

Franklin W. Olin College of Engineering

*Rose-Hulman/Foundation-Coalition
Sophomore Engineering Curriculum*

Don Richards

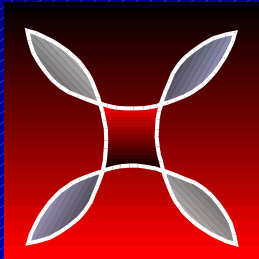
Professor of Mechanical Engineering
Rose-Hulman Institute of Technology

14 December 2001

Objectives of My Talk

- Introduce the *systems, accounting, and modeling approach* for organizing engineering science material.
- Describe the *Rose-Hulman Sophomore Engineering Curriculum (SEC)* based on this approach.
- Entice you to consider these ideas for the Olin College curricula.

*But first a word from my
sponsors.*



Foundation Coalition

“Creating an enduring foundation for student development and life-long learning” by rebuilding engineering curricula from the foundation up.

***An NSF Engineering Education Coalition
since 1993.***

FC Contacts

FC Web Site

www.foundationcoalition.org

FC Project Director -- Jeff Froyd

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What faculty beliefs motivated the development of the SEC ?

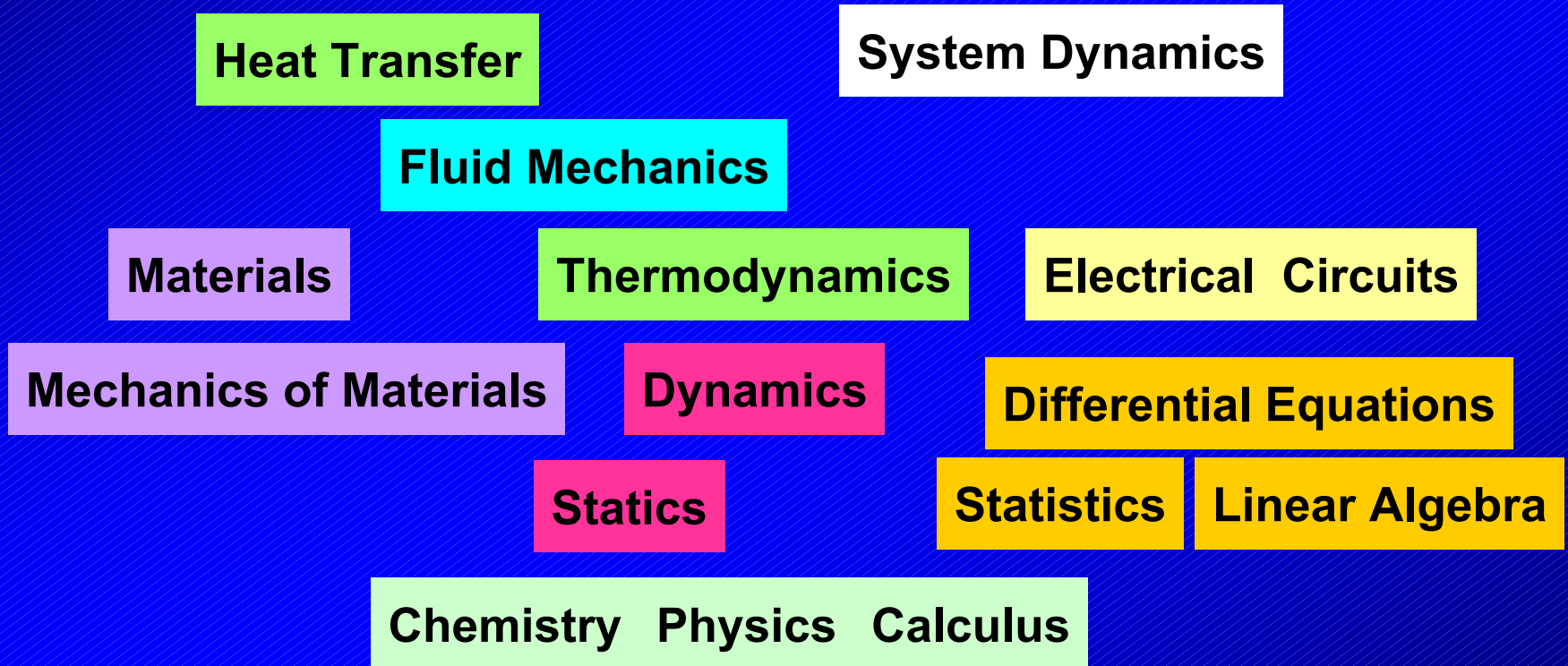
- There is a **common engineering science and mathematics core** for *all* engineers.
- This **core should serve as a foundation** for discipline specific education.
- Both **vertical and horizontal integration** of course material are important.
- Learning can be improved if the core is built around **a few key concepts**.

Systems, Accounting & Modeling Approach

- A conceptual framework for engineering analysis.
- A unified format for presenting and interpreting the basic laws that is uniquely suited for engineering applications.
- A common, consistent problem-solving approach based on constructing problem-specific solutions from the underlying physical laws.

Conceptual framework

*Engineering Science Core**



* One possible core

What are the topics and concepts in the core?

Mass
Electric Charge
Linear Momentum
Angular Momentum
Mechanical Energy
Energy
Entropy

Electric Current
Torque
Force
Work
Heat Transfer
Mass Flow

Node

Free-Body Diagram
Closed System
Open System
Control Mass
Control Volume

Equilibrium

Steady state

Rigid Boundary

Pinned Joint

Linear Translation

Rigid Body

Insulated Boundary

Lumped Circuit Element

Ohm's Law
Ideal Spring
Dry Friction
Ideal Gas Law
Steam Tables
Friction Factor
Newtonian Fluid
Viscous Drag

$F=ma$

KCL

Energy Equation

Bernoulli's Eqn

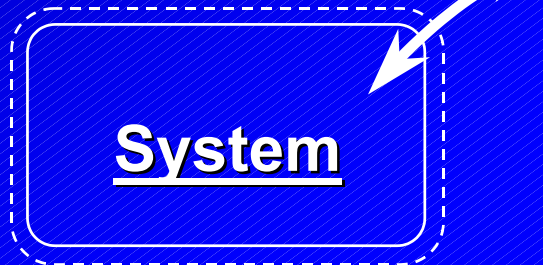
Extensive Property

Mass
Electric Charge
Linear Momentum
Angular Momentum
Mechanical Energy
Energy
Entropy

Constitutive Relations

Ohm's Law
Ideal Spring
Dry Friction
Ideal Gas Law
Steam Tables
Friction Factor
Newtonian Fluid
Viscous Drag

What's the method?



Node

Free-Body Diagram

Closed System
Open System
Control Mass
Control Volume

Accounting Principle

$F=ma$
KCL
Energy Equation
Bernoulli's Eqn

Interactions

Electric Current
Torque
Force
Work
Heat Transfer
Mass Flow

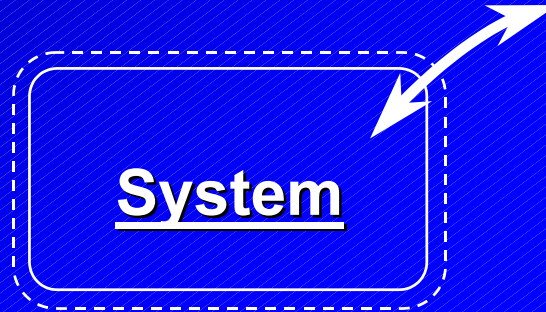
Modeling

Assumptions

Equilibrium
Steady state
Rigid Boundary
Pinned Joint
Linear Translation
Rigid Body
Insulated Boundary
Lumped Element

Extensive Property

Interactions



Constitutive
Relations

Modeling
Assumptions

Accounting Principle

Accounting Equation for Extensive Property B

$$\frac{dB_{sys}}{dt} = \left[\dot{B}_{in} - \dot{B}_{out} \right] + \left[\dot{B}_{gen} - \dot{B}_{cons} \right]$$

Rate of Accumulation
of B
inside the system
at time t

Net Transport Rate
of B
into the system
at time t .

Net Generation Rate
of B
inside the system
at time t

Concepts & Definitions

- Model
- System
 - Open system
 - Closed system
- Property
 - Intensive property
 - Extensive property
- State of a system
- Process
 - Steady state
 - Finite time
 - Transient
- Interaction
- Accounting Principle
- Conserved Property
- Constitutive Relation

Accounting Equation for Extensive Property B

$$\begin{aligned}
 \frac{d}{dt} B_{\text{sys}} &= \underbrace{\left[\dot{B}_{in} - \dot{B}_{out} \right]}_{\substack{\text{net rate transported} \\ \text{across the boundary} \\ \text{into the system}}} + \underbrace{\left[\dot{B}_{\text{generated}} - \dot{B}_{\text{consumed}} \right]}_{\substack{\text{net rate generated} \\ \text{within the system}}} \\
 &= \left[\dot{B}_{\text{net},in} \Big|_{\substack{\text{without} \\ \text{mass flow}}} + \dot{B}_{\text{net},in} \Big|_{\substack{\text{with} \\ \text{mass flow}}} \right] + \left[\dot{B}_{\text{generated}} - \dot{B}_{\text{consumed}} \right] \\
 &= \left[\dot{B}_{\text{net},in} \Big|_{\substack{\text{without} \\ \text{mass flow}}} + \sum_{in} \dot{m}_i b_i - \sum_{out} \dot{m}_e b_e \right] + \left[\dot{B}_{\text{generated}} - \dot{B}_{\text{consumed}} \right]
 \end{aligned}$$

*Presentation and interpretation
of the basic physical laws*

Systems & Accounting Framework for Physical Laws

- What's the extensive property?
- How can it be counted?
- How can it be stored in the system?
- How can it be transported?
- How can it be generated or consumed?

$$\begin{array}{|c|} \hline \text{Rate} \\ \text{of} \\ \text{Storage} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Net} \\ \text{Transport} \\ \text{Rate In} \\ \hline \end{array} + \begin{array}{|c|} \hline \text{Net} \\ \text{Generation} \\ \text{Rate} \\ \hline \end{array}$$

Fundamental Physical Laws

Extensive Property

Physical Law

Mass

Conservation of Mass

Charge

Conservation of Charge

Momentum

Conservation of Momentum

Energy

Conservation of Energy

Entropy

Entropy Production & Accounting

Example

Conservation of Linear Momentum

Conservation of Linear Momentum

What is linear momentum?

