FUNdaMENTALS of Design

Creating Ideas
Concepting
(ME 481, Fall 2023)
FUNdamentals of Design

Introduction
"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
“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’s Maxims (1700’s, a father of modern machine tools)
Design is a Series of Steps Blended Together

- Follow a design process to develop an idea in stages from **coarse** to **fine**:
  - **First Step:** Take stock of the resources that are available
  - **Second Step:** Study the problem and make sure you have a clear understanding of what needs to be done, what are the constraints (rules, limits, time, budget), and what are the physics of the problem!
    - Steps 1 & 2 are often interchangeable
  - **Third Step:** Start by creating possible **strategies** *(ways to approach the problem)* using words, analysis, and simple diagrams
    - Imagine motions, data flows, and energy flows from start to finish or from finish back to start!
    - Simple exploratory analysis and experiments can be most enlightening!
    - Whatever you think of first, others will too, so think about how to defeat what you think first!
  - **Fourth Step:** Create **concepts** *(specific ideas for machines)* to implement the best **strategies**, using words, analysis, and sketches
    - Use same methods as for **strategies**, but now sketch specific ideas for machines
    - Often simple experiments or analysis are done to investigate effectiveness or feasibility
    - Select and detail the best **concept**…
  - **Fifth Step:** Develop **modules** *(sub-assemblies of parts)* using words, analysis, sketches, and solid models
  - **Sixth Step:** Develop **components** *(individual elements)* using words, detailed analysis, sketches, and solid models
  - **Seventh Step:** Detailed engineering & manufacturing reviews
  - **Eighth Step:** Detailed drawings
  - **Ninth Step:** Build, Test, Modify…
  - **Tenth Step:** Fully document process and create service manuals…

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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://pergatory.mit.edu/2.007), [http://www.efu](http://www.efu)
    - Look at other machines and search patents
    - 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

- A strategy is a general approach to a problem, and there may be many different actually ways of implementing it (i.e., many different concepts).

- Strategies are developed by:
  - 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 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 FRDPARRRC 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 and study geometric packaging options
    - Sketch free-body-diagrams to understand how the forces flow within the system
    - Create a preliminary power budget (see Power_budget_estimate.xls)
  - Load your mind with information
    - let your bio-neural-net create images of what gets the most done with the least effort
Fourth Step: Developing Concepts

- A **concept** is a specific 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
  - **Brain Storming & Simple sketch**
    - A simple hand-drawn isometric figure of the machine often suffices
    - A simple solid model can also be very useful
    - A sketch model made from simple materials (Rapid Prototyping/3D Printing) 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…
  - **Refine the power budget to ensure your idea can be powered by the batteries**
    - 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 the scoring 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
Fifth Step: Developing Modules/Subsystems

- 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 (FRDPARRC)
FRDPARRC Table: Functional Requirements, Design Parameters, Analysis, References, Risks, and Countermeasures

- 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 call 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

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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/strain, deflection, corrosion…
      - This is the super detailed phase of design
Patterns from the Process: 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!*
Deterministic Design: **FRDPARRC** *(Functional Requirements, Design Parameters, Analysis, References, Risks, and Countermeasures) Table*

<table>
<thead>
<tr>
<th><strong>Functional Requirements (Events)</strong></th>
<th><strong>Design Parameters (Idea)</strong></th>
<th><strong>Analysis</strong></th>
<th><strong>References</strong></th>
<th><strong>Risk</strong></th>
<th><strong>Countermeasures</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Words</td>
<td>Words &amp; Drawings</td>
<td>Experiments, Words, FEA, Equations, Spreadsheets…</td>
<td>Historical documents, www…</td>
<td>Words, Drawings, Analysis…</td>
<td>Words, Drawings, Analysis…</td>
</tr>
<tr>
<td>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 Function Structure</td>
<td>Ideally independent means to accomplish each FR CAN HAVE SEVERAL POTENTIAL DPs. The “best one” ultimately must be selected</td>
<td>Economic (financial or maximizing score etc), time &amp; motion, power, stress, etc…. EACH DP’s FEASABILITY MUST BE PROVEN Analysis can be used to create DPs!</td>
<td>Anything that can help develop the idea including personal contacts, articles, patents, web sites….</td>
<td>High, Medium, Low (explain why) risk of development assessment for each DP</td>
<td>Ideas or plan to mitigate each risk, including use of off-the-shelf known solutions</td>
</tr>
</tbody>
</table>

