



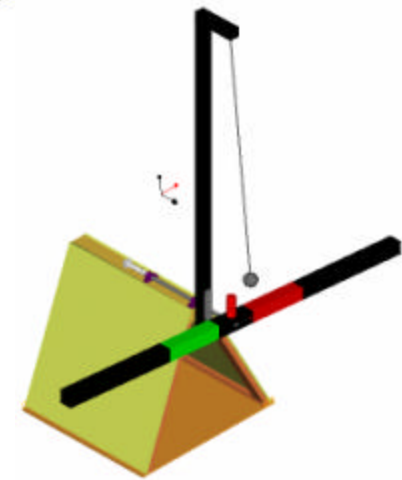
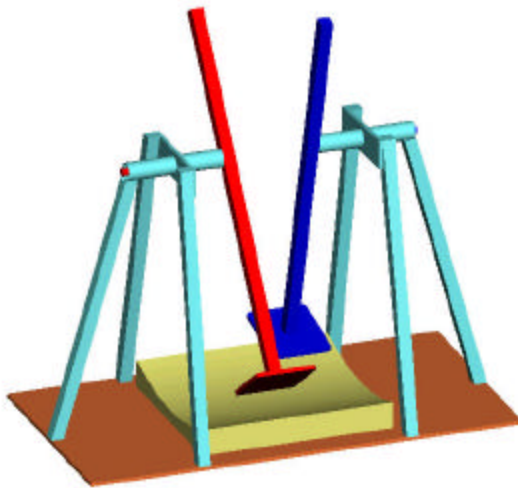
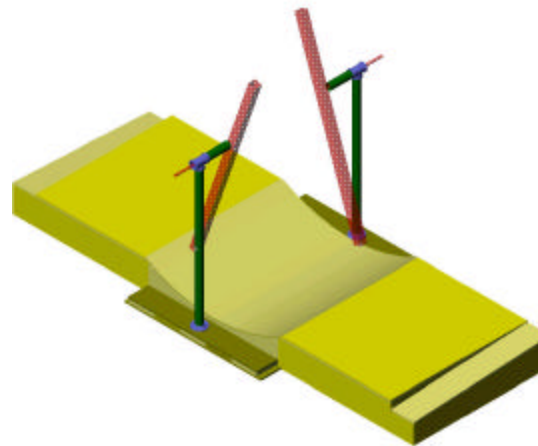
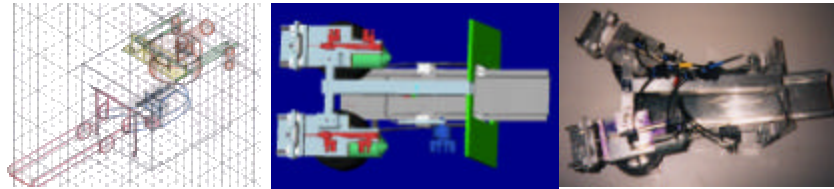
Topic 1

Design is a *?Passionate?* Process



Topics:

- *Passion*
- Deterministic design
- Systematic Organization of Ideas
- Design Process
- Milestones

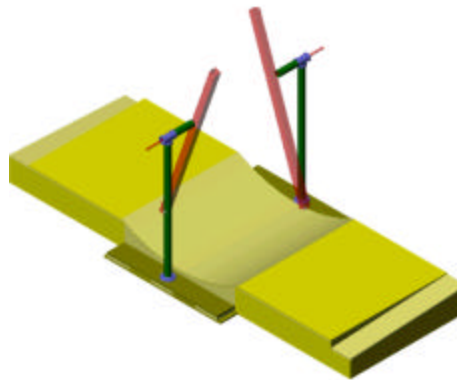


Design Contest: *The MIT and the Pendulum!*

- “Rules”:
 - Only use materials in the kit and plus fasteners and adhesives
 - Machine must fit into starting zone (0.5 m cube) at the base of each pendulum
 - You can start with your machine engaged (wheels preloaded) to a pendulum
 - “Score” is evaluated at the end of 45 second contest:

$$Score = \left(q_{Total_ \#_ pendulum_ revolutions} + 1 \right) \left(m_{total_ mass_ in_ grams} + 500 \right)$$

- You may not damage the table or willfully damage your opponent
 - No nets or entanglement devices
- What would *you* do?
 - How would you go about designing and building a machine to participate?
 - How would you balance your effort with all the other obligations you have?



1-2



? Passion? LOVE to Create

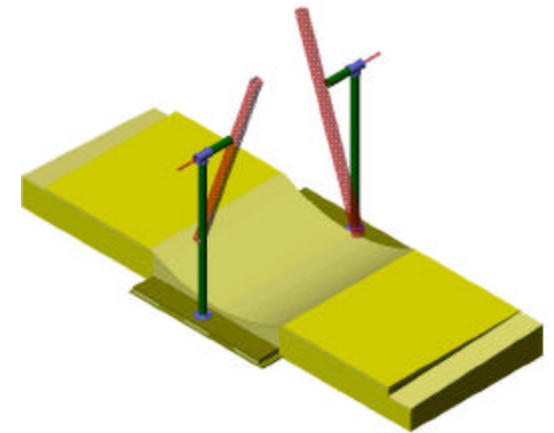
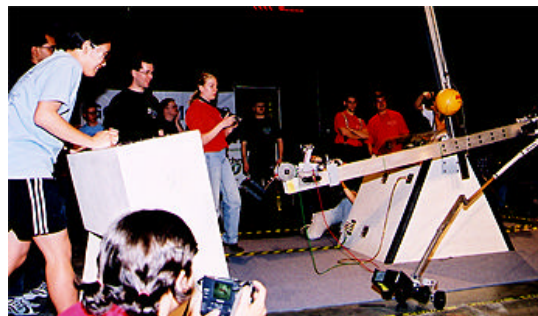
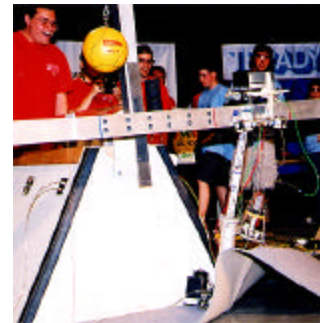
"Enthusiasm is one of the most powerful engines of success. When you do a thing, do it with all your might. Put your whole soul into it. Stamp it with your own personality. Be active, be energetic, be enthusiastic and faithful and you will accomplish your object. Nothing great was ever achieved without enthusiasm"

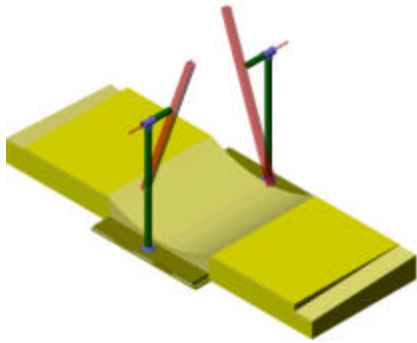
Ralph Waldo Emerson

- Use ? Passion? as a catalyst to make ideas become reality:
 - Never stop asking:
 - “Is this really the best I can do”
 - “Can the design be made simpler”
 - Create, never stagnate
 - Do you see machines in ink blots?



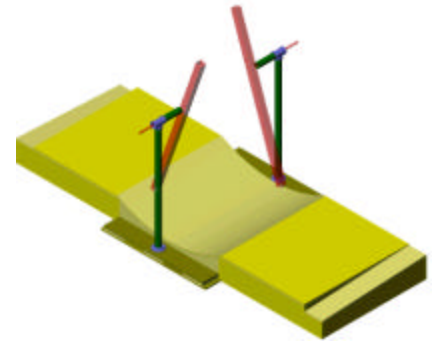
Ink-Blot milling machine by Peter How





? Passion? FOCUS!

Keep Your Eye on the Prize



***“You can’t always get what you want
But if you try sometimes well you might find
You get what you need”***

Mick Jagger & Keith Richards 1969

<http://lyrics.all-lyrics.net/r/rollingstones/letitbleed.txt>

Get a clear notion of what you desire to accomplish, then you will probably get it

Keep a sharp look-out upon your materials: get rid of every pound of material you can do without. Put yourself to the question, ‘What business has it there?’

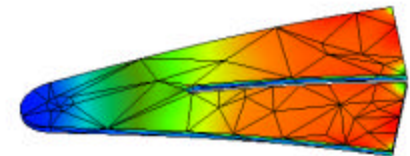
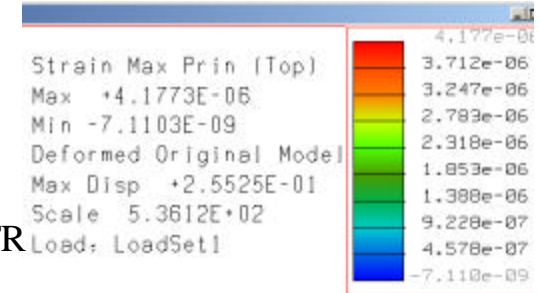
Avoid complexities and make everything as simple as possible

Remember the get-ability of parts

Henry Maudslay (1700’s, the father of modern machine tools)

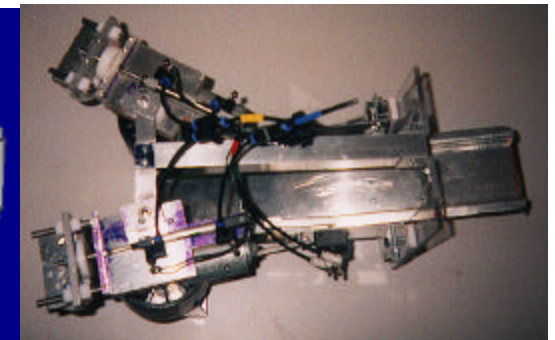
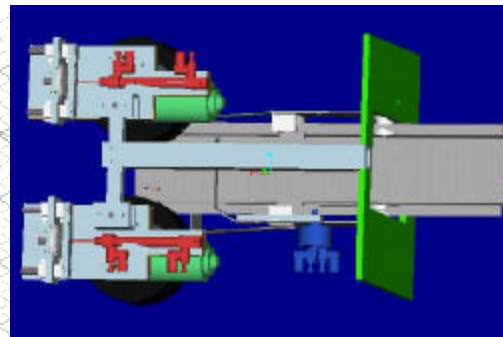
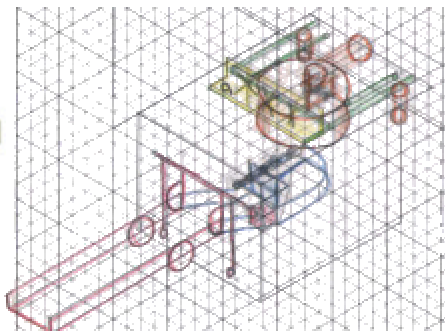
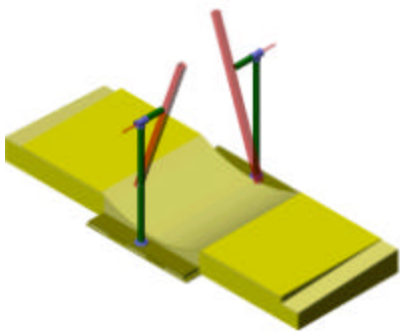
?Passion? *Best Engineering Practice*

- Before we can talk about a process for design, we must consider the things the best designers do as they solve problems
 - *Best Engineering Practice* entails careful forethought and following standards
 - **62.5 grams of prevention is worth a kilogram of cure!**
 - **“Random Results are the Result of Random Procedures”** *Geffe Portes*
 - Prevent problems before they occur:
 - Does not meet customer needs
 - Prevention:
 - » Identify the *Functional Requirements* (FR)
 - » Develop a *Design Parameter* that accomplishes each FR
 - Failure
 - Prevention: Design to withstand external and internal loads
 - Poor performance
 - Prevention: Design to be robust to tolerances and errors
 - Cost too much
 - Prevention: Create clever, frugal, manufacturable designs
- *Deterministic Design* is a key element of *Best Engineering Practice*
 - It is a means to systematically solve even the most complex problems in a rational, logical manner, while still allowing you to have wild crazy creative zoombah illimational thoughts!

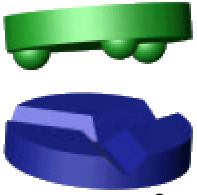


?Passion? *Play, Sketch, Model, Detail, Build & Test*

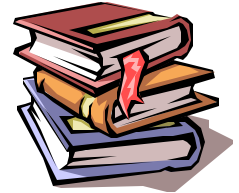
- Engineering is often a tactile, visual, verbal, cerebral, and physical activity:
 - Play with the table and the kit parts
 - Sketch ideas
 - Create physical and analytical models to identify opportunities and test possible strategies
 - Detail the machine using all the engineering skills and tools at your disposal
 - Build & test your machine!
- Students who follow *best engineering practice* create very impressive machines with just the correct amount of effort (and have time for a life!)



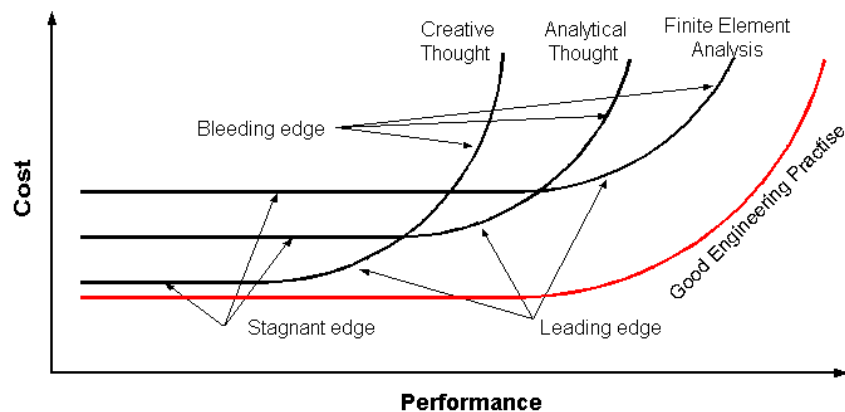
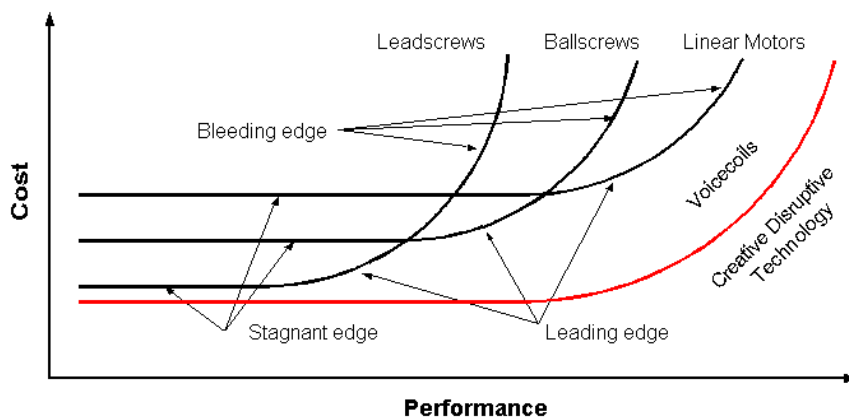
Alex Sprunt's machine was almost exactly like the solid model, and it worked "out of the box"!

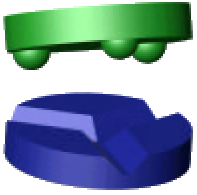


Deterministic Design



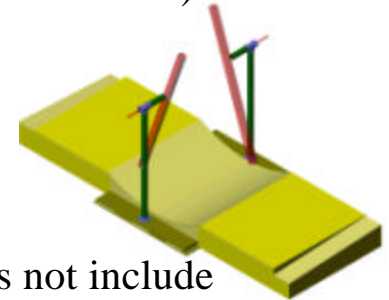
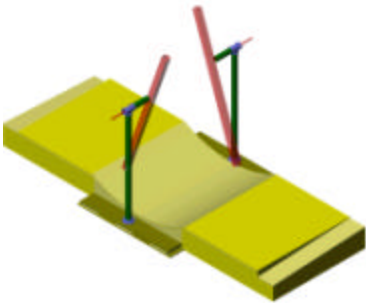
- Everything has a cost, and everything performs (to at least some degree)
 - If you spend all your time on a single tree, you will have no time for the forest
 - If you do not pay attention to the trees, soon you will have no forest!
 - You have to pay attention to the overall system and to the details
- Successful projects keep a close watch on budgets (time, money, performance)
 - Do not spend a lot of effort (money) to get a small increase in performance
 - “Bleeding edge” designs can drain you!
 - Do not be shy about taking all the performance you can get for the same cost!
- Stay nimble (modular!) and be ready to switch technology streams
 - It is at the intersection of the streams that things often get exciting!

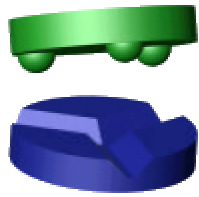




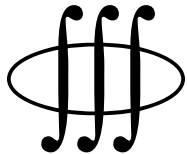
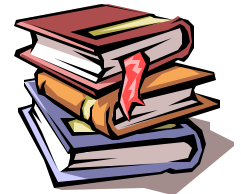
Deterministic Design: *Reverse Engineering*

- How would you create a contest where the overall goals are:
 - The inertia of the machines is on the order of the inertia of the system
 - The system is SIMPLE to build and solid model (for the staff and the students!)
 - The contest can have MANY different possible winning strategies
 - Engineering analysis can tip the scales in a student's favor!
- The answer is to:
 - Envision potential *strategies*
 - A *strategy* is an approach to solving a problem, but it does not include mechanism detail
 - Consider the feasibility of *strategies* in terms of physics, resources required, and resources available (available materials, equipment, time...)
 - Select one or two *strategies* for further development which define the detailed mechanism....
 - *Concepts, Modules, Components*
 - Follow a process whose pattern of development repeats at each level of detail
- What better way to design a robot for a contest than to understand and use the process used to design the contest?!
 - Try to *reverse engineer* the contest, including building and taking apart a model (CAD solid model or a physical model) of the table and recreating the analysis that likely went into its design





Deterministic Design: *Disruptive Technologies*



Hyoseok Yang

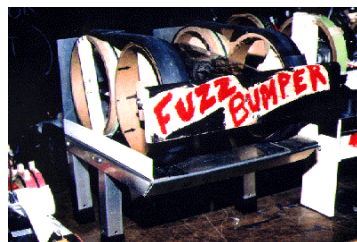
- Analysis is the lens which brings a problem into focus and lets you clearly see the best return on your investment
 - Value analysis of scoring methods
 - Physics of scoring methods
 - Risk analysis
 - Schedule analysis

1995's *Pebble Beach!*

Sami Busch

1996's *Niagara Balls!*

Tim Zue



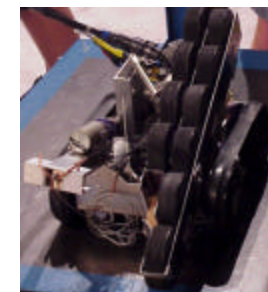
1997's *Pass The Puck!*

Colin Bulthap



1998's *Ballcano!*

David Arguellis



1999's *MechEverest!*

Will Delhagen & Alex Jacobs

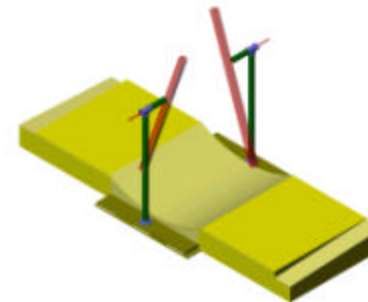


2001's *Tiltulator!*

Kevin Lang

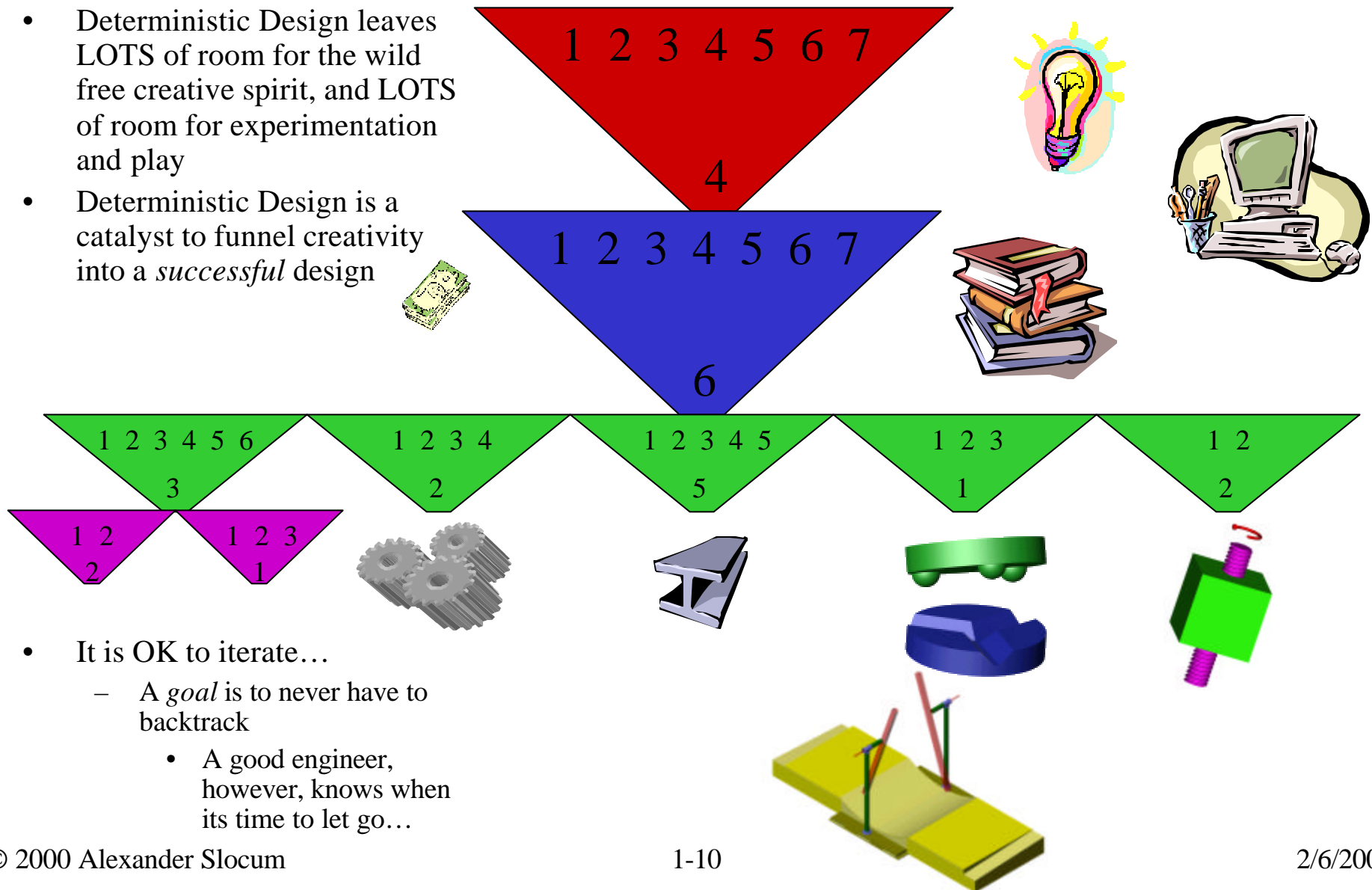


2000's *Sojourner This!*

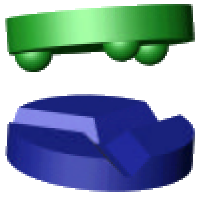


Deterministic Design: *Funnels: Strategies* Concepts Modules Components

- Deterministic Design leaves LOTS of room for the wild free creative spirit, and LOTS of room for experimentation and play
- Deterministic Design is a catalyst to funnel creativity into a *successful* design

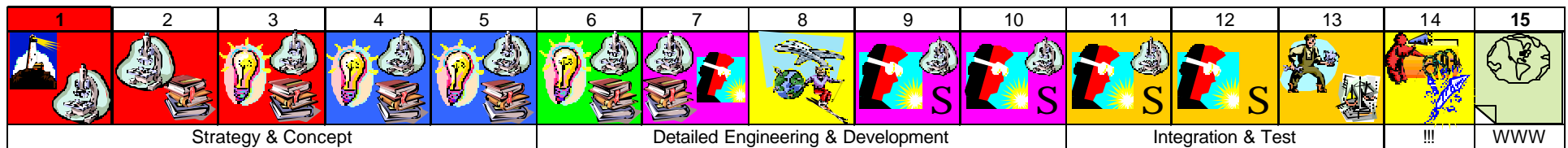
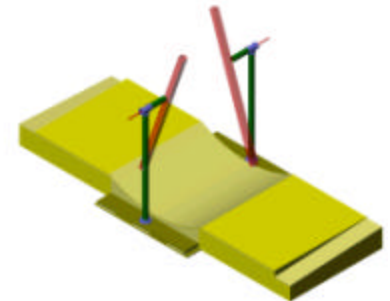


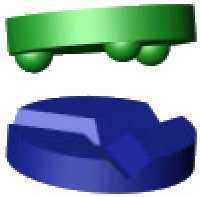
- It is OK to iterate...
 - A *goal* is to never have to backtrack
 - A good engineer, however, knows when its time to let go...



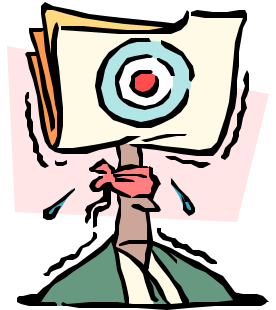
Deterministic Design: *Schedules*

- Time is relative, but you will soon run out of it if you keep missing deadlines!
 - No matter how good your ideas are, their value decays exponentially with every day they are late
 - Once a customer starts buying a product, if the manufacturer maintains diligence, you will find it extremely difficult to regain market share
- The process of getting a product to market involves phases
 - Identify & study problem, develop solution strategies and evolve “best one”
 - Create concepts and evolve “best one”
 - Create modules
 - Detail design, build, & test the modules starting with the most risky
 - Assembly integration, test, and modify as needed
 - Document and ship
- You must create a schedule and stick to it!
 - This is true in ALL pursuits
 - Yes, sometimes the schedule will slip...this is why you have countermeasures for risky items that fail, and you build in capacitances (float time) to allow for troubles...

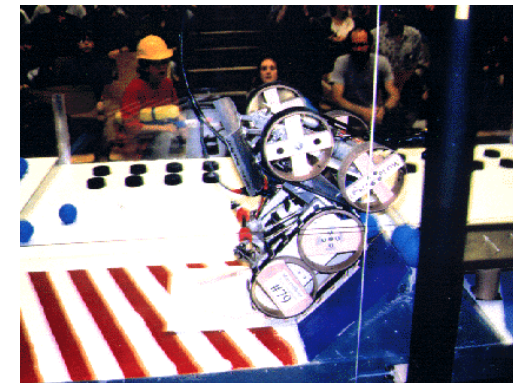
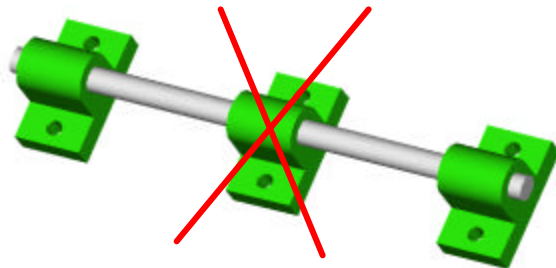




Deterministic Design: *Risk Management*

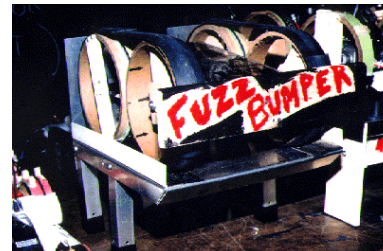
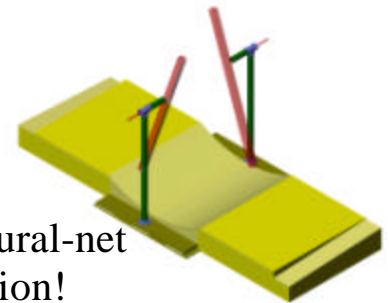
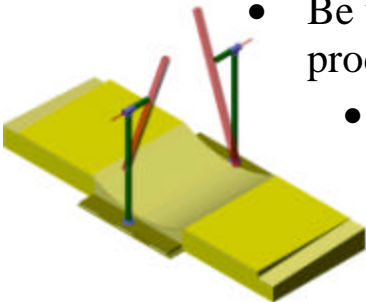


- The key to deterministic design is risk management
- For every idea, risk must be assessed
 - Ask yourself which ideas and analysis (physics) are you most unsure of?
 - Which element, if defined or designed wrong, will neutralize the machine?
 - For every risk identified
 - Estimate the probability of occurrence (High, Medium, Low)
 - Identify a possible countermeasure
 - Prioritize your risk and continue to do analytical, computational, or physical *Bench Level Experiments* (BLEs) to test ideas before you move forward!
 - *Good Engineering Practice* continually applies!
 - Prayer is for your personal life!
 - Determinism is for design!



Deterministic Design: *Analytical Instinct*

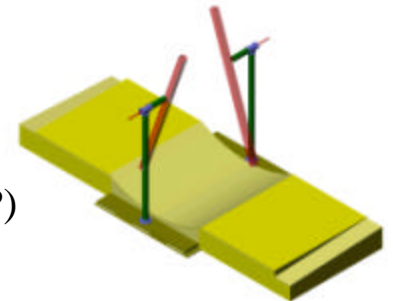
- **TRUST** your analytical & deterministic training
 - Seek to create and then defeat ideas by exploring ALL possible alternatives
 - In a Mr. Spock™ - Commander Data™-like manner, logically seek to establish the need, understand the problem, create many concepts, subjectively evaluate ideas, analyze the bajeebees out of the idea.
 - This is the careful execution of the *Design Process*
 - This is what the best designers do to turn dreams into realities
- **& LISTEN** to your instincts
 - Be wild, random, and impulsive, and take great ideas that your bio-neural-net produces and keep evolving and hammering it until it yields an invention!
 - Sketch the first thoughts that come to mind when you encounter a problem!
 - This is the Captain Kirk™, shoot from the hip, John Wayne approach.
 - This is the element of passion that is the essence of great design!
 - This is what drove Mozart, Edison, Einstein, Elvis....the great creators!
- Combine *analysis & instinct* to become a successful *passionate* design engineer!
 - Learn from experience how much of each to use!
 - Tim Zue's tracked vehicle won, because he used sandpaper to increase the friction on his starting platform!



Systematic Organization of Ideas

<i>Functional Requirements (Events)</i> <i>Words</i>	<i>Design Parameters (Idea)</i> <i>Words & Drawings</i>	<i>Analysis</i> <i>Experiments, Words, FEA, Equations, Spreadsheets...</i>	<i>References</i> <i>Historical documents, www...</i>	<i>Risk</i> <i>Words, Drawings, Analysis...</i>	<i>Counter-measures</i> <i>Words, Drawings, Analysis...</i>
A list of independent functions that the design is to accomplish. Series (1,2,3...) and Parallel (4a, 4b..) FRs (Events) can be listed to create the <i>Function Structure</i>	Ideally independent means to accomplish each FR. AN FR CAN HAVE SEVERAL POTENTIAL DPs. The “best one” ultimately must be selected	Economic (financial or maximizing score etc), time & motion, power, stress... EACH DP's FEASIBILITY MUST BE PROVEN. Analysis can be used to create DPs!	Anything that can help develop the idea including personal contacts, articles, patents, web sites....	High, Medium, Low (explain why) risk of development assessment for each DP	Ideas or plan to mitigate each risk, including use of off-the-shelf known solutions

- To actually use the FRDPARRC Table:
 - Create one actual table that becomes your development roadmap
 - Dedicate one sheet to each FR/DP pair
 - This can become your Milestone Report (“Press Release”) for an idea (DP)



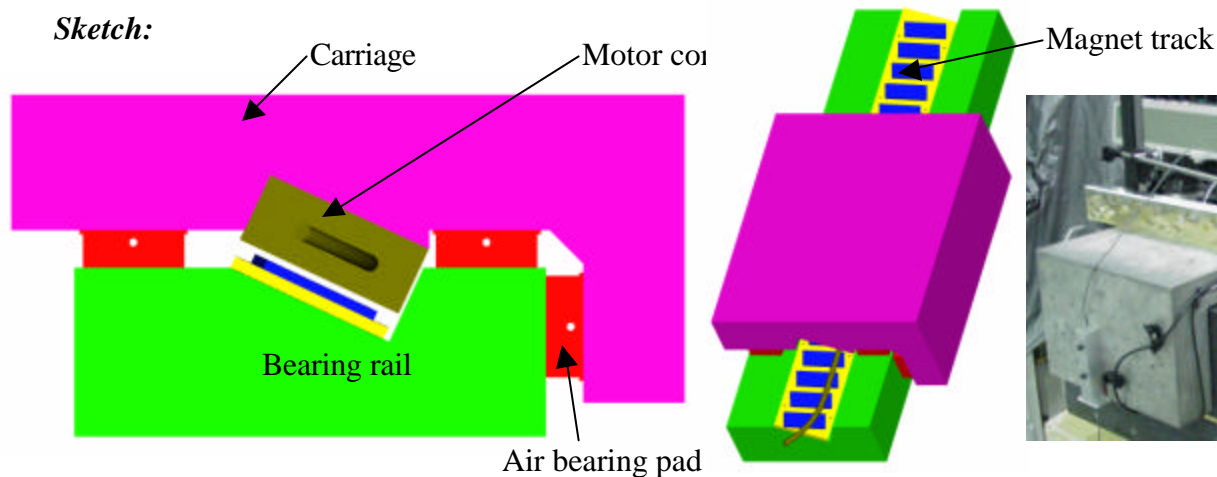
FRDPARRC Example: A Precision Linear Motion System

FRDPARRC Sheet Topic: Precision Low Cost Linear Motion Stage

Functional Requirement (Event) Preload air bearings

Design Parameter (description of idea) Preload air bearings using magnetic attractive force of motor, so air bearings need only ride on two surfaces instead of having to wrap around a beam; thus many precision tolerances to establish bearing gap can be eliminated

Sketch:



Assume we want even preload pressure per pad	
Motor preload angle	26.57
Motor attraction force, F _m	4000
Motor width (mm), L	130
Motor thickness	47
Space for motor thickness	65
Supply pressure, P _s (Pa, atm)	600000
bearing efficiency, m	0.35
preload proportion of total load capacity, f	0.5
vertical/horizontal load capacity, v _h	2
X direction pads' total area (mm ²), A _x	21994
Y direction pads total area, (mm ²) A _y	43989

Analysis (physics in words) The magnet attraction force is 5x greater than the motor force, so it can be positioned at an angle such that even preload is applied to all the bearings. As long as the magnet attraction net vertical and horizontal force are proportional to the bearing areas and is applied through the effective centers of the bearings, they will be evenly loaded without any applied moments.

Analysis

$$F_v = F_{\text{magnets}} \sin q \quad \frac{F_v}{F_H} = \frac{A_v}{A_H} = \tan q$$

$$F_H = F_{\text{magnets}} \cos q \quad q = \arctan\left(\frac{A_v}{A_H}\right)$$

References: Vee & Flat bearings used on many common machine tools where gravity provides preload. NEAT uses two magnet tracks, one horizontal and one vertical, to provide horizontal and vertical preload force. Patent search revealed no other relevant art.

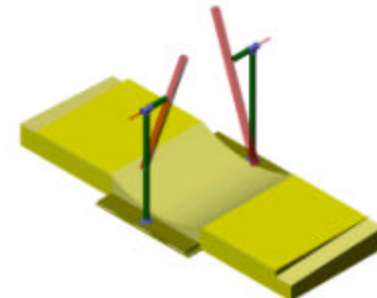
Risks: The magnet pitch may cause the carriage to pitch as the motor's iron core windings pass over the magnets

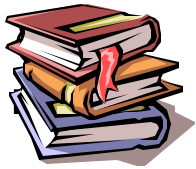
Countermeasures: Add steel out of phase with motor core position, or if the error is repeatable, map it and compensate for it in other axes

Design Process



- Follow a design process to develop an idea in steps from **coarse** to **fine**:
 - **First Step:** Evaluate the resources that are available
 - **Second Step:** Carefully study the problem and make sure you have a clear understanding of what needs to be done and what are the constraints (rules, limits)
 - Steps 1 & 2 are often interchangeable
 - **Third Step:** Start by creating possible **strategies** using words, analysis, and simple diagrams
 - Imagine possible motions, data flows, and energy flows from start to finish or from finish back to start!
 - Continually ask “Who?”, “What?”, “Why?”, “Where”, “How?”
 - Simple exploratory analysis and experiments can be most enlightening!
 - Whatever you think of, others will too, so think about how to defeat that about which you think!
 - **Fourth Step:** Create **concepts** to implement the best **strategies**, using words, analysis, and sketches
 - Use same methods as for **strategies**, but now start to sketch ideas
 - Often simple experiments or analysis are done to investigate effectiveness or feasibility
 - Select and detail the best **concept**...
 - **Fifth Step:** Develop **modules**, using words, analysis, sketches, and solid models
 - **Sixth step:** Develop **components**, using words, detailed analysis, sketches, and solid models
 - **Seventh Step:** Detailed engineering & manufacturing review
 - **Eighth Step:** Detailed drawings
 - **Ninth Step:** Build, test, modify...
 - **Tenth Step:** Fully document process and create service manuals...





First Step: *Resource Assessment*

- Before even thinking about potential solutions to a problem, one has to first take stock of the available resources:

- What time is available?

- When is the project due?
- How many person-hours a week can be spent on the project?
- What are the hours of operation for support facilities (library, shop, computers...)
- Designer engineers are often *way too* ambitious!

- What materials and components are available?

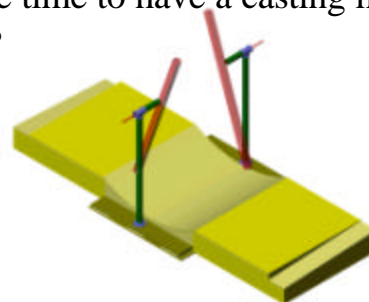
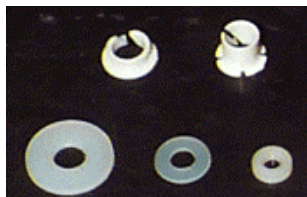
- Lay out all the materials you have (physically or catalogs) in front of you and play with them, let them talk to you, what are their limits, how have others used them...
- Look through hardware magazines
- Check the Web: <http://pergatory.mit.edu/2.007> , <http://www.efunda.com/home.cfm>
- Look at other machines
- Knowing your hardware is a POWERFUL design catalyst

- What manufacturing processes are available?

- You may not have access to a wire EDM, nor the time to send out the parts!
- You may not have the time to have a casting made!

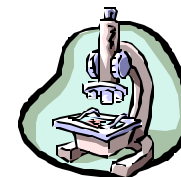
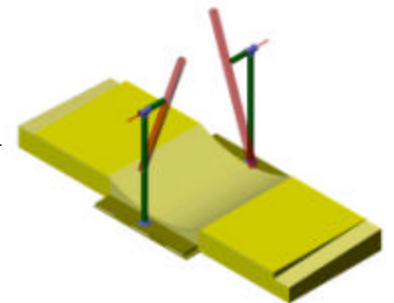
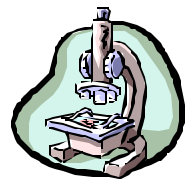
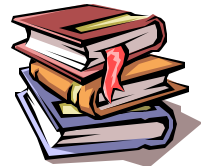
- What people are available?

- Engineering?
- Manufacturing?
- Management?
- Marketing....?



Second Step: Understanding the *Problem (Opportunity!)*

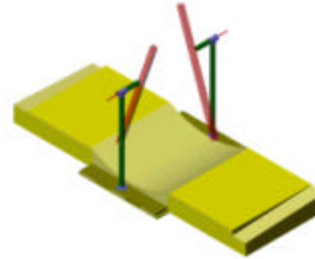
- Any problem can be dissected and understood by establishing a starting point, and then analyzing the system and its elements
 - It is like creating a design in reverse
- Study a problem and then define it in terms of its energy storage and dissipative elements, and its geometry and materials:
 - ***Simple physical models***
 - Physically play with the kit and contest table: Let the hardware talk to you....
 - A *sketch model* made from simple materials enables you to play with the problem
 - ***Simple drawings***
 - A simple hand-drawn isometric figure helps you to pattern the problem into your bio neural net
 - A simple solid model can also be very useful, particularly when later seeking to test your solid model solution on the problem
 - ***Physics: First-Order-Analysis***
 - Words to describe the physics
 - Simple analysis with guestimates of realistic numbers (spreadsheets)
 - ***Words*** (in a table or bulleted list) to describe what problem must be solved
 - What must be accomplished? (e.g., tip a balance...*functions, events*)
 - What are the constraints? (e.g., rules, cost, size, time)



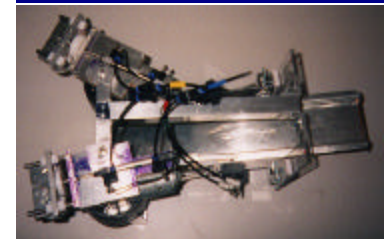
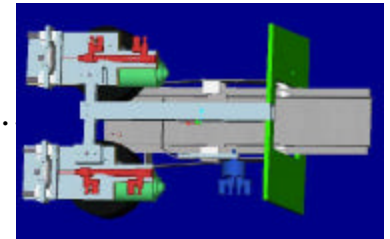
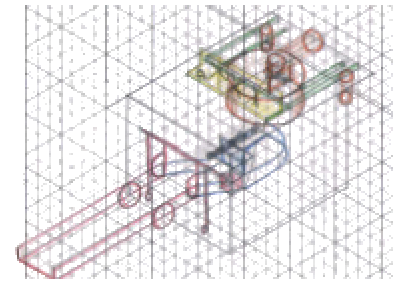


Third Step: *Developing Strategies* Concepts Modules Components

- Playing
 - Play with the contest table and the kit parts
 - Create simple experiments
- Drawing
 - Sketch all the motions that might occur (use arrows to indicate motions)
 - ROUGH Sketch potential concepts (just stick figures)
 - Overlay sketches and search for patterns and AHAs!
- Reading
 - Study past 2.007 contests
 - Study construction equipment, websites of mechanisms and other robot contests.
- Writing
 - Write a story about how the contest was won.....imagine the future!
 - The FRDPARRC Table is a fantastic catalyst
- Arithmetic (analysis)
 - Analyze the effectiveness of different scoring methods with a sensitivity study
 - Create time/motion studies of the table
 - Investigate geometric packaging options
 - Sketch free-body-diagrams to understand how the forces flow within the system
- Load your mind with information
 - let your bio-neural-net start creating broad overall pictures of what gets the most done with the least effort



Alex Sprunt's 2.007 machine development



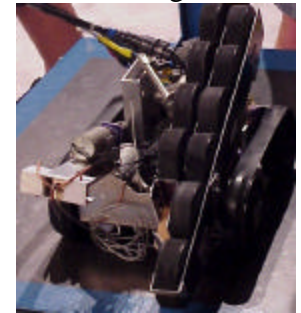
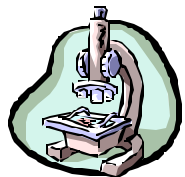
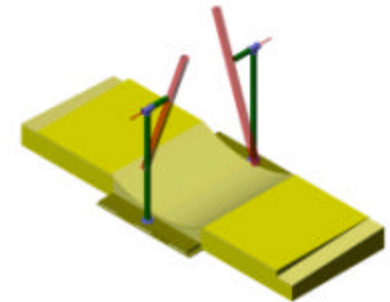
Third Step Example:

Strategies for The MIT and the Pendulum!

Functional Requirements	Possible Design Parameters (Concept's FRs)	Analysis	References	Risk	Counter-measures
Score with balls	1) Acquire balls and move them into the goal 2) Collect balls and pucks and deposit in goal 3) Bat them into the goal	1) Linear motion 2) Linear motion, Power to raise the balls to the goal 3) Trajectories, Conservation of momentum	1) 8.01 text 2) Past 2.007 contests 3) Ball shooters from past contests	1) Opponent scatters balls and pucks 2) Machine becomes too big, opponent blocks 3) Balls are too large and heavy	1) Acquisition device must also be able to pick up from the ground 2) Gather a few, Set up blocking gate 3) Ball on ramp, pinball shooter
Score with pendulum	1) Actuate from ground 2) Actuate from pendulum	?	?	?	?
Block opponent from scoring	1) Scatter pucks and balls 2) Anchor the pendulum	?	?	?	?

Fourth Step: *Developing Concepts*

- A *concept* is a vision of how one could actually accomplish the *Strategy*:
 - Words to describe what the concept must do, and how it will work
 - Ideally in simple tabular form, like a FRDPARRC Table
 - Simple sketch
 - A simple hand-drawn isometric figure often suffices
 - A simple solid model can also be very useful
 - A sketch model made from simple materials can also be very useful
 - First-Order-Analysis
 - Spreadsheet-based time and motion study
 - More detail based on better estimates of machine size...
 - Preliminary power, accuracy, or stress calculations
 - More detail based on better estimates of machine weight...
 - The design engineer needs to take care to propose a concept in just enough detail to be assured that it could indeed be implemented
- Example: *Concepts* for *Gather pucks and balls and deposit in goal Strategy*
 - *Concept A* for *Strategy 1*: Drive around picking up pucks and balls and deposit them into the goal one-by-one, so as to avoid complexity or jamming
 - After scoring with objects, the vehicle could go and actuate the pendulum
 - *Concept B* for *Strategy 1*: Gather pucks and balls using a combine-like harvester that collects them and dumps them into a bin, and then drives over and raises the bin and dumps it into the scoring goal
 - After scoring with objects, the vehicle could go and actuate the pendulum

1999's *MechEverest!*

Fourth Step Example:

Concepts for the Knock Down Balls Strategy

Functional Requirements (Distilled from Strategy's DPs)	Possible Design Parameters (Modules FR's)	Analysis	References	Risk	Counter-measures
Gather pucks and balls and deposit in goal	1) Pick up and score one at a time 2) Harvest lots and dump loads	1) Time/Motion study, Friction/slip, Linkage design 2) Friction, slip, linkage design	8.01 text and Past 2.007 contests. Farm equipment websites	1) Not enough time to make multiple trips 2) Gather bin is too large	1) Gather 2 or 3 objects 2) Gather 2 or 3 objects
Actuate pendulum from ground	1) Vehicle knocks pendulum as it drives by 2) Fixed-to-ground spinning actuator	?	?	?	?
Block opponent	1) Molestabot 2) Pendulum clamp	?	?	?	?

Fifth Step: *Developing Modules*

- A **module** is a subassembly that has a defined envelope and specific inputs and outputs that can be engineered, built, and tested and then assembled with other **modules** to implement the **concept**

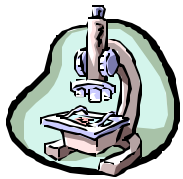


- Pick any **module**, and you will also get sub- **modules**
 - Example: Powertrain: Transmission, Motors, Crawler tracks
 - Hence the term “**module**” implies a *granularity* of detail

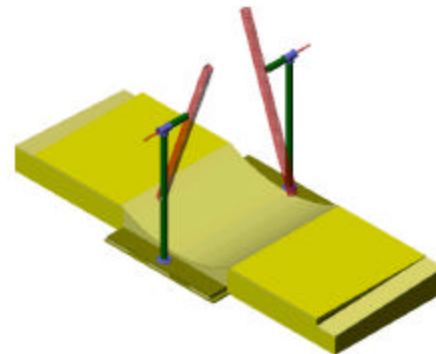


Words to describe what the **module** must do, and how it will work (FRDPAARC)

- Drawings
 - Initially a simple hand-drawn isometric will suffice
 - There may be many different ways of designing the **module**
 - » The process of **strategy**, **concept**, **module**, **components** can be applied again!
 - A solid model (layout drawings) will eventually need to be created
- First-Order- and Detailed-Analysis
 - Motion, power, accuracy, stress...
 - Greater detail as the module detail increases
- Developing **modules** is the first part of what some called the “**embodiment**” phase of design



- Example: **Modules** for the **Harvester Concept**
 - **Module 1** for **Concept B**: Gatherer
 - **Module 2** for **Concept B**: Bin
 - **Module 3** for **Concept B**: Deposit mechanism
 - **Module 4** for **Concept B**: Vehicle



Fifth Step Example:

Modules for the Harvester Concept

Functional Requirements (Distilled from Concept's DPs)	Possible design Parameters (Components' FRs)	Analysis	References	Risk	Counter-measures
Harvest objects	1)Rotary paddles or brush 2)Reciprocating paddle 3)Crab-claws	1)Angular acceleration 2)Linkages 3)Triggers	1)Street sweepers, Combine Harvesters 2)Hungry Hippos game 3)Crabs	1)Objects jam 2)Complexity 3)Complexity	2)Reversible, or raise and lower 2)Single central arm to make T 3) Rotary system
Bin	1)Sheet metal dump truck bin 2)Welded wire "cage"	?	?	?	?
Deposit mechanism	1)Comveyor 2)Raise & dump	?	?	?	?
Vehicle	1)Crawler treads 2)4WD	?	?	?	?

Sixth Step: Developing *Components*

- *Modules* are made from *components*, *sub-assemblies* or *machine elements*:



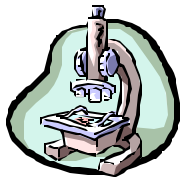
- Words to describe what the *component* must do, and how it will work

- Ideally in simple tabular form, like a FRDPARRC Table



- Drawings

- Initially a simple hand-drawn isometric will suffice



- There may be many different ways of designing the *component*

» The process of *strategy*, *concept*, *modules*, *components* can be applied again!

- A solid model (part drawing) will eventually need to be created

- Detailed engineering analysis


- Motion, power, accuracy, stress, corrosion...

- This is the super detailed phase of design

An advertisement for Alpha's CYMEX sizing software. It features a photograph of a scuba diver standing on a sandy beach, looking out at the ocean. The diver is wearing a black wetsuit and a yellow and black scuba tank. The background is a blue sky and ocean.

AS FRANK SOON FOUND OUT, CHOOSING MOST OF THE RIGHT COMPONENTS IS NOT EXACTLY THE SAME AS CHOOSING ALL OF THE RIGHT COMPONENTS.

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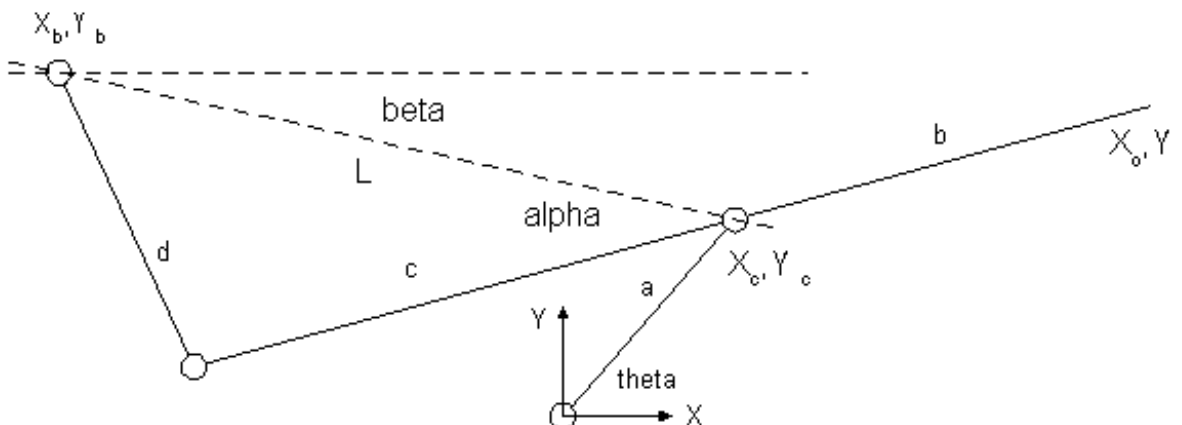
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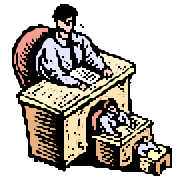
Sixth Step Example:

Components for the Reciprocating Paddle Module

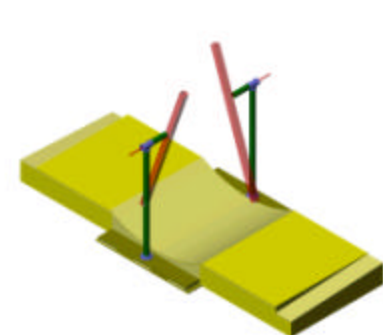
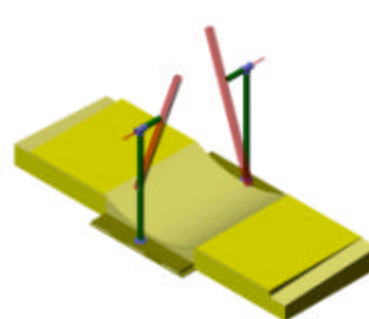
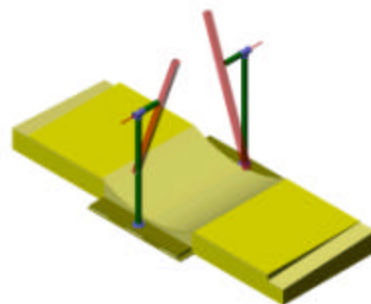
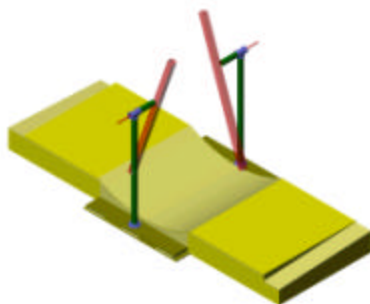
Functional Requirement's (Distilled from Module's DPs)	Possible design Parameters	Analysis	References	Risk	Counter-measures
Linkage	1) Revolute joint linkage 2) Revolute & prismatic linkage	1) 4-bar synthesis & force analysis 2) Trigonometry & force analysis	Freshman physics, Chapter 4 of this book	1) Too simple motion 2) Complexity	1) Use option 2, or a paddle 2) Make one single center linkage
Paddle	1) Bent sheet metal 2) Welded truss	?	?	?	?
Bearings	1) Nylon 2) Metal pins				
Actuator	1) Screwdriver motor 2) Piston				

What else?...

Patterns from the Process: *Repeats* *Repeats* *Repeats* *Repeats*



- Notice how each *Strategy's* Functional Requirements will each generate one or more *Design Parameters (Concepts)*...
 - Notice how each *Concept's Functional Requirements* will each generate one or more *Design Parameters (Modules)*...
 - Notice how each *Module's Functional Requirements* will each generate one or more *Design Parameters (Components)*...
- Executing a systematic design process can help you develop a *rapid design reflex*:
 - Rapidly and effectively solve design problems with a minimum of floundering!
- *As you take more and more trips around the sun, the design process and a rapid design reflex becomes hard-wired into your bio-neural-net!*





2.007 2002 Milestones

The MIT and the Pendulum

Week	Milestone Goals	Points	
1	Resource Assesment: Play with kit & table, solid model the table	10	Grading
2	Generating & Creating Strategies, make gearbox	10	Ideas 30%
3	Developing & Selecting the Best Strategy	20	Analysis 25%
4	Generating & Creating Concepts	10	Execution 25%
5	Developing & Selecting the Best Concept	10	Presentation 10%
6	Generating & Creating Modules	10	Rhorbach peer review 10%
7	Developing the Most Critical Module (MCM)	15	
8	Spring break	NA	Final grade
9	Build, Test, Finalize Most Critical Module	15	>230 = A+
10	Design, Build, Test, Finalize Modules	10	200 - 230 = A
11	Design, Build, Test, & Begin Integration	10	170 - 199 = B
12	Finish Integration, Demonstrate Working Machine	20	140 - 169 = C
13	Final Tweaking, In-Class Contest & "Ship" Machine	10	110 - 139 = D
14	Compete with a good working machine in the Final Contest!	80	<109 = F
15	Create awesome web page about your machine	20	BONUS Pts
	Rohrbach evaluation team effectiveness	20	BONUS Pts

Most of the milestone elements should NOT be done in Lab

Most of your lab time should be spent experimenting!

It is very acceptable to work ahead!

Milestones are to be turned in the Friday of the week or their #

FRDPARRC Sheet Topic:_____Milestone#____Section Instr.____Student:_____

Functional Requirement (Event)_____

Design Parameter (description of idea)_____

Sketch:

Analysis (physics in words)_____

Analysis

References:_____

Risks_____

Countermeasures_____

APPEND ADDITIONAL SHEETS AS NEEDED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test				

Week 1: Milestone **ONE** (10 pts)

Resource Assessment

Deliverables: (must be completed before your first lab section meeting)

- Go to Pappalardo Lab and get locker & kit (check contents) (ONLY Feb. 4, 12:30-4:00 PM)
 - PUT YOUR NAME ON YOUR TOOLS AND Critical KIT PARTS (motors!!)
 - There are no free lost motor replacements for lost: you can buy your own replacements at Home Depot or from Amazon.com!
- Play with the table and kit parts, and observe and discuss scoring physics (**Strategies**)
- Create a solid model of the table, post it on your website, and also turn in a hardcopy
- Create a spreadsheet or Matlab script for at least one strategy that models its physics and scoring potential (e.g., a basic time & motion study using freshman physics knowledge)
- Prepare for first lab section meeting in week 2:
 - Review sample *Milestone Reports* on the web, so you know what to do in the future (not too much, not too little)
 - **CAREFULLY READ AND ASSIMILATE TOPICS 1,2, 3, and 4!**
 - Create a personal website for 2.007 where you can post your milestone summaries
 - If you build a good website as you go, you can get 20 extra bonus points added to your grade!
 - A great website that illustrates how you design is an invaluable interviewing tool



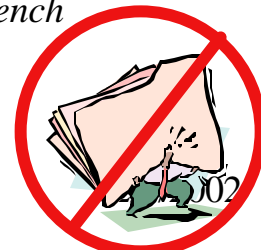
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Strategy & Concept					Detailed Engineering & Development					Integration & Test				

Week 2: Milestone **TWO** (10 pts)

Generating & Creating **Strategies**

Deliverables:

- Play with the table and kit parts to investigate different scoring ideas (**Strategies**)
 - This includes making simple sketch models and Bench Level Experiments (BLEs)
 - Record observations, including sketches, pictures of sketch models, and analysis
- Describe the physics of the contest, including the dominant variables and means by which you can influence them (1 or 2 pages, be brief)
- Describe various scoring methods and their physics, including the dominant variables and means by which you can influence them (1 or 2 pages, be brief)
- Sketch lines of motion (actions) or simple stick figures for different **Strategies** that come to mind on printouts of your solid model of the contest table.
 - DO NOT SKETCH detailed MACHINE CONCEPTS!
- See the course website for instructions on completing the “Modular Right Angle Gearbox” design & manufacturing exercise, & demonstrate a working right angle gearbox
 - Two such gearboxes allow you to easily create a vehicle
 - If you think a vehicle may be a useful module, go ahead and assemble one and test it as a *Bench Level Experiment!*



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 3: Milestone **THREE** (20 pts)

Developing & Selecting the Best **Strategy**

Deliverables:

- Develop and refine your **Strategies** with sketches, pictures of sketch models, and analysis:
 - Lines of motion (actions) or simple stick figures for different strategies on a printout of your solid model of the contest table. DO NOT SKETCH detailed MACHINE CONCEPTS!
 - FRDPARRC Sheet for **Strategies** to *exploit* the physics of the scoring methods
 - FRDPARRC Sheet for **Strategies** to defend
 - FRDPARRC Sheet for **Strategies** to attack
 - Analysis to predict your score (time budget, physics, etc)
 - Bench Level Experiments (make simple machines from kit parts and play with them!)
- With your evaluation team, complete a Rohrbach evaluation of each other's **Strategies**
 - Modify your **Strategies** based on feedback you get from the Rohrbach process
- Create a weighted **Strategy** selection chart to evaluate your ideas
 - Show how you combine elements of different **Strategies** to create “best overall evolved **Strategies**”
 - Based on contemplating of possible **Concepts**, FINALIZE & LOCK-IN your **Strategy**
 - Be VERY CAREFUL to analyze risks and countermeasures of each **strategy** to ensure you have a workable contingency plan if some elements of your **strategy** prove too risky!
- Present the final description of your chosen “best” **Strategy** in a FRDPARRC Sheet



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 4: Milestone **FOUR** (10 pts)

Generating & Creating **Concepts**

Deliverables:

- Play with your kit elements and sketch several **Concepts** to realize your “best” **Strategy**
 - The reality of what you can actually build may be cause for **strategy** modification!
 - This is where a careful assessment of risk and countermeasures is critical
- Evolve and refine **Concepts** for your final **Strategy**, and for the top three **Concepts** create:
 - FRDPARRC Sheets
 - Be VERY CAREFUL to analyze the risks and countermeasures for each **Concept**
 - Appropriate analysis
 - Appropriate sketches (hand or simple solid model)
 - Bench Level Experiments and/or sketch models
- Rohrbach evaluation of each other’s **Concepts**
 - Modify your **Concepts** based on feedback you get from the Rohrbach process



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 5: Milestone **Five** (10 pts)

Developing & Selecting the Best **Concept**

Deliverables:

- Develop and refine your **Concepts** with sketches, pictures of sketch models, and analysis:
 - FRDPARRC Sheets for 3 most promising **Concepts**
 - Appropriate analysis
 - Appropriate sketches (hand or simple solid model)
 - Bench Level Experiments (make simple machines from kit parts and play with them!)
- With your evaluation team, complete a final Rohrbach evaluation of each other's **Concepts**
 - Modify your **Concepts** based on feedback you get from the Rohrbach process
- Create a weighted **Concept** selection chart to evaluate your ideas
 - Show how you combine elements of different **Concepts** to create “best overall evolved **Concepts** ”
 - Based on contemplating of possible **Modules**, FINALIZE & LOCK-IN your “best” **Concept**
- Present the final description of the **Concept** in a FRDPARRC Sheet
 - This must include a first-attempt solid model of the overall concept with appropriate detail (and solid reserve space blobs as needed)
 - Be VERY CAREFUL to analyze risks and countermeasures of your **Concept** to ensure you have a workable contingency plan if some elements of your **Concept** prove too risky!



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 6: Milestone **Six** (10 pts)

Generating & Creating **Modules**

Deliverables:

- Separate your **Concept** into **Modules**, and for each module create:
 - A solid model showing each **Modules'** configuration and how the **Modules** fit together
 - FRDPARRC Sheets for 3 most promising ideas for each **Module**
 - Appropriate analysis
 - Bench Level Experiments (make simple machines from kit parts and play with them!)
- With your evaluation team, complete a Rohrbach evaluation of each other's **Modules**
 - Modify your **Modules** based on feedback you get from the Rohrbach process
- Create weighted **Module** selection charts to evaluate your ideas
 - Show how you combine elements of different **Modules'** ideas to create “best overall evolved **Modules**”
 - Based on contemplating possible **Components**, FINALIZE & LOCK-IN your **Modules**
 - Be VERY CAREFUL to analyze risks and countermeasures of each **Module**!
 - Identify your **Most Critical Module (MCM)**
 - Make sure to have 1 or 2 very simple “countermeasures” to revert to in case the MCM cannot be made to work!
- Present the final description of the **Modules** in FRDPARRC Sheets



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept						Detailed Engineering & Development				Integration & Test				WWW

Week 7: Milestone **Seven** (15 pts)

Developing the **Most Critical Module (MCM)**

Deliverables:

- Proceed with detailed engineering of **Components** for the **MCM**:
 - Sketches of components and FRDPARRC Sheets where appropriate
 - Appropriate analysis
 - Bench Level Experimentation (if analysis too tough for you, or your instructor, run an experiment!)
 - Sketch the designs and identify sensitive design parameters (e.g., dimensions)
 - Solid Modeling of **Components** (you need drawings to machine parts!)
 - Manufacturing drawings and process plans (plan what and how to do before you try to)
- Rohrbach evaluation of each other's **MCM** design (just one idea) and process plans
 - Modify your drawings and process plans based on feedback you get from the Rohrbach process
- Develop a manufacturing, assembly, and test schedule for rest of the course
- Start building your **MCM**!



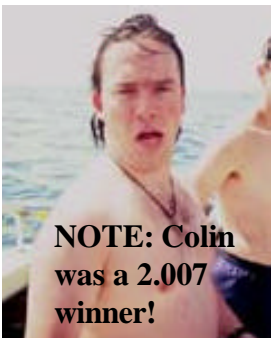
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Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW



Week 8: Milestone **EIGHT** Spring Break: Relax!

Deliverable:

- Come back Relaxed!



NOTE: Colin
was a 2.007
winner!



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 9: Milestone **NINE** (15 pts)

Build, Test, Finalize **Most Critical Module**

Deliverables:

- Build, test, and modify **Most Critical Module**
 - It should now be a working module, ready to integrate into the rest of your machine!
 - IF it is not working, revert to simplest countermeasure and complete it this week.
- Proceed with detailed engineering of **Components** for the remaining **Modules**:
 - FRDPARRC Sheets
 - Use what you learned in building the **MCM** to carefully do the risk and countermeasures analysis!
 - Appropriate analysis
 - Bench Level Experimentation (if analysis too tough for you or teacher, run an experiment!)
 - Sketch the idea and identify sensitive design parameters (e.g., dimensions)
 - Solid Modeling of **Components** (you need drawings to machine parts!)
 - Manufacturing drawings and process plans (plan what and how to do before you try to)
- Rohrbach evaluation of each other's drawings and process plans
- Revise schedule for next week



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 10: Milestone **TEN** (10 pts)

Design, Build, Test, Finalize **Modules**

Deliverables:

- Manufacture **Components** from drawings made last week
- Test **Modules** from **Components** made
 - Evaluate what did and did not work, and take appropriate action (fix it!)
- Proceed with detailed engineering of **Components** for the remaining **Modules**:
 - FRDPARRC Sheets
 - Use what you learned in building the **MCM** to carefully do the risk and countermeasures analysis!
 - Appropriate analysis
 - Bench Level Experimentation (if analysis too tough for you or teacher, run an experiment!)
 - Sketch the idea and identify sensitive design parameters (e.g., dimensions)
 - Solid Modeling of **Components** (you need drawings to machine parts!)
 - Manufacturing drawings and process plans (plan what and how to do before you try to)
- Rohrbach evaluation of each other's drawings and process plans
- Revise schedule for next week



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 11: Milestone **ELEVEN** (10 pts)

Design, Build, Test, & Begin Integration

Deliverables:

- Manufacture **Components** from drawings made last week
- Test **Modules** from **Components** made
- Begin Integration of **Modules**
- Evaluate what did and did not work, and take appropriate action (fix it!)
- Proceed with detailed engineering of **Components** needed to FINISH your machine:
 - FRDPARRC Sheets
 - Use what you learned in building the MCM to carefully do the risk and countermeasures analysis!
 - Appropriate analysis
 - Bench Level Experimentation (if analysis too tough for you or teacher, run an experiment!)
 - Sketch the idea and identify sensitive design parameters (e.g., dimensions)
 - Solid Modeling of **Components** (you need drawings to machine parts!)
 - Manufacturing drawings and process plans (plan what and how to do before you try to)
- Rohrbach evaluation of each other's drawings and process plans
- Revise schedule for next week



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 12: Milestone **TWELVE** (20 pts)

Finish Integration, Demonstrate Working Machine

Deliverables:

- Manufacture **Components** from drawings made last week
- Finish integration, testing, and debugging of your machine
 - Evaluate what did and did not work, and take appropriate action (fix it!)
- Tweak machine as needed to optimize performance and ***Practice driving!***
- Demonstrate working machine (at least to some degree)
 - Evaluate what did and did not work, and create a plan to fix it!
- Complete manufacturing drawings and process plans for any **Components** needed to **finish!**
- Revise schedule for next week



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 13: Milestone **THIRTEEN** (10 pts)

Final Tweaking, In-Class Contest & “Ship” Machine

Deliverables:

- *Practice driving, practice driving, practice driving...!*
- Have a working machine ready to compete in the in-class contest
 - Your score will determine your seeding in the final contest
 - High score machines will be matched against low score machines
 - Evaluate what did and did not work and try to fix it!
- “Ship” your machine:
 - Machine is judged for size and weight:
 - **If your machine fits in the sizing container with lid on and meets the weight requirement, then you get a Green dot which means you can compete and win**
 - **Red dot means you can compete in first round, but cannot win. No major modification will be allowed, but do not fret, effect on grade is likely to be minor.**
 - Machine is boxed in green FREM container and put into locked locker
- Recycle unused materials and components
- Clean up your personal 2.007 web site, get your design notebook in order, and make arrangements to turn in your notebook to your section instructor



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 14: Milestone **FOURTEEN** (80 pts)

Final Contest (Celebration!)

Deliverables:

- Check the website for details
- Pick up your machine (and FREM box) from the Lab before 5 PM on the first contest day and take it to the Contest Arena
 - Place your machine in your designated section area
 - Make sure your batteries are charged and you bring your charger
- You **MUST** (please) wear your 2.007 T-Shirt and *safety glasses* to the contest
- Everyone must stay for the entire con test time (it's really not nice to compete and leave!)
- Have FUN!
- After the contest, place your machine in the space provided for your section in the Johnson Center until final contest day
- Only minor repairs will be allowed the morning & afternoon of the final contest day



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Strategy & Concept					Detailed Engineering & Development					Integration & Test			!!!	WWW

Week 15: Milestone **FIFTEEN** (20 pts)

Document the Design

Deliverables:

- Website describing what you did for each milestone:
 - Either this is already done (you did it each week as a milestone report), OR:
 - A clear description of how you evolved your machine
 - Final FRDPARRC Sheets for final **Strategy, Concept, Modules**
 - One page summary from each earlier milestone
 - Post-contest analysis:
 - What worked and what didn't?
 - What would you have changed if you could do it all over again?
 - How well did you follow the schedule
 - What do you think your grade should be, based on point allocation chart