The linear momentum of a particle is the product of the mass of the particle m and its velocity \mathbf{V} . Students already know this definition from physics.

$$\vec{P} = m\vec{V}$$

Conservation of Linear Momentum

How can it be stored in and quantified for a system?

$$\vec{P}_{\text{sys}} = \int_{V_{\text{sys}}} \vec{V} \rho dV$$

$$\vec{P}_{\text{sys}} = \sum \vec{P}_j = \sum m_j \vec{V}_j$$

Conservation of Linear Momentum

How can it be transported across the system boundaries?

- External Forces
 - Contact Forces
 - Body Forces
- Mass transport

$$\vec{F}_{\text{external}}$$

$$\dot{m}\vec{V}$$

Conservation of Linear Momentum

How can linear momentum be generated or consumed within the system?

Experience has shown that it is impossible to create or destroy linear momentum; hence, we say that ***linear momentum is conserved.***

$$\dot{\vec{P}}_{gen} = \dot{\vec{P}}_{con} = 0$$

Conservation of Linear Momentum (Rate form)

$$\frac{dB_{\text{sys}}}{dt} = \underbrace{\dot{B}_{in} - \dot{B}_{out}}_{\text{Non-flow boundary}} + \underbrace{\sum_{in} \dot{m}_i b_i - \sum_{out} \dot{m}_e b_e}_{\text{Flow boundary}} + \left[\dot{B}_{gen} - \dot{B}_{cons} \right]$$

$$\frac{d\vec{P}_{\text{sys}}}{dt} = \underbrace{\dot{\vec{P}}_{in} - \dot{\vec{P}}_{out}}_{\text{Non-flow boundary}} + \underbrace{\sum_{in} \dot{m}_i \vec{V}_i - \sum_{out} \dot{m}_e \vec{V}_e}_{\text{Flow boundary}} + \left[\dot{\vec{P}}_{gen} - \dot{\vec{P}}_{cons} \right]$$

Note: A red '0' is written above the last term, and a red arrow points from it to the right. A green arrow points from the first term to the external force equation below.

$$\sum \vec{F}_{\text{external}}$$

Conservation of Linear Momentum

$$\vec{P}_{sys} = \int_{V_{sys}} \vec{V} \rho dV$$

$$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F}_{ext} + \left[\sum_{in} \dot{m}_i \vec{V}_i - \sum_{out} \dot{m}_e \vec{V}_e \right]$$

where \dot{m} is the mass flow rate.

Recovering $F = ma$

$$\frac{d\vec{P}_{\text{sys}}}{dt} = \sum \vec{F}_{\text{ext}} + \left[\sum_{\text{in}} \dot{m}_i \vec{V}_i - \sum_{\text{out}} \dot{m}_e \vec{V}_e \right]$$

Closed System

$$\vec{P}_{\text{sys}} = m_G \vec{V}_G$$

$$\dot{m} = 0$$

$$\frac{d}{dt} \left(m_G \vec{V}_G \right) = \sum \vec{F}_{\text{ext}} \quad \rightarrow \quad m_G \frac{d}{dt} \left(\vec{V}_G \right) = m_G \vec{a}_G = \vec{F}_{\text{net}}$$

Rate Form of Basic Laws

$$\frac{dm_{\text{sys}}}{dt} = \sum_{\text{in}} \dot{m}_i - \sum_{\text{out}} \dot{m}_e \qquad \frac{dq_{\text{sys}}}{dt} = \sum_{\text{in}} \dot{q}_i - \sum_{\text{out}} \dot{q}_e$$

$$\frac{d\bar{P}_{\text{sys}}}{dt} = \sum_j \vec{F}_{\text{ext},j} + \left[\sum_{\text{in}} \dot{m}_i \vec{V}_i - \sum_{\text{out}} \dot{m}_e \vec{V}_e \right]$$

$$\frac{d\vec{L}_{o,\text{sys}}}{dt} = \sum_j \vec{M}_{o,j} + \left[\sum_{\text{in}} \dot{m}_i (\vec{r}_i \times \vec{V}_i) - \sum_{\text{out}} \dot{m}_e (\vec{r}_e \times \vec{V}_e) \right]$$

$$\frac{dE_{\text{sys}}}{dt} = \dot{Q}_{\text{net},\text{in}} + \dot{W}_{\text{net},\text{in}} + \left[\sum_{\text{in}} \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i \right) - \sum_{\text{out}} \dot{m}_e \left(h_e + \frac{V_e^2}{2} + gz_e \right) \right]$$

$$\frac{dS_{\text{sys}}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \left[\sum_{\text{in}} \dot{m}_i s_i - \sum_{\text{out}} \dot{m}_e s_e \right] + \dot{S}_{\text{gen}}$$

*A common, consistent
problem solving approach.*

Common Problem Solving Format

- Known
- Find
- Given
- Analysis
 - Strategy
 - Constructing model
 - Solution
- Comments

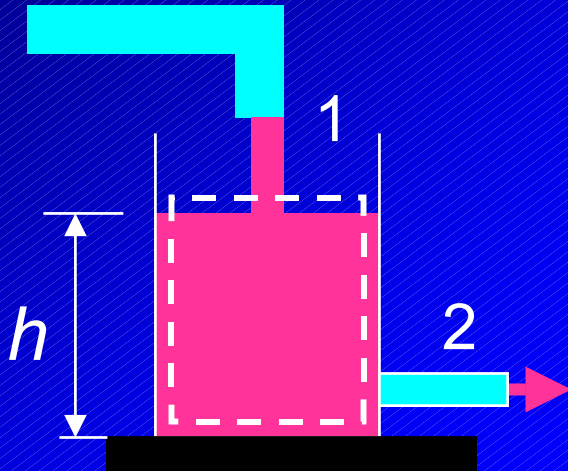


Typical Questions

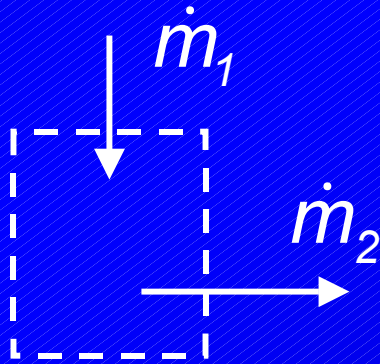
- What's the system?
- What properties should we count?
- What's the time interval?
- What are the important interactions?
- What are the important constitutive relations?
- How do the basic equations simplify?
- What are the unknowns?
- How many equations do I need?

A couple of examples

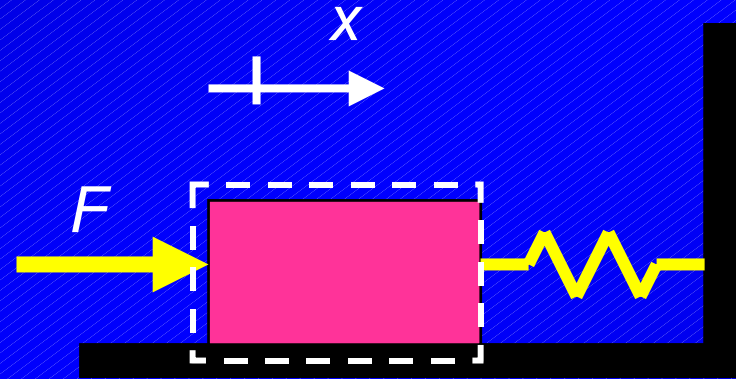
Find $h(t)$.



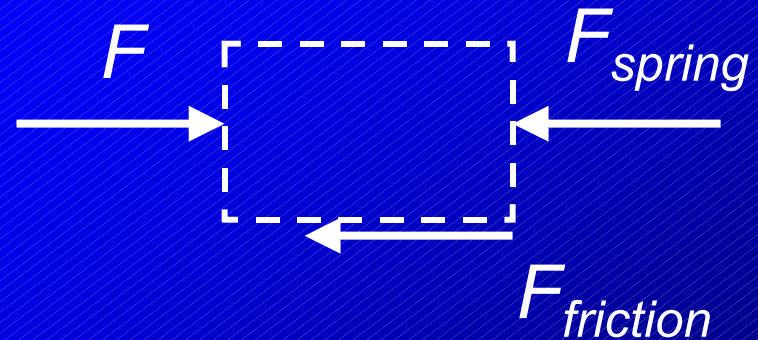
Extensive Property?
System?



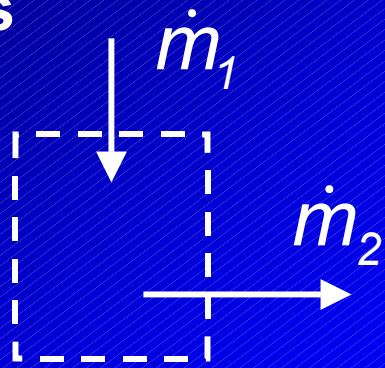
Find $V_x(t)$.



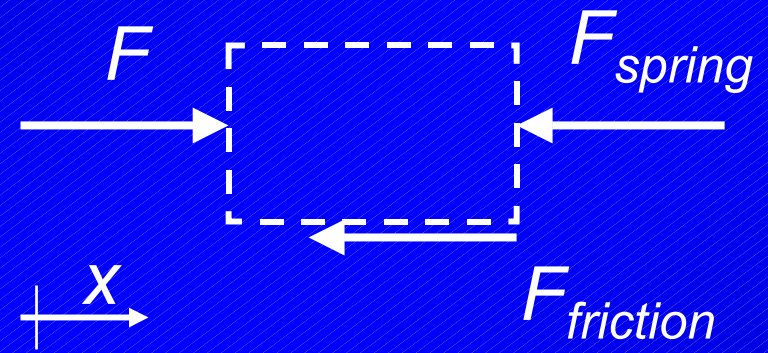
Extensive Property?
System?