- To actually use the FRDPARRC Table:
  - Create one actual table that becomes your development roadmap
  - Dedicate one sheet to each FR/DP pair

*The FRDPARRC table is an exceptional catalyst to help you identify opportunities for applying reciprocity to uncover new ideas and solve problems!*
Creation: Coarse-to-Fine

Contest Problem

Strategy 1 - Score with Balls

Concept 1 – Harvest Lots of Balls and Dump

Module 1 – Harvest Objects

Module Idea 1 – Rotary Paddles

Module Idea 2 – Reciprocating Paddle

Component 1 – Linkage

Element 1 – Revolute Joint

Element 2 – Link

Module Idea 1 – Conveyor

Module Idea 2 – Raise and Dump

Module 2 – Deposit Mechanism

Module Idea 1 – Crawler Treads

Module Idea 2 – 4 Wheel Drive

Module 3 – Vehicle

Component 2 – Paddle

Component 3 – Bearings

Component 4 – Actuator

Strategy 2 - Score with Pendulum

Concept 2 – Pick Up Balls and Score One at a Time

Module Idea 1 – Rotary Paddles

Module Idea 2 – Reciprocating Paddle

Component 1 – Linkage

Element 1 – Revolute Joint

Element 2 – Link

Module Idea 1 – Crawler Treads

Module Idea 2 – 4 Wheel Drive

Strategy 3 - Block Opponent

Concept 3 – Hit balls into the goal

Module Idea 1 – Conveyor

Module Idea 2 – Raise and Dump

Module 3 – Vehicle

Component 2 – Paddle

Component 3 – Bearings

Component 4 – Actuator

Special thanks to Pat Willoughby for creating this flowchart of the coarse-to-fine development process
Deterministic Design: *Coarse-to-Fine Funnels:*

### Strategies

- 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

### Concepts

- **Strategy:** Plan or tactics to score but there may be many different types of machines that could be used
- **Concept:** An idea for a specific machine that can execute a strategy
- **Module:** A sub assembly of a machine that by itself executes a certain function
- **Component:** An individual part

### It is OK to iterate…

- A *goal* is to never have to backtrack
- A good engineer, however, knows when its time to let go…
FUN\textit{d}aMENTALS of Design

Creating Ideas
Creating Ideas
Concepting

Topics
- Creation: Coarse-to-Fine
  - Thought Processes
- Experimentation
- Drawing
- Research
- Writing
- Analysis
- Evolving Ideas

“Curiosity is one of the permanent and certain characteristics of a vigorous mind” – Samuel Johnson
Thought Processes

- "Personal self-satisfaction is the death of the scientist. Collective self-satisfaction is the death of research. It is restlessness, anxiety, dissatisfaction, agony of the mind that nourish science" Jacques-Lucien Monod

- To help generate and create ideas, thought processes can be used as catalysts
  - Systematic Variation
    - Consider all possibilities
  - Persistent Questioning
  - Reversal: Forward Steps
    - Start with an idea, and vary it in as many ways as possible to create different ideas, until each gets to the end goal
    - Also called the method of divergent thought
  - Reversal: Backwards Steps
    - Start with the end goal and work backwards along as many paths as possible till you get to the beginning
  - Nature’s Way
    - How would nature solve the problem?
  - Exact Constraints
    - What are the minimum requirements
**Thought Processes: Systematic Variation**

Consider all possibilities:

- **Energy:** How can it be applied, generated, stored?
  - Mechanical: springs, flywheels…
  - Hydraulic: piston, bladder, reservoir, propeller…
  - Electrical: line source, battery, capacitor, magnet, optical…

- **Material:**
  - State: solid, liquid, gas
  - Behavior: rigid, elastic, plastic, viscous…
  - Form: bar, sheet, powder…

- **Motions:**
  - Type: fixed, linear, rotary
  - Nature: uniform, non-uniform, transient
  - Direction & Magnitude

- **Controls:**
  - Passive
  - Active

AND all combinations of the above!

Analytical models of systems are invaluable.

Sensitivity studies can be easily conducted.
Thought Processes: Reversal

- When an element has a risk, a countermeasure is often the inverse of the element
  - When a naysayer in a design review points out a weakness (risk) bring them onto your side by saying “that’s a good observation, lets make sure we consider 1/weakness”

- Being able to rapidly switch between the methods of Forward Steps and Backward Steps is an invaluable skill
  - Example: