines in an automation system for the purpose of constructing motion events and sequences, saving those events in sequences in a format that facilitates playback during rehearsals or performance, and providing the means to edit, save, and initiate the preprogrammed actions on demand. Systems of this type are available from several manufacturers in the entertainment automation industry and, while each manufacturer provides somewhat different methodologies and features, there are aspects that are common to almost all systems.

Typical System Features and Terminology

A typical system will provide an operator interface that allows manual control of individual devices or groups of devices via a joystick or similar device, "go" and "stop" buttons to initiate preprogrammed motion sequences, an emergency stop button to allow the operator to stop all motion when necessary, and a programming interface to allow the operator to construct motion actions and sequences.

The programmed sequences constructed by the operator are typically referred to as "cues." Cues can consist of one or more motion or action commands and a show can contain multiple cues, usually played back in order during the performance. The following sections will discuss some basic cueing commands and actions and means of playback.

Components of a Cue

Cue Structure

Cues are generally assembled as sequential lists or trees of motion and action commands. These commands will execute in order to provide the desired sequence of motion on stage when the cue is started by the operator.

Types of Commands

Cue commands generally fall into a few specific categories. Commercial manufacturers provide systems that are capable of executing from a few basic commands up to dozens of complex commands. Most systems will provide command capabilities of at least the following types:

- **Motion commands:** Motion commands provide the means to move a machine from its current position to a target position. Command parameters generally include target position, acceleration, deceleration, and velocity. Velocity is also sometimes expressed as a function of time (i.e., "move to target position in X time") rather than entering the velocity value or percentage directly.
- **Timing commands:** Timing commands allow the operator to insert pauses or wait periods in the playback sequence. This provides the means to sequence motion starts or other actions without the need to separate those commands into separately executed cues, as well as the means to achieve repeatable and accurate timing in playback of sequences.
- **Sequence commands:** Like timing commands, sequence commands control the playback of motion and action commands within a cue. Sequence commands control the start of subsequent cue actions based on the state of other machines or actions in the system, for instance "wait for curtain to reach 'in' position." Sequence commands can also start other cues from within the currently executing cue, sometimes referred to as an "auto follow."

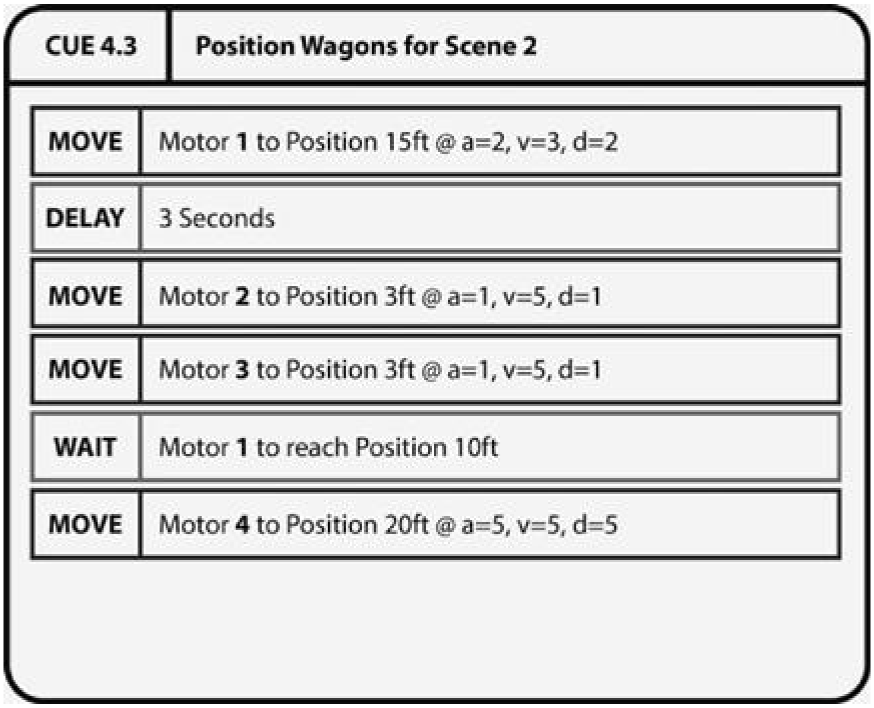


Figure 9.25 Simple motion cue

ASSEMBLING CUES

Using the different types of commands in the proper execution sequence, a system programmer can construct fairly complex motion sequences that execute consistently and reliably from show to show. Interfaces for cue construction are usually list-based, and the actions execute in the sequence that they appear in the list. Generally, back-to-back motion commands in the list (i.e., commands that are not separated by other timing or wait commands) will execute simultaneously, even though they're in a sequential list, as that construction effectively means "do all of these actions at the same time." Some programming systems represent the cue in a nested tree structure to represent the relationships between the commands, and others use a flow chart style, but the most common is the basic command list.

Playback

Playback of cues is usually initiated by the operator by pressing a "go" button of some type on the interface to start the cue at the appropriate time in the production. This is known as "operator initiated." Cues can also be started automatically through the use of various sequence commands and, in theory, an entire show could be constructed where everything plays back automatically and in the correct timing from a single "go" command at the start. However, in practical application, operators and stage managers use their best judgment based on the requirements of the production to construct automated sequences that balance the needs for consistency and ease of execution with the fluid nature and ever-changing nature of live productions.

All systems allow the execution of a single cue by the operator, and some allow the execution of multiple cues from multiple "go" commands, causing more than one cue sequence to be executed live on stage at the same time. Operators should take into account the capabilities of the system that they are operating when formulating their programming and playback strategy for any production.

Motion Safety

Safety is paramount in any motion control system, as stage and rigging automation is one of the few disciplines in technical theatre that produces physical "kinetic" actions on stage. Automation systems are equipped with many safety features and functions to prevent unintended motion or motion outside of normal parameters and to provide a means of stopping all motion quickly and safely in the event of an emergency. The following sections describe some of the basic safety systems and parameters included in modern automation systems.

Emergency Stop and Braking Systems

The most basic and ubiquitous safety measure provided in an automation system is the emergency stop system. This provides the means for the operator or other theatre personnel to initiate a full system stop in the event that personnel or property are in jeopardy due to the motion of the machinery and its attached loads. Emergency stops are typically initiated as one of two types: The "category zero" stop, where power is immediately cut from the machines and all braking systems are immediately engaged; and the "category one" stop, where the control system is allowed to bring the machinery to a rapid but controlled decelerated stop before setting the brakes and removing power. The category one stop is preferred, as it can be considerably more gentle and smooth than a category zero stop, but all machinery and structural systems should be able to handle a category zero stop at any time, as this can also be induced by a complete power failure.

Position Control and Limitation

Another safety measure is the control and limitation of the allowable motion envelope of the machine and the attached load. This is typically accomplished in two ways:

1 Computer controlled limits, where the minimum and maximum position that the operator can enter as a valid target is restricted by the programming system, and the motion of the machinery is also restricted beyond that value during jogging or other manually controlled motion.
2 Electromechanical limits, where the control signal to the machine controller is physically interrupted by a limit switch located at the physical end of travel. Secondary limit switches that initiate an emergency stop are sometimes located just beyond these limits as well.

Force Control and Limitation

Many machines are equipped with load cells or other means of detecting and measuring the load on the machinery. This feedback can be used to either stop the motion of the machine if a maximum allowable value is reached, or to limit the output of the machine to a maximum force value. This can prevent overloading and damage to the machinery or the attached load.

Machinery Interlocks and Enables

Machinery interlocks can be used to prevent collisions or other motion into dangerous areas. For example, a suspended piece of scenery may be interlocked to the lateral position of a piece of scenery on a stage wagon such that the suspended piece may not be brought to a low enough position to cause contact with the scenery below. Similarly, enable switches and other interlock devices can be provided to stage managers and other personnel to allow a second visual "all clear" check, and the motion of the object being checked will be disallowed unless that enable is constantly activated.

Operation Practices

There are a few key operational practices that will greatly increase safety in and around the stage when using automated machinery. Theatre staff and management should incorporate well-defined and clear safety and operation practices in any facility using automated machinery. Some key items are as follows:

COMMUNICATION AND VISIBILITY

The automation operator must have a clear and constant method of communicating with stage management personnel and other persons monitoring or controlling the actions in the performance space or anywhere automation machinery is being used. The operator should also have a clear line of sight to any devices or objects being moved by the system. This line of sight can be provided via closed circuit video monitoring, but in no circumstances should the operator be operating machinery in a "blind" situation.

Availability of Emergency Stops/Enables

The automation system operator and technicians must assure that emergency stop actuators are available anywhere that motion of machinery or objects is being executed so that qualified personnel in those areas can initiate a stop if any dangerous situations are detected. The emergency stop function should not be delegated to the operator alone at the control station, as communication of the necessity for a stop is not always reliable.

Safe States

A "safe state" for each piece of motion controlled machinery should be determined so that it can be reliably placed in that safe state at any time necessary. Depending on the environment and the type of machinery and load in question, a "safe state" can be anything ranging from the system being in emergency stop mode, to a complete removal of power from the device, to a secondary structural support or stop in the machinery or rigging. "Safe" has a definition, and all operators and maintenance personnel must use the same definition and terminology when describing a device as "safe."

Practice and Rehearsal Speeds

Initial practice and rehearsal of motion sequences should always be performed at low speeds to assure the motion path and envelope is clear and safe and to provide operators and spotters with more time to initiate a stop if necessary. This is especially important in motion sequences utilizing complex timing or motion interlock commands, or where there is a large amount of machinery in motion. Once the paths and motions have been determined to be free of interference or other issues, speeds can be increased up to the levels to be used in the performance.

Nomenclature and Clarity

It is important that all operators, technicians, managers, or other personnel communicating on stage during motion controlled sequences speak the same "language" when giving instructions or information. The methodology and terminology for expressing readiness, clear for motion, directions of motion, desired speeds, stopping and starting motion and cues, and emergency stopping should be known and clear to all personnel, and always used when giving commands or expressing status. Lack of clarity in communication is one of the main contributing causes to accidents, and it is important that it be eliminated from the performance space.

Note: This chapter is intended to familiarize the reader with the basics of mechanical stage automation concepts and systems. Stage automation involves electricity, high pressures, machinery with potential pinch points and other hazards, and overhead loads, and can be dangerous if improperly applied or executed. This chapter is not intended as a "how to" guide or instruction in the construction and commissioning of stage automation equipment, and readers should not take it as such. Just as we would not recommend that readers attempt to forge their own shackles for use in rigging systems, we also do not recommend that readers of this text attempt to fabricate their own automation equipment. It is important to use equipment engineered and manufactured by reputable and qualified suppliers, and to obtain proper training in the installation and use of that equipment prior to operation.

10

The Mechanics of Stage Automation

DAN CULHANE

Winches and hoists have been traced back to the Greeks, who considered them their "deus ex machina" or "god of the machine."

A hoist is a winch that raises and lowers battens, electric sets, scenery, orchestra shells, and almost anything else. In this chapter, we will be using the terms "winch" and "hoist" interchangeably. There are dead haul winches that lift the entire weight of the flown element and there are counterweight assist winches, where the weight of the flown element is partially counterbalanced by a counterweight allowing the hoist to lift only the imbalanced weight of the system. At a minimum, a hoist has one lift line, more often they have two or more. There are three types of dead haul winches: the line shaft winch, the drum winch and the traveling drum, or zero fleet, winch.

Line shaft winches have multiple cable drums connected to each other and the gear reducer with a shaft. A drum winch has a single cable drum with the cable or cables coming off of that one drum.

For line shaft winches the cable comes off of the drum and then attaches to the batten. The cable spools on to the drum from one side; if all of the drums spooled in the same direction the flown object would travel to one side. On line shaft winches, half of the cable drums have a have a left-hand winding and the other half wind to the right. The net effect is that the flown object will not travel to one side as it is flown.

A counterweight assist winch typically uses a chain sprocket attached to the gear reducer. A roller chain is attached to the bottom of the arbor, travels down and around the chain sprocket on the gear reducer, then travels up to the head block. At some point between the chain sprocket and head block, the roller chain terminates to a piece of cable that travels over the head block and attaches to the top of the arbor.

A traveling drum winch is typically a winch in which the drum travels along guides allowing the cable to spool on and off the drum at a rate that equals the cable wrap on the drum. For example, if the cable is wound around the drum at three wraps per inch, the cable drum will travel the distance of one inch in three revolutions.

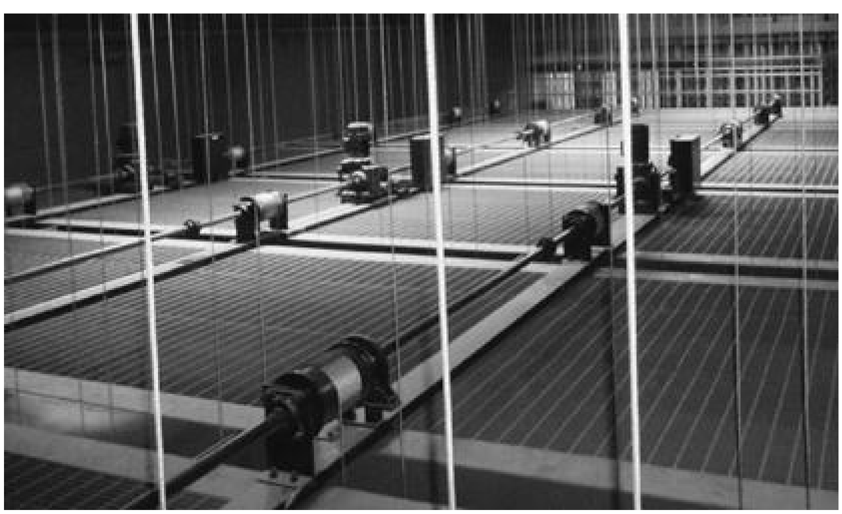


Figure 10.1 Line shaft winch. Photo courtesy of SECOA.

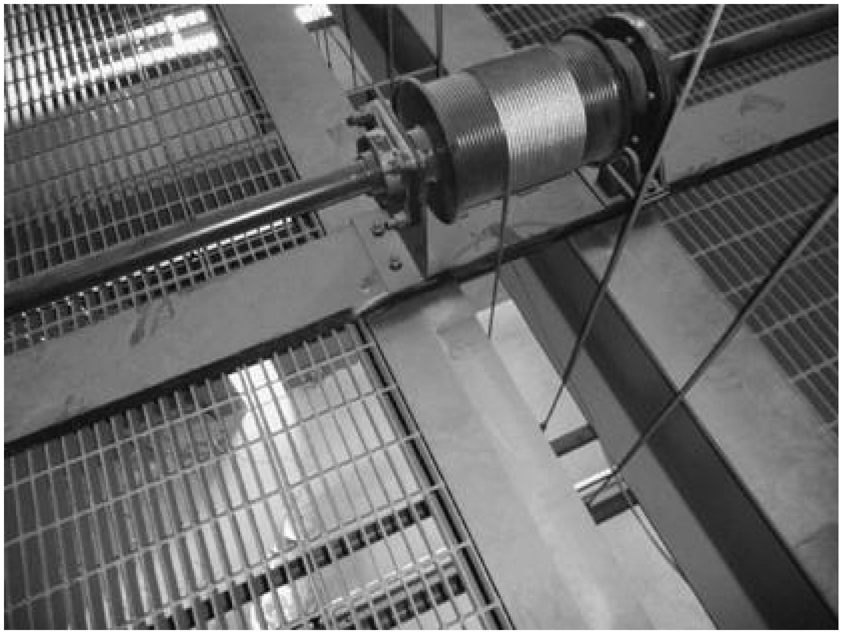


Figure 10.2 Line shaft winch. Photo courtesy of SECOA.

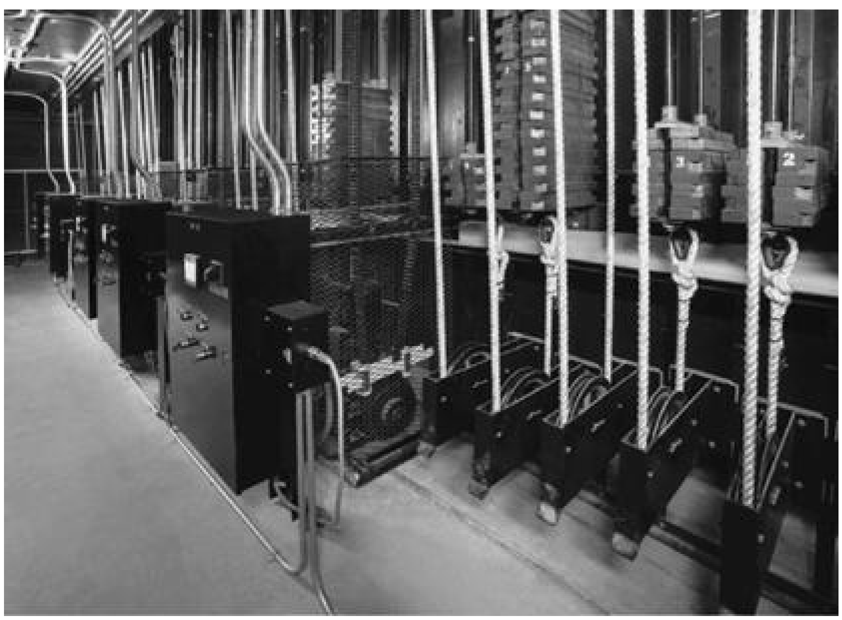


Figure 10.3 Counterweight assist winch. Photo courtesy of SECOA.