Mass



Linear Momentum



$$\frac{dm_{\text{sys}}}{dt} = \dot{m}_1 - \dot{m}_2$$

$$\frac{d}{dt}(\rho A_{\text{tank}} h) = \dot{m}_1 - C\sqrt{gh}$$

$$\frac{dh}{dt} = \frac{\dot{m}_1}{\rho A_{\text{tank}}} - \frac{C\sqrt{gh}}{\rho A_{\text{tank}}}$$

$$\frac{dP_{x,\text{sys}}}{dt} = F - F_{\text{friction}} - F_{\text{spring}}$$

$$\frac{d}{dt}(mV_x) = F - \mu_k mg - kx$$

$$\frac{dV_x}{dt} = \frac{F}{m} - \mu_k g - \frac{kx}{m}$$

Advantages of this Approach

- Provides a conceptual framework for the core.
- Provides a unified format for presenting and understanding the basic laws that is uniquely suited for engineering applications.
- Enables the use of a common, consistent problem solving approach.
- Helps students (and faculty) see links between apparently unrelated topics by reinforcing the underlying similarities.

How could you use this?

- As the basis for modifying an existing course.
- As the basis for a new course
 - ME 10 - Introduction to Engineering Analysis (Stanford)
 - BioE 252 - Conservation Principles in Biology & Medicine (Rice)
- As the basis for a new curriculum
 - Sophomore Engineering Science Sequence (TAMU)
 - Sophomore Engineering Curriculum (Rose-Hulman)

Where did this approach come from?

- 1987 - Unified Engineering Science Curriculum Project
 - NSF-funded project at Texas A&M
 - Developed a four-course sequence of sophomore engineering courses (the “20X sequence”):
 - Conservation Principles in Engineering
 - Properties of Matter
 - Modeling/Behavior of Engineering Systems
 - Conservation Principles of Continuous Media
 - <http://www-chen.tamu.edu/uesc/>

Where did this approach come from?

- L. Prandtl's fluid mechanics work in the early 1900's.
- Discipline of System Dynamics
- References from physics
 - H. Burkhardt, "System physics: A uniform approach to the branches of classical physics." *Am. J. Phys.* 55, 344-350, 1987.
 - Chapter 1 in H. Fuchs, *The Dynamics of Heat*. Springer-Verlag, 1996.

What Engineers Know and How They Know It
Walter G. Vincenti, Johns Hopkins Press, 1990.

- “Engineers, unlike physicists, are after useful artifacts and must predict the performance of the objects they design.”
- **“Organization according to control-volume ideas is thus not only simpler but brings clearer understanding of the physical principles common to otherwise disparate situations.”**
- “By organizing knowledge according to physical laws rather than known problems, it aids in recognizing a control-volume problem when met in an unfamiliar disguise.”

- “Control-volume analysis, by setting up an explicit method of bookkeeping for the various flow quantities, provides such a procedure for the many engineers who must deal with fluid-mechanical devices.”
- **“Control-volume analysis is useful precisely because it provides a framework and method for thinking clearly about a large class of the often confusing problems that arise in engineering design.”**

From Chpt 4, “A Theoretical Tool for Design: Control-Volume Analysis, 1912-1953”

Rose-Hulman / Foundation-Coalition
Sophomore Engineering Curricula

What is the Rose-Hulman Sophomore Engineering Curriculum?

An eight-course sequence that integrates core material in engineering science and mathematics.

- Designed for all engineering majors.
- Developed by a multi-disciplinary faculty team.
- Taught since 1995-1996.
- Required of all electrical, computer, and mechanical engineering students.

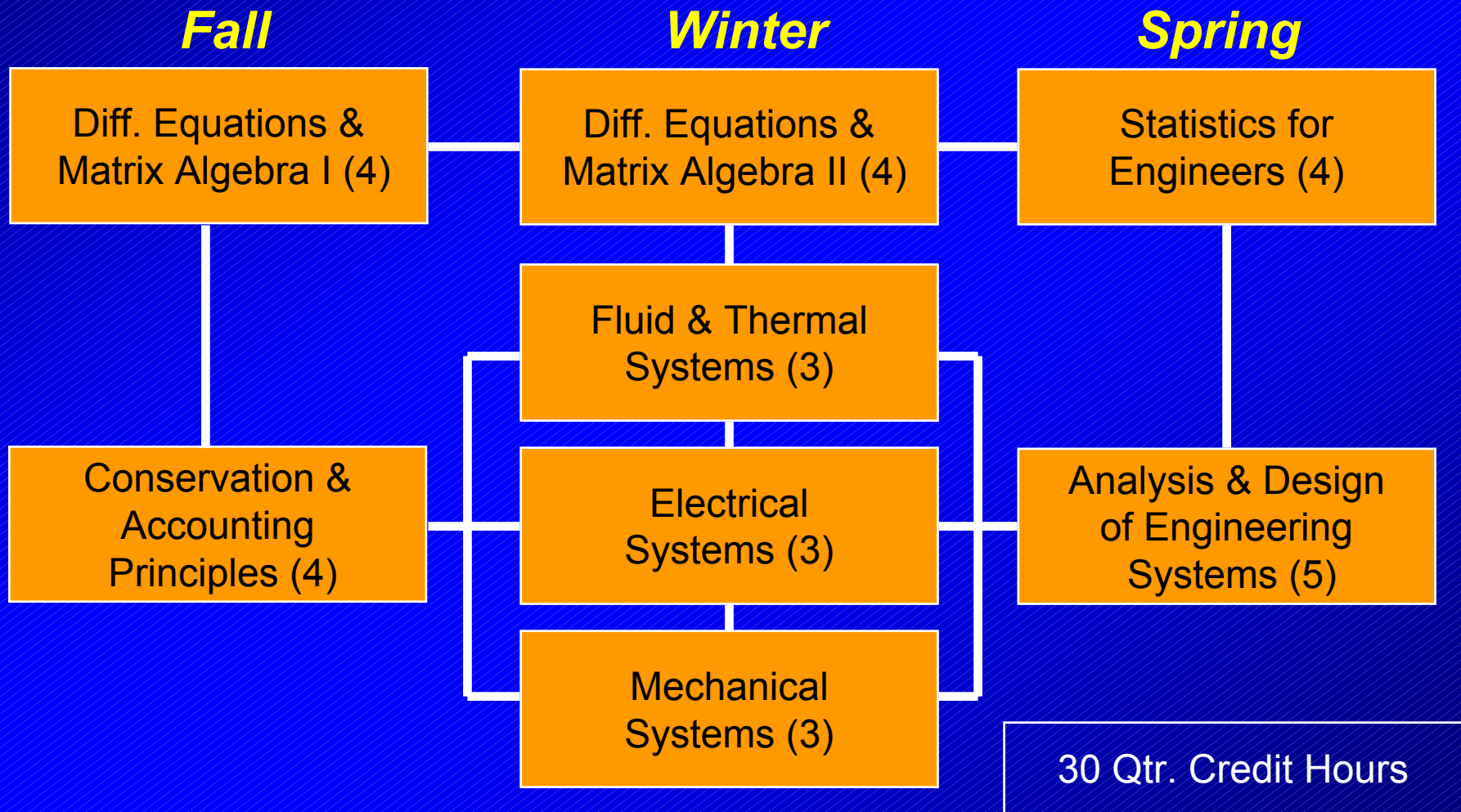
What's in our Core?

Diff. Equations I	Dynamics
Fluid Mechanics	Circuits
Thermodynamics	Diff. Equations II
Statistics	System Dynamics
Matrix Algebra	

32 Qtr. Credit Hours

Sophomore Engineering Curriculum

Our New Approach



Sophomore Engineering Curriculum

Advantages for Students

- Participate in a coordinated curriculum that consciously stresses the links between engineering science and mathematics.
- Provide a common foundation of engineering science and mathematics knowledge for future learning.
- Learn to apply a common framework for problem solving based upon an understanding of the conservation and accounting principles.
- Learn to handle open-ended problems.
- Work with multi-discipline problems.
- Learn cooperatively and work in teams.
- Use computer technology across the curriculum.

Sophomore Engineering Curriculum

A Brief History

Fall 1993

- Foundation Coalition funded by NSF.

1993-1994

- Institute considered various ideas for Sophomore Curriculum (Friday afternoon meetings)

Summer 1994

- Workshops on teaming, active learning, curriculum design. (Approximately 4 days total)
- Multidisciplinary faculty team developed overall framework for SEC. (12 faculty)

Sophomore Engineering Curriculum

A Brief History

1994-1995

- Met with departments and finalized proposal.
- Proposal for pilot approved by Institute.
- Required by electrical and computer engineering department.

Summer 1995

- Team of 12 faculty and 3 students developed detailed curriculum material for eight courses.

Sophomore Engineering Curriculum

A Brief History

1995-1996

- Offered RH/FC SEC for first time to 90 students
- Rose-Hulman required students to purchase a laptop computer.

1996-1997

- Adopted by mechanical engineering department for Fall 1998.

2000-2001

- Currently taken by 220-230 mechanical, electrical, and computer engineering students.

