ENTERTAINMENT RIGGING SESSIONS

Math Workbook

V2.7.19

www.entertainmentriggingservices.com

ERS
ENTERTAINMENT
RIGGING SERVICES

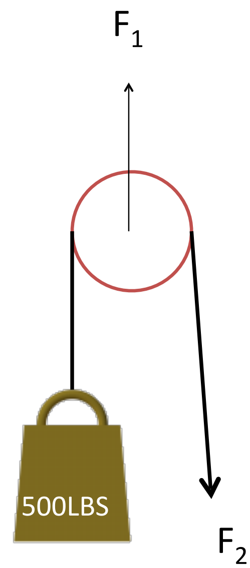
---

http://files.entertainmentriggingsessions.com/

ERS
ENTERTAINMENT
RIGGING SERVICES

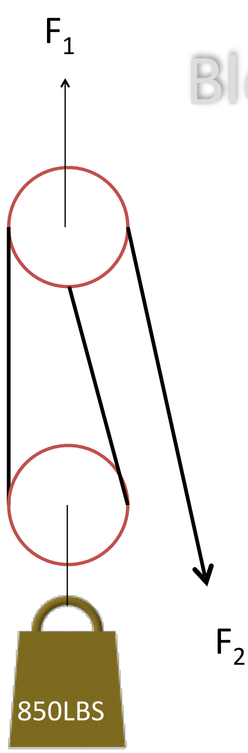
Block and Fall

$$F_1 = \frac{NumberOfLinesOnStandingBlock}{NumberofLinesonRunningBlock}(FA)$$



Block and Fall

$$F_1 = \frac{NumberOfLinesOnStandingBlock}{NumberofLinesonRunningBlock}(FA)$$



Wind Loads

Wind Speed MPH	10	20	30	40	50	60	70	80	90	100	110	120	130
Wind Pressure (Q_S)	.03	1.0	2.3	4.3	6.5	9.3	12.6	16.4	20.8	25.6	31	36.9	43.3

Height in Feet	Exposure Coefficient C_E	
	Average Location	Location Near Large Body of Water
15	1.06	1.39
20	1.13	1.45
25	1.19	1.50
30	1.23	1.54
40	1.31	1.62
60	1.43	1.73

$$WindForce = P = (1.4)(Q_S)(C_E)(AREA)$$

ENTERTAINMENT RIGGING SERVICES

Wind Loads

- 10’ tall by 30’ wide banner on a truss goalpost.
- Top edge at 25’ from the ground.
- The wind is gusting at 40 MPH.

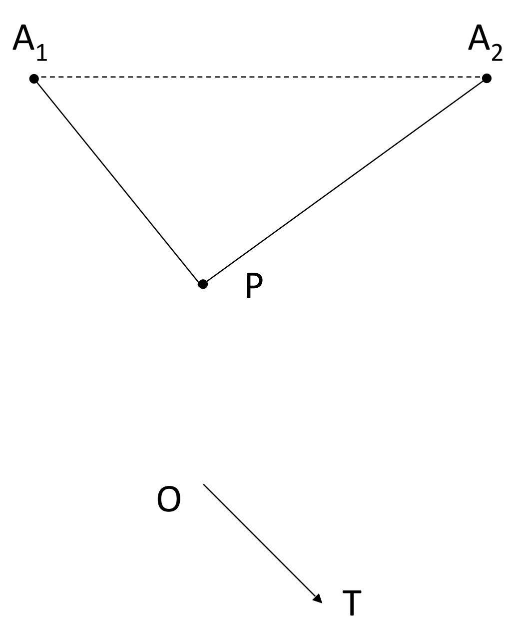
ENTERTAINMENT RIGGING SERVICES

Standard Definitions

Reference points

- ***A*(n)** = Anchorage (n is the anchorage number)
- ***P*** = The point at which the force is applied
- ***O*** = The origin of a force vector
- ***T*** = The termination of a force vector

Standard Definitions



Standard Definitions

Distances

- ***S*** = The horizontal distance between anchorages. This distance is also commonly referred to as ***Span.***
- ***D***(n) = The horizontal distance from anchorage (n), where (n) is the anchorage number, to the applied force. This form is only used when all distances are horizontal.
- ***DV*** = The vertical distance between the anchorages of a bridle and the bridle point. This form can only be used when all anchorages are at the same height.
- ***DZ*** = An alternative to ***DV***. Used if the Cartesian coordinate system is being used to describe points.

ENTERTAINMENT RIGGING SERVICES

Standard Definitions

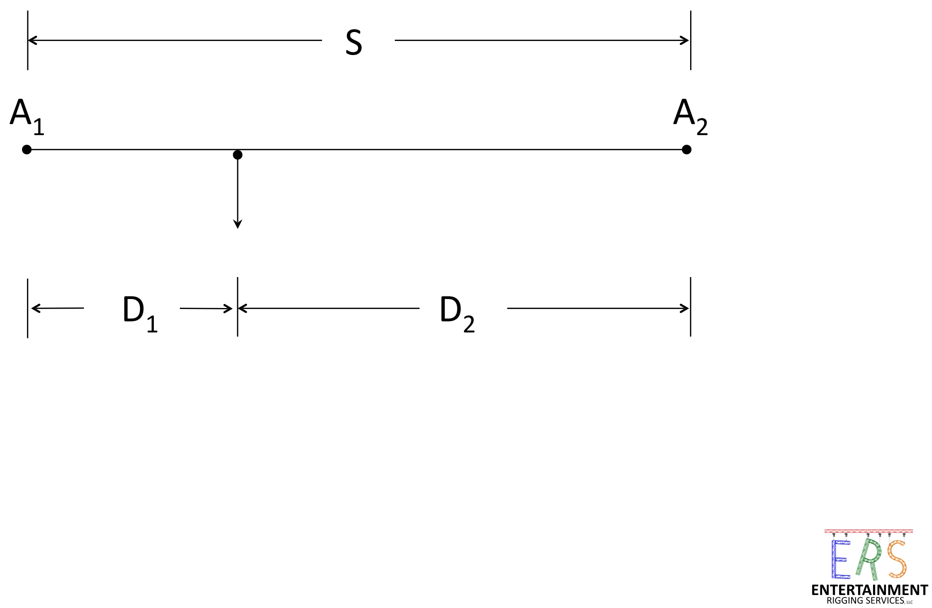
Distances

- ***D***(n)(***x***) = The distance from anchorage (**n**), where (**n**) is the anchorage number, to the applied force in the direction (**x**). The direction ***(*x*)*** would be one of the following:
  - ***H*** = Horizontal in-line with the bridle leg
  - ***V*** = Vertical
  - ***X*** = In the x-axis
  - ***Y*** = In the y-axis
  - ***Z*** = In the z-axis
  - ***L*** = In-line with the bridle leg

ENTERTAINMENT RIGGING SERVICES

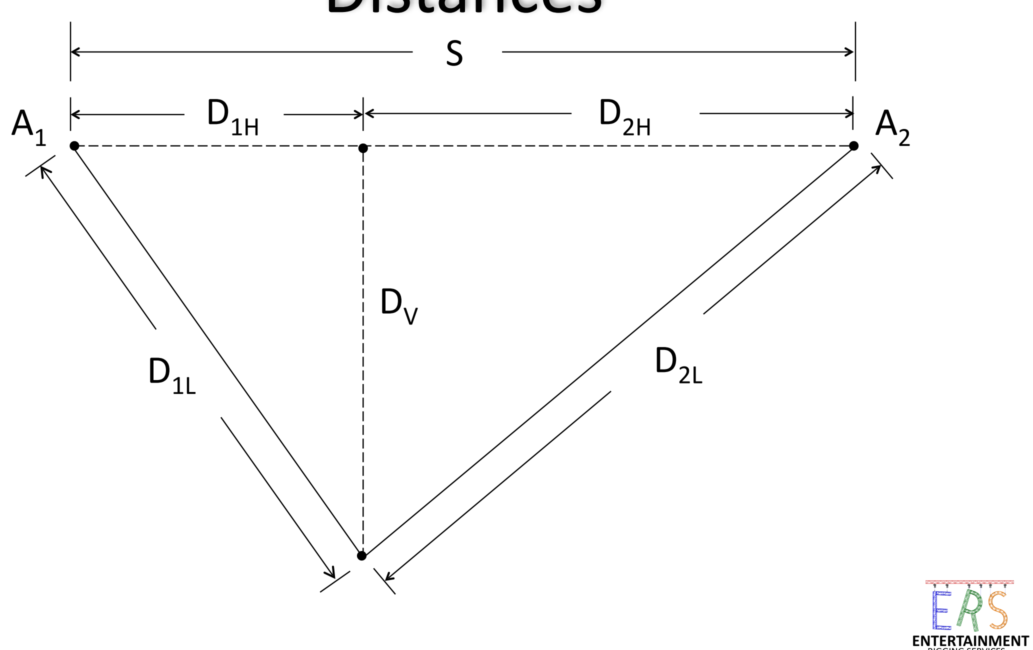
Standard Definitions

Distances



Standard Definitions

Distances



Standard Definitions

Forces

- ***FA*** = The applied force
- ***FA(*x*)*** = A component of the applied force in the direction (**x**).
  - The direction (**x**) would be one of the following:
    - ***H*** = Horizontal in-line with the applied force
    - ***V*** = Vertical
    - ***X*** = In the x-axis
    - ***Y*** = In the y-axis
    - ***Z*** = In the z-axis

ENTERTAINMENT RIGGING SERVICES

Standard Definitions

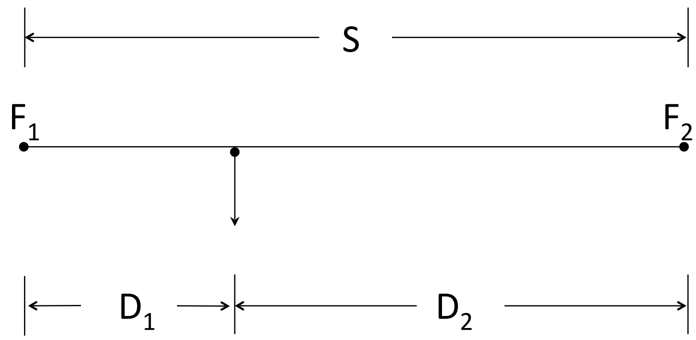
Forces

- ***F(*n*)*** = The vertical force at anchorage (n), where (n) is the anchorage number. This form is used only when all forces being analyzed are vertical.
- ***F(*n*)(x)*** = The force at anchorage (n), where (n) is the anchorage number, in the direction (x). The direction (x) would be one of the following:
    - ***L*** = In-line with the bridle leg
    - ***H*** = Horizontal in-line with the bridle leg
    - ***V*** = Vertical
    - ***X*** = In the x-axis
    - ***Y*** = In the y-axis
    - ***Z*** = In the z-axis

ENTERTAINMENT RIGGING SERVICES

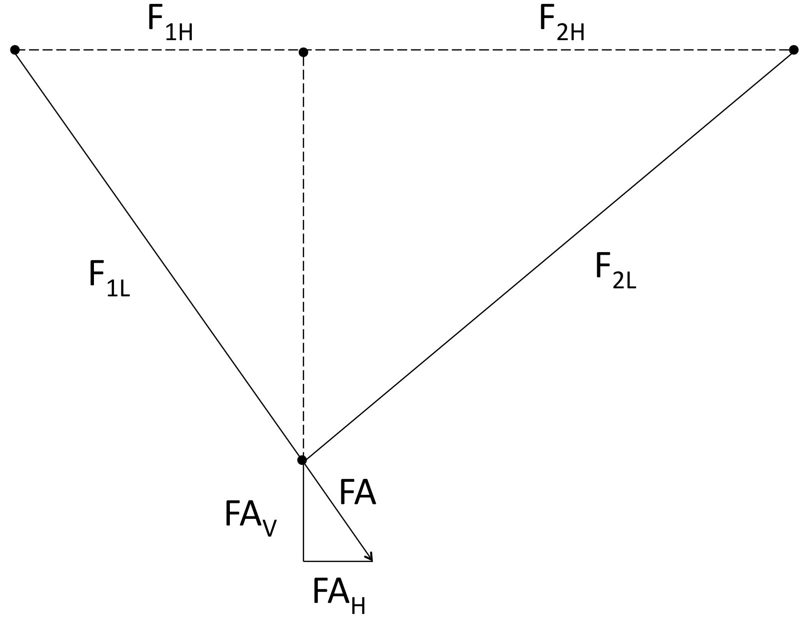
Standard Definitions

Forces



Standard Definitions

Forces



Standard Definitions

Angles

- ***a*(n)** = The angle between the bridle leg and horizontal at point
- ***A*(n)**, where (**n**) is the anchorage number.
- ***a*(*n*)*r*** = The angle of rotation of the bridle leg around ***A*(n)**, where (**n**) is the anchorage number.
- ***p*(n)** = The angle between the anchorage and vertical at point ***P***, where (**n**) is the anchorage number.
- ***p*** = the angle between the bridle legs with a base at ***P***.
- ***o*** = The acute angle between ***FA*** and horizontal with a base at ***O***.
- ***or*** = The angle of rotation of the force around ***O***.
- ***t*** = The acute angle between ***FA*** and vertical with a base at ***T***.

ENTERTAINMENT
RIGGING SERVICES

Order of Operation

PEMDAS

Rule 1: First perform any calculations inside parentheses.

Rule 2: Next perform all exponents, working from left to right.

Rule 3: Next perform all multiplications and divisions, working from left to right.

Rule 4: Lastly, perform all additions and subtractions, working from left to right.

ENTERTAINMENT
RIGGING SERVICES

Order of Operation

7 x 2 + (7 + 3 x (5-2)) ÷ 4 x 2

Basic Engineering Principles

Newton's First Law

Every body persists in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed

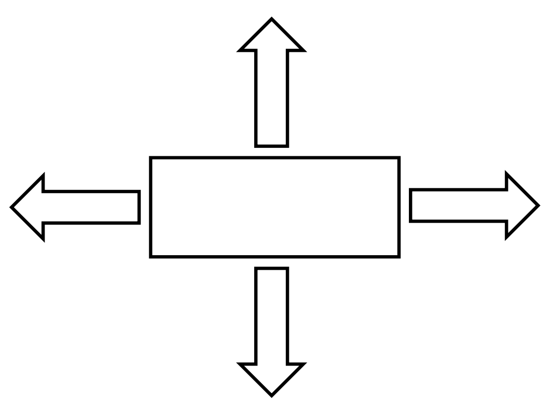
Basic Engineering Principles

Newton's First Law

An object that is at rest will stay at rest unless an unbalanced force acts upon it.

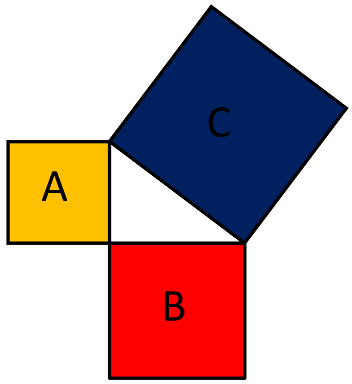
Basic Engineering Principles

Equilibrium of forces



Basic Engineering Principles

Pythagorean Theorem

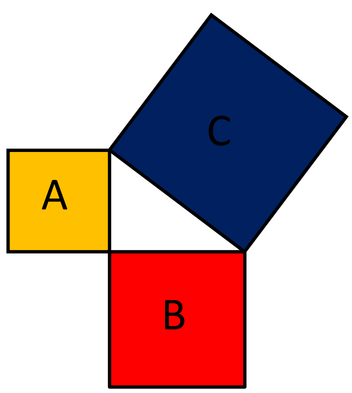


The area of Square A plus the area of Square B is equal to that of the area of Square C

ENTERTAINMENT RIGGING SERVICES

Basic Engineering Principles

Pythagorean Theorem

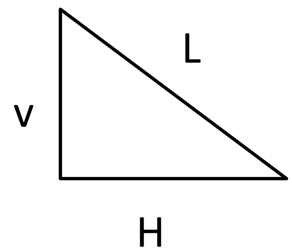


$$A^2 + B^2 = C^2$$

ENTERTAINMENT RIGGING SERVICES

Basic Engineering Principles

Pythagorean Theorem

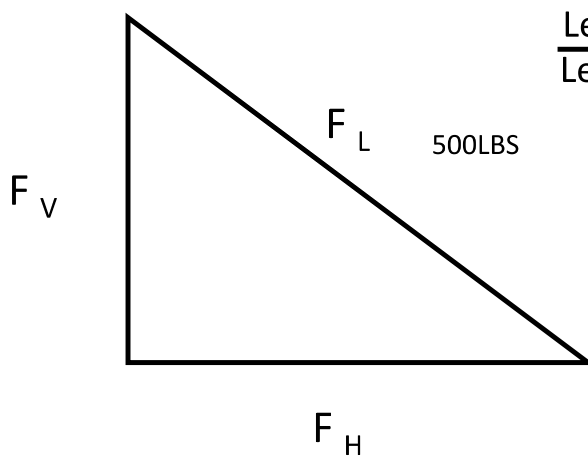


$$V^2 + H^2 = L^2$$

ERS
ENTERTAINMENT
RIGGING SERVICES

Basic Engineering Principles

Equal Ratios



$$\frac{\text{Length } L}{\text{Length } H} = \frac{\text{Force } L}{\text{Force } H}$$

ERS
ENTERTAINMENT
RIGGING SERVICES

Basic Engineering Principles

$$\frac{\text{Force L}}{\text{Force V}} = \frac{\text{Length L}}{\text{Length V}}$$

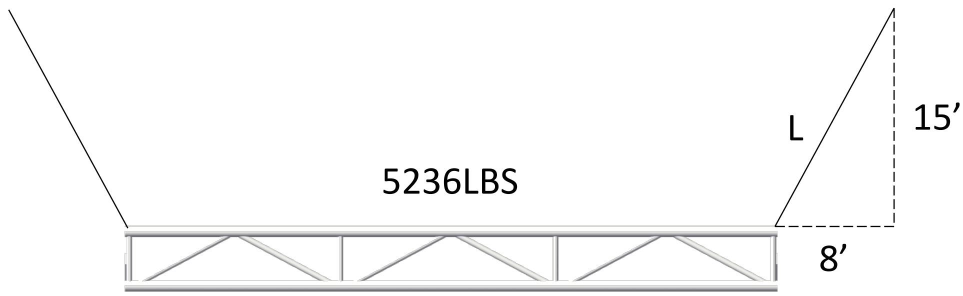
ENTERTAINMENT RIGGING SERVICES

Basic Engineering Principles

$$\text{Force L} = \frac{\text{Length L}}{\text{Length V}} (\text{Force V})$$

ENTERTAINMENT RIGGING SERVICES

Basic Engineering Principles



What is the Length of L?
What is the Force on L?

Point Loads

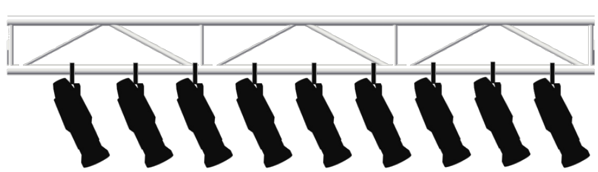
- A single concentrated load on a truss, batten, Etc.
  - Moving Lights
  - Projectors
  - Audio
  - Other rigging
- Know as PL

Uniformly Distributed Loads

- Multiple point loads that are evenly spaced along a span
  - Lighting Fixtures
  - Truss Self Weight
  - Cable
  - Drape
- Know as UDL

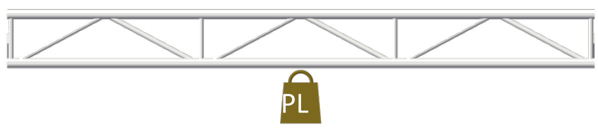
Uniformly Distributed Loads

UDL



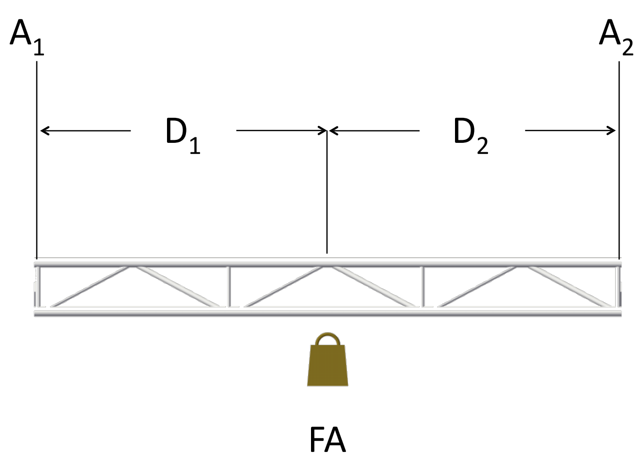
Uniformly Distributed Loads

UDL can be treated as a PL centered between the suspensions



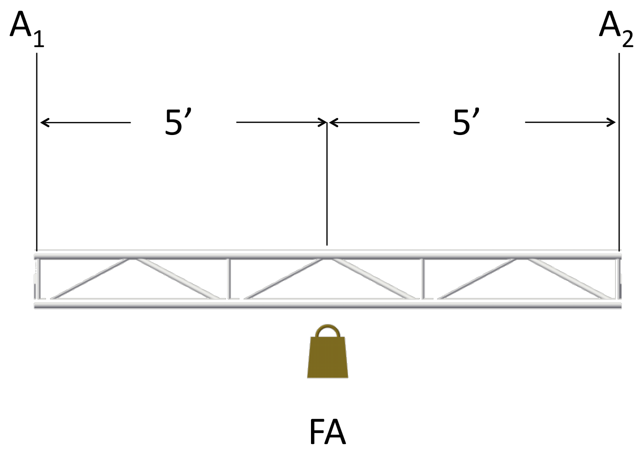
ENTERTAINMENT RIGGING SERVICES

Simple Span

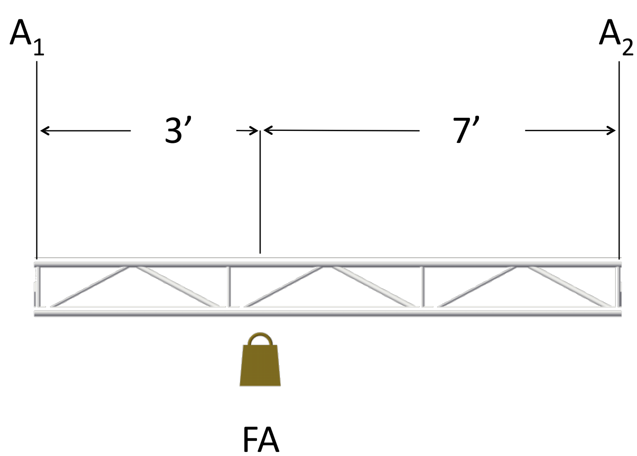


ENTERTAINMENT RIGGING SERVICES

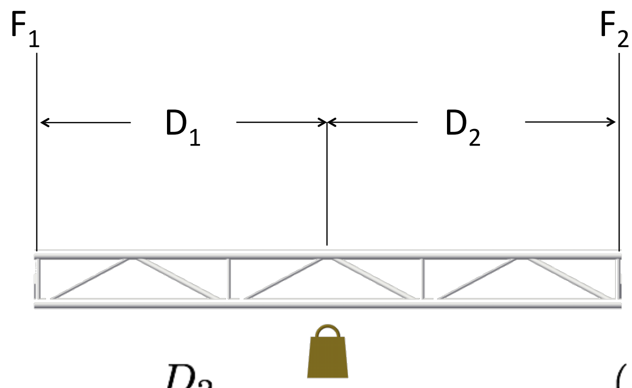
Simple Span



Simple Span



Simple Span



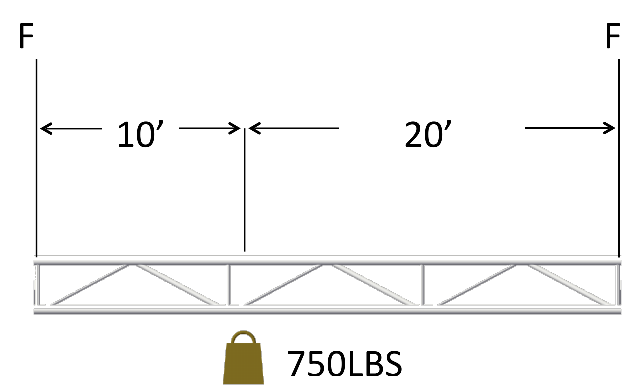
$$F_1 = (FA)\frac{D_2}{S}$$

FA

$$F_2 = \frac{(FA)(D_1)}{S}$$

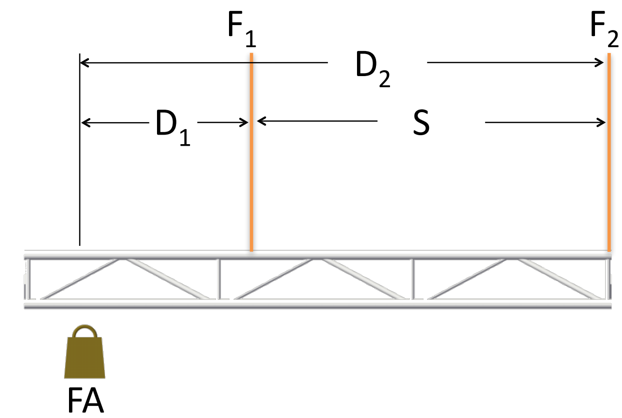
ENTERTAINMENT RIGGING SERVICES

Simple Span



ENTERTAINMENT RIGGING SERVICES

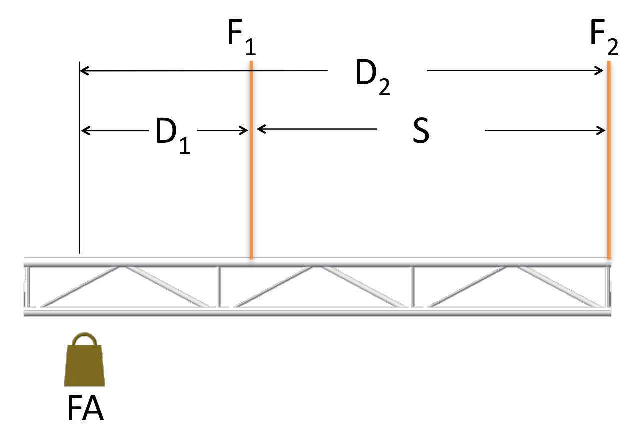
Cantilevers



$$F_1 = \frac{(FA)(D_2)}{S}$$

ENTERTAINMENT
RIGGING SERVICES

Cantilevers



$$F_2 = \frac{-(FA)(D_1)}{S}$$

ENTERTAINMENT
RIGGING SERVICES

Cantilevers

The total weight to be placed on the cantilevered truss must be Less than the allowable CPL for a span (4) times the length of the Cantilever.

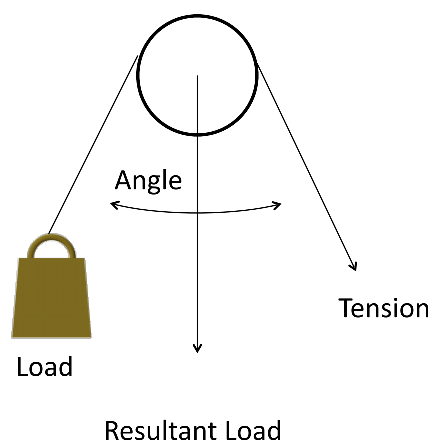
Cantilevers

	Uniform Loads			Center Pt. Load		Third Pt. Load		Quarter Pt. Load	
span (ft)	load (plf)	load (lbs)	defl (in)	load (lbs)	defl (in)	load (lbs)	defl (in)	load (lbs)	defl (in)
5	817	4085	0.016	2398	0.015	1199	0.012	1182	0.017
10	406	4060	0.124	2372	0.116	1186	0.099	1174	0.136
15	262	3930	0.409	1965	0.329	1173	0.334	982	0.389
20	145	2903	0.727	1451	0.587	1089	0.743	726	0.692
25	91	2276	1.136	1138	0.921	854	1.160	569	1.083
30	62	1850	1.636	925	1.334	694	1.670	463	1.561
35	44	1538	2.227	769	1.828	577	2.272	385	2.127
40	24	950	2.235	475	1.867	356	2.276	238	2.143

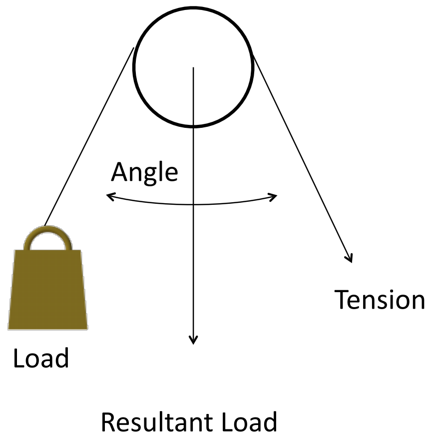
Resultant Loads

What is a Resultant load?

Resultant Loads



Resultant Loads



2 ways to determine the Resultant Load

Use a multiplying Factor

Use Trigonometry

ENTERTAINMENT RIGGING SERVICES

Resultant Loads

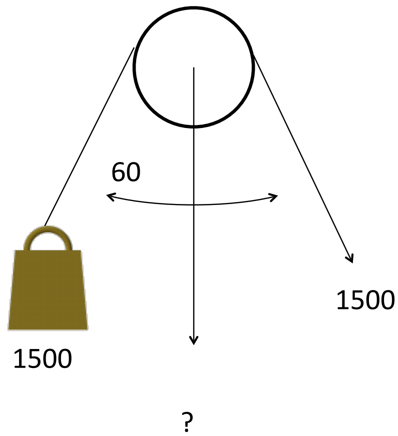
Angle	Multiplying Factor	Angle	Multiplying Factor
0	2.00	100	1.29
10	1.99	110	1.15
20	1.97	120	1.00
30	1.93	130	0.85
40	1.88	140	0.68
50	1.81	150	0.52
60	1.73	160	0.35
70	1.64	170	0.17
80	1.53	180	0.00
90	1.41		

2 ways to determine the Resultant Load

Resultant Load = (Force)(Multiplying Factor)

ENTERTAINMENT RIGGING SERVICES

Resultant Loads

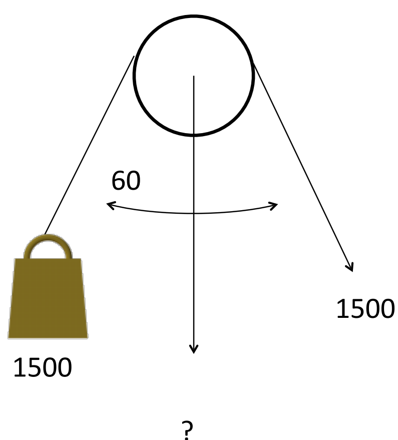


Angle	Multiplying Factor
60	1.73

Resultant Load = (1500)(1.73)

Resultant Load = 2595

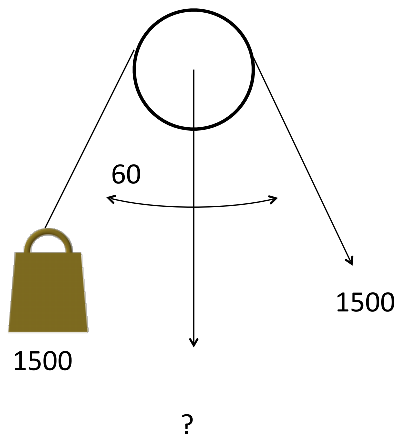
Resultant Loads



Trigonometry

$$ResistantLoad = \frac{(FA)(Sin(Angle))}{Sin(\frac{Angle}{2})}$$

Resultant Loads



Trigonometry

$$\frac{(1500)(Sin(60))}{Sin(\frac{60}{2})}$$

$$\frac{(1500)(.866)}{Sin30}$$

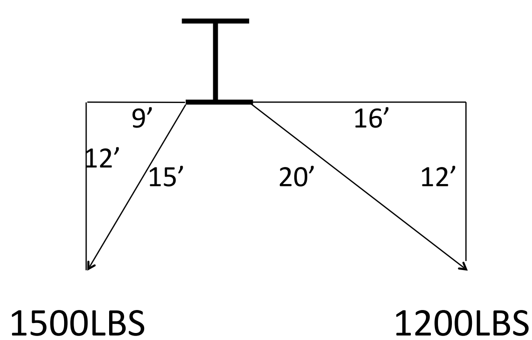
$$\frac{1299}{0.5}$$

$$ResultantLoad = 2598$$

ENTERTAINMENT RIGGING SERVICES

Resultant Loads

Using Resultants to figure out loads on beams



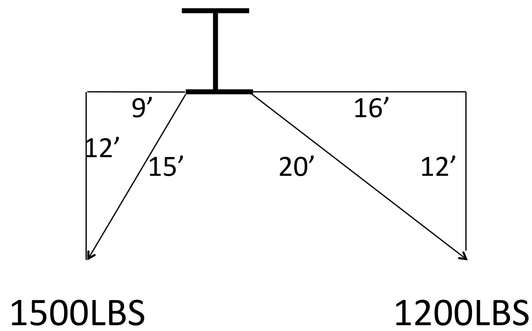
1. Figure out Horizontal Forces
2. Figure Out Vertical Forces
3. Add (or Subtract) Horizontal forces
4. Add (or Subtract) Vertical forces
5. Using the Pythagorean Theorem, Find the Resultant Load

ENTERTAINMENT RIGGING SERVICES

Resultant Loads

Using Resultants to figure out loads on beams

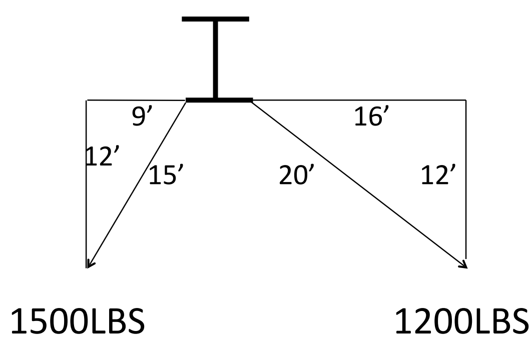
$$F_H = (\frac{D_H}{D_L})(FA)$$



Resultant Loads

Using Resultants to figure out loads on beams

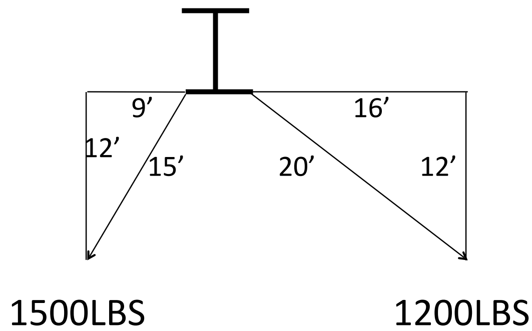
$$F_H = (\frac{D_H}{D_L})(FA)$$



Resultant Loads

Using Resultants to figure out loads on beams

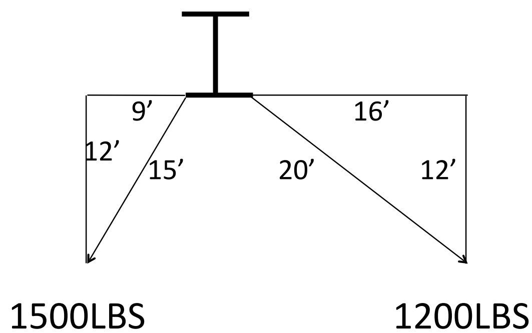
$$F_V = (\frac{D_V}{D_L})(FA)$$



Resultant Loads

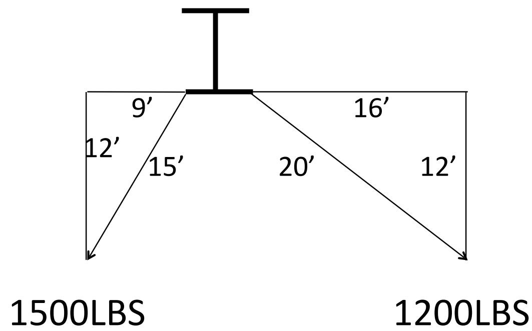
Using Resultants to figure out loads on beams

$$F_V = (\frac{D_V}{D_L})(FA)$$



Resultant Loads

Using Resultants to figure out loads on beams

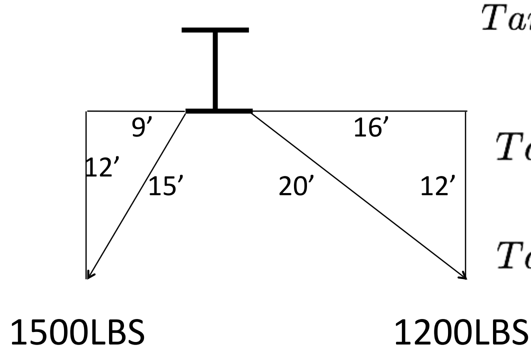


Slope of Resultant Force

$$\frac{F_H}{F_V}$$

Resultant Loads

Using Resultants to figure out loads on beams



$$Tan(ResultantAngle) = \frac{TotalF_H}{TotalF_V}$$

$$Tan(ResultantAngle) = \frac{60}{1920}$$

$$Tan(ResultantAngle) = 0.03125$$

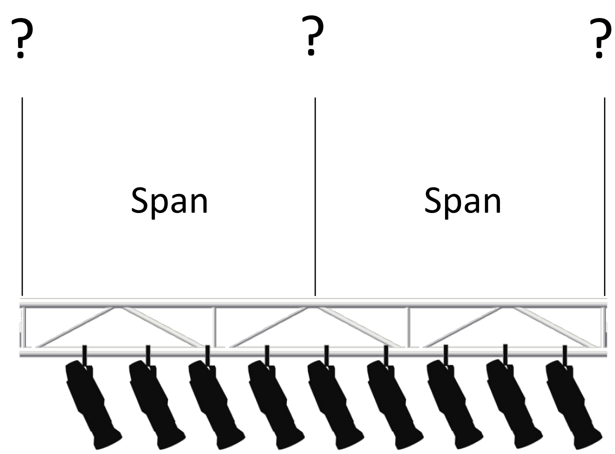
$$ResultantAngle = acrTan(0.03125)$$

$$ResultantAngle = 1.790^{o}$$

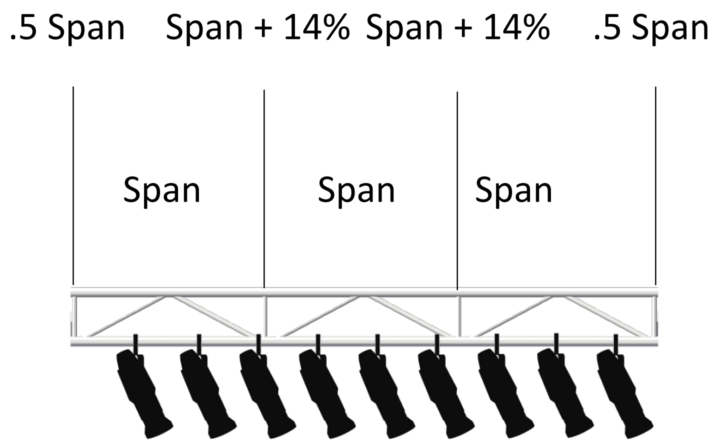
Complex Structures

What happens when we add a suspension point?

Complex Structures

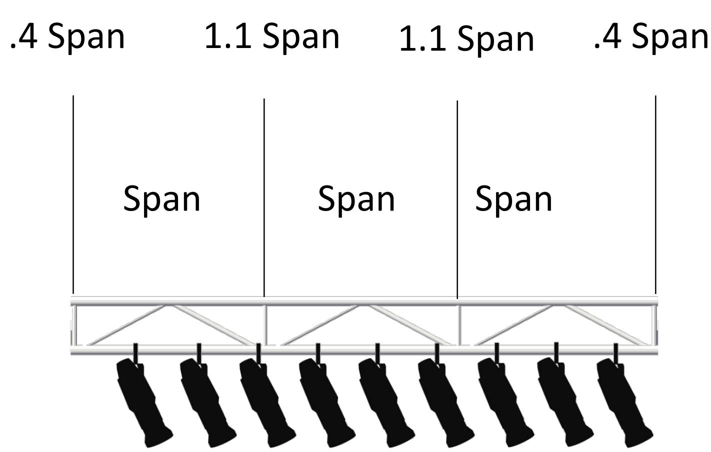


Complex Structures



Complex Structures

Mathematically the loads are different



Complex Structures

So why not just use the Mathematical solution?

The process for calculating the loads uses the Three Moment Theorem, which is not very practical in the field due to the complexity of the math

ERS ENTERTAINMENT RIGGING SERVICES LLC

Complex Structures

Use a "Rule of Thumb"

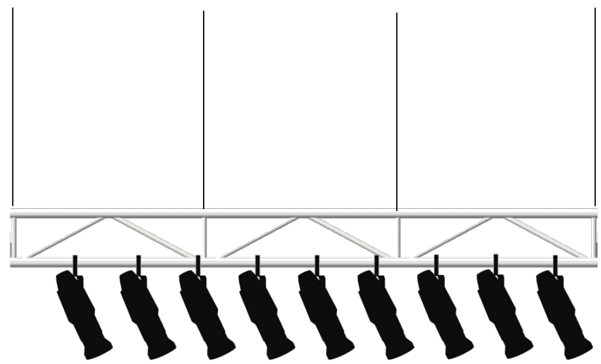
Harry Donovan figured out that the biggest difference between intuition and the mathematically correct answer on a structure with 3 suspensions is 25% and a structure with 4 or more suspensions is 14%

ERS ENTERTAINMENT RIGGING SERVICES LLC

Complex Structures

Rule of Thumb for 4 or more suspensions

.5 Span   Span + 14% Span + 14%   .5 Span



ERS ENTERTAINMENT RIGGING SERVICES

Complex Structures

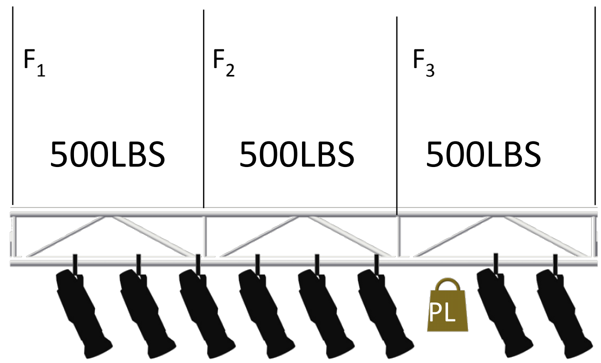
What happens when we add a Point Load?

We can use the simple span equation in combination with the “Rule of Thumb”

ERS ENTERTAINMENT RIGGING SERVICES

Complex Structures

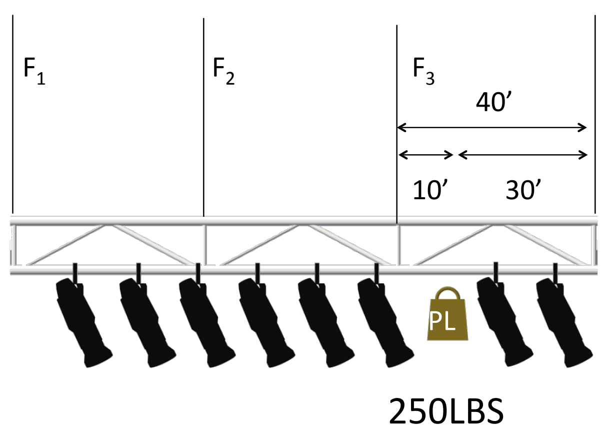
.5 Span Span + 14% Span + 14% .5 Span



ENTERTAINMENT RIGGING SERVICES

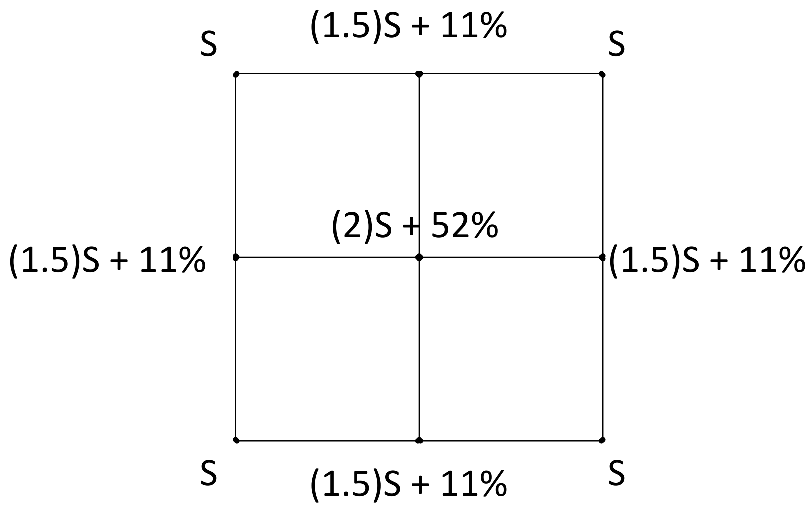
Complex Structures

.5 Span Span + 14% Span + 14% .5 Span



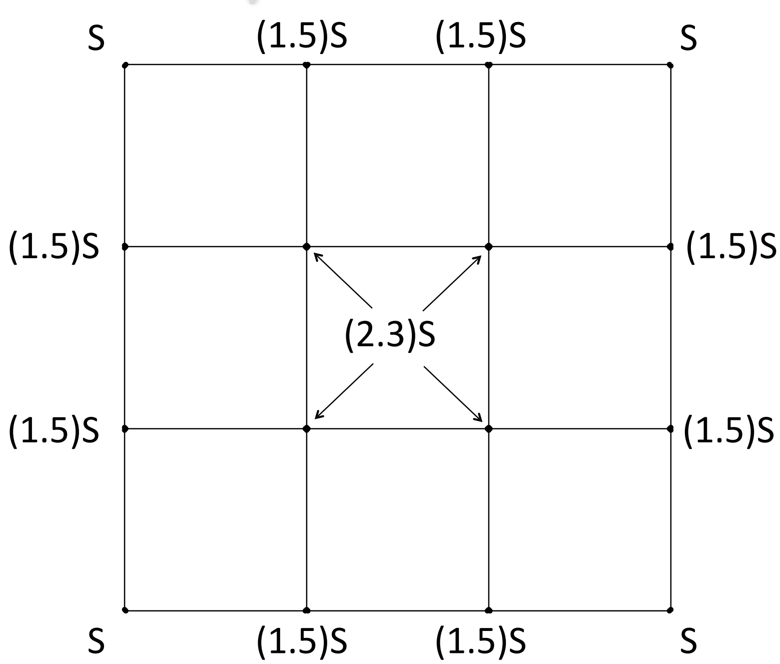
ENTERTAINMENT RIGGING SERVICES

Complex Structures



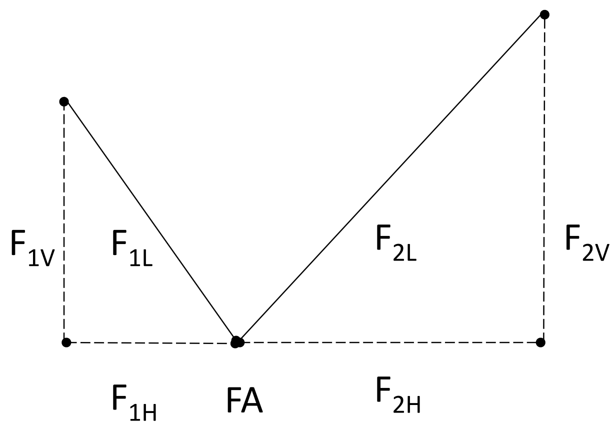
ENTERTAINMENT RIGGING SERVICES

Complex Structures



ENTERTAINMENT RIGGING SERVICES

Math Solutions to Simple Bridles



$$F_{1L} = \frac{(FA)D_{2H}D_{1L}}{D_{1V}D_{2H} + D_{2V}D_{1H}}$$

$$F_{2L} = \frac{(FA)D_{1H}D_{2L}}{D_{1V}D_{2H} + D_{2V}D_{1H}}$$

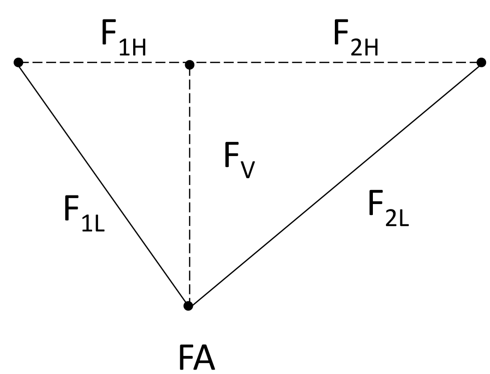
$$F_{1V} = \frac{(FA)D_{2H}D_{1V}}{D_{1V}D_{2H} + D_{2V}D_{1H}}$$

$$F_{2V} = \frac{(FA)D_{1H}D_{2V}}{D_{1V}D_{2H} + D_{2V}D_{1H}}$$

$$F_H = \frac{(FA)D_{1H}D_{2H}}{D_{1V}D_{2H} + D_{2V}D_{1H}}$$

ENTERTAINMENT RIGGING SERVICES

Math Solutions to Simple Bridles



If the beams are at the same height you can simplify the equation

$$F_{1L} = \frac{(FA)D_{2H}D_{1L}}{D_V(Span)}$$

$$F_{2L} = \frac{(FA)D_{1H}D_{2L}}{D_V(Span)}$$

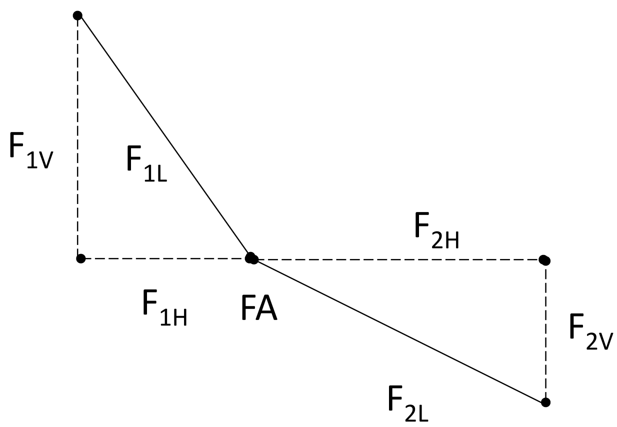
$$F_{1V} = \frac{(FA)D_{2H}}{D_V(Span)}$$

$$F_{2V} = \frac{(FA)D_{1H}}{D_V(Span)}$$

$$F_H = \frac{(FA)D_{1H}D_{2H}}{D_V(Span)}$$

ENTERTAINMENT RIGGING SERVICES

Math Solutions to Simple Bridles



If one beam is BELOW the junction

$$F_{1L} = \frac{(FA)D_{2H}D_{1L}}{D_{1V}D_{2H} - D_{2V}D_{1H}}$$

$$F_{2L} = \frac{(FA)D_{1H}D_{2L}}{D_{1V}D_{2H} - D_{2V}D_{1H}}$$

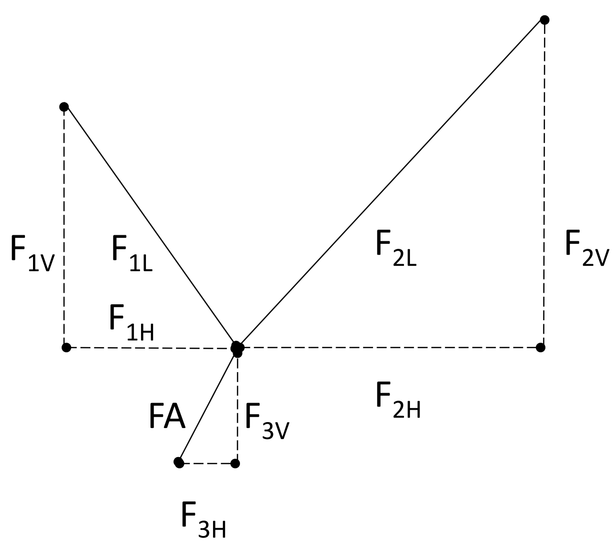
$$F_{1V} = \frac{(FA)D_{2H}D_{1V}}{D_{1V}D_{2H} - D_{2V}D_{1H}}$$

$$F_{2V} = \frac{(FA)D_{1H}D_{2V}}{D_{1V}D_{2H} - D_{2V}D_{1H}}$$

$$F_H = \frac{(FA)D_{1H}D_{2H}}{D_{1V}D_{2H} - D_{2V}D_{1H}}$$

ENTERTAINMENT RIGGING SERVICES

Math Solutions to Simple Bridles



$$F_{1L} = FA(\frac{D_{1L}}{D_{3L}})(\frac{D_{3V}D_{2H} - D_{2V}D_{3H}}{D_{1V}D_{2H} - D_{2V}D_{1H}})$$

$$F_{2L} = FA(\frac{D_{2L}}{D_{3L}})(\frac{D_{3V}D_{1H} - D_{1V}D_{3H}}{D_{1V}D_{2H} - D_{2V}D_{1H}})$$

$$F_{1V} = (F_{1L})(\frac{D_{1V}}{D_{1L}})$$

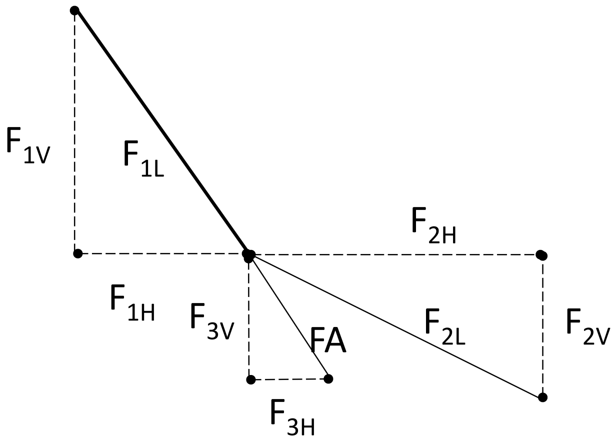
$$F_{2V} = (F_{2L})(\frac{D_{2V}}{D_{2L}})$$

$$F_{1H} = (F_{2L})(\frac{D_{1H}}{D_{1L}})$$

$$F_{2H} = (F_{2L})(\frac{D_{2H}}{D_{2L}})$$

ENTERTAINMENT RIGGING SERVICES

Math Solutions to Simple Bridles



$$F_{1L} = D_{1L}(\frac{F_{3V}D_{2H} - F_{3H}D_{2V}}{D_{1V}D_{2H} - D_{2V}D_{1H}})$$

$$F_{2L} = D_{2L}(\frac{F_{3V}D_{1H} - F_{3H}D_{1V}}{D_{1V}D_{2H} - D_{2V}D_{1H}})$$

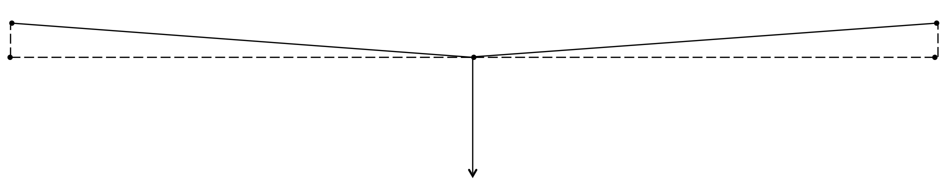
ENTERTAINMENT RIGGING SERVICES

Math Solutions to Simple Bridles

2 Workers on this horizontal lift line.

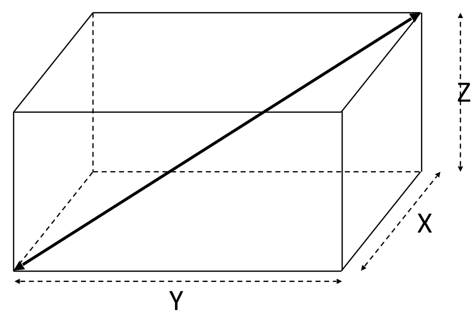
40’

Deflection = 1/20 of span



ENTERTAINMENT RIGGING SERVICES

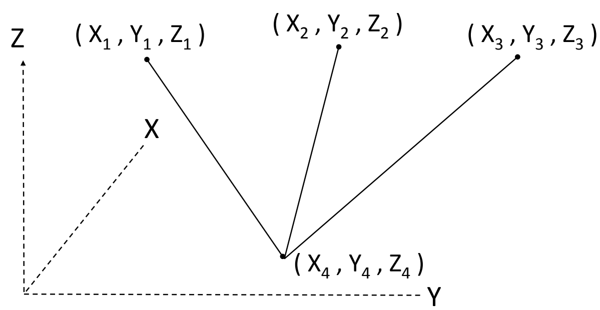
3 leg Bridles



$$L = \sqrt{X^2 + Y^2 + Z^2}$$

ERS ENTERTAINMENT RIGGING SERVICES

3 leg Bridles



$$L_1 = \sqrt{(X_1 - X_4)^2 + (Y_1 - Y_4)^2 + (Z_1 - Z_4)^2}$$

$$L_2 = \sqrt{(X_2 - X_4)^2 + (Y_2 - Y_4)^2 + (Z_2 - Z_4)^2}$$

$$L_3 = \sqrt{(X_3 - X_4)^2 + (Y_3 - Y_4)^2 + (Z_3 - Z_4)^2}$$

ERS ENTERTAINMENT RIGGING SERVICES

3 leg Bridles

$$N_{1X} = \frac{X_1 - X_4}{L_1} \qquad N_{1Y} = \frac{Y_1 - Y_4}{L_1} \qquad N_{1Z} = \frac{Z_1 - Z_4}{L_1}$$

$$N_{2X} = \frac{X_2 - X_4}{L_2} \qquad N_{2Y} = \frac{Y_2 - Y_4}{L_2} \qquad N_{2Z} = \frac{Z_2 - Z_4}{L_2}$$

$$N_{3X} = \frac{X_3 - X_4}{L_3} \qquad N_{3Y} = \frac{Y_3 - Y_4}{L_3} \qquad N_{3Z} = \frac{Z_3 - Z_4}{L_3}$$

ENTERTAINMENT
RIGGING SERVICES

3 leg Bridles

$$D = (N_{1X})(N_{2Y})(N_{3Z}) + (N_{2X})(N_{3Y})(N_{1Z}) + (N_{1Y})(N_{2Z})(N_{3X})$$
$$-(N_{3X})(N_{2Y})(N_{1Z}) - (N_{3Y})(N_{2Z})(N_{1X}) - (N_{2X})(N_{1Y})(N_{3Z})$$

ENTERTAINMENT
RIGGING SERVICES

3 leg Bridles

$$F_1L = ((N_{2X})(N_{3Y}) - (N_{3X})(N_{2Y}))(\frac{FA}{D})$$

$$F_2L = ((N_{3X})(N_{1Y}) - (N_{1X})(N_{3Y}))(\frac{FA}{D})$$

$$F_3L = ((N_{1X})(N_{2Y}) - (N_{2X})(N_{1Y}))(\frac{FA}{D})$$

ERS ENTERTAINMENT RIGGING SERVICES LLC

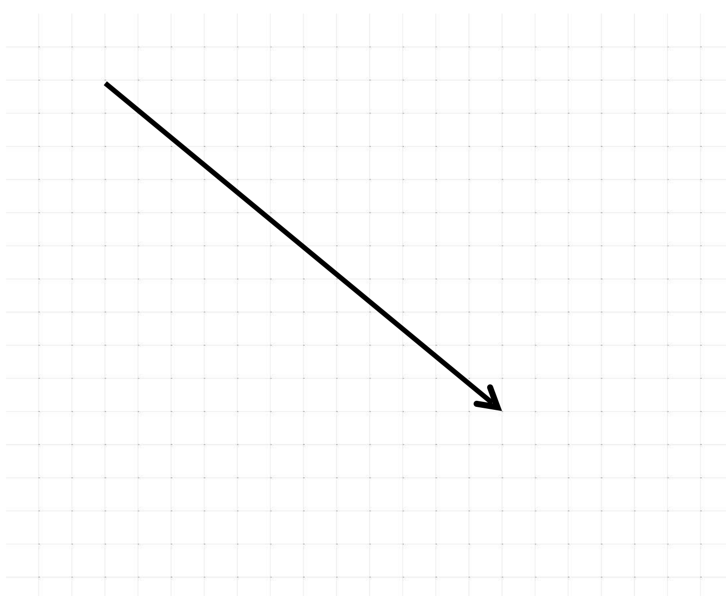
Vector Solutions to Simple Bridles

- Vectors offer an alternative to Algebra
- Helps to visualize the forces
- Slower to calculate loads
- Not as Accurate

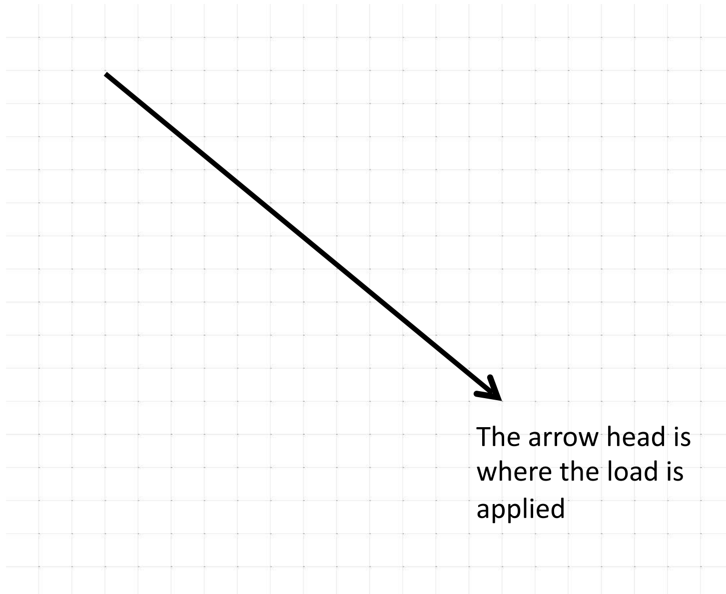
ERS ENTERTAINMENT RIGGING SERVICES LLC

Vectors

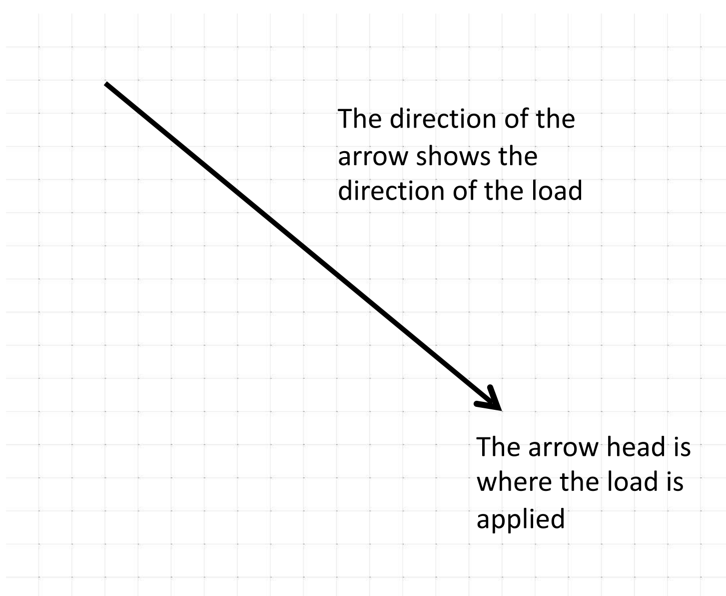
Vectors



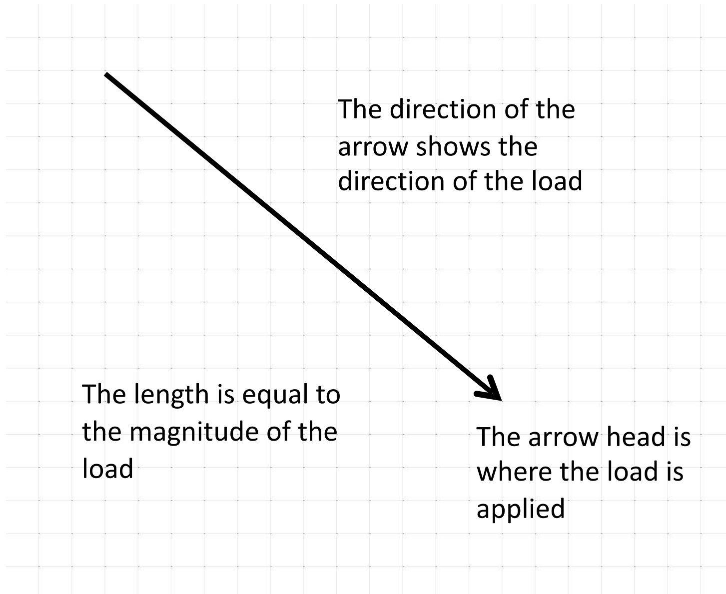
Vectors



Vectors

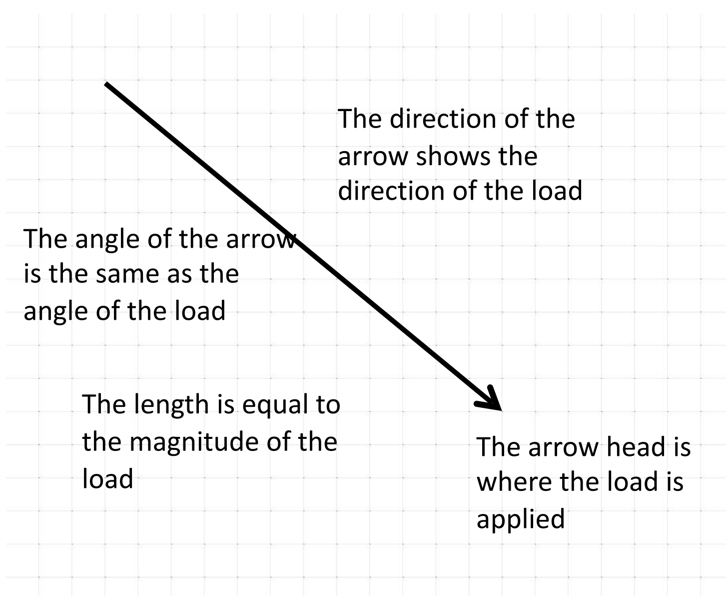


Vectors



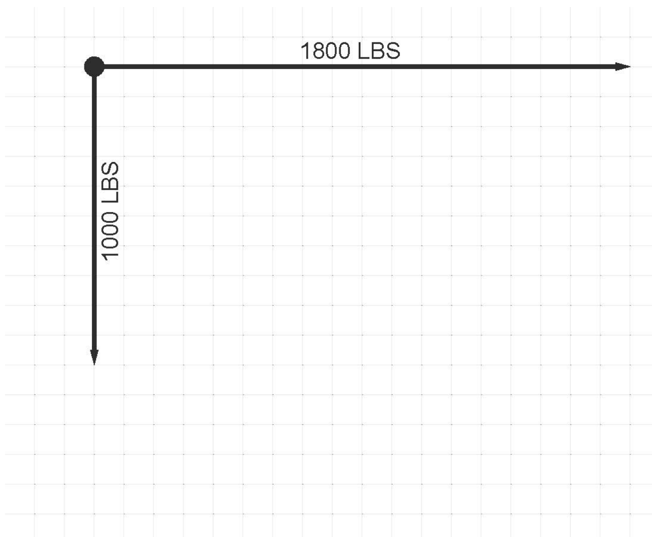
ENTERTAINMENT RIGGING SERVICES

Vectors

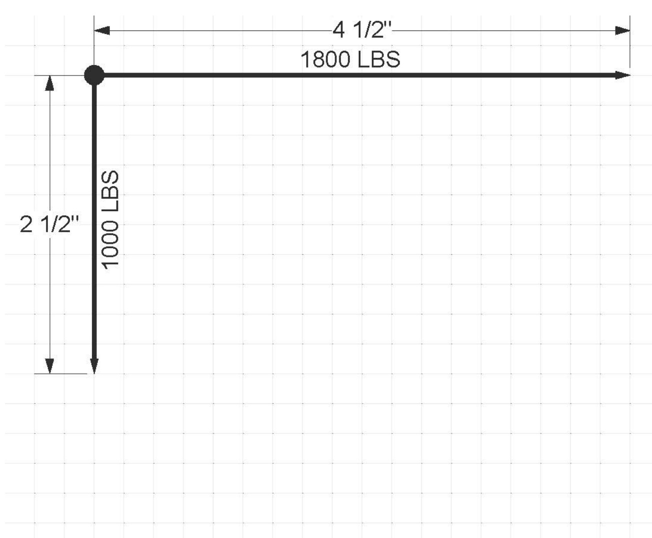


ENTERTAINMENT RIGGING SERVICES

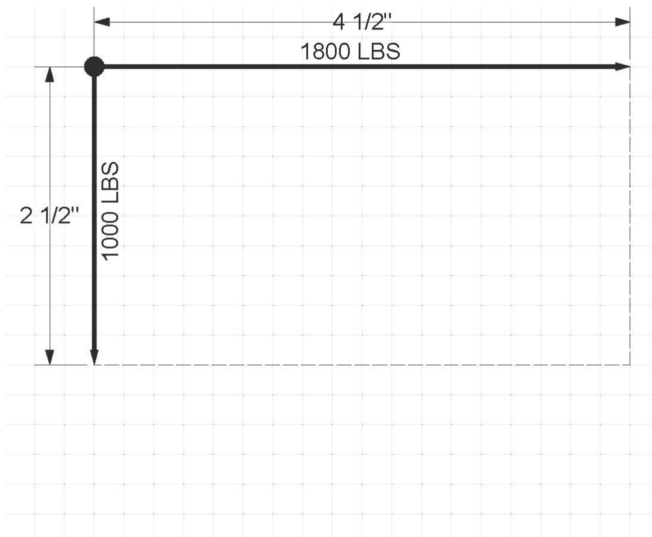
Vector Problem 1



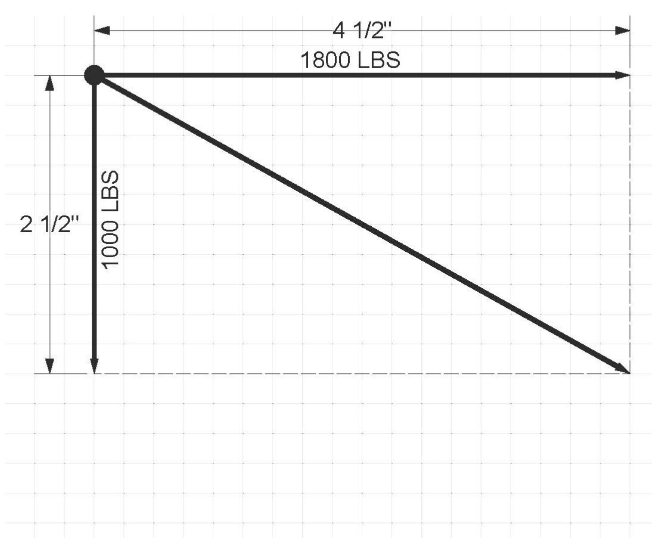
Vector Problem 1



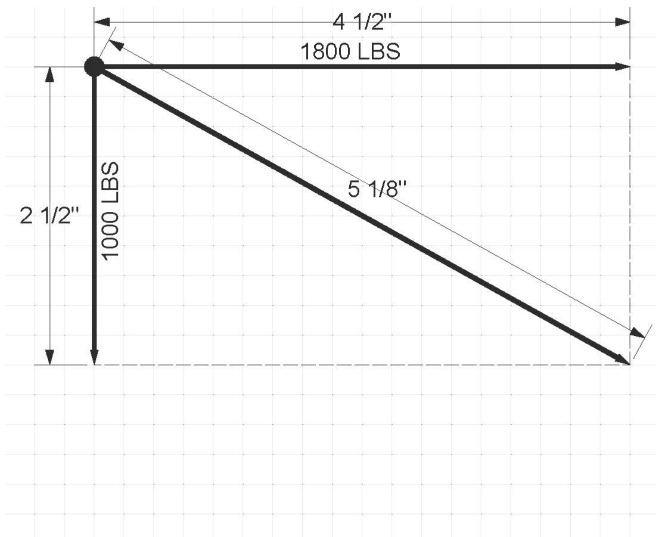
Vector Problem 1



Vector Problem 1

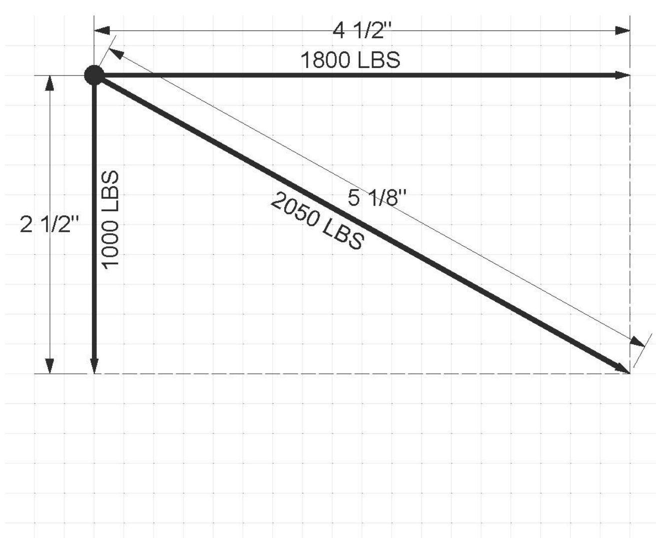


Vector Problem 1



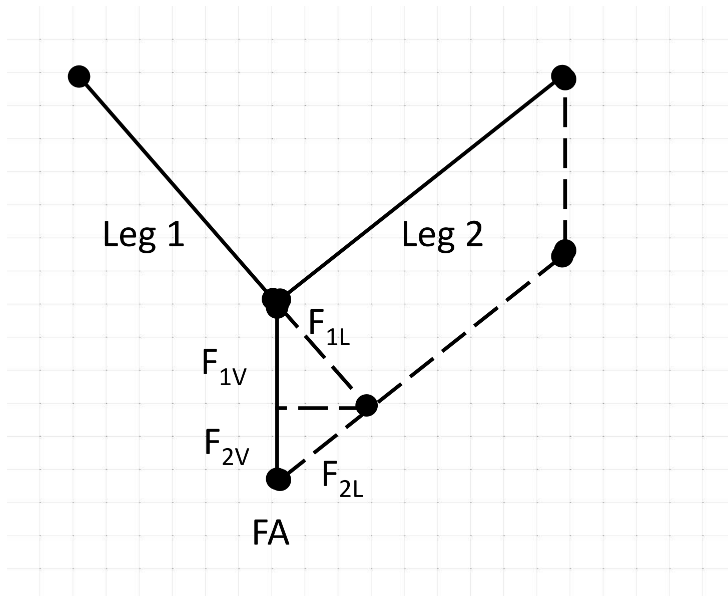
ERS ENTERTAINMENT RIGGING SERVICES

Vector Problem 1



ERS ENTERTAINMENT RIGGING SERVICES

Vector Problem 1



ENTERTAINMENT RIGGING SERVICES