Figure 10.4 This is a 7,750lb capacity traveling line shaft winch for orchestra shell storage. This winch has two gearmotors on a common shaft. Photo courtesy of SECOA.

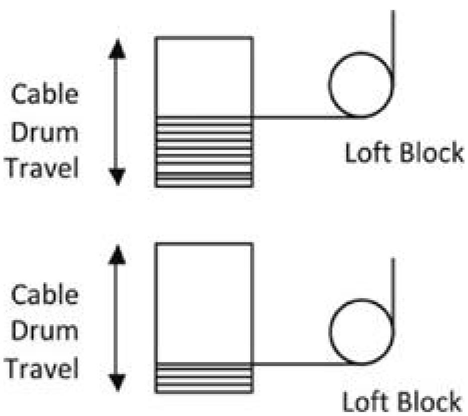


Figure 10.5 Cable drum travels as the cable winds/unwinds off of the drum, maintaining a consistent cable location relative to the loft block

In this manner, the cable leaving the drum will stay in a constant place relative to the building. The advantage of this method is that the fleet angle for the cable from the drum to the loft block remains the same, and the distance between the loft block and the drum can be very small.

Cables terminating at a steel drum will have three dead wraps on the drum before the active wraps start. At a minimum, cable terminations need to hold at least 80% of the cable's strength. In addition to the actual cable termination, the three dead wraps generate friction between the cable and the drum to accomplish the 80%. If the drum has a synthetic surface, additional dead wraps may be necessary to achieve enough friction to obtain 80% of the cable strength.

The diameter of the cable drum is determined by the cable diameter. All cables have a minimum bending radius allowed by the manufacturer. For 7 × 19 small diameter specialty cord, also known as aircraft cable, the minimum bend radius is 26 times the cable diameter.[1] This is known as the D:d ratio; the ratio of the tread diameter (Δ) of the drum or sheave to the diameter (d) of the wire rope. The smaller the diameter the shorter the service life is for the cable. For ¼″ cable the minimum diameter for the drum would be 6½". Example: ¼″ × 26 = 6¼″.

Cable drums used in the theatre have a single layer of cable on a grooved drum. The groove in the drum is a single helix.

Recommended cable drum design:[2]

- The minimum groove radius for new rope: 0.53 to 0.535 × diameter of the wire rope.
- The maximum groove radius: 0.55 to 0.56 × diameter of the wire rope.
- The minimum drum pitch for a single layer of cable: 2.065 × the groove radius.
- The maximum drum pitch for a single layer of cable: 2.18 × the groove radius.
- The drum groove depth: minimum × 0.375 × diameter of the cable.

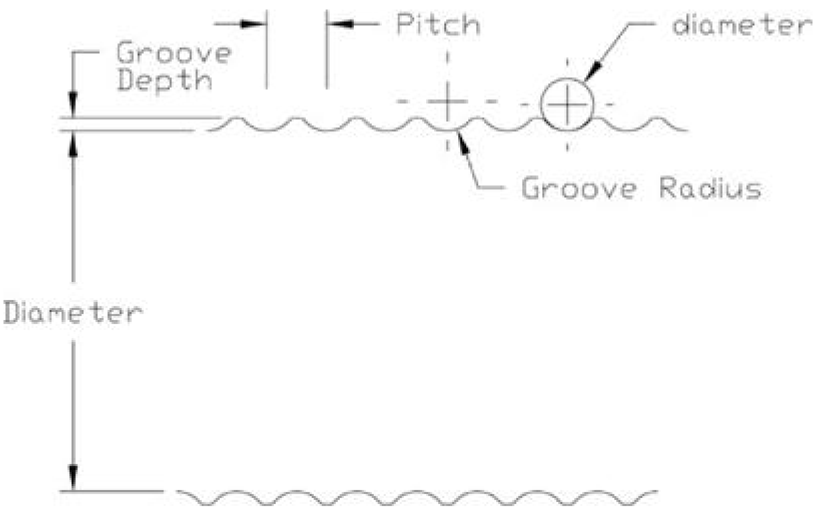


Figure 10.6

The Wire Rope User's Manual published by the Wire Rope Technical Board is a very good source for additional information regarding drum design and cable bending information. When designing cable drums for a system it is often impossible to keep the fleet angle less than two degrees, while keeping the distance between the cable drum and the loft block to a reasonable distance. When the distance needs to be shorter, a larger diameter drum is necessary to maintain the fleet angle at ≤ 2°.

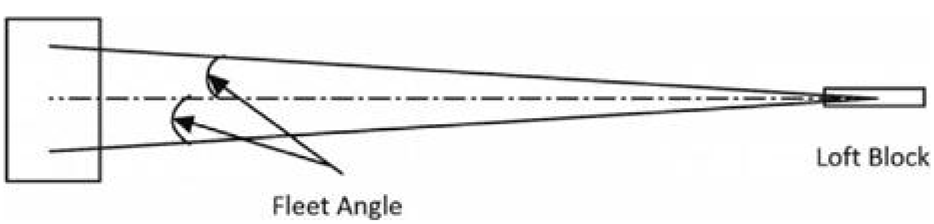


Figure 10.7 The longer the travel the greater the distance between the loft block and the cable drum to maintain an acceptable fleet angle of two degrees or less

All winches have a number of parts generally consisting of a motor with a motor brake, a gear box, and a cable drum or chain sprocket. Dead haul hoists have a secondary brake. A necessary part of the winch is a set of limit switches. There are at least four of these, two of which are the normal end of travel limit switches that stop the hoist at the extreme ends of normal travel but allow it to travel in the opposite direction. The other two are over travel, or ultimate limit switches. The limit switches are usually placed just beyond the normal travel limit switches in the event the hoist does not stop when the normal end of the travel limit switches are tripped. The over travel limit switches are wired to a special circuit that will remove power to the hoist and ensure that the hoist stops. No further movement of that hoist is allowed until the limit switch is reset.

Rigging in the 21st century began in earnest with the advent of the packaged hoist, brought to market by Hoffend and Sons. They designed and mass produced an integrated hoist and control system to a market receptive to that concept. Mass production and standardization of features was key to producing a system that was affordable. Many safety features were integrated into the hoists and controls, such as load-sensing, which informed the controls that the intended load would stop the hoist when the batten snagged on something that made it too heavy or landed on something that overly lightened the load. They made a passive drive-through brake that would hold the load should there be a motor brake failure. The controls have intuitive graphical touchscreen displays to select features. The operator can combine hoists together into groups that can be assigned, or individual hoists into queues. The graphic display shows the operator the process precisely as the queue is played out. In the packaged hoist market there are numerous competing manufacturers. The dominant players are: Daktronics Vortek line of hoists, J.R. Clancy's Power Lift line of hoists, and Electronic Theater Controls (ETC) with their Prodigy line of hoists. The packaged hoist is a self-contained zero fleet winch.

Winches designed for the theatre need to conform to many standards. At a minimum, ANSI E1.6-1, Entertainment Technology-Powered Hoist Systems must be referenced and followed.

Most winches today use a paired motor and gear box integrated into one unit which is called a "gearmotor." One of the many advantages to this unit is that the motor and gearbox are designed to work together and are built as a single unit that does not require assembly.

Motors used on winches are generally three-phase type motors with brakes. The type of motor used is totally enclosed and fan-cooled, designated as TEFC. This type of motor does not have openings, which facilitates keeping dirt and dust out of sensitive areas. The fan is essential for keeping the motor cool and, mounted on the end of the motor opposite to the gear reducer, it blows air over the outside of the motor frame. Normally the fan is plastic and is relatively light in weight. Most motors that use a reversing contactor use a high inertia fan, which is heavy cast iron. When a motor starts and stops with a regular fan it does so very abruptly, which can jar the load. This abrupt start and stop is hard on lamp filaments and other moving lights. Using a cast iron fan adds weight to the rotor of the motor which creates higher inertia and slows down the motor wind-up and wind-down, allowing for smoother starting and stopping. The high inertia fan is the "Z" option for both NORD Gear Corporation and SEW Eurodrive Corporation motors. If a motor is going to be controlled with a variable frequency drive (VFD), the motor does not need the high inertia fan because the VFD is capable of producing ramped starts and stops in the motor.

Single-phase motors are not used for hoisting winches; they are used in low horsepower industrial applications, such as fans or on farms.[3] Single-phase motors are generally not instant-reversing. This means that when started in one direction, if the motor is reversed without stopping the motor rotation, the single-phase motor will continue rotating in the same direction. This can be a problem when, in an emergency, it is necessary to back away from a problem quickly. A more expensive instant reversing single-phase motor is available.

A brake motor comes as a pre-connected package. The brake is a spring-set, stop and hold type. When power is removed from the brake, the brake sets and holds the load. On most winches using a reversing contactor, the power for the brake is taken directly from the power sent to the motor. There is a rapid reaction option to activate the brake. This is advantageous for hoists, as it sets the brake very quickly after the motor power is turned off. If the motor is using the high inertia fan, the rapid reaction option for brake activation is not used to stop the motor, since the high inertia fan is cancelled out by the rapid reaction brake activation. On winches with a variable frequency drive, the brake power must be switched separately from the power provided to the motor. There is a double motor brake option from both NORD and SEW.

A motor is comprised of a couple of parts. The rotor controls the rotation while the stator, which is stationary, contains a set of motor windings. Three-phase induction motors are high-efficiency, have a high starting torque, a relatively low current draw, and are available in various speeds. The speed of the motor comes from the number of poles wound into the stator. The following table gives the approximate RPM speed at rated load for 60hz. The most common three-phase motor is a four-pole motor.

No load speed can be determined by the following formula: [5]

$$RPM = \frac{Frequency_{(Hertz)} \times 120}{Number\ of\ Poles.}$$

Motors are rated by horsepower (HP). 1 HP = 745.7 watts.

= 33,000 ft-lb$_f$/minute.

= 396,000 in-lb$_f$/minute.

Table 10.1

Number of Motor Poles	*Motor RPM*[4] *at 60 hz.*
2 pole	3,450
4 pole	1,725
6 pole	1,140
8 pole	850

The 745.7 watts is typically rounded off to 746 watts. Since no motor can operate at 100% efficiency, 80% efficiency is a reasonable approximation to use, until the actual motor efficiency is obtained. The other 20% is used in creating heat or friction. A one HP motor that is 80% efficient will use 932.5 watts of energy.

$$\frac{746\ \text{watts}}{.8\ (80\%)} = 932.5\ \text{watts}$$

Horsepower can be calculated if the torque is known using the following formula:[6]

$$HP = \frac{Torque_{(lb-in)} \times RPM}{63{,}000.}$$

By rearranging the above formula torque can be broken out:

$$Torque\ (lb-in) = \frac{HP \times 63{,}000}{RPM.}$$

The motor service factor (SF) is the amount of continuous overload capacity the motor can operate without damage or overload, provided the other design parameters such as frequency, rated voltage and ambient temperature remain within norms.[7]

Example: A 1½ HP motor with a service factor of 1.10 SF can operate at 1.65 HP without overheating or other damage if the frequency, rated voltage and ambient temperature are within norms.

$$1.5\ HP \times 1.10\ SF = 1.65\ HP$$

All motors need thermal or overload protection. This prevents motors from getting too hot and causing a fire. Overload protection devices protect the motor from both excessive current and temperature.

Gear reducers take the RPM and torque input provided by the motor and convert it to a lower RPM and correspondingly higher output torque. Gear reducers are also defined by the number of stages they have. A single-stage gear reducer reduces the input RPM to the output RPM in one set of gears or one stage. A two-stage gear reducer has two steps or stages to go from the input shaft to the output shaft. All gear systems have gaps or clearance between the moving parts—this amount of movement is called backlash. Backlash can be significant enough to cause repeatability problems in winch systems, particularly when the encoder for the winch is connected to the end of the motor and the piece of scenery on the other end is hanging by cables. Generally, the more gear stages involved, the larger amount of backlash in the system. While unavoidable, the effects of backlash in the gear system must be kept to a minimum for the winch system to provide consistent results every time.

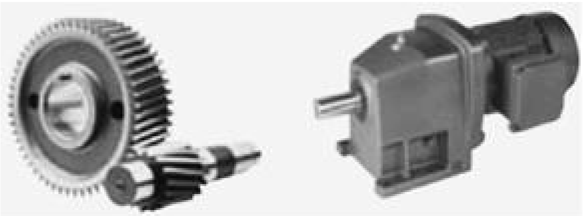


Figure 10.8 Helical gears and helical gearmotor. Photo courtesy of NORD Gear Corporation.

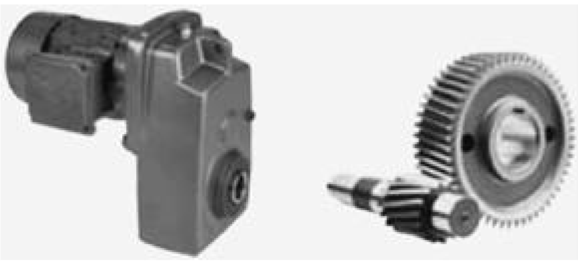


Figure 10.9 Helical gears and parallel shaft gearmotor. Photo courtesy of NORD Gear Corporation.

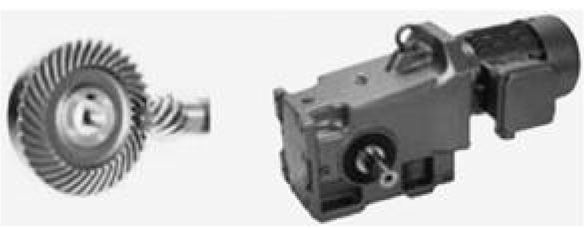


Figure 10.10 Helical bevel gears and helical bevel gearmotor. Photo courtesy of NORD Gear Corporation.

Figure 10.11 Helical worm gears and helical worm gearmotor. Photo courtesy of NORD Gear Corporation.

There are four basic types of gear reducers on the market today: helical gears, parallel shaft helical gears, helical bevel gears, and helical worm gears. The latter three types of gear reducers are often used in the theatre industry. Both parallel shaft and helical bevel gear reducers are very efficient in transmitting power from the motor to the output shaft. The helical worm gear reducer is inefficient in its transmission of power from the motor to the output shaft. The helical worm design is the most widely used gear reducer type, offering long service life, overload and shock tolerance.

Efficient gear reducers are used on most of today's packaged winch systems. They are also used on most fire curtain motor systems as they are easy to back-drive, which is the reverse of the normal operation. The output shaft is used to turn the input shaft. Many fire curtain release systems release the brake on the motor, using the weight of the fire curtain to turn the output shaft of the gear reducer, which turns the motor. A hydraulic dampener attached to the motor controls the descent speed of the fire curtain.

An inefficient gear reducer design does, however, have advantages in the theatre world. A helical worm gear reducer with a gear ratio greater than 60:1 statistically cannot be back-driven. This means that a load on the output shaft will remain stationary even if the motor brake is released. Most line shaft, drum, and counterweight assist winches use this type of gear reducer because of this feature. Helical worm gear reducers are a simple design that is very cost-effective to produce. This design lends itself to the lower output RPM and higher gear ratios used in the theatre industry.

Gear reducers are filled with oil and are vented because the oil will expand as the reducer is used. The oil helps to keep the reducer cool. The reducer will have a breather vent and a drain plug. While it may look like as if they can be mounted or oriented in any position, it is very important to be certain that the vent is at the top and the drain at the bottom when the reducer is mounted in its final position. The amount of oil with which the reducer is filled varies with the orientation that is used. The orientation is also important regarding the bearings that are installed into the reducer. The manufacturer will install different bearings depending on whether the bearing is below or above the oil level in the reducer. Thus it is important to order a gear reducer for the specific orientation for which it will be used.

Gear reducers also have their own service factor, which is defined by the American Gear Manufacturers Association (AGMA). AGMA adjusts a reducer's ratings relative to the individual load characteristics of the reducer. AGMA's ratings are based upon time duration. For winches used up to three hours per day a 1.00 service factor is recommended. For winches used for between three and ten hours per day the service factor is 1.25. For winches used for more than ten hours per day the service factor is 1.5.[8]

There are a number of considerations in the selection of a gearmotor. These include service factor, speed, horsepower, ratio, physical size, location, orientation, and temperature, and the cost of the unit.[9] All gearmotor suppliers are more than willing to assist you in determining the best gearmotor for your situation. SEW Eurodrive, a leading gearmotor manufacturer, has a number of programs online and available for download that will help you select the best gearmotor for your situation. Their online tool is called "PT Pilot" and is widely used by most rigging suppliers to insure that the gearmotor has been sized properly. PT Pilot performs the necessary calculations to properly size a gearmotor and provides spare parts lists, documentation and downloadable CAD details for the gearmotor selected. SEW also has a standalone program called "Workbench," which will perform the necessary calculations to size a gearmotor.[10] The software will also identify product-specific documents such as spare parts lists and data sheets, and will provide downloadable CAD drawings. SEW has many online tutorials and documentation to facilitate the maintenance of your gearmotor.[11] NORD Gear, another leading gearmotor manufacturer, has extensive online documentation and downloadable CAD drawings as well.[12] NORD has the better written documentation for sizing a gearmotor, but at this time does not have an online calculation tool for sizing a gearmotor. As mentioned previously, all gearmotor manufacturers will accommodate you in sizing a gearmotor to meet your specific requirements. They will walk you through the sizing calculations to make certain the gearmotor will work for your application.

There are a number of steps that need to be taken as part of selecting the proper gearmotor for a specific application. Sizing a gearmotor can be an iterative process. The design and calculations may have to be repeated several times as you work through the process before realizing a successful winch design. This is especially true the first few times the design and calculations are performed.

The very first thing in the design of a winch is to determine its capacity. This will also define many things such as the quantity and size of the lift cable(s). For a counterweight assist winch the capacity will determine the size and makeup of the chain used. For a line shaft winch, the cable size will determine the minimum diameter for the cable drums. It is important to know the size of the drum or sprocket. This determines the amount of torque that the gearmotor needs to generate. The size of the cable drum or sprocket is necessary to determine the speed in rotations per minute (RPM) for the gear reducer. It is important to know the motion profile for the winch as this determines the size of the gearmotor. A gearmotor that is moving a load at a fixed speed of 20′ per minute will be much smaller than a gearmotor moving the same load at a fixed speed of 100′ per minute. It is important to know the minimum amount of time needed to accelerate the load to its top speed. Accelerating a load from zero to 20′ per minute in half a second will be a different value than accelerating the same load from zero to 20′ per minute in ten seconds.

The following are some steps necessary in determining the proper gearmotor.[13]

1 Determine the speed or gear ratio of the reducer.

2 Determine the required torque.

3 Determine a service factor or service classification.

4 Select the gearmotor.

5 Determine the required mounting position.

6 Add options to the gearmotor.

7 Perform the required checks:

- Overhung load.
- Thrust load.
- Thermal considerations.

The speed of the gear reducer is usually expressed in rotations per minute (RPM) and can be determined using the following formula:[14]

$$RPM = \frac{FPM \times 3.820}{Dia}$$

Where:

RPM = rotations per minute

FPM = feet per minute

Dia = pitch diameter in inches of the drum or chain sprocket

Next, determine the required torque. Most gearmotor manufacturers express their output values in pound-inches (lb-in) of torque. It is necessary to work in the same value as it is very easy to confuse the different values. We will be using lb-in of values. Another common value used is pound-feet (lb-ft) of torque.

Determining output torque of the gearmotor can be an involved process requiring a number of steps.

Initially, determine inertia calculations for all parts of the hoist components beyond the gearmotor. Inertia is typically represented by the letter "*J*" in these formulas. Each piece of shaft, drum and sprocket will need to be calculated separately.

For a solid cylinder the inertia formula will be:[15]

$$J = \frac{(r^4 \times L \times \rho)}{C_2}$$

Where:

J = inertia in lb-in-s^2

r = radius of cylinder in inches

L = length of cylinder in inches

ρ = specific gravity of the cylinder material

Steel = 0.284 lb/in^3

Aluminum = 0.0955 lb/in^3

C_2 = conversion factor 246.0

For a hollow cylinder the inertia formula will be:[16]

$$J = \frac{W}{g} \times r^2$$

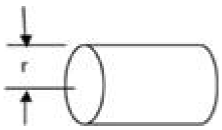


Figure 10.13

Where:

J = inertia in lb-in-s^2

W = weight of cylinder in lb

g = gravitational acceleration 386 in/s^2

r = radius of cylinder in inches

Now the load torque is calculated. The force in the following formula is the lifting capacity of the hoist.[17]

$$T_L = F \times r$$

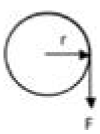


Figure 10.14

Where:

T_L = torque in lb-in

F = force perpendicular to the rotated shaft

r = radius to where the force F is applied in inches

The motion profile of the motor must be understood, as accelerating a weight will take more energy than it would take to maintain constant speed for that weight. The less time it takes to accelerate a weight from a dead stop to operating speed, the more torque from the motor is required. A typical motion profile graph would look like Figure 10.15.

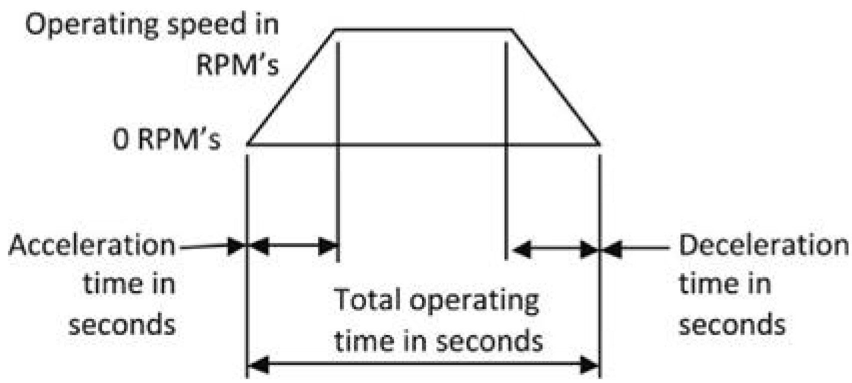


Figure 10.15

A typical acceleration time for a constant speed hoist to accelerate from zero to 20′ per minute will be in the ½-second range.

The inertias, J, calculated previously can be converted to torques using the following formula. This calculation needs to be done for all of the inertias previously calculated.[18]

$$T = \frac{J \times RPM}{9.55 \times t}$$

Where:

T = torque in lb-in

J = inertia in lb-in-s^2

RPM = rotations per minute

t = acceleration time in seconds

Next the root mean square (RMS) torque is calculated using the above information. In this formula all of the above torques are compiled. This includes the load torque (T_L) value calculated previously.[19]

$$T_{RMS} = \sqrt{\frac{T_1^2 \times t_1 + T_2^2 \times t_2 + T_n^2 \times n}{t_1 + t_2 + t_n}}$$

Where:

T_{RMS} = torque root means squared in lb-in

T_1, T_2, T_n = Torque 1 through n in lb-in

t_1, t_2, t_n = times 1 through n in seconds

The T_{RMS} value is the minimum torque output from the gearmotor that is required to move the load given the amount of lifted weight, shafting, drums and time parameters.

The next step is to multiply the T_{RMS} value with a design factor. A typical design factor in the order of 1.25 is not uncommon. A formula multiplying the T_{RMS} value with a design factor would be the following.[20]

$$T_M = T_{RMS} \times D_f$$

Where:

T_M = required torque in lb-in

T_{RMS} = torque root means squared in lb-in

D_f = design factor

The T_M value is the output torque of the gearmotor along with the RPM required and can be found in the gearmotor tables of the manufacturer's catalog. It is very rare that both of these exact values are available in the catalog. When selecting a gearmotor it is important to choose a torque value that is greater than the T_M value calculated. The associated RPM of the selected gearmotor may also be slightly faster or slower than the ideal RPMs calculated. It will be necessary to use the RPMs from the selected gearmotor and reverse calculate how fast the hoist will be traveling. The following formula will yield the feet per minute speed of the hoist.[21]

$$FPM = Dia \times RPM \times 0.2618$$

Where:

FPM = feet per minute

Dia = pitch diameter of the drum or chain sprocket in inches

RPM = rotations per minute

After a gearmotor has been selected several checks must be performed to be certain the gearmotor will perform satisfactorily.

An overhung load is a force that is applied at right angles to the shaft beyond the shaft's outermost bearing. Sprockets and drums will create an overhung load. The amount of this load will vary depending upon its location on the shaft. Overhung loads exceeding the capacity indicated in the gearmotor selection table will cause premature bearing failure. Overhung loads given in the tables are applied at the midpoint of the shaft and are without thrust loads to the shaft. If there is a combination of overhung and thrust loads on the shaft, consult the manufacturer to determine if the loads are acceptable for the reducer.[22]

An overhung load can be calculated in the following formula:[23]

$$F_{OHL} = \frac{2 \times T \times f_z}{d_o}$$

Where:

F_{OHL} = calculated overhung load (OHL) on the gear reducer shaft

T = load torque on the shaft in lb-in

d_o = pitch diameter of overhung component in inches

f_z = power transmission component factor from table below

Table 10.2

Transmission Component	*Factor f_z*	*Notes*
Chain sprocket	1.40	13 teeth or less
Chain sprocket	1.20	14 to 20 teeth
Chain sprocket	1.00	21 teeth or more
Cable drum	1.00	

After calculating F_{OHL}, compare it to the overhung capacity found in the motor selection tables.

If $F_{OHL} \leq F_R$ for the output shaft the reducer is fine. If F_{OHL} ampdontgtsemi F_R then the reducer either needs larger bearings that will meet or exceed the F_{OHL} or a larger reducer must be selected.

If the overhung load is not in the center of the shaft, consult the manufacturer of the reducer to calculate the overhung load and shaft strength to ensure acceptability.

Thrust loads, or axial loads, are loads that are directed toward or away from the gear reducer along the axis of the shaft. Output shaft thrust loads are commonly designated as F_a and are listed in the gearmotor selection table. Thrust loads cannot exceed the value indicated in the table; if it does, a larger gear reducer must be selected. If there is a combination of overhung and thrust loads on the shaft, consult the manufacturer to determine if the loads are acceptable for the reducer.[24]

Consult the gearmotor manufacturer if the gearmotor will be running constantly and has two or more of the following: is in an environment where the temperature is greater than 86° F; has a motor oriented either up or down; has a motor speed greater than 1,800 RPM. This usually is not applicable for the theatre industry as most hoists are not run constantly.

As mentioned earlier in the chapter, most manufacturers use gearmotor sizing software that will do most of the calculations and document the results. The motor sizing software is good but there are a couple of calculations that should be performed outside of the software for input into the software. The software does not calculate the inertia for the sprockets, shafting and drums. Fortunately calculating the inertia for drums, shafting, and sprockets is not very difficult. The software will guide you to a selected set of acceptable gearmotors that saves having to page through the entire catalog trying to find an acceptable gearmotor. Most gearmotor catalogs are over an inch thick and are mostly tables of information.

When the software has selected a gearmotor, all of the checks listed above must be performed to ensure that the published values are not exceeded.

Using PT Pilot to calculate a 2,000lb cable drum speaker hoist, Figures 10.16 and 10.17 are a printout of the calculations generated. The first page is mostly information that is contained in the software and includes: the lifted load, speed, drum pitch diameter, additional inertia (the calculated inertia for the drum, side plates and shafting), the lifting efficiency for the cable on the drum, operating criteria (the motion profile), brake torque, and high inertia fan. The second page has the results from the software calculated for both up and down motion including: calculated static HP, actual speed, acceleration time, starting time, and braking distance. The lower part of the page has the selected gear motor model, the HP, gear ratio, output speed in RPM, output torque, nameplate service factor, reducer efficiency, and brake torque.

12/12/13 PT Pilot

SEW-EURODRIVE

PT Pilot® Calculator Report

Company | **Date** 12/12/2013

Project Name Center Speaker Hoist

Created By

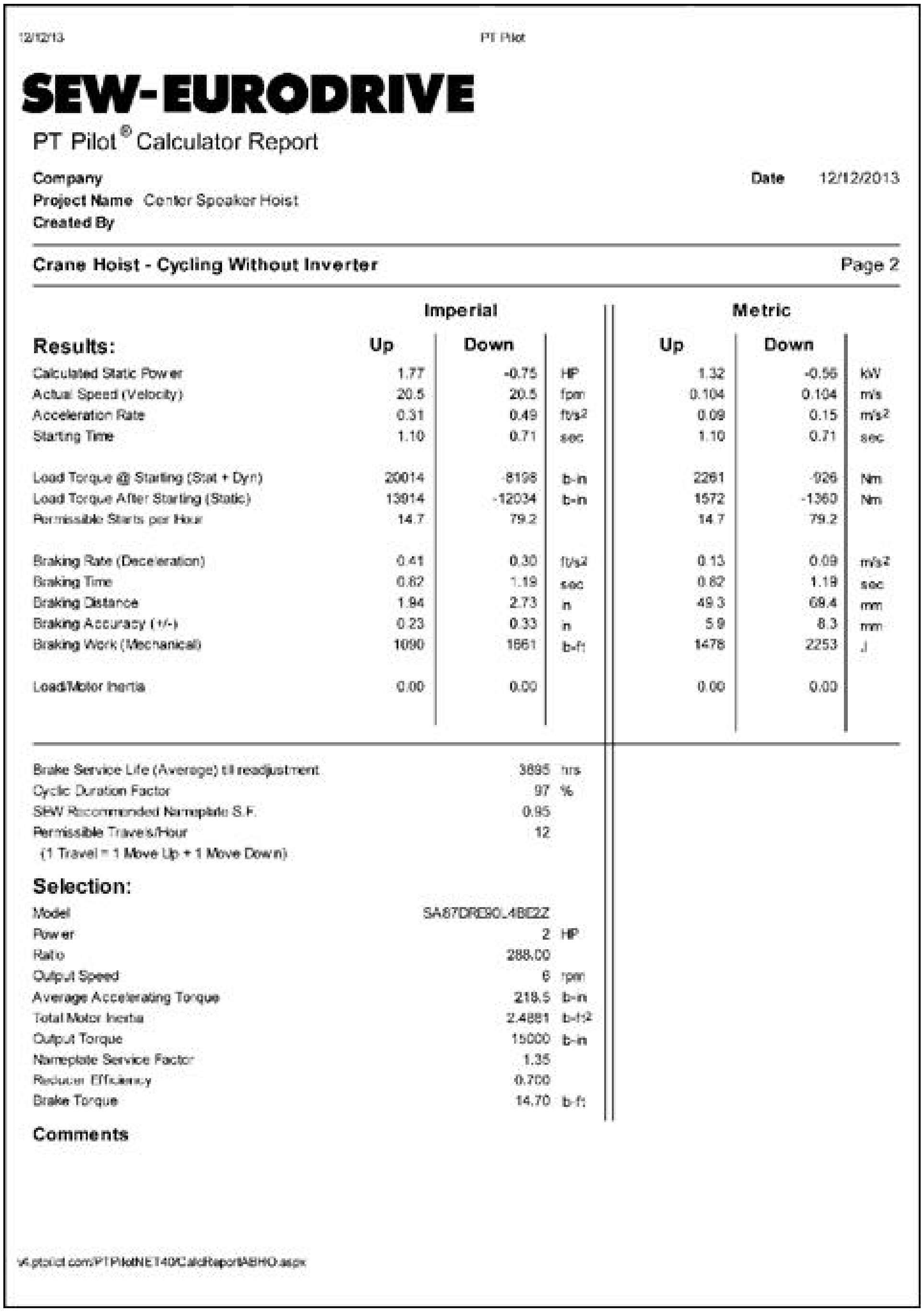
Crane Hoist - Cycling Without Inverter | Page 1

Input:

	Imperial		Metric	
Maximum Weight/Mass - Up	2000	lb	907	kg
Maximum Weight/Mass - Down	2000	lb	907	kg
Counterweight Mass	0	lb	0	kg
Load Velocity	20.0	ft/min	0.102	m/s
Counterweight Velocity	--	ft/min	--	m/s
Reeving Ratio	1		1	
Drum or Sprocket Diameter	12.94	in	328.7	mm
Additional Inertia	14.008	lb-ft²	0.59	kgm²
Minimum Acceleration	--	ft/s²	--	m/s²
Minimum Deceleration	0.00	ft/s²	0.00	m/s²
Lifting Type	Steel Cable & Drum			
Lifting Efficiency	0.93			
Hours Operation Per Day	8			
Run Time	146.00	sec		
Cycle Time	150.00	sec		
Desired Starts/Hr	24.0			
Desired Travels/Hr (1 Travel = 1 Up + 1 Down)	12.0			
Desired Nameplate S.F.	1.00			
Motor Poles / Frequency	All / 60	Hz		
Brake?	Yes			
Brake Torque Desired	100%			
Rapid Reaction?	No			
Include High Inertia Z-Fan?	Yes			
Class H Insulation plus Forced Cooling Fan?	No			

v4.ptpilot.com/PTPilotNET40CalcReportASHO.aspx

Figure 10.16



12/12/13 PT Pilot

SEW-EURODRIVE

PT Pilot® Calculator Report

Company **Date** 12/12/2013
Project Name Center Speaker Hoist
Created By

Crane Hoist - Cycling Without Inverter Page 2

Results:	Imperial Up	Imperial Down		Metric Up	Metric Down	
Calculated Static Power	1.77	-0.75	HP	1.32	-0.56	kW
Actual Speed (Velocity)	20.5	20.5	fpm	0.104	0.104	m/s
Acceleration Rate	0.31	0.49	ft/s²	0.09	0.15	m/s²
Starting Time	1.10	0.71	sec	1.10	0.71	sec
Load Torque @ Starting (Stat + Dyn)	20014	-8198	b-in	2261	-926	Nm
Load Torque After Starting (Static)	13914	-12034	b-in	1572	-1360	Nm
Permissible Starts per Hour	14.7	79.2		14.7	79.2	
Braking Rate (Deceleration)	0.41	0.30	ft/s²	0.13	0.09	m/s²
Braking Time	0.82	1.19	sec	0.82	1.19	sec
Braking Distance	1.94	2.73	in	49.3	69.4	mm
Braking Accuracy (+/-)	0.23	0.33	in	5.9	8.3	mm
Braking Work (Mechanical)	1090	1661	b-ft	1478	2253	J
Load/Motor Inertia	0.00	0.00		0.00	0.00	

Brake Service Life (Average) till readjustment	3895	hrs
Cyclic Duration Factor	97	%
SEW Recommended Nameplate S.F.	0.95	
Permissible Travels/Hour	12	
(1 Travel = 1 Move Up + 1 Move Down)		

Selection:

Model	SA67DRE90L4BE2Z	
Power	2	HP
Ratio	288.00	
Output Speed	6	rpm
Average Accelerating Torque	218.5	b-in
Total Motor Inertia	2.4881	b-ft²
Output Torque	15000	b-in
Nameplate Service Factor	1.35	
Reducer Efficiency	0.700	
Brake Torque	14.70	b-ft

Comments

v6.ptpilot.com/PTPilotNET40/CalcReportABHO.aspx

Figure 10.17

Endnotes

1 MacWhyte Wire Rope Company, Catalog G-18 (Kenosha, WI) p. 170.

2 Unirope, Ltd., Wire Rope, www.unirope.com/wireropes/pdfs/wr_technical_info.pdf, p. 11 (December 15, 2013).

3 Leeson Electric Corp., Basic Training Industrial-Duty Electric Motors, Gearmotors & Commercial-Duty Gear Reducers, AC & DC Drives (Grafton, WI: Leeson Electric Corp.,1999), p. 24.

4 Leeson Electric Corp., p. 25.

5 Leeson Electric Corp., p. 24.

6 Leeson Electric Corp., p. 25.

7 Leeson Electric Corp., p. 26.

8 NORD Gear Corp., Constant Speed Drives, Simple Reliable Efficient Drive Systems 100200001/ 01.11(Waunakee, WI: NORD Gear Corp.), p. A68.

9 NORD Gear Corp., p. A11.

10 SEW Eurodrive Corp., SEW Workbench www.seweurodrive.com/produkt/electronic-catalog-system-engineering-sew-workbench.htm (December 14, 2013).

11 SEW Eurodrive Corp., Documentation www.seweurodrive.com/support/index.php (December 14, 2013).

12 NORD Gear Corp., Documentation www.nord.com/cms/en/documentation/dop_documentation.jsp (December 14, 2013).

13 NORD Gear Corp., p. A11.

14 NORD Gear Corp., Formula Card (Waunakee, WI: NORD Gear Corp.).

15 Kollmorgen Corp., Application Sizing Guide, Servomotor Selection www.kollmorgen.com/en-us/search/?searchText=application+sizing, p. 3 (December 14, 2013).

16 Kollmorgen Corp., p. 3.

17 Kollmorgen Corp., p. 5.

18 Kollmorgen Corp., p. 6.

19 Kollmorgen Corp., p. 6.

20 Oriental Motor Corp., Technical Reference www.orientalmotor.com/products/pdfs/2012-2013/G/usa_tech_calculation.pdf, p. G-4.

21 NORD Gear Corp., Formula Card (Waunakee, WI: NORD Gear Corp.).

22 NORD Gear Corp., p. A12.

23 NORD Gear Corp., p. A52.

24 NORD Gear Corp., p. A52.

11

Training in the 21st Century (US version)

EDDIE RAYMOND

We live in an age where most information is available to us at the click of a mouse or keyboard. We also live and work in a world where technological changes have created opportunities to do more things and to jump into doing them sooner. This is a great thing and has allowed unprecedented growth and change in the entertainment technologies sector. It does, however, often impart the feeling that we know what we need to move to the next level. So, given all this access to information and opportunity, in a constantly evolving workplace, what are we doing to ensure that our technicians are properly trained and vetted?

Let me begin this chapter on training with a notion about learning: learning is linear. Over the span of a lifetime there's a beginning, several middles and, occasionally, an end to the learning curve. In the entertainment industries we often think that once we learn the basics we can skip those middle steps and jump right in at an advanced level. However, in doing so, we are denying the complexity of the crafts as well as dishonoring the real experts in the field. This is as much because the crafts in the entertainment industries are "avocational" long before they are vocational, as we have lost the tradition of progressive learning in our industry. We do these jobs because they are interesting and sometimes fun and we don't want to deny ourselves the experience (or the money) just because we have yet to learn the nuances.

There is a metric taught in coaching clinics that explains the levels of learning in a succinct way. There are, in this metric, four levels of competency:

1 Unconsciously incompetent—you don't even know what you don't know.

2 Consciously incompetent—you are aware of your lack of knowledge.

3 Consciously competent—you know stuff, but you have to think about it.

4 Unconsciously competent—you can perform certain tasks without thinking about it.

For example, a person who has never rigged professionally or who comes from a sport climbing background may not know to tie a bowline with a long loop to send a basket and bridle to a high rigger. He's unconsciously incompetent.

Once he's been told to use a bowline, but before he learns how, he's consciously incompetent.

After some practice, he can tie a bowline and knows when to do so most of the time. He's consciously competent.

After rigging for a few years, he no longer has to think about how to tie a bowline or when to use it. He is unconsciously competent.

This is a useful tool when talking with students about the learning curve and progressive learning. It isn't pejorative, but it does illustrate the point in an accessible way.

Another way to think of this is in terms of the foundations necessary to learn certain skills. Jean Piaget was a Swiss developmental psychologist and philosopher. In his theory of cognitive development, Piaget defined learning as mental processes dependent on biological maturation and environmental experience. He posited that an individual was incapable of "owning" a new concept until, through experience and exposure, they "owned" (had a working grasp of) the concepts on which it was built. Until a child had reached a certain biological maturity and been exposed to ideas from which they learned, they could not learn above the level of that experience.

A child who doesn't own the concept of "more and less" can't learn to count. They can repeat the sequence of numbers, but they will not understand the values of those numbers until they own the concept of "more and less" on which it depends. He referred to this as conservation, the idea that things have a value and that the redistribution of things doesn't change their inherent value.

In the same sense, learning to be a rigger (or an electrician or an automation technician) relies on ownership of the concepts that precede the new skill you are learning. You may be able to imitate what someone else has done in building a bridle or hanging scenery on a batten, but if you don't understand the reasons why it was done in a particular method or order, eventually you will make a mistake, and this could have serious consequences. We must be exposed to a number of variations in our crafts in order to own the concepts on which those crafts are based.

Learning is a different experience for each of us. Adult learners in particular are very much set in their ways of learning. Depending on who you read, there are variations on how those ways are defined. I favor David Kolb's theory that there are four primary styles of learning and that each of us operates with a combination of all four. They are as follows:

- **Convergers:** These are people who learn best by abstract conceptualization (AC)—understanding an idea by reading about it or listening to an explanation of it—and active experimentation—doing it. They are good at making practical applications of ideas and using deductive reasoning to solve problems.
- **Divergers:** Those who tend toward concrete experience (CE)—learning by doing while being coached—and reflective observation—watching someone else demonstrate a skill. They are imaginative and are good at coming up with ideas and seeing things from different perspectives.
- **Assimilators:** These are characterized by those who learn by reflective observation (RO) *and* abstract conceptualization. They are capable of creating theoretical models by means of inductive reasoning.
- **Accommodators:** These use concrete experience (CE) and active experimentation, trial and error to learn a skill. They are good at actively engaging with the world and actually doing things instead of merely reading about and studying them.

Few of us learn purely by using one of the four learning styles. Each of us learns through a combination of these styles, although we usually have one or two that work best for us. There are ways to approximate an individual's learning preferences and illustrations that graphically demonstrate the results. Below is one such exercise.

Exercise Instructions

There are four sets of four descriptions listed in this inventory. Mark the words in each row that are most like you, second most like you, third most like you, and least like you. Put a four (4) next to the description that is *most* like you, a three (3) next to the description that is second most like you, a two (2) next to the description that is third most like you, and a one (1) next to the description that is *least* like you (4 = most like you; 1 = least like you). Be sure to assign a different rank number to each of the four words in each row; do not make ties.

EXAMPLE

happy 4	fast 2	angry 1	careful 3

Some people find it easiest to decide first which word best describes them (4 happy) and then to decide the word that is least like them (1 angry). Then you can give a three to that word in the remaining pair that is most like you (3 careful) and a two to the word that is left over (2 fast).

The person "described" above shows a preference toward learning through active experimentation and concrete experience over reflective observation. This also demonstrates that this person will do poorly if the only option for learning a concept is abstract conceptualization (reading about it). Notice, however, that there is some possibility for learning in each style. The primary point here is not that we have to test each student to determine their strongest learning style, but rather that we cover all four styles whenever possible.

To use a simple example of how this strategy might be employed in an effective training, think about how we teach a stagehand to tie a bowline. There are those who could read or listen to a description of how to tie the knot and figure it out from that alone. Many could learn the knot by watching someone else tie it. Most can learn the knot by being coached step-by-step through the process. Still others might simply look at the knot already tied and figure it out on their own.

EXERCISE

A	Feeling ____	Watching ____	Thinking ____	Doing ____
B	Concrete ____	Reflective ____	Abstract ____	Active ____
C	Experience ____	Observation ____	Conceptualization ____	Experimentation ____
D	Practical Application ____	Modeling Another's Behavior ____	Reading ____	Trial and Error ____
	TOTAL CE ________	TOTAL RO ________	TOTAL AC ________	TOTAL AE ________

Figure 11.1

However, if in a single class the students are taught using all four learning styles, then the possibility of success would be much higher. In this scenario they would be:

1 handed a sheet of paper with an illustration of the knot and an explanation of its uses and properties;

2 presented with a demonstration of how the knot is tied;

3 followed by a coaching session where they practice tying the knot;

4 finally, left to practice on their own.

If you subscribe to this idea, then any effective training must include opportunities for each of these styles of learning. Being exposed to a variety of experiences over a prolonged period of time provides us with opportunities to learn in our most effective style or styles. But even with the best teaching strategy there are no shortcuts; skills can’t be learned overnight.

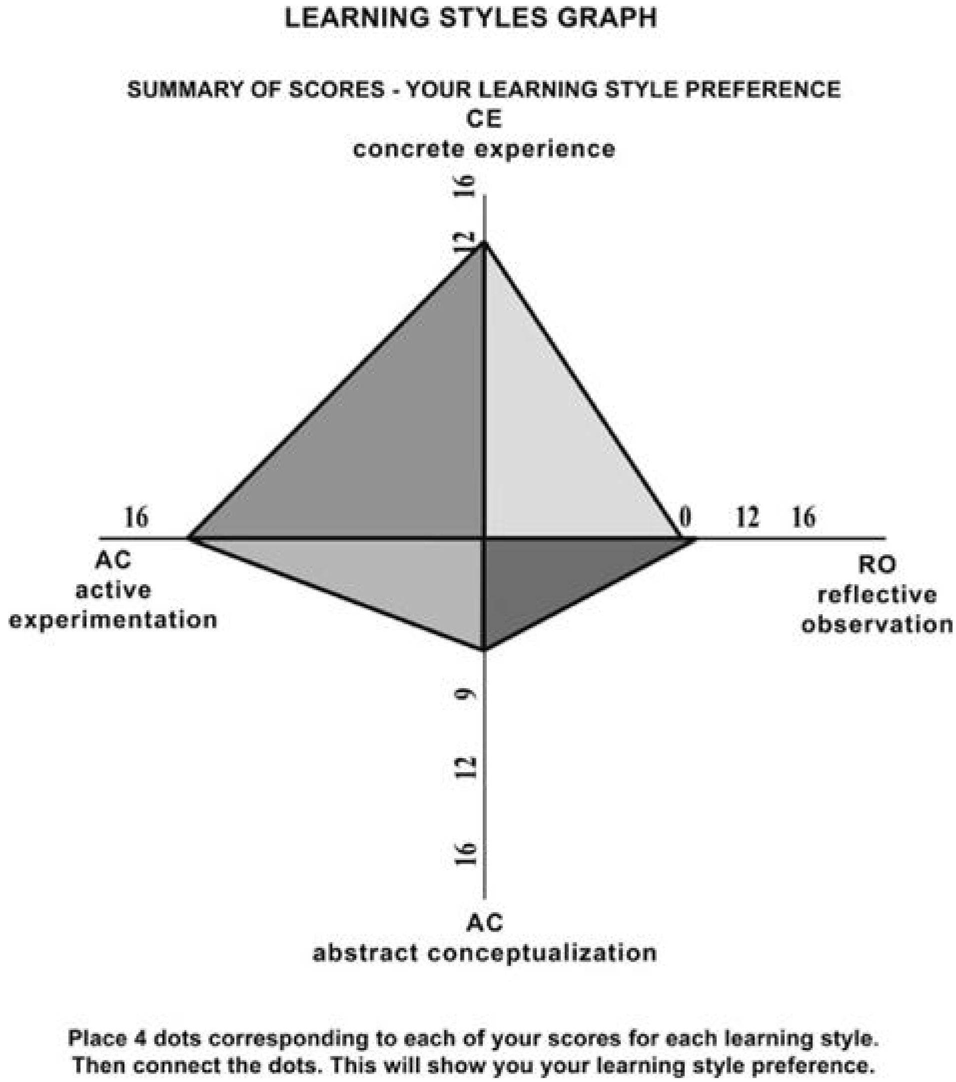


Figure 11.2

OK, enough psychobabble for now. Let's look a little at how the craft of rigging has evolved and where we are in terms of training.

Theatrical rigging goes back at least to the Greeks. Granted, the materials they used were only vaguely similar to what we have at our disposal now, but the concept and problem-solving matrix was the same—gravity makes things fall down, rigging prevents things from falling down, at least when you don't want them to.

In the early days of "modern" theatre, the rigging systems were based on the practices used in the tall ships that sailed the oceans. While we may think that this was a crude way to do theatre, the skills learned by the sailors employed as riggers and flymen in the old hemp houses were learned under the most harrowing and crucial of circumstances. If they screwed up the rigging on a three-masted schooner in a squall or hurricane, people died—and they themselves were among the dead. It was imperative that they understood the entire system of ropes, pulleys, block and falls, and belaying methods in order to survive. Recruiting them to take charge of the rigging in theatres was a logical choice. Their survival proved their skill and worth, and they brought with them a sense of professionalism and competence.

Today there are only a handful of hemp houses left in the country. While you'll not likely ever work in one, learning how things are done in a hemp house has great residual value as you move through your career as a rigger. If you can, go spend some time talking to an old-timer about how it's done. If nothing else, the stories are worth the effort. Telling stories is part of the rich heritage of stagehands around the world.

In the first part of the twentieth century, counterweight rigging systems began to be developed. While these systems were possibly less flexible than the old hemp systems, they were certainly more efficient for the majority of theatrical applications. Fixed line-sets with single operating lines and counterweight arbors with uniformly weighted “bricks” were easier to load, balance, and use than any five-line hemp set with a sandbag and a haul-down line. Load-ins and load-outs were streamlined and more shows hit the road. Just as learning from the old hemp house flyman is valuable, learning to properly use, inspect, and maintain a counterweight system is equally valuable. The lessons are inherent to all rigging.