Sophomore Engineering Curriculum

Curriculum Structure

FALL Quarter	8 Credit Hours
MA 221 - Differential Equations & Matrix Algebra I (4)	
ES 201 - Conservation & Accounting Principles (4)	
WINTER Quarter	13 Credit Hours
MA 222 - Differential Equations & Matrix Algebra II (4)	
ES 202 - Fluid & Thermal Systems (3)	
ES 203 - Electrical Systems (3)	
ES 204 - Mechanical Systems (3)	
SPRING Quarter.	9 Credit Hours
MA 223 - Engineering Statistics (4)	
ES 205 - Analysis & Design of Engineering Systems (5)	
TOTAL CREDITS	30 Credit Hours

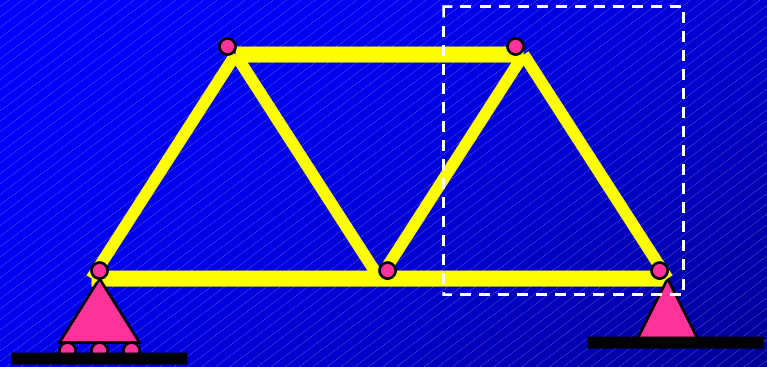
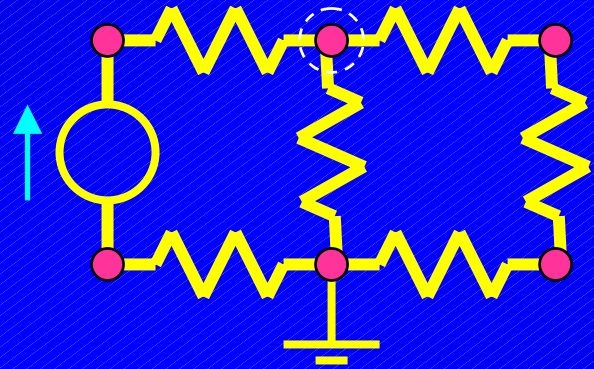
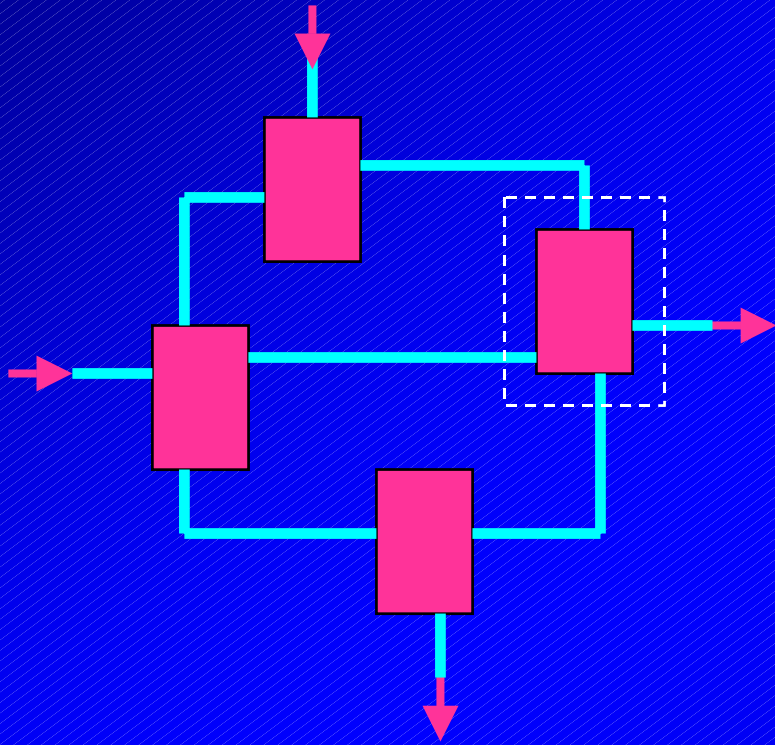


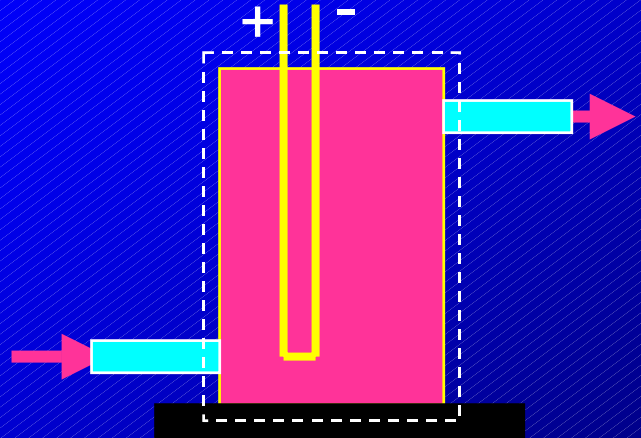
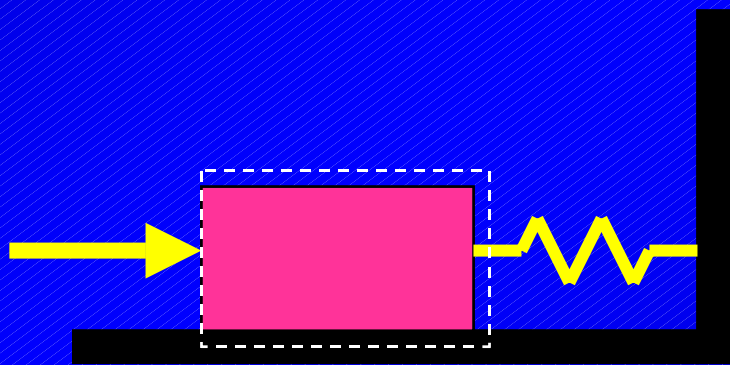
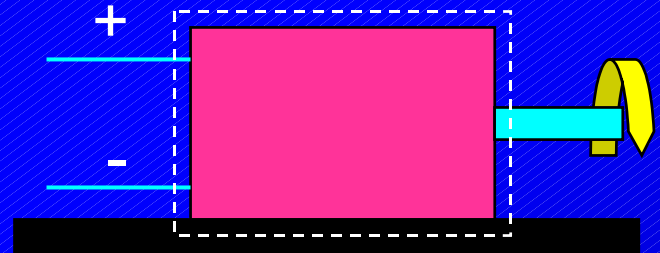
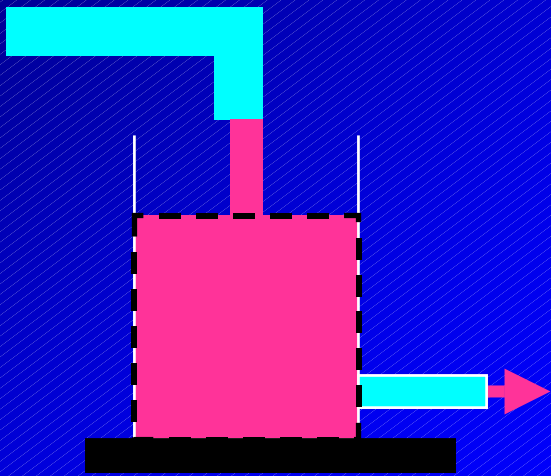
ES 201
*Conservation & Accounting
Principles*

Fall Quarter - 4 credits

Conservation & Accounting Principles

- Basic Systems, Accounting, and Modeling Concepts
- Laws
 - Conservation Laws: Mass, Charge, Energy, Linear & Angular Momentum
 - Accounting Principle: Entropy
- Simple open and closed systems





ES 202
Fluid & Thermal Systems

Winter Quarter - 3 credits

Shared 3-hr Laboratory

Fluid & Thermal Systems

- Thermodynamic Properties
 - Pure simple compressible substances
 - Gases: ideal gas & Z-Chart
 - Solids/Liquids: incompressible substance
- Applications to Open and Closed Systems
- Simple Cycles

Fluid & Thermal Systems

- Dimensional Analysis
- Mechanical Energy Equation
 - Bernoulli Equation
 - Pipe Flow of Incompressible Fluids
 - Pump/Turbine Efficiencies
- Lift and Drag
- Hydrostatics



Fluid & Thermal Systems

Laboratory Experiences

Lab 1 - Dimensional Analysis

Lab 2 - Torricelli's Principle, Friction Factors, Water-Wall Exhibit

Lab 3 - Back-pressure steam turbine

ES 203
Electrical Systems

Winter Quarter - 3 credits

Shared 3-hr Laboratory

Electrical Systems

- Circuit Elements
- Kirchhoff's Laws
- Equivalent circuits and Voltage and current dividers
- Operational amplifiers
- First, second, and higher order circuits
- Transient and steady-state behavior
- AC circuits and power



ES 204
Mechanical Systems

Winter Quarter - 3 credits

Shared 3-hr Laboratory

ES204 - Mechanical Systems

- More Kinematics
 - Normal-Tangential coordinates
 - Radial - Transverse coordinates
 - Dependent motion
 - Relative motion
 - Rigid bodies
- Impacts (coefficient of restitution)

Mechanical Systems (cont.)

- Use Working Model, Maple, Concept maps
- Three labs
- Immediate application to kinetics problems
- Combination problems



Assessment - Is it worse?

- Year 2 - Gave 17 identical multiple choice and 1 identical workout problem to ES204 and to dynamics students
 - 4 ES204 sections/3 professors
 - 5 Dynamics sections/3 professors
- Year 3 - Gave identical finals to ES204 and to dynamics students (20 multiple choice, 3 workout)
 - 4 ES204 sections/2 professors
 - 5 Dynamics/3 professors

Year 2 - Multiple Choice

Prob. #	First Assessment			Second Assessment		
	SEC - ES204	Dynamics	Difference	SEC - ES204	Dynamics	Difference
1	45.7	43.0	2.7	40.2	32.0	8.2
2	24.7	48.6	-23.9	56.3	61.0	-4.7
3	88.9	90.8	-2.0	94.3	94.0	0.3
4				87.4	81.0	6.4
5	80.2	45.8	34.5	71.3	56.0	15.3
6	72.8	66.9	5.9	82.8	79.0	3.8
7	91.4	62.7	28.7	82.8	76.0	6.8
8	59.3	47.2	12.1	57.5	55.0	2.5
9	87.7	85.2	2.4	87.4	94.0	-6.6
10	74.1	28.9	45.2	78.2	49.0	29.2
11	95.1	95.8	-0.7	90.8	93.0	-2.2
12	48.1	33.8	14.3	46.0	57.0	-11.0
13				96.6	98.0	-1.4
14	92.6	88.0	4.6	90.8	95.0	-4.2
15	90.1	80.3	9.8	66.7	63.0	3.7
16				62.1	54.0	8.1
17	61.7	52.1	9.6	50.6	79.0	-28.4
18	45.7	39.4	6.2	41.4	47.0	-5.6
19				9.2	47.0	-37.8
20	71.6	44.4	27.2	63.2	56.0	7.2

*Workout problems**

Year 2			
Prob. #	SEC - ES204	Dynamics	Difference
1	33.3	23.3	10

Year 3			
Prob. #	SEC - ES204	Dynamics	Difference
1	35.8	17	19.8
2	70.1	22	48.1
3	46	6	40

* Essentially an “A” solution

ES 205

*Analysis & Design
of Engineering Systems*

Spring Quarter - 5 credits

3-hr Laboratory

ES205 - Analysis & Design of Engineering Systems

- Pre-vibrations/controls
- Mechanical, Electrical , Electro-mechanical, Hydraulic, Fluid, Thermal systems
- Governing differential equations
- System Response
- System identification

Systems Concepts in ES205

- Modeling of system elements
- Equations of motion
 - Natural frequency, Damping ratio, Static gain
 - 2nd order matrix form, state space form
- Transfer functions
- Free response
 - log decrement

Systems Concepts in ES205

(cont.)

- Forced Response
 - Step input
 - performance specifications
 - Harmonic input
 - Frequency response plots
 - General periodic forcing
 - Fourier Series
- Simulink, Matlab and Maple

Analysis & Design of Engineering Systems

Laboratory

- Introduction to the design process.
- Teams of students study and develop *design specifications*** for products.
- Includes written and oral presentations.

** S. Pugh. *Total Design*, Addison Wesley, 1991.

K. T. Ulrich and S. D. Eppinger. *Product Design and Development*, McGraw-Hill, 1995.



Mathematics Sequence

- Differential Equations & Matrix Algebra I
- Differential Equations & Matrix Algebra II
- Statistics for Engineers

Sophomore Engineering Curriculum

Mathematics

- Stresses Linear Structures
 - systems of algebraic equations ($Ax=b$)
 - 1st & 2nd order differential equations
 - systems of differential equations
 - Laplace transforms
 - Fourier series
 - linearization
- Applications of Statistics
- Students have laptops with access to MAPLE, MATLAB, and MINITAB.



Differential Equations & Matrix Algebra I

- Basic Matrix Algebra
 - systems of linear equations (algebraic and geometrical viewpoints)
 - least squares
 - eigenvalues and eigenvectors
- Differential Equations
 - Review of first-order de's
 - Second-order linear de's with constant coefficients (homogeneous and non-homogeneous cases)
- Introduction to Complex Arithmetic



Differential Equations & Matrix Algebra II

- Laplace Transforms
- Systems of First-Order Linear DE's
 - solution using Laplace transforms
 - investigation of solution structure determined by eigensystems.
- Phase Portrait Analysis and Stability of Critical Points for Systems of Equations
- Approximation of Functions
 - Taylor and Fourier series



Statistics for Engineers

- Introductory course in statistical data analysis emphasizing
 - hypothesis testing
 - analysis of variance
 - quality control charts
 - simple and multiple regression
 - simple experimental designs
- Computer Tools: MINITAB and Excel



Experience with SEC at RH

- Reduced engineering credit hours from 20 to 18 without sacrificing material.
- Faculty like
 - common problem solving approach that does not reinforce “plug and chug.”
 - emphasis on modeling assumptions and mathematics that apply across disciplines.
 - ability to restructure material and “spiral” back, e.g. dynamics in two courses.

Experience with SEC at RH

- Students comment favorably on “integration” and “big picture” view of curriculum.
- Quantitative comparisons
 - SEC students did better than traditional students on final exam “workout” problems in dynamics, e.g. 20-40% more SEC students got problems right.

Student Comments after Completing the SEC

Student A

“ES201 was an excellent foundation to start on. A solid handle on this class is a must for success in the following classes. All classes were connected to this class.”

Student Comments

Student B

“The sophomore curriculum has won me over. At first, I thought it was a complete waste of time. Then during winter quarter I saw the importance of it. Now, I am glad to have gone through it. The book didn’t help much, it was vague and made the class more difficult.”

Student Comments

Student C

“I was very pessimistic about the course (ES205) at the beginning of the quarter. This course defeated every pessimistic premise I had before it was completed. This course brought all the engineering disciplines together and, at the very least, made this skeptical EE a believer in the SEC. Not only was the course an eye-opener, but it also enhanced my ability to solve general complex-system problems regardless of what discipline they came from?”

Student Comments

Student D

“Perhaps one of my other gripes with the class is that it is so different from freshman physics. I actually prefer this method of teaching when it comes to frictions, tensions, angular momentum, etc. These are all topics with which I felt uncomfortable during freshman physics although I understand them better now. In the future, I would appreciate seeing the ConApps and Physics curriculums more closely integrated so that students only have to learn concepts once.

Examples of how students are taught to solve problems

Heat Engine Performance



Monkeys on a Rope



Colliding Train Cars



Grain Conveyor Belt



Example - Carnot Cycle Revisited

What is the maximum thermal efficiency of a steady-state heat engine that receives energy by heat transfer at a surface temperature T_H and rejects energy by heat transfer at a surface temperature T_L ?

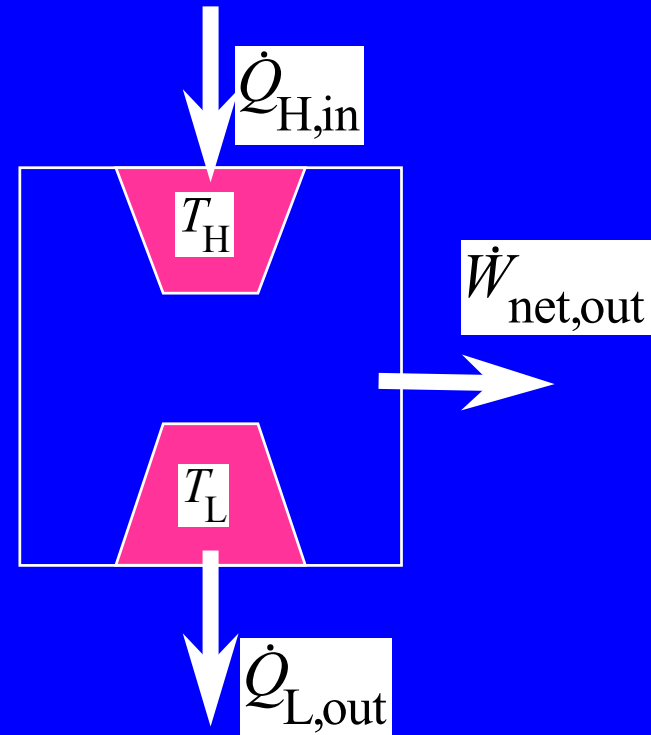
Analysis

What's the system?

What properties should we count?

What is the time interval?

What are the important interactions?



$$\frac{dE_{sys}}{dt} = \overset{0,SS}{\cancel{0}} \dot{Q}_{net,in} + \dot{W}_{net,in}$$

$$0 = \left[\dot{Q}_{H,in} - \dot{Q}_{L,out} \right] - \dot{W}_{net,out}$$

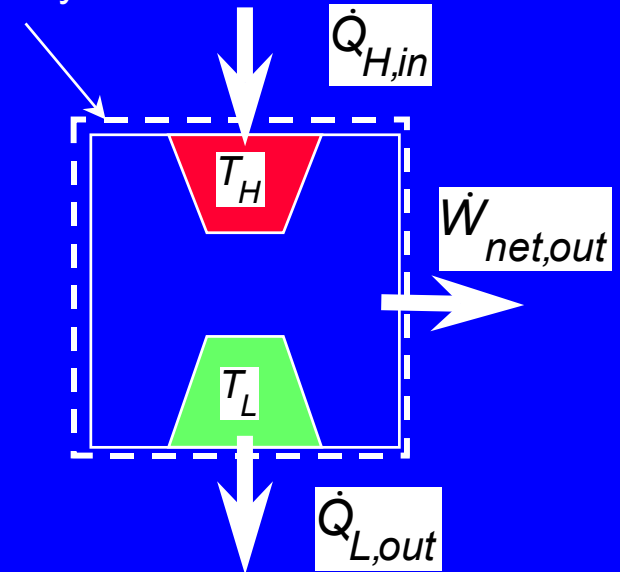
$$\dot{W}_{net,out} = \dot{Q}_{H,in} - \dot{Q}_{L,out}$$

$$\frac{dS_{sys}}{dt} = \overset{0,SS}{\cancel{0}} \sum_j \frac{\dot{Q}_j}{T_j} + \dot{S}_{gen}$$

$$0 = \left[\frac{\dot{Q}_{H,in}}{T_H} - \frac{\dot{Q}_{L,out}}{T_L} \right] + \dot{S}_{gen}$$

$$\dot{Q}_{L,out} = \dot{Q}_{H,in} \left(\frac{T_L}{T_H} \right) + T_L \dot{S}_{gen}$$

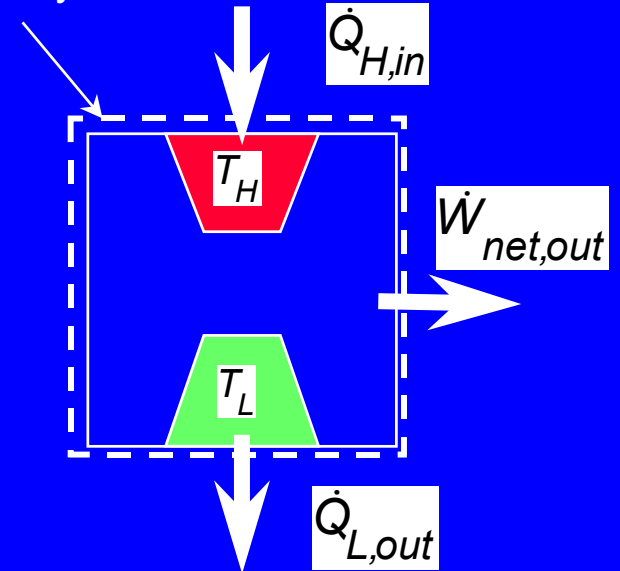
Closed System



$$\dot{W}_{net,out} = \dot{Q}_{H,in} - \left[\dot{Q}_{H,in} \frac{T_L}{T_H} + T_L \dot{S}_{gen} \right]$$

$$\eta = \frac{\dot{W}_{net,out}}{\dot{Q}_{H,in}} = \left[1 - \frac{T_L}{T_H} \right] - \frac{T_L \dot{S}_{gen}}{\dot{Q}_{H,in}}$$

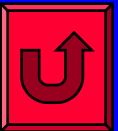
Closed System



$$\eta = \frac{\dot{W}_{net,out}}{\dot{Q}_{H,in}} = \left[1 - \frac{T_L}{T_H} \right] - \frac{T_L \dot{S}_{gen}}{\dot{Q}_{H,in}}$$

$$\eta_{max} = \left[1 - \frac{T_L}{T_H} \right]$$

$$\frac{T_L \dot{S}_{gen}}{\dot{Q}_{H,in}} \geq 0$$



Example - Monkeys on a Rope

Three monkeys *A*, *B*, and *C* with masses of 10, 12, and 8 kg, respectively, are climbing up and down the rope suspended from point *D*. At the instant shown in the figure, *A* is descending the rope with an acceleration of 1.6 m/s^2 , and *C* is pulling himself up with an acceleration of 0.9 m/s^2 . Monkey *B* is climbing up with a constant speed of 0.6 m/s .

Determine the tension T in the rope at *D*, in newtons.

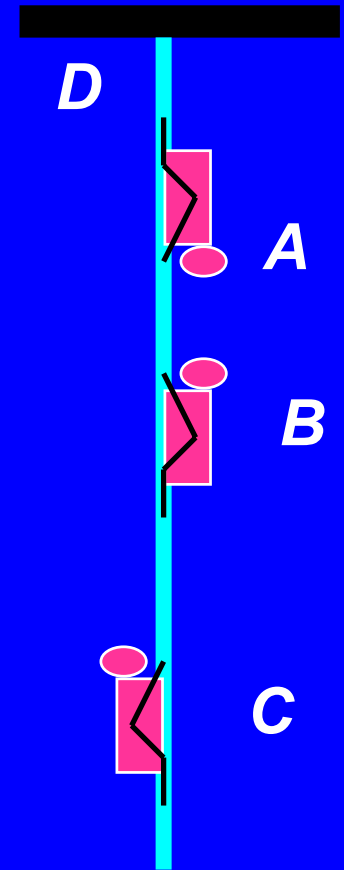
Analysis

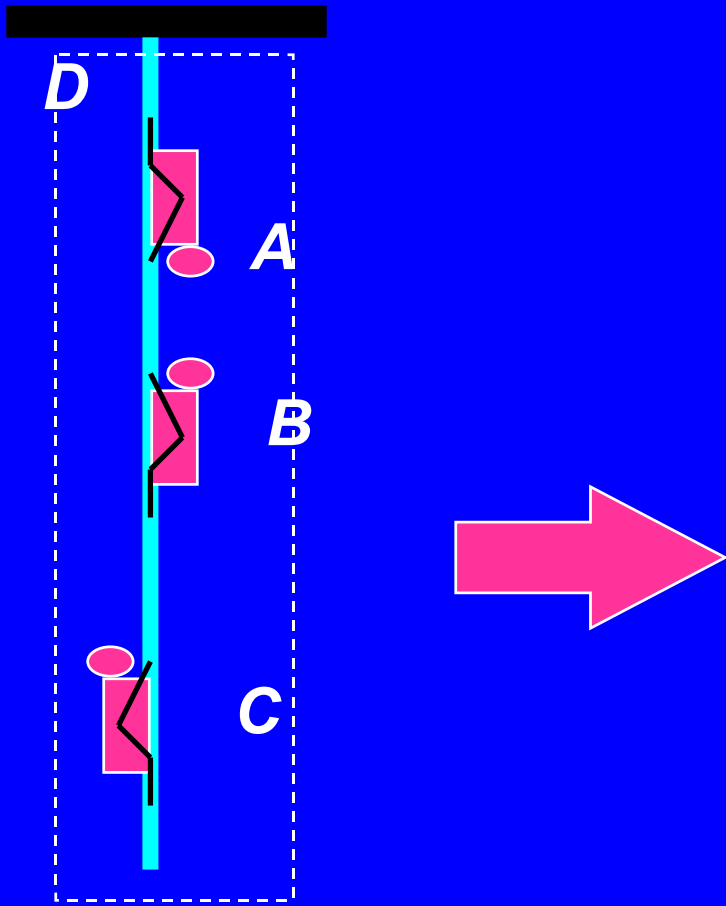
What's the system?

What properties should we count?

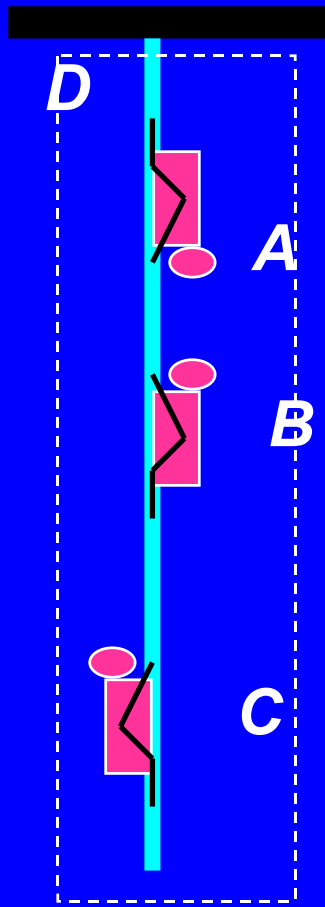
What is the time interval?

What are the important interactions?

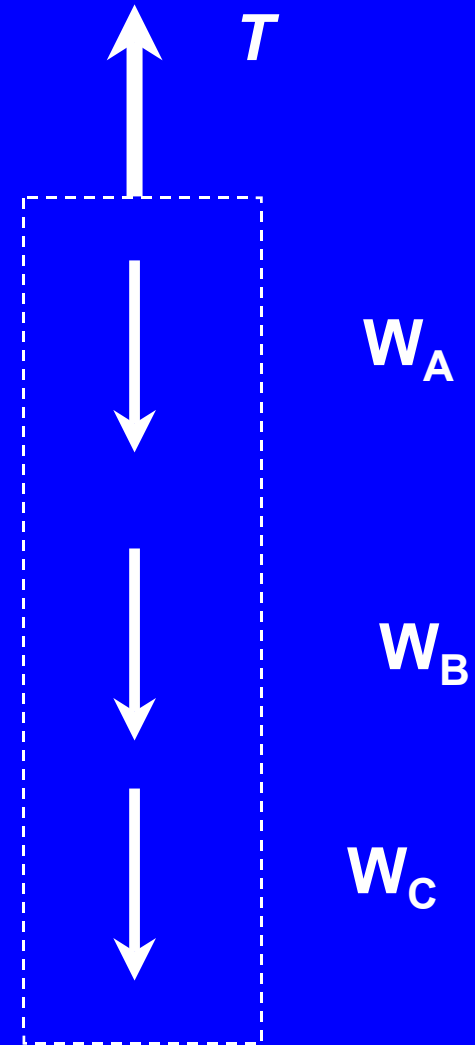
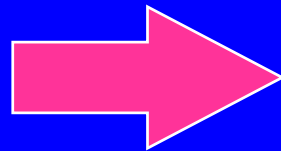




Physical System



Physical System



Free-body Diagram

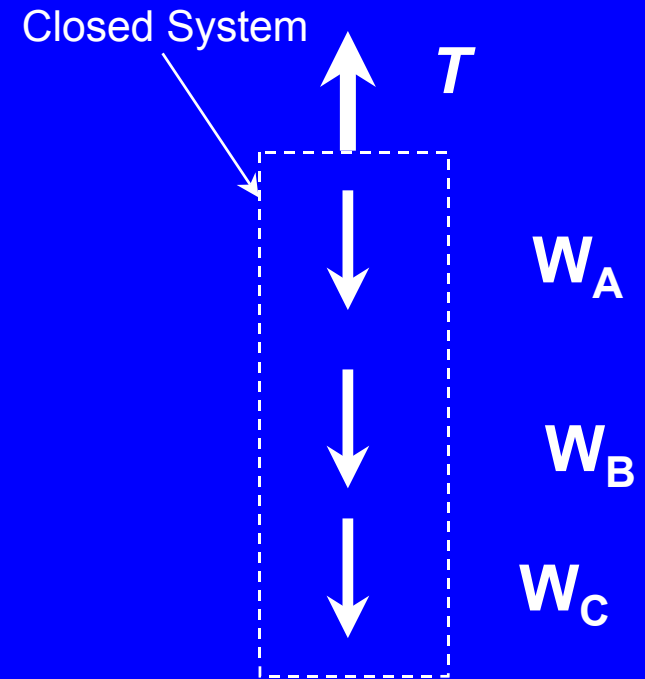
$$\frac{d\vec{P}_{\text{sys}}}{dt} = \sum_j \vec{F}_{\text{ext},j}$$

$$\sum_j \vec{F}_{\text{ext},j} = \vec{W}_A + \vec{W}_B + \vec{W}_C + \vec{T}$$

$$\vec{P}_{\text{sys}} = m_A \vec{V}_A + m_B \vec{V}_B + m_C \vec{V}_C$$

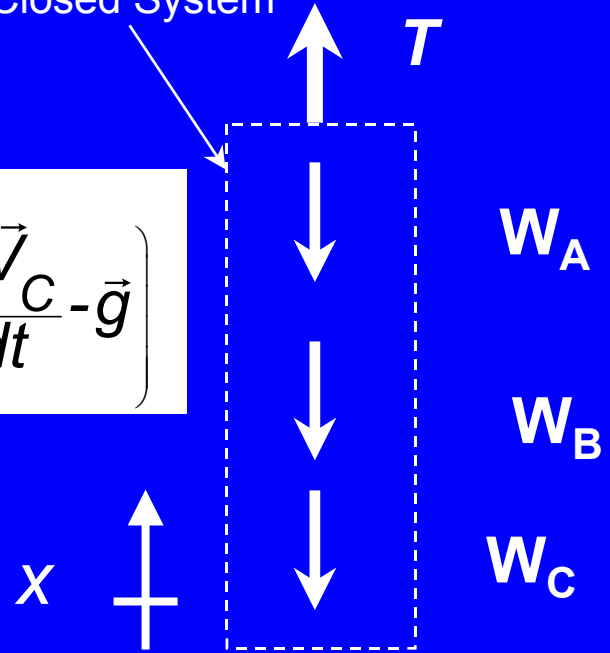
$$\frac{d}{dt} (m_A \vec{V}_A + m_B \vec{V}_B + m_C \vec{V}_C) = \vec{W}_A + \vec{W}_B + \vec{W}_C + \vec{T}$$

$$m_A \left(\frac{d\vec{V}_A}{dt} \right) + m_B \left(\frac{d\vec{V}_B}{dt} \right) + m_C \left(\frac{d\vec{V}_C}{dt} \right) = m_A \vec{g} + m_B \vec{g} + m_C \vec{g} + \vec{T}$$



$$\vec{T} = m_A \left(\frac{d\vec{V}_A}{dt} - \vec{g} \right) + m_B \left(\frac{d\vec{V}_B}{dt} - \vec{g} \right) + m_C \left(\frac{d\vec{V}_C}{dt} - \vec{g} \right)$$

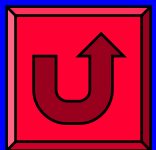
Closed System



$$T = (10 \text{ kg})[-1.6 + 9.81] \left(\frac{\text{m}}{\text{s}^2} \right) + (12 \text{ kg})[0 + 9.81] \left(\frac{\text{m}}{\text{s}^2} \right) + (8 \text{ kg})[0.9 + 9.81] \left(\frac{\text{m}}{\text{s}^2} \right)$$

$$= 82.1 \text{ N} + 117.7 \text{ N} + 85.6 \text{ N}$$

$$T = 285.4 \text{ N}$$

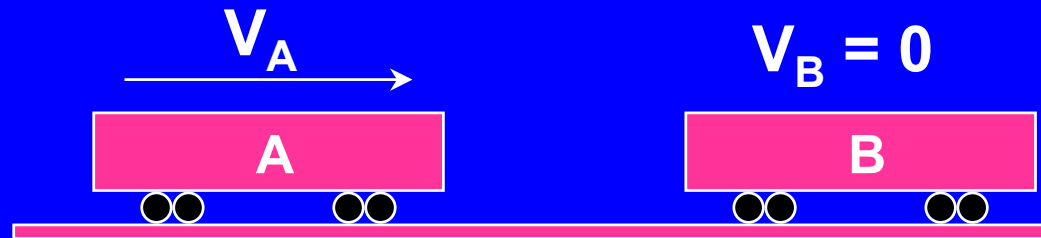


Examples - Rail Cars on the Move

A 45-Mg railroad car moving with a velocity of 3 km/h is to be coupled to a 25-Mg car which is at rest.

Determine

- (a) the final velocity of the coupled cars
- (b) the average impulsive force acting on each car if the coupling is completed in 0.3 s.



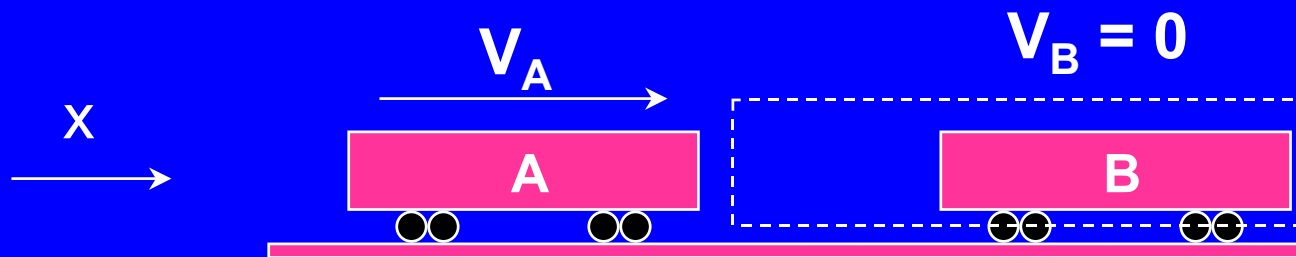
Part (a) - Final velocity after coupling

System: Assume an **open, moving system**.

Initially it contains car *B* only and finally it contains both cars.

Property:

$$\frac{d\vec{P}_{sys}}{dt} = \sum_j \vec{F}_{ext,j} + \sum_{in} \dot{m}_i \vec{V}_i - \sum_{out} \dot{m}_e \vec{V}_e$$



Conservation of Linear Momentum (x-direction)

Integrate over time interval t_1 to t_2 .

- 1 - Initial state
- 2 - Final state

$$V_{B,1} = 0$$

$$\frac{dP_{sys,x}}{dt} = \dot{m}_i V_{x,i}$$

$$\int_{t_1}^{t_2} \left(\frac{dP_{sys,x}}{dt} \right) dt = \int_{t_1}^{t_2} \left(\dot{m}_i V_{x,i} \right) dt$$

$$P_{sys,x,2} - P_{sys,x,1} = m_A V_{A,1}$$

$$(m_A + m_B) V_{AB,2} - \cancel{m_B V_{B,1}}^0 = m_A V_{A,1}$$

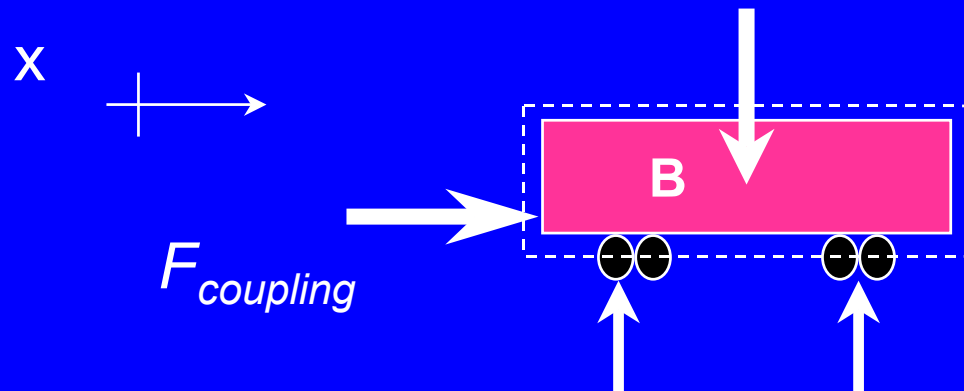
$$V_{AB,2} = \frac{m_A V_{A,1}}{m_A + m_B}$$

Part (b) Coupling Force

System: Assume a **closed system** that only contains car *B* throughout the process. This system moves with car *B*.

Property:

$$\frac{d\vec{P}_{sys}}{dt} = \sum_j \vec{F}_{ext,j} + \sum_{in} \dot{m}_i \vec{V}_i - \sum_{out} \dot{m}_e \vec{V}_e$$



Conservation of Linear Momentum (x-direction)

Integrate over time interval t_1 to t_2 .

- 1 - Initial state
- 2 - Final state

$$V_{B,1} = 0$$

$$V_{B,2} = V_{AB,2}$$

from part (a)

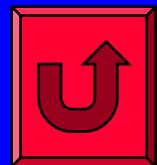
$$\frac{dP_{sys,x}}{dt} = F_x$$

$$\int_{t_1}^{t_2} \left(\frac{dP_{sys,x}}{dt} \right) dt = \int_{t_1}^{t_2} F_x dt$$