In the late twentieth century, counterweight systems began a slow decline in popularity as new motorized systems came on the market. We are now in the midst of what will likely be a decade-long transition from counterweight to computer-controlled mechanical systems.

In addition to fixed rigging systems, theatres more and more utilize rigging systems that were developed for touring concert and arena shows by pioneers in the industry such as Roy Bickel and Rocky Paulson. These systems have evolved from older and more traditional elements of rigging to highly specialized systems using engineered truss systems, motorized chain hoists and drum winches with computer controls, load sensors and a variety of other specialized hardware.

The variety of rigging tools in the theatre has never been greater. Many houses use combinations of counterweight systems, mechanical and arena style rigging, and even hemp systems to hang and run a show. Many elements of modern scenery have made this a necessity. For one thing, scenery is heavier. Automation systems that work above the stage require stability that is not always possible with counterweight sets. Lighting units are heavier and more complicated than ever before. Projection systems require specialized rigging as well. The modern theatre rigger must be familiar with all of the possibilities in order to be at the top of their game.

Which brings us back to training and learning. Remember the basic precept that learning is linear? In a world where a practitioner of rigging in a modern theatre must know at least three and hopefully four systems of rigging, there is a need to develop curricula that ensures that as a young person learns the ropes (pun intended) there are no holes in that learning that may cause problems down the road. So where are these curricula coming from today? Good question!

In past decades, young stagehands often learned from older, more experienced craftsmen (or parents) and were told to keep their eyes open, their mouths shut, and their hands busy. This “mentor” model served the industry well for a very long time, but as the technologies evolved, became more complicated, and the stakes grew higher (both in dollars and in risk) “this is how I have always done it” became a less viable answer to technological problems. The value of mentoring has been eroded, even though there is great value in learning the oral history of how and why the industry evolved from someone who was there.

Universities, with a few notable exceptions, are by design not intended to be craft schools. In the first place, their purpose is not necessarily to develop “blue collar” practitioners of the crafts, but to develop designers, technical directors, and managers. Due to this, and budget constraints, many don’t expose the majority of their theatre students to the craft side of the industry in a studied manner. All are required to participate in some craft activities, but not so as to thoroughly learn the crafts. They do their stint in the shop or on the stage to support a production and then go back to their chosen discipline. Which is not to say that a university education for a theatre technician is a bad thing. A person who graduates with an MFA in theatre, who is willing to put the time in to learn the crafts, brings a more developed sense of the big picture and can be a great asset in the collaborative world that is theatre.

The International Alliance of Theatrical Stage Employees (IATSE) has taken a long time to embrace training from the top down. However, under the current leadership, many new training and education initiatives have taken root in the past four years. Many individual locals have developed programs to train young stagehands so as to meet the demands of the workplace and to protect their members and their jurisdictions. Building on an already strong workforce and traditions of old school apprenticeships or learning from the elders, these locals have utilized a number of resources to bring training to their locals. Training Trust Funds have sprung up around the Alliance, and now IATSE itself has a robust Training Trust Fund to aid locals in this endeavor. Each local has developed its own method and criteria, and there is a nascent but coordinated effort to define the skills needed in each craft and to standardize training. Individual trainers are being identified and put into a database so that locals can find the training they need to meet their needs.

As the stakes have risen and it has become more important to know exactly who is being trusted with the work at hand, the industry has embarked on efforts to introduce certification to some of the skill sectors. In North America under the PLASA banner, the Entertainment Technician Certification Program (ETCP) has launched three certifications—Entertainment Rigger Theatrical, Entertainment Rigger Arena, and Entertainment Electrician—so that employers can have some assurance that the people they hire to run crews, analyze jobs, and practice the higher levels of the craft have been vetted in a systematic way that is recognized across the industry here. With more than 1,500 certifications issued to date, this effort is proving to be useful and popular.

In turn, the demand for training so that technicians can study, practice, and eventually qualify to become certified technicians has increased greatly since the introduction of ETCP in 2005. That resources are being developed to deliver the much-needed training is a great sign that the craft is being taken more seriously. Individuals, unions, equipment manufacturers, and production companies are all jumping in to answer the call for more and better training.

What's missing at this point is an agreed curriculum that lays out a progressive order of training from how to tie a knot to how to calculate complicated loads, that includes everything in between and builds skills based on the concept of linear learning. Additionally, there is yet to be developed a way to train instructors in the best methods for adult education (yes, I know, not all stagehands are adults) and to ensure the best success of the majority of students they teach. Many stagehands are far removed from the classroom and training methods must take that into account. We must accommodate all styles of learning.

The Canadian Human Resources Council has addressed the first of these missing elements with the development of a Chart of Competencies for a variety of theatrical jobs, including riggers. This is an attempt to determine what a person must know to be a competent craftsperson, what resources are in place to impart that knowledge and skill, and where there are unmet needs in training resources. I submit that there is a need in the US as well as worldwide to further develop such charts and to develop resources that parallel those findings. It is in our best interest to begin to develop the learning curve, the lessons to achieve that learning and the people to deliver those lessons.

In looking at the requirements of technicians in today's quickly evolving and financially restrictive world, there are other skills equally important to the future success of individuals that need attention. Communication skills are among the least recognized and developed of these. It is often thought that people either are or are not good communicators. While this may be true at face value, the skills employed by good communicators are learnable. Learning how to translate an idea into words, how to assess your audience and how to evaluate your success as a communicator are all things that can be taught and learned.

Learning how to motivate a crew and/or fellow workers is another skill that can be learned. It is most important in the entertainment industries where the hours are often long and the information frequently slim. Working with motivated people can make the difference not only between a good or a bad day at work, but also in the success and safety of a project.

Learning to be a good communicator and to motivate those around you to a high level of performance creates efficiencies and a safer working environment for all involved. These skills make clear the expectations of those in charge and ensure that everyone is aware of the procedures, expectations, and resources of a work site. Especially for lead positions, these are essential skills that can and should be taught.

The entertainment industry has come of age recently and acknowledged that what we do is complicated. Being a professional entertainment technician requires recognizable skills gained through experience and training, and the stakes are high. A concern for the safety of our workers and the talent and audiences we work around has been more in focus of late than ever before.

The response to this acknowledgement has led to a great enthusiasm for more and better training. In order to make this a reality, we need to break the crafts down into bite-size pieces, recognize the progression of skills needed so as to train technicians on a strong foundation, and use diverse training methods that play to the strengths of those learning the crafts. We are blessed with a small handful of great trainers. Now we need to develop a small army of new trainers who understand what is at stake and the best methods to meet our goals.

The future is bright in this regard. The changes in just the past decade or so are evidence that there is a movement afoot that can yield a better trained and more skillful workforce in the entertainment industries. However, there is a great deal of work to be done before we get there and we all need to be a part of that process.

12

Training in the 21st Century (UK version)

CHRIS HIGGS

The phrase 'a steep learning curve' is generally thought of as referring to something that's difficult to learn. In fact, when plotted against time and experience – on the x and y axes, respectively – a steep curve actually more accurately represents a quick process. However, the learning curve for a given task generally levels out once the basics are accomplished, allowing someone to achieve more in a given time. The entertainment industry is usually very fast to react to advances, almost always in response to production or creative demands. Therefore it's odd that rigging has been around for so long, but in many ways, until recently, has progressed fairly slowly relative to other disciplines in the industry.

This learning curve is not so different from the entertainment rigging industry itself! In the UK, rigging has been a stand-alone trade for about 25 years. Once the province of concert lighting crews, the development of touring lighting systems eventually required dedicated crewmembers to take care of the rigging. A twentieth century master carpenter was required, someone with a fairly unique set of skills combining engineering, carpentry, mechanical handling and a keen understanding of the business of show.

This was all quite new as a blend of skills and activities, so nobody knew what worked or had any preconceptions; there were definitely no codes of practice …

Structures were required to support first lights, then flown sound systems and scenic pieces. Frequently those structures were suspended on ropes, then wire ropes and chain motors – we'd done that for years over stages, but now they started to encroach on public areas, the auditoria, exhibition hall floors and sports spaces. The principles first employed to get some front lighting on a stage in a hall were being used to transform warehouses and ballrooms into theatres and studios. Sports venues were being used to stage concerts and, before we knew it, using chain motors was as common as using line-sets in theatres had been for 100 years. 'Industrial theatre' (corporates) and the rise of business communications had great influence and effect. Large numbers of theatre technicians were attracted to the even brighter lights and larger budgets of the corporate events. Production houses and the wide range of support services – including rigging and staging – blossomed.

People are people, of course, and some technicians were also climbers. The mind-set of technician blended with climber meant that very few places in a venue were inaccessible. Couple that attitude with the evolution of access machines and industrial fall protection systems and the world was our oyster. We could, and did, hang sh*t anywhere.

The pressures of a touring schedule required speed and efficiency in rigging. Climbing is faster and cheaper than using access machinery. Producers and production managers love a 'can do' attitude – and the smaller budget required. After all, if they can save renting access equipment then that's a bonus, and the skill and courage of the crew meant anything was possible.

The entertainment industry rigger had been born and was often an essential part of a project. Expectations of riggers and from riggers were almost as big as the egos involved.

Riggers were frequently known to and trusted by production managers as someone who had the right attitude (who wouldn't say no). Whether that individual actually understood what he was doing with the equipment was often secondary; if the show went up and nobody got hurt then it was a success. Trust accounts for a great deal when there is risk involved – financial or otherwise – but frankly, reputation was usually the thing nobody wanted to risk. You're only as good as your last job.

Productions got bigger, more riggers were needed; this spawned bespoke rigging companies and venue rigging departments. Soon the 'freelance rigger' emerged, someone who would probably work in every capacity in an average year. So the independent 'head rigger', the rigging company employee, the house rigger and the freelance rigger all became common job descriptions and functions.

Something puzzling is that, if training is so important, why have so few of the riggers we see at assessment had any training? There are very few courses available, but the vast majority have learned what they know on the job. The proportion is increasing slightly but the vast majority of both company and freelance riggers who have also had some formal training are few and far between. It's possible that training is seen as either too expensive or not necessary. Achieving the National Rigging Certificate without attending a training course is perhaps testament to the fact that there are other ways of learning than attending a course. I firmly believe in an apprenticeship route, but it is expensive for employers and in the UK there are many hoops to jump through to obtain funding, presumably to maintain quality and discourage using such schemes to provide cheap labour. It seems that as a society we are pushed down the road of being trained to a standard simply to gain employment. The most worrying reason is the thought that because an individual is already being paid for work as a rigger, that individual believes their competence to be sufficient; they already know all that they need to know, so why do they need any training? As we find at assessment, frequently very experienced and adroit people have no understanding of the fundamentals of statics, for example, or the correct use of fall protection equipment. Riggers don't need to be engineers but they do require a solid grasp of how forces work, what the law says and how manufacturers designed their equipment to be used.

One of the driving forces for me was that I wanted to know things and often couldn't find anyone who could answer my questions about forces, factors of safety and the like. Of course, the more you look, the more you find and it becomes a realisation that a lot of the information was not understood by the industry at all and there was a lot of job protection going on. This is where a Bertrand Russell quotation applies very well: 'Fools and fanatics are always so certain of themselves and wiser people so full of doubts.' Without suggesting that there are too many fools or fanatics involved with rigging, the principle is probably right. 'Ignorance is bliss' would be another way of putting it.

It is a question, then, of who to ask and how to check their competence. In time a network of engineers, suppliers, manufacturers and like-minded colleagues can compile information. Nobody has the whole picture and probably nobody ever will have, but what is happening to arena rigging, now at least, is a more formal approach. Theatre still lags a little way behind in the UK because the landscape is very different.

In the early 1990s, the flagship venue rigging teams were sent to get their powered access training and to the CM 'Motor School'. That was because that was virtually all that was available. The head rigger of the largest exhibition venue (and a great mentor) very wisely sent his riggers on a five-day (industrial) mechanical handling course. Not completely relevant but a very sensible move because it was a recognised, well-established course with the support of large construction companies and there was an element of assessment involved in the certification.

Otherwise there was very little; a couple of theatrical flying courses, a few lifting equipment inspection courses but that was about it.

People learn rigging by doing. They also copy what they assume is correct or appropriate. Sometimes they are right. Often they need little more than confirmation that they are doing the right things. However, the extra layer of quality and competence comes from knowing why.

People need to touch and feel the materials they will be using. Call it a rehearsal. Remove production pressures and the feeling of being scrutinised by peers.

The law in most parts of the world is exactly the same – don't hurt people. Plan work, make sure you are acting reasonably. Be prepared to defend yourself if it all goes wrong. Understand your competence and its limits, know your trade and communicate. Using problem-solving in training (which is really the definition of rigging anyway) will usually level the field of play in terms of age, experience, gender and attitude. Throw people in at the deep end but in a controlled environment where they know they are safe and can't damage anything.

Clearly there are common items in rigging inventories across the globe – the Lodestar, the 20.5″ truss, the polyester roundsling and the ⅝″ bow shackle. There are many variations in chain clutches (grabs), rigging steels, rings and links, but the really important thing is to ensure the people attending understand what the item is for, how it works and why. This is when the knack to getting people to remember stuff comes in. People like a real life story, and frequently there will be a part of the story that everyone can relate to. Maybe that's why people with experience in the field can deliver the information better than anyone else, even if they are not 'educators' by training. They have probably got a story for every occasion and can deliver it with authority and confidence. It also begs the question about an industry so self-absorbed that there is seemingly no funding or organisation to train trainers. These people are the key to the future.

It's all well and good having found the next generation to employ, but the industry also needs people who can properly deliver the information and skills to them, on the job and externally.

Our people are resourceful and imaginative; a demonstration is often all they need before being given the resources and time to try out the new information. They don't want to sit behind a desk for hours; they get fidgety when grouped around a flightcase for five minutes. They need to be given the tools and the time to figure it out. If they struggle or if it is clearly outside their comfort zone then intervention is called for in proportion to the issue at hand. What people don't need, at least at the beginning of the process, is longwinded theory, legal and safety stuff. That can come later when they see the relevance of it. Things that aren't relevant are the things they won't use or can't practice.

Training on offer in the UK has nothing to do with the National Rigging Certificate(NRC) and is completely unregulated.The providers aren't scrutinised and there is a blind belief that the information being delivered is kosher; the fact that someone is offering training must mean they are competent. Is that information current and valid? There will be a need to accredit training providers soon. It is often the case that content is based on opinion and experience rather than solid facts, especially regarding legislation and standards.

The fundamental part of designing training is that the employer needs to identify what their staff need, not the training provider. Too often 'you know what they need' is the reply when a brief is requested. One way to combat the management's woeful lack of knowledge is to ask the employer to confirm that the syllabus is appropriate to their needs. At the conclusion of the course, the management often assume attendees will be expert on their return. Employers will often say they want as much from the training as possible – 'cover everything'.

The commercial aspects of training are not healthy. We are in an environment where training is still seen as a luxury because the people ordering it probably had none themselves and they have managed perfectly well without it during their careers. If you want to 'learn everything' then take an engineering degree – but that costs even more. Time is money. It is unlikely that the numbers of people requiring rigging training in our industry are ever going to be enough to allow rigging training to be anything more than a short-term course. Taking time out from work is always difficult, especially for freelance workers. Rigging by its nature needs practice in a real workplace situation, so the ideal method of delivery is the apprenticeship style. This requires commitment from the individual and the employer and needs to be structured so each obtains benefit without either side suffering from lack of involvement. It doesn't exclude short courses, they are complementary and can be repeated if necessary. What it does ensure is that the apprentice gets practice and supervision as well as seeing how they contribute to the production or service. However, by definition they are expensive and the employer has to be able to see the outcome as being of benefit. The desire to commit to any long-term arrangement doesn't seem that common these days and young people frequently aspire to be producers, not technicians.

Two fatalities at Earls Court, one in 1999 and another in 2000, and a serious fall in 2004 started to shake things up. At the time people were complaining that riggers were too inexperienced and lacking the basic skills. It was felt in some quarters that much of the industry was working beyond its competence at that time.

A small group of people had already worked together in the late 1990s on a UK project to design a rigging qualification. This was supported by a college and a trade association but was ultimately a commercial scheme. Education is big business. The college registered the course but the lack of numbers was its downfall. There just aren't enough people who need the qualification to justify the expense of delivering the training.

We regrouped and approached several trade associations before finally deciding to work with PLASA on what turned into the NRC. We were determined to produce a nationally recognised qualification that could hold its head up rather than something perceived as a commercially driven exercise or an old boys' network. It had to be transparent (riggers being a sceptical breed at the best of times) and it had to be relevant. The last thing we wanted was something that was imposed by a well-meaning but misinformed government department.

It became apparent very quickly this was going to be expensive and the basic plan was that PLASA would blaze the trail, develop the rigging qualifications and use the learning curve to develop qualifications in the future for other sectors of the industry such as temporary electrical installation.

There were a number of factors that influenced our thinking with the qualification. Probably the foremost in our minds was that we hadn't had any training. It therefore seemed inappropriate to demand that the qualification had to be the result of any training. We wanted the next generation of riggers to be better informed and better skilled than we had been. Most of what our generation learned was by trial and error, through practice good and bad. People who had broken the ice previously then handed down the knowledge. The idea of training riggers would steepen the learning curve – reduce the hours needed to really know something or to be able to perform a task. What it couldn't do was teach people behaviours or how to communicate. Most importantly, it would never be able to teach that most important factor in our business – attitude.

The overarching principle was that, by establishing benchmarks, because we assess against National Occupational Standards, we were producing a known quantity that could be used by employers when recruiting or putting teams together and by venues when vetting contractors working on their premises.

The National Rigging Certificate (NRC) is the only entertainment rigging qualification in the UK and it is starting to gain acceptance in several European countries. It is not just about certification. The NRC is about the recognition of skills that are vital to the rigging industry, which are often overlooked.

The qualification is for life, but in order to allow the industry to self-regulate and ensure riggers are meeting current practices the ID Card expires after five years. This renewal will only involve assessment if there are any significant changes to legislation, techniques or equipment during that time. It does not mean the whole assessment process has to be gone through again. On achievement, the candidate receives a certificate for the qualification and can then apply for the NRC ID Card.

Assessment takes into account knowledge, skill and experience in equal measure – so simply being good at climbing or physics is not enough – it is the combination of the essential skills that make up competence. The body of knowledge required is contained within a comprehensive NRC handbook and candidates are sent this when they register with PLASA Qualifications.

The assessment is based not on the assessor's opinion of a candidate's performance or knowledge, but on National Occupational Standards (knowledge and performance standards set out by the industry). These act as the benchmark by which the assessors make their decisions. Assessors are monitored by qualified internal verifiers based at the assessment centres, who themselves are verified by the awarding body, making it a three-tier quality assurance process.

The qualification is available at two levels. Level 2 is for riggers working independently, not fully supervised. Level 3 is the qualification for someone who supervises riggers. These levels represent the minimum competence required for rigging and are just as applicable to the theatre, concert touring, event, film and TV – anywhere entertainment or event rigging is carried out.

This is holistic assessment and builds a picture of an individual's competence overall, not necessarily requiring outstanding ability in any or all areas of competence, simply meeting the National Occupational Standards at the required standard is sufficient.

At Level 2, practical assessment covers the methods generally used in entertainment rigging. A written test examines underpinning knowledge in combination with verbal questioning. Training records and qualifications further support the candidate's evidence of competence. Importantly, previous experience is demonstrated by verified witness testimonies from employers and submission of rigging plots. After 12 months of appropriate rigging experience candidates are eligible to be assessed at Level 3, should they so wish. Centre assessment involves carrying out a risk assessment and sitting a written paper, submission of paper evidence including risk assessments, method statements, rigging plots, qualifications and training records. Following achievement at the centre, Level 3 candidates also undergo an on-site assessment that must include supervising riggers working at height.

The NRC assessment is entirely separate from training. This was a key feature in its development. We wanted to get away from the idea of doing training and then being assessed at the end of the week, especially by the same person that delivered the training. The NRC rules prevent a trainer from assessing some-one they've trained and there has to be a 12-month gap between training and assessment at a facility where the candidate's training was carried out.

For the same reasons, training providers may not advertise their courses as preparing for the NRC, simply that training 'may provide some of the knowledge required at assessment for the NRC at Level 2 or 3' to prevent 'cramming' for assessment. The scheme assesses experience, knowledge and understanding over time rather than being an examination.

The benefits of the NRC have been enormous. It has brought all the major players together, standardised many working practices and generally raised the standards of safety and workmanship. It has created a series of benchmarks and established a credible and mature industry body. The dangers are also many. Managers and venue people often don't understand rigging, so certification simply means to them that the rigger is qualified to do anything that has to do with rigging rather than it being a prescribed set of skills and standards at a particular level of responsibility.

There will always be riggers who satisfied the assessor they were competent but who choose not to use good practice on site. The similarities with driving are the best analogy. We all have to pass our driving test to obtain a licence but look at the standards of driving. Some people display exemplary skills and attitudes, some frighten us to death, but the majority of us have licences.

Can you imagine what it would be like if none of us were tested? A colleague has an expression that sums it up. He says 'just turn up and be average'. Meaning that employers don't need superstars. A good employer will have planned the work and will direct people on what to do and how to do it, the way it's been designed and, importantly, in the way it has been budgeted.

These days many companies are looking to buy in skilled labour on short contracts rather than train in-house because of the cost. It could be argued this is short-sighted, but this industry is notorious for 'just in time' philosophies. Lead times are short, sometimes to the point of lunacy. Promoters know people want the work and use that as leverage to obtain the best value for money. As an employer, you need the flexibility to be able to service those contracts and that will often mean using freelance labour and requiring them to perform a mix of tasks for an intense period. Very difficult to plan and to budget for if you've also an obligation to supervise young and inexperienced apprentices. You need experienced, versatile, resourceful people. Those people are now 45 years old, and there is a dearth of young riggers in the UK. The fascinating thing is that of the many people who have attended training, very few have ended up as riggers. It's always been a contention that providing knowledge and teaching rigging and work at height skills actually puts people off rigging. It is almost a necessary safety valve, to leave people in no doubt that rigging is not an easy option, it's not a job for people who don't want responsibility and it is not glamorous. The reason that someone wants to be a rigger is something none of us can put our finger on. It's almost a calling. On the other side of the coin, people being satisfactorily employed as riggers and being paid as such seem to believe they know all they need to know and don't need any training. We can always learn more, and as a responsible person should be aware of any conscious incompetence and commit to improve that to at least the point of conscious competence.

Certification is one way forward – employers and venues can use it as a benchmark and our experience in the UK is that is has formalised many of the methods we use, it has promoted safe systems of work and it has really sharpened our understanding of fall protection. It is alarming to see how many very experienced riggers coming for assessment bring PPE that is well past its sell-by date and don't know how to use it correctly. That in itself proves that a rigger will spend many hundreds of pounds on gear and work with it on site with nobody picking up on the shortcomings, including employers, co-workers or, alarmingly, venue management – another symptom of a lack of training.

Now the NRC exists, there is a minimum requirement to understand fall protection. Nothing complex, it's very basic stuff but it provides a benchmark and, for the venues, it means that, by demanding proof of NRC qualification, there should be no reason why the rigger shouldn't be competent to carry out the tasks the candidate was assessed against. It is therefore very important that employers know what the essential knowledge and skills are at each level.

Another important factor to recognise is that, like a driving licence test, certification isn't going to stop accidents or make everything safe. What it should do is mean that accidents are less likely because of the increase in awareness, better knowledge and that the people working have all reached at least a basic standard when they were tested. This is when the whole issue of currency or retesting rears its head. Should we be retested? The thinking seems to be that if you are working you will be using the skills and increasing your knowledge, therefore you will keep the skills honed. However, it may be that most people benefit from the threat of a retest every few years to keep their attention on the bigger picture. You can use some skills more than others; while you doubtless remember how to pedal the bike, you may need some practice to ride it without injuring yourself or others. This clearly entails cost and, given the current climate, we are probably a way off being in that position at the present.

In summary, we are in a period of consolidation. The industry has woken up and started to invest in its own future. We have instigated our own certification, won some battles with the safety authorities and in the process started and maintained healthy dialogue with them. We have a number of effective trade associations, we have regular seminars and even a conference where ideas are shared and discussed. We have a number of the 'original' riggers starting to plough back what they have learned. Their apprentices, now close to middle age, are running facilities and companies. It should only get better. Time will tell. We're still on a learning curve.

13

Working Safely at Height

A Common Sense Approach to the Challenges of Rigging in the Entertainment Industry

BILL SAPSIS

Rigging in the entertainment rigging industry got its start in the early 1960s on the touring ice shows. There was little concern for safety in those days and it took about 30 years, and some highly publicized accidents, to get the industry to start adopting a culture that included personal safety. Fortunately, that culture has now taken hold and safety equipment is becoming more commonplace around the country. The trick now is to not only keep this trend moving forward but also ensure that the right equipment is being used, and used properly.

Fortunately, we get some help from folks in high places:

- The Occupational Safety and Health Administration (OSHA) sets the rules for worker safety in the United States.
- The Canadian Centre for Occupational Health and Safety (CCOHS) does the same for Canada.
- The American National Standards Institute (ANSI) provides a framework for trade associations to develop voluntary standards that assist in the protection of workers within their respective industries.

Out of these organizations and government agencies have grown rules, regulations, standards, white papers, articles, and all manner of information that comprises our collective safety awareness. It is the goal of this chapter to distill this information into a digestible size and make it easier for all of us to understand what it takes to stay safe while working overhead.

There are three common terms—fall protection, fall restraint and fall arrest—that are used on an interchangeable basis within the rigging industry. They shouldn't be. They each have their own place in our industry and it's important to understand the distinctions between them.

Fall protection is what you do to eliminate a fall hazard. This should be the first action taken after identifying a fall hazard in the workplace. Taking a fall is no fun, so the best response to a fall hazard is to simply remove the possibility of a fall. A railing placed on the edge of a platform, for example, eliminates the fall hazard and no further action is necessary.

Fall restraint is used when you can't eliminate the hazard but you still want to avoid the falling part. An example would be running a rope or cable from the technician to the back of the platform that is long enough to allow the technician to move around and complete their work but not long enough to let them fall over the edge.

Fall arrest is what you do when neither fall protection nor fall restraint are possible. What you are left with is arresting (stopping) the person's fall before they hit the deck or other obstruction. Arresting a fall is a complicated and dangerous business and most safety experts feel that if you are using fall arrest to resolve a hazardous condition, you have failed to address the problem properly. Most safety experts, however, have not worked an arena concert load-in.

The issue with fall protection and fall restraint is they are situational and site specific and it's very difficult to cover all the potential scenarios and permutations in any sort of detail. Fall arrest, on the other hand, lends itself to general discussions and is something we can discuss in more global terms and still cover the bases.

First, the Rules

OSHA provides the rules, which can be found in 29 CFR Parts 1910 & 1926. However, these rules are not designed specifically for the entertainment industry and many times we are left to our own devices to sort out how to stay safe while we work.

First there's the 6′ rule. This rule states that if you have the ability to fall 6′ or more, you must be protected from injury or death. Using fall protection to eliminate the hazard would be ideal, as would fall restraint. When these don't work, fall arrest is required. This means that you have the ability to fall but the safety equipment will stop (arrest) your fall before you hit the deck or some other object.

It's important to remember that the 6′ rule requires you to be protected from hitting anything that can hurt you. If you are on a catwalk 60′ above the stage and the catwalk doesn't have a railing, you need to protect yourself from hitting the deck should you fall off the catwalk. However, if there's a plaster ceiling 3′ below the catwalk, then you have to protect yourself from hitting that ceiling. Obviously, if your fall is arrested before you hit the ceiling then it follows that you cannot hit the stage floor either. The point is, take nothing for granted. Evaluate the entire situation before determining the best course of action.

More Rules

All fall arrest equipment, when used by one person, must maintain a minimum tensile strength of 5,000lb (22.2kN).* Tensile strength means that the equipment could fail at 5,000lb but not at a force less than that. Not only must each component maintain this strength level but also the way each component is joined to the other parts of the assembly.

Then there's the one-time-use rule. Should you take a fall and survive, all of the safety equipment that was involved in arresting your fall must be removed from service. Most of the equipment—the harness, lanyard and lifeline, for example—should be discarded. Other elements of an arrest system, a self-retracting lifeline, for example, can be sent back to the manufacturer for repair and recertification. The reason for the one-time-use rule lies in the math of arresting a fall. Lots and lots of testing, combined with real world experience, has shown us that it takes, on average, about 3,000–3,300lb of force to arrest a human free-falling 6′. Knowing that the equipment is designed to resist failure up to 5,000lb, you are well protected the first time you fall. However, if you continue to use the same equipment and you have the misfortune to fall a second time, your equipment may no longer have the available strength to arrest that fall.

We could eliminate this rule by simply making the fall arrest equipment stronger. We don't do that for the simple reason that in making the equipment stronger it would become so big and bulky you'd look like the Pillsbury Dough Boy and you wouldn't be able to work. As a result, you wouldn't wear the gear at all. The one-time-use rule exists to help ensure that you actually do wear the gear.

Some of the other rules appear, on the surface, to be a bit mundane, but they're just as important as the more exciting ones.

First and foremost, your employer is responsible for providing you with the safety equipment. Not just fall arrest equipment, but all safety equipment. Please note that I said *providing* you with the safety equipment. I did not say they could sell you the equipment or make you purchase it on your own. You do not have to pay for the safety equipment that you need to conduct the job you've been hired to do.

The employer is responsible for proper training in the use of the equipment. Handing you a harness while saying "here, put this on" is *not* training. Make sure you know exactly how to wear and use the equipment you are being given. Never forget that it takes at least 3,000lb of force to arrest a fall and you don't want that force impacting on your body in the wrong place because you weren't wearing the gear properly.

The employer is also responsible for keeping the equipment safe by storing it in an appropriate location when it is not in use. The floor of the loading bridge or catwalk is not an appropriate location. A storage locker in the shop is.

Finally, the employer is responsible for maintaining records of the equipment and training. This is a government program, after all.

Your job, gentle reader, is to wear the equipment whenever it's required and abide by the training you have received. You may think this sort of thing would go without saying but roughly 50% of the fatalities from falling in the entertainment industry over the past 25 years have involved a technician who was either wearing the proper fall arrest equipment but did not use that equipment or was wearing the wrong equipment. Do not follow in their footsteps.

A cautionary note: in other industries it's relatively simple to identify the employer as typically they're the one signing the paychecks. That's not always the case with us. When your paycheck comes from a payroll service in Des Moines, the employer may be a little more difficult to identify. Ambiguities and confusion with things like identifying the employer will create problems for you should a legal issue be raised and you end up in court. Lawyers love to play in loopholes but it's in your best interests to keep those holes plugged as best as possible.

The Gear

Safety harness. Fall arrest harness. Full-body harness. Five-point harness. These are the most common terms used for the primary defense against becoming a brown spot on the floor with a chalk outline. No matter what you call it, a fall arrest harness must meet specific specifications for it to work properly and be approved for use. Fortunately, these specifications make sense and do exactly what we need them to do to protect ourselves.

It's practically impossible to find a fall arrest harness in the US that doesn't meet the OSHA specifications but, just to be sure, a quick review is in order.

When using a harness that claims to be approved for fall arrest, first check the label. If the harness simply says that it meets OSHA requirements but does not add a reference to a particular ANSI code or OSHA regulation number then it does *not* meet OSHA requirements. The label must identify a specific standard that the harness has been built to meet. There are a number of standards that are acceptable. An example is ANSI Z359.1-2007. So remember: no standard number on the label means that the device is not approved.

The harness must be a full-body style harness with leg and shoulder straps. In a suspender-style harness where the shoulder straps come straight down to your waist, there must also be a chest strap connecting the two shoulder straps. This is to ensure that you cannot fall out of the harness should you end up hanging upside down. The design of crossover style harnesses inherently solves this problem.

Figure 13.1 Basic harness, front

Figure 13.2 Basic harness, back

Please note that body belts and climbing harnesses are not permitted, nor are they safe. Because the tie-off point on this equipment is down around your belly button, the arresting force is transmitted through your stomach and over to your lower back and it is very easy, and quite likely, that you will break your back should you fall when wearing a body-belt or climbing harness. If that's not enough of a deterrent for you, there is a very good chance that once you stop bouncing around after the fall you will be left hanging upside down. That position is extremely uncomfortable but will be resolved in just a few moments. Because neither a body-belt or climbing harness has shoulder straps it is altogether likely that, once you stop bouncing around, you will fall out of the harness.

Once you've established that the harness you have is OK to use, the next thing is to make sure it fits you properly. Just as wearing the wrong type of harness can kill you, so too can a harness that doesn't fit properly. Some points to remember:

- The harness should be snug around your body but should not restrict your movements.
- The leg straps should be pulled up into your groin, snug against your leg and away from any personal bits you don't want damaged. Loose or poorly placed leg straps will do serious and possibly permanent damage to technicians of either gender. You don't want to think about the consequences should you ignore this advice. Make sure your harness fits properly.
- The base of the dorsal ring (where the harness webbing weaves through the dorsal ring) should be even with the centerline of your shoulder blades.
- If your harness has a sternum (front) ring it should be located between your belly button and the bottom of your rib cage.

A cautionary note: if you wear a crossover-style harness, make sure that the point where the shoulder straps cross on your chest is low enough and far enough apart so they do not press against your neck. If these straps are not positioned properly and you do have a fall, you may compress your carotid arteries and restrict blood flow to the brain. It can take just a few seconds for brain damage to occur if the brain isn't getting enough blood. (Still want to be a rigger?)

Figure 13.3 Crossover harness, front

Figure 13.4 Crossover harness, back

Your harness may have other rings, loops and hooks on it. More than likely, they are *not* fall arrest connection points. Some rings are for work positioning (fall restraint) and others, usually on the shoulders, are for confined space rescue. You should consult your owner's manual to determine each item's function.

Only one hook is permitted in a fall arrest ring (the dorsal ring, for example) at a time. Should you fall with two hooks mounted in one ring there is a risk that the arresting forces will push one of the hooks out of the ring. Murphy's Law says that if a ring does get forced out it will be the one you were relying on to protect you.

A lanyard is commonly the next component in a fall arrest system. It's used to connect the harness to a lifeline or anchorage point.

A fall arrest lanyard can be made of rope, webbing, or steel cable. Whatever the material, it must have an integral shock absorber. The shock absorber is your BFF and should receive all of the attention and respect you can give it. When you fall, the shock absorber will keep the lion's share of the arresting force from reaching your body. Remember the 3,000lb of force required to arrest a fall? The shock absorber on your lanyard can reduce that amount to less than 1,000lb.

Figure 13.5 Single-leg lanyard

Figure 13.6 Double-leg lanyard

Many riggers tend to think that lanyards are available in only 6′ lengths. The truth is that lanyards are available in almost any length up to and including 6′. The key is to have the right length for the job. Remember, the shorter the lanyard the shorter the fall. The shorter the fall, the less force required to arrest that fall. Less force means less pain for you. If you only need a 4′ lanyard you should only use a 4′ lanyard. No point in taking a fall that's 2′ longer than necessary, right?

It's also important to remember that as it deploys, a shock absorber will add up to 3′-6″ to the overall length of the fall. If you are standing on an 8′ tall platform, a 6′ long lanyard isn't going to do you much good. Yet another reason for using a lanyard of the appropriate length.

Self-retracting lifelines (SRL) are typically used for protection in ladder applications. They are reliable and extremely efficient, usually activating before the worker has fallen 1′.

Figure 13.7 Self-retracting lifeline (SRL)

They function pretty much the same way as the seatbelt on your car. They use cable or webbing to connect the worker to the device and, when that cable or webbing is pulled out quickly enough (about 5′ per second), their centrifugal braking mechanism engages and locks up the line, thereby arresting the worker's fall. There's no subtlety in this action. The line runs free until the speed is reached and then … instant stop. This is why it's so important to use these devices properly (something the entertainment industry hasn't quite figured out yet).

For any number of reasons, none of them good, SRLs are typically placed in the wrong location. This is particularly true when it comes to truss-mounted wire rope ladders. It's important to understand that an improperly placed SRL may lead to a catastrophic failure in the safety system.

Here are two rules that will help you avoid said failure:

1 An SRL must be above the technician at all times.
2 The SRL must be located such that, after a fall, the technician can reach whatever it was they were climbing when they fell.

An SRL locking mechanism can only work when it senses the line being pulled out at approximately 5′ per second. If the technician is situated above the SRL when they fall, the SRL won't know it until the technician has reached a spot lower than the device and the safety cable starts to pull out. This could mean a significant fall distance. As there is no shock absorption in a standard SRL, any fall greater that 6–12″ is going to really hurt and could cause serious injuries.

The same effect might happen when the SRL is located too far away, laterally, from the ladder the technician is climbing. In addition to the extended fall distance, there's also the possibility of the technician hitting something as they swing back and forth, eventually coming to a stop under the SRL. The end result is an injured worker who cannot rescue themselves because they can't reach the ladder. You now have to go get them down. Where's the fun in that?

The recent development of smaller, lighter SRLs has led to an increase in their use, especially in unorthodox locations.

Figure 13.8 Mini-SRL

Of particular interest is on horizontal lifelines (HLL). Slap an appropriately rated cable trolley on the HLL, hang a small SRL from the trolley and you get a safety line that not only moves along the catwalk or truss with you but also engages fast enough to actually eliminate the fall. This is great, especially in places where falling, arrested or not, is a really bad idea. A counterweight loading bridge, for example, typically doesn't have an OSHA approved railing on its offstage side. Even if it did, loading counterweight in and out of an arbor usually requires you to lean over or through the rail, placing your center of gravity outside of the railing. A lifeline is clearly needed here but a 6′ lanyard will allow the technician to fall far enough to land on top of nearby counterweight arbors. Ouch! If they use a shorter lanyard then they may not be able to reach the arbor. Enter the SRL. It is robust enough to allow the technician to complete their work and sensitive enough to engage fast enough to stop the technician from hitting an arbor top.

The final safety system on the agenda is the horizontal lifeline (HLL) itself. There are so many variables when designing, installing, and using HLLs that many safety officers simply won't allow them in their venues. Many engineers refuse to design them. However, riggers, electricians, audio crew, and other entertainment technicians still have to walk on truss, catwalks, and loading bridges on occasion, so solutions need to be found. To help make our HLL discussion a little less confusing, let's break it down into temporary and permanent HLL installations.

A permanent HLL is typically mounted above a catwalk or loading bridge that either has had its railing removed or the technicians are required to climb over or through the railings to complete their job.

The components of a HLL will include:

- Anchorage points. These are the brackets that connect the HLL to the building structure.
- The lifeline itself. This will be a length of steel cable that is stretched between the two anchorage points.
- Tensioning device. This is usually a heavy duty turnbuckle permanently mounted in-line with the HLL.
- A heavy-duty shock absorber is sometimes used in this system but it's not required.
- The technicians can either use a lanyard clipped to the HLL or a small SRL/trolley assembly can be placed on the line and the technician would clip directly into the SRL.

Regardless of how you attach to the HLL there are some things you should know about the installation:

- Do not use wire rope clips when terminating the HLL. OSHA allows wire rope clips as long as they are sized and installed properly. The problem is that wire rope clips require annual maintenance or they could loosen over time. Let's face it, no one ever does this maintenance so it's pointless to use clips. Use a compression sleeve instead. A compression sleeve provides a 100% efficiency rating for the wire rope termination and requires no maintenance after installation. Ever.
- When tensioning the cable please keep in mind that you are not installing a tightrope for a circus act. There is no need for the wire rope to be tightened to a point where it is exerting a significant force on the anchorage points. A small dip in the cable is fine.
- Do not use ¼″ Ø wire rope. At 7,000lb tensile strength, the wire rope has an OK rating, but this is a permanent installation that will probably not be inspected or maintained for many years. Over time you could lose enough rating in the wire rope that you might run into a problem. Spring for the extra $0.15 a foot and go with a larger diameter wire rope.
- To shock absorb or not to shock absorb? It all depends on the situation. Using a shock absorber will increase the fall distance and in some cases that might mean the difference between a worker hitting something below, or not. You will have to evaluate your situation and decide what works best. Keep in mind the two mantras of fall arrest: limit the amount of force that is applied to the workers' body and make sure the worker cannot hit anything when they fall.

Temporary HLL are trickier. A lot trickier. The most common place you're likely to find a temporary HLL is on a lighting truss. The HLL is there because someone will eventually have to be on that truss to focus a light, run a followspot, or maybe conduct an emergency repair on a light fixture. In any case, the dynamics of the situation are complex.

The elements of a temporary HLL are the line, the anchorage points, a tensioning device and a shock absorber. Usually the line is a synthetic rope. A ⅝″ Ø double braid is the most common. The tensioning device is an adjustable rope grab; one that allows you to pull the slack out of the line and locks in place so the line cannot run backward through it. Shock absorption is a must on a temporary line and the most common shock absorbers look and work just like the ones found on most lanyards.

Figure 13.9 Temporary horizontal lifeline (HLL)

Finding appropriate anchorage points on a truss is difficult. Keeping in mind that the minimum tensile strength of 5,000lb must be maintained throughout the system, where on a stock piece of truss can you tie off the line? There isn't a single point on a truss that has that kind of rating. The best solution is to attach the line to the truss in multiple locations. One popular method calls for roundslings to attach the HLL to the bottom chords of the truss in four places at each end of the HLL. That gives you a total of eight connection points with which to absorb the shock of someone falling off the truss.

The other thing to remember is that the synthetic line will stretch a lot more that wire rope and that will add to the fall distance. There's also a shock absorber in place that will also increase the length of the fall. When using an HLL on a truss please make sure you have at least 20′ of clear space below the truss to make sure the person falling off the truss doesn't hit anything under the truss.

Given the multitude of horizontal lifeline and truss configurations coupled with the enormous forces that can be developed when arresting a fall from one, great care should be exercised when working with a horizontal safety line. You should always have a professional engineer work out the details, including the calculation of the anticipated forces, before attempting to install one of these systems.

While we are on the subject of horizontal lifelines on truss, we should discuss a common problem faced by riggers and electricians who, as part of their job, have to climb a wire rope ladder to the truss and then walk along the truss to reach their final destination.

This business of climbing a ladder and then walking on a truss involves two separate safety systems. An SRL is usually used for the ladder climb and an HLL with a lanyard is used on the truss. The SRL clips directly to the harness but what do you do with the lanyard? You can't clip it into the dorsal ring because the SRL is there already and you're only allowed one hook in a ring. Carrying the lanyard with you and clipping in when you reach the truss requires you to first unclip the SRL and then clip in the lanyard. The dorsal ring is not all that easy to reach and doing all this while sitting on a truss 43′ in the air isn't the best idea you've ever had. The solution lies with the harness.

Some harnesses come with an additional dorsal ring, usually on an 8–9″ web extension.

The secondary dorsal ring is for the SRL and your primary dorsal ring takes the lanyard. Here's how it works:

1 Connect the lanyard hook to the standard dorsal ring on your harness. Put the other end of the lanyard in your pocket, clip it to a convenience ring on your harness or let it hang free.
2 Connect the SRL hook to the secondary dorsal ring with the web extension.
3 Climb the wire rope ladder.
4 When you are sitting comfortably on the truss, take the lanyard hook out of your pocket or wherever you stored it and connect it to the HLL.
5 Disconnect the SRL from the secondary ring (it's easy to reach because it's on that web extension) and walk out on the truss.

Figure 13.10 Harness with additional dorsal ring

Once you are finished your work then you reverse the steps and make your way safely down to the deck.

Rescue

Which brings us to the last, and arguably the most important, topic in this chapter. Rescue.

Having safety systems in place for all of your people who work at height is a wonderful thing. But there's more to it than just arresting the fall. Once the worker has fallen they need to be rescued and this needs to be done so quickly. Many things can go wrong even after someone has fallen. A human body can only take a certain amount of abuse and being suspended in a harness for a relatively long period of time counts as significant abuse. Rescue plans and systems have to be in place and everyone involved in the rescue has to know their role if the victim is to be brought down in a safe and timely manner.

There are as many rescue plans and requirements as there are different hazardous locations in the overhead steel of your venue. What follows is a broad outline of what is needed when a good day turns bad and someone falls off the high steel.

The Rescue Plan

This plan is a written document that covers everything needed to conduct the rescue. It is a living document that changes as situations, equipment and personnel change. It contains:

- the names and contact information for everyone needed in the rescue (this includes not only those inside the building but also those in the emergency response units who work for the municipality where you are located);
- the location of the rescue and first aid equipment as well as instructions for their use;
- the roles that each member of the rescue team must play during and after the rescue;
- the documentation on the training of the staff and the outside organizations (EMTs, high-angle rescue team, etc.) who will be involved in the rescue.

The Training

Everyone who works backstage must be trained in the rescue plan. They should be trained in as many of the roles as possible because you won't know who will be in the building when the accident happens. This should be hands-on training. A classroom setting can only go so far in preparing people for the real thing. Set up scenarios based on the requirements of your venue and run drills until everyone involved can take on any role in the plan. Time the drills. Real-time drills can reduce the rescue time by 50–75% even after just two or three drills.

The Rescue Kit

The contents of the kit will be determined by the needs of your venue. Have extra pieces of hardware. In a real-time adrenaline-pumping accident situation, many things will go wrong. Carabiners and shackles will get dropped. Rope will get tangled. Make sure you have enough gear to cover as many possibilities as you can. Then get a little more.

The Roles

It's easy for panic to set in once an accident takes place. Proper training and rehearsals help reduce that panic. Knowing what is expected of you and your coworkers helps reduce the panic level even more. In an ideal situation and assuming an assisted rescue, the rescue team consists of five people.

1 The leader: This person is in charge. They keep an eye on everything and everyone else.

2 The announcer: This is the person who alerts the venue staff and the outside organizations that an accident has happened and maintains contact with these people.

3 The rescuer: This is the person who goes up to the victim with the rescue kit and sets up the rescue equipment.

4 The floor person: This person handles the actual rescue. Their role will depend on the type of equipment being used but it's their job to make sure the victim is lowered to the deck safely.

5 The communicator: This person has the job of staying in constant contact with the victim. The communicator keeps the victim informed of the progress of the rescue and what the victim can do to help promote that progress. The communicator will also continually assess the victim's physical and mental condition and alert the leader of any changes in those conditions, no matter how minor.

Ideal situations seldom occur, however, and it's incumbent on the staff to make sure everyone knows and understands all of the roles. Murphy's Law says that an accident will happen only at the worst possible time and in the worst possible location. Proper planning and training will cover anything that Mr. Murphy throws in your path.

While all rescues are different, there are a couple of rules that you can follow no matter what the situation.

1 Never work alone when working overhead. There should be at least one other person in the immediate vicinity that can begin the rescue process. If you are working above the stage and the only other person in the building is working in the box office with the door closed and the radio on, that person is not going to be of any help to you. The second person should have clear line of sight and hearing.

2 Always lower the victim to the floor, even if the catwalk they just fell from is only 5′ away. The goal is to get the victim safely on the floor. You don't want to have to carry them across the catwalk, down the ladder, around the spiral staircase and down five flights of steps. Any injuries they may have sustained in the fall will only be exacerbated by a protracted trip through the venue.

3 Once the victim is on the stage do not attempt to diagnose their problems unless you are trained to do so. A medical person of some stripe—be they EMT, paramedic or something else—should have been notified as part of the rescue plan and should already be on site. Let them do their job.

4 Do not let the victim convince you that they're OK. Do not let them wander off to shake it off or go home. Internal injuries are not an uncommon result of a fall, whether the victim feels them or not. Keep the victim calm until the medical personnel have made their assessment and then follow their instructions.

Summary

In an industry that seems to change faster than the weather, it's nice to know that there is at least one constant in this business. Gravity works exactly as it always has and it doesn't look to be changing any time soon. Defeating gravity, or at least amicably cohabitating, need not be the dangerous occupation that it once was. But it remains a challenge. And who doesn't like a challenge now and then?

Staying safe while working at height requires skill, training, experience, respect, and a decent dose of common sense. Fortunately, it's no longer a case of "Climb up there and hang this hoist. Don't fall." We now have safety gear to help protect us and, yes, on occasion, save us from ourselves. Whatever the intent, the result can be the same. Work hard. Enjoy it and come back and do it again tomorrow.

Happy rigging.

---

*kN (kiloNewtons) are the scientific (and appropriate) way to measure force. Riggers tend to not be appropriate about many things and measuring force is one of them. For reasons beyond the scope of this book, we'll continue to measure force in pounds.

14

Medical Issues in Fall Arrest/Rescue

Orthostatic Intolerance, Harness Trauma, and Fall Arrest/Rescue-Related Medical Issues

CARLA D. RICHTERS

And now for something completely different …

This chapter addresses the point when the human/rigging interface goes wrong. None of us likes to think about this. However, quickly recognizing that something bad is happening and having a plan to do something about it greatly increases the chances of surviving the event.

An unarrested fall is an ugly thing. The ballistics of a body's fluid post fall is more than nine meters, and is described as the splash zone for a reason. Even after a professional decontamination, small dried droplets will be found for years. Think glitter.

The discussion in this chapter assumes an arrested fall. If you are not wearing a harness in conjunction with a properly designed fall arrest system and with a crew well versed in the rescue then this chapter cannot help you. Once, when walking past an open road box I noticed a photo of one of the most adorable children ever. On the bottom of the photo was this caption: "Dakota says, 'Wear your harness!'" Enough said.

"Orthostatic" means to stand upright. The definitions vary as to whether the "static" part of the word includes "stillness" as part of the definition. There are some animals that stand on their hind legs to browse or as a form of display. As a rule, these animals do not walk upright. That particular party trick is a relatively new development on the human evolutionary timeline. We are, as a species, still working on it. The second word "intolerance" speaks to exactly that. There are situations when we physically do not cope very well.

You may have heard of other terms used for orthostatic intolerance such as orthostatic insufficiency or orthostatic hypotension. They all mean basically the same thing. The heart cannot pump enough blood to maintain the blood supply to the brain. Similarly a search for "parade ground faint" on YouTube will result in hundreds of video hits for soldiers, sailors, and marching band members lopping over. The same reaction occurs in the costume shop when actors lock their knees during a long fitting. The blood flow back to the heart is restricted and blood pools in their lower legs. They are encouraged to walk around periodically and to sit down if they feel lightheaded. This helps to redistribute the blood from the lower legs; it gets the blood back to the brain, and keeps the actors from taking a nosedive.

From the brain's perspective, if it can get the body more horizontal, the heart will be able to reestablish that blood flow to vital organs. The solution, then, is to pass out and fall down. Your body solves the blood flow problem and you come to.

Harness or suspension trauma describes the same grouping of signs and symptoms with blood pooling in the legs until there isn't enough blood available to supply the brain with oxygen and nutrients. Except in the case of harness trauma, the bodies aren't allowed to fall down and self-correct in that they cannot become horizontal, because they are being held upright by the harness.

Almost everyone has experienced the brief lightheadedness of standing up too quickly, rising past their available blood pressure. Bending at the waist helps to increase the blood flow to the brain. This brief lightheadedness and vague sense of nausea are the harbingers of orthostatic intolerance.

Let's take a moment here and talk a little about the implications of orthostatic intolerance. Plain and simple: it can kill you. Even after the fact, we don't understand all of the ramifications of this brisk return of circulation to the tissues or reperfusion syndrome.

We are a group of people making our living by using our brains and strength to alter our world. We use physics to make magic for the audience. We are often pushing our own laws of physics working in stressful situations, against a time deadline, in need of just that one tweak before the end of the call, the start of rehearsal, the well-earned break. Orthostatic intolerance is physics as well. It can sneak up on you, or it can hit you like a hammer. We need to pay attention to the signals and to understand and respect our physical reaction to even a relatively simple arrested fall.

The onset of symptoms happens quickly and unpredictably. There is no marker to predict who is more at risk, or how long it will take to become symptomatic. The recommended rescue time is ten minutes, fall to floor. Since symptoms can begin much sooner, you may very well be working at an extreme disadvantage.

These symptoms cascade, occurring in no particular order, tumbling over each other, and may include:

- cool clammy skin
- shortness of breath
- loss of judgment
- dizziness
- nausea/vomiting
- confusion leading to panic
- syncope (fainting)

which may lead to:

- obstructed airway
- seizures
- cardiac arrest
- death.

While there are no predictable signposts for the development of orthostatic intolerance, other than the fall, there are several factors that can contribute to its development.

Any situation that leaves you dehydrated can, and will, contribute. Possibilities include some medications, working in the heat, untreated hyperglycemia, vomiting or diarrhea, and hangovers. If you stay hydrated then there is less of a possibility for the relative hypervolemia of orthostatic insufficiency. Health care professionals recommend keeping your body's fluid volume at appropriate levels. This helps ensure there's enough blood volume to deal with minor insufficiencies.

What is Happening

Short answer: the body is going into shock.

Long answer: Shock, aka hypo-perfusion, is the circulatory system's inability to provide nutrient-rich blood to the tissues. In order to compensate for any sort of shock you need a number of things: enough oxygen in the atmosphere, intact and functioning organs, and the ability to offload the nutrients on the cellular level.

During an orthostatic intolerance event the body is lacking the circulating blood volume. Fluid volume is drawn down as the blood pools in the legs. The veins in your legs expand to collect the pooled fluid rather than push the blood past the mechanical impedance of compressed vasculature and gravity without the assistance of the efficient muscle pump of the legs.

When the body is under stress, the sympathetic nervous system swings into gear. It produces adrenaline, and this kicks in the "fight or flight" reaction. Push the body too far down this response path and it moves into uncompensated shock, which is when you see the signs of panic that are the classic hallmarks of the onset of suspension trauma.

But, wait a minute! No one said anything about blood loss …

Not yet anyway.

Anatomy and physiology

Anatomy is how something is built. Physiology is how it works, and why. When you are looking at something going wrong, it helps to understand how that something is put together and how it's supposed to work. This is true regardless of whether it's a rigging system or the body. The below will give us a basic working vocabulary so we speak the same language; we'll know what we're talking about. Here's the basic list:

Orthostatic: to stand upright on the back legs

Intolerance: (in the context of this chapter) the heart and lungs cannot keep up with the demand placed on them—they don't tolerate or support a particular position

Harness trauma: the constellation of signs and symptoms surrounding hanging vertically after an arrested fall.

Symptomatic: showing or feeling the effects of a physical process. Later on in this chapter there is a list of symptoms of orthostatic intolerance; in this chapter "symptomatic" refers to showing or feeling the effects of orthostatic intolerance.

Hypervolemia: "hyper" means over or above; "volemia" refers to the volume of fluid in the system. In this chapter, "hypervolemia" refers to there being too much fluid in the vascular system.

Hypovolemia: "hypo" means under or below; "volemia" refers to the volume of fluid in the system. In this chapter, "hypovolemia" refers to there being too little fluid in the vascular system.

Vascular system: the arteries, arterioles, capillaries, venules, and veins that carry blood.

Hypo-perfusion: "hypo" means under or below; "perfusion" refers to supplying the body's tissues with oxygen and nutrients. Hypo-perfusion is the inability of the bodily systems to supply the body. It is the definition of shock.

Pulmonary system: "pulmonary" refers to the lungs, so the pulmonary system is its structures and functions.

Venous system: part of the vascular system. This refers specifically the pipes that carry blood back to the heart and lungs. Blood in the veins has delivered its oxygen and then picked up the waste products from the tissues.

Cardiovascular: the heart and the veins and arteries.

Cardiopulmonary: how the heart and lungs interact.

Central nervous system: the brain and the spinal cord.

Several structures require a little more in-depth discussion.

The veins are the body's storm drain, returning blood laden with waste products to the waste treatment plants of the liver, kidneys, and lungs. They also serve as the body's municipal water tank. The vein's smooth muscle walls expand to accommodate a relatively large volume of blood for when the body would have the need. The walls can then contract to decrease the size of the container. This increases the *relative* blood volume and raises the blood pressure. This is called a compensation mechanism, and is designed to solve a lot of problems.

Arteries move oxygen-rich blood away from the heart and are protectively located deeper in the muscle. Veins are closer to the surface. Arteries are held open by the systolic blood pressure of the pumping heart. Back flow in the veins is managed by a series of valves in the outer extremities and something called the "muscle pump" of the larger muscles, particularly in the legs. This particular function *can* be lost if you are unable to use those muscles when suspended in a rescue harness.

The central nervous system requires a constant supply of oxygen and glucose. Denied these things it turns into a cranky toddler, throwing itself to the ground in a fit of temper.

Now for the physiology. Hypovolemia, in this case, is not caused by the traditional culprit, blood loss. Here, the available blood volume is reduced as it pools in the lower extremities. A combination of three factors contributes to this: gravity, a lack of efficient muscle pumping action, and the compression of the greater veins from the body's weight on the harness straps ganging together and reducing the available blood volume.

As the blood remains pooled in the lower extremities several things occur:

- The heart continues to pump available blood into the lower extremities, but it is not efficiently returned. It will continue to do this until there simply isn't enough blood to pump.
- The business of tissue nourishment continues. The body continues to offload oxygen from the hemoglobin and add the waste products back into the mix. This will become very important. These waste products have a lower pH. So, a sort of acidotic stew is cooked up in the pooled blood. With no chance of moving this blood back to the lungs, things begin to get messy.

After the arrested fall victim is on the deck you will want to consider these facts very carefully, as that increased blood flow back to the heart becomes a tsunami of acidotic sludge.

As the brain is deprived of its blood supply things start to deteriorate. It sends several warning signals out along the central nervous system. Combined with the first symptom, lack of judgment, bad choices are made: the drunk frat boy/stagehand interface; the rigger who simply slips off the steel and decides not to call for help.

Everyone who has ever walked into a bar understands that consciousness is a continuum. We can go from rational humans to talking like pirates after several adult beverages. In fact, the emergency services have a way to codify this progression called the Glasgow Coma Scale. As in the bar and with the toddler, the first thing to go is your judgment. Things then move down the list of symptoms from there.

Accidents Happen

Unscheduled. Unplanned. Often in a "jelly-side down" sort of way.

That's why they are called accidents.

This is *not* going to be a first aid class. It will, however, speak to some logistical planning. Part of that plan should be to have solid CPR and automated external defibrillator (AED) training in place. If first aid training is available, please include that. Many things can happen.

Similarly, much of the training around accidents is their prevention, and where to find and file the paperwork once they do happen. Please include at least one additional step that adds a list of where to find the first aid kits, where the cell phone dead zones are, and where the ambulance should respond if the accident is in the steel or in the front of house. You might think about the things you'd want other people to know if you were the one that was hurt. Now, I don't think you can expect your ground-rigger to be a trauma surgeon, but it couldn't hurt to ask.

When an accident happens around you or you happen upon one, there is the possibility of you being the first on the scene. This is different than being a first responder. The goal in a "first-on-scene" situation is to make it somebody else's problem (SEP) as quickly as possible. Don't waste any of the platinum ten minutes on the time between the discovery and accessing the 911-system. Make sure you are safe, and then call 911.

Please don't miss the bit in the last paragraph about "make sure you are safe." Don't become part of the problem.

Let your EMS providers take on the liability of assessment, treatment, and—if necessary—transportation. Do not throw yourself into your vehicle and make a run for the hospital. The ambulance personnel have the training and equipment, and are paying the insurance premiums for it. Let them handle the patient. The fall arrest victim will receive care the moment they make patient contact. And that care will continue until the patient is transferred to definitive care. That's best practice for this situation.

> Sometimes teaching people to recognize that something bad has happened is the most difficult concept. We don't want to be seen as the weak member of the herd. And then there is the whole denial thing. When hurt, many people will isolate themselves. You might see them go into the bathroom with their severed finger or refuse to be seen by the EMTs after an arrested fall. Please keep your index of suspicion high. Get help.

The rule of thumb is: ten minutes "fall-to-floor." Own it. Love it. Practice it. Really. Those in emergency services call this process scenario-based training. It creates providers who move through situations and can think past basic logistics. In the theatre we call it "rehearsing." It's brilliant for creating a crew that can handle these situations and feel confident in their abilities.

After the fall arrest victim is on the deck, if the EMS crew is not on-site, your next question should be "what is going to kill them first?" The standard wisdom heard around the arrested fall is "don't *let* them lie down." This is assuming, of course, that they are able to listen and follow directions. Placing the fall arrested on a chair could lose you points in the style competition when they pass out and fall off the chair.

If they are not talking to you, but they are breathing and there are signs of life, put them in a "Barcalounger" position: butt and heels on the deck. Knees bent. Hips flexed in an approximately 30–45-degree angle. This position will help keep the heart from being overwhelmed with acidotic blood that will cause electrical malfunctions, as well as slow down the wave of pooled blood returning back to the heart, which creates structural stretch and possible physical damage. It is also very easy to turn their head to the side should they start to vomit, and to get them flat to start CPR should you need to. Apply the pads for the AED now if you haven't already done so. Watch their pulse and responsiveness.

If they are talking to you but they're not making much sense, or if they are combative, make sure that the ambulance is on its way, and keep track of the patient. Do not let them wander off. It sounds silly, but patient searches are not fun. Whatever you do, don't let them go in a restroom by themselves. Prying someone out of a bathroom after they've passed out makes for a very bad day.

If they are talking to you and claim they're fine, and they seem just fine, this is when you need a policy for the situation. This policy should be written in conjunction with the medical control officer for the nearest hospital, the rescue squad responsible for the venue, the employer, union rep, and anyone else who should weigh in. It should include language regarding the circumstances when employees need to be seen by medical professionals. The parameters of these circumstances need to be clear and within local prehospital protocols.

There is something called "reperfusion syndrome" that can occur an hour or more after an event. Orthostatic insufficiency, reperfusion syndrome, or even positional rhabdomyolysis (which would require an entire other chapter on renal failure to cover fully) do not care if you are the crusty codger, the call steward, or the largest donor's son, so please do not let personality or seniority dictate survival. Get everyone to definitive medical care.

There is also "the index of suspicion." Somewhat along the lines of "just because you're paranoid." Be alert for a second patient. The stress of the accident and rescue can exacerbate heart problems or other chronic conditions. Consider also whether the fall might have had a medical component. Did they pass out and then fall? Or vice versa? Voice any concerns regarding these possibilities to the emergency responders.

It helps to understand your employer's concerns and requirements. Realize that many times the only written rule is how the accident must be reported. Be active in crafting something more proactive, supportive, and effective. Prove to the office that you're interested in creating a safe work environment.

Besides the paperwork, the last part of the fall arrest event is transitioning your friend's care to the EMS crew that has come to treat them. The ambulance crew will ask for demographic information: name, address, and date of birth. They will want to know if their patient has any allergies to medications, or any health issues. It helps if someone on your crew has this information. A good recommendation is for every person on the crew to keep it in their cell phone or wallet.

In the best of all possible worlds, someone should have thought to keep track of the time that things happened, but that is "Advanced Emergency Scenarios 204" (or a knee-jerk reaction for the stage manager). Time seems to expand and contract at will in an emergency situation, and one person with a watch, a pencil, and a clipboard can make all the difference.

Send their wallet, cell phone, glasses, jacket, and—believe it or not—shoes with the patient to the hospital. If there is more than one possibility, find out where the ambulance crew will take them.

Finally, make sure that the event is documented and reported appropriately. Plan a formal review that is not simply a search for the guilty. While painful, these are incredibly rich teachable moments. Don't let them slip away without serious consideration.

I'll Take "Hodgepodge" for a Thousand

Risk management has made a distressing move toward risk removal. There are venues that do not have first aid kits because of the liability involved in the treatment of small wounds. Orthostatic intolerance isn't a splinter. We need to work to ensure that appropriate training is funded and maintained.

Take your training seriously and be proactive. It helps to put together proposals, budgets, and training calendars on our own that fit into our regularly scheduled lives. This will help ensure that the investment in your health and well-being is a good one.

Encourage attendance and a positive attitude with a professional demeanor. One of the most discouraging questions for the instructor/trainer is "how long is this going to take?" Remember that if you are the one that's hurt, you will need others to take care of you. Hopefully they stayed through the end of class.

There will need to be recertification too. Keep that in mind, both in the budget and on the calendar. Keep concise records, and consider mentioning completed training and continuing education in annual performance reviews.

Like your fall arrest systems, other safety equipment needs to be inspected and updated periodically. There will be expiration dates. Having someone come through and ask for a couple of aspirin, only to find an outdated bottle looks careless. Because it *is* careless.

Consider training with your local rescue squad or fire department. The CPR and AED instructors need to teach classes in order to maintain their certification. Bringing them in and developing a rapport with your colleagues is helpful and just plain fun. You haven't lived until you've been roped down in the Stokes basket from the grid.

In a recent "meeting of the pickup trucks," EMS and theatre people were astonished at the knowledge both groups had of high-angle rescue. The EMS people didn't quite realize that those riggers worked at high-angle rescue every day of their work life. There was newfound respect on both sides over pizza at the end of the day. That simple understanding and camaraderie goes a long way to smoothing the path during a high-stress rescue.

Many times, nothing is done at an accident scene because people are afraid of doing the wrong thing, or being sued. Look into your local Good Samaritan laws, as each state is different. While Good Samaritan laws will not stop you from being sued, they will, however, support and encourage the basic human responsibility for each other.

If you are a certified and licensed emergency or health care worker, know and respect your personal scope of practice. Good Samaritan laws are particularly tricky for you. Do not, I repeat, *do not* exceed your scope of practice. Let people know what your scope of practice is so they don't think you should be cracking a chest, or anything else they saw on television last week.

ICE stands for In Case of Emergency. Stop right now. Put this book down and check your phone's contacts list. Please put in a phone number for your emergency contact person. First responders are trained to look at your cell phone for the number under ICE. "Mom" could very well be someone in a condo in Boca. Check this number on a regular basis, like you check your smoke detectors and change the batteries. Remember that after a bad breakup, an emergency worker calling your ICE number may be told "let them die, it's what they would have wanted." Make sure your emergency contact person has access to your basic medical information and your DNR if you have one. Oh, and please sign your donor card.

Index