$$P_{sys,x,2} - P_{sys,x,1} = F_{x,avg} \Delta t$$

$$m_B V_{B,2} - m_B V_{B,1} = F_{x,avg} \Delta t$$

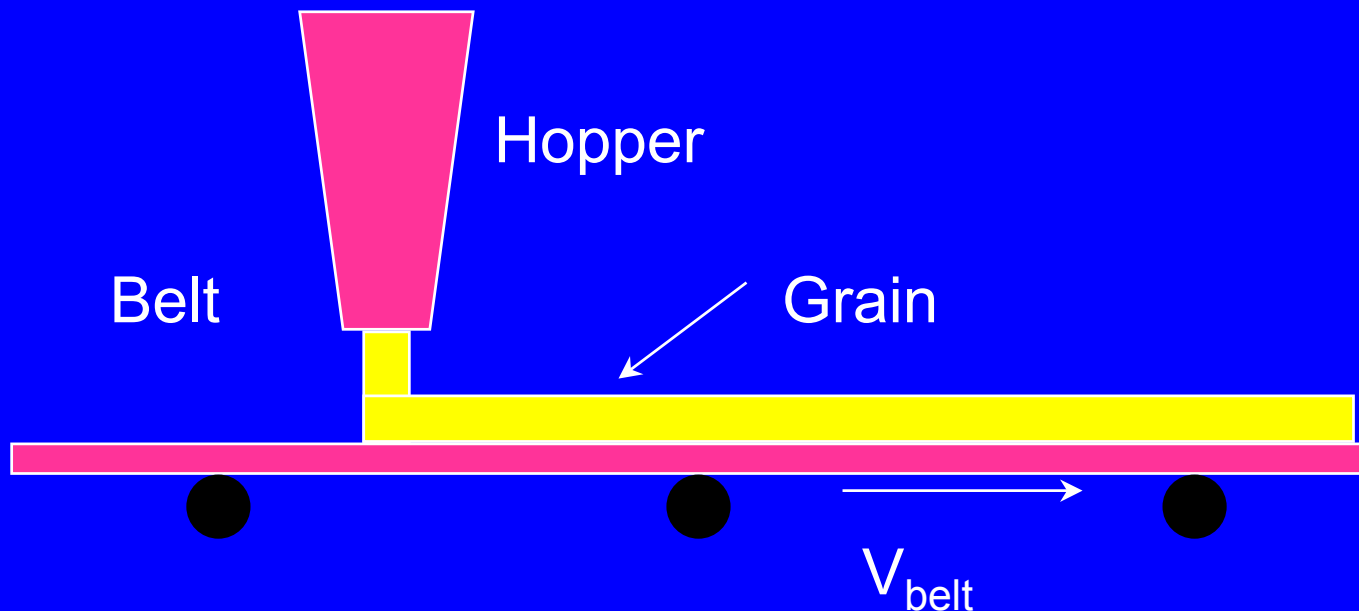
$$F_{x,avg} = \frac{m_B V_{B,2}}{\Delta t}$$

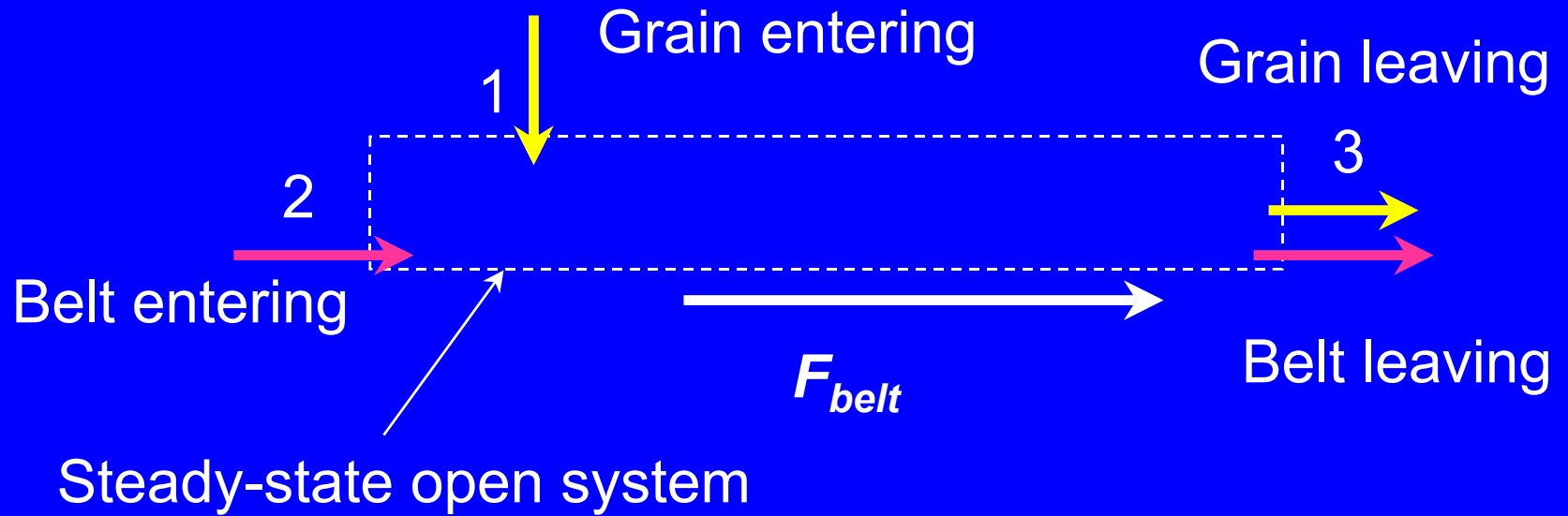
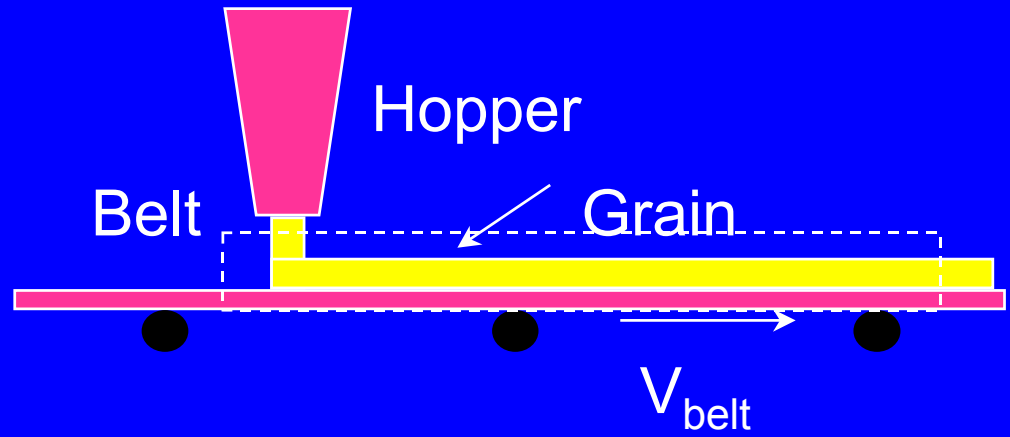


Example - Conveyor Belt

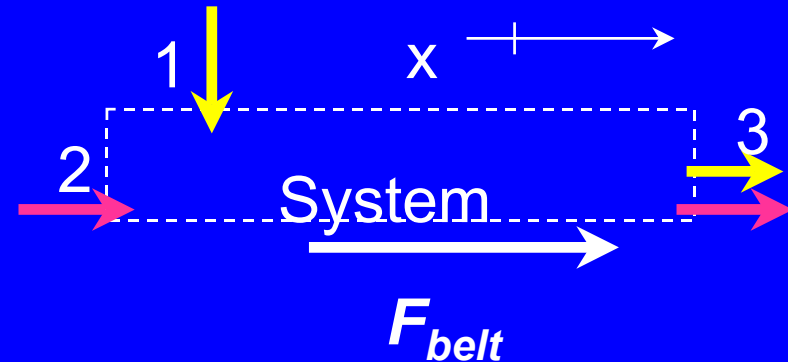
Grain falls from a hopper onto a conveyor belt at the rate of 200 kg/min. The conveyor belt carries the grain away at a constant velocity of 2 m/s.

Determine the force on the belt required to keep the belt moving at a constant speed.





Conservation of mass for this system.



$$\frac{dm_{sys}}{dt} = \dot{m}_{grain,1} + \dot{m}_{belt,2} - \dot{m}_{belt,3} - \dot{m}_{grain,3}$$

$$m_{sys} = m_{belt,sys} + m_{grain,sys}$$

0, SS

$$\frac{dm_{belt,sys}}{dt} = \dot{m}_{belt,2} - \dot{m}_{belt,3}$$

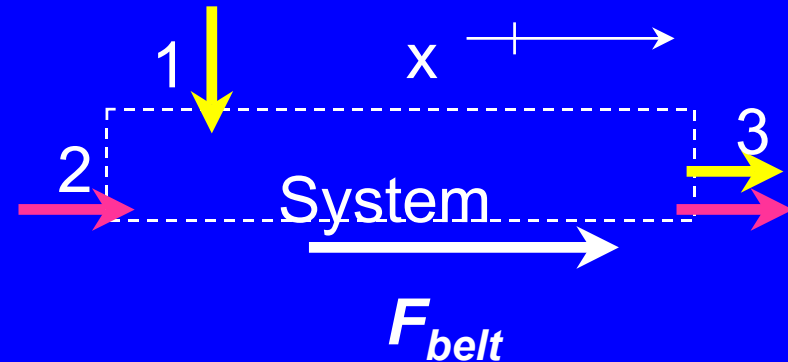
0, SS

$$\frac{dm_{grain,sys}}{dt} = \dot{m}_{grain,1} - \dot{m}_{grain,3}$$

$$\dot{m}_{belt,2} = \dot{m}_{belt,3}$$

$$\dot{m}_{grain,1} = \dot{m}_{grain,3}$$

Conservation of Linear Momentum for this system. (X-direction)



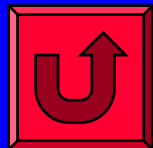
0, SS

$$\frac{dP_{x,sys}}{dt} = \sum_j F_{x,ext,j} + \sum_{in} \dot{m}_i V_{x,i} - \sum_{out} \dot{m}_e V_{x,e}$$

$$0 = F_{belt} + \dot{m}_{grain,1} V_{x,grain,1} + \dot{m}_{belt,2} V_{x,belt,2} - \dot{m}_{belt,3} V_{x,belt,3} - \dot{m}_{grain,3} V_{x,grain,3}$$

$$0 = F_{belt} + \dot{m}_{grain} \left(\cancel{V_{x,grain,1}}^0 - V_{x,grain,3} \right) + \dot{m}_{belt} \left(\cancel{V_{x,belt,2}}^0 - V_{x,belt,3} \right)$$

$$F_{belt} = \dot{m}_{grain} V_{x,grain,3} = \dot{m}_{grain} V_{belt}$$



End of Examples

Thank You !

For further information about Sophomore
Engineering Curricula -----

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Check the Foundation Coalition Web Site --

<http://www.foundationcoalition.org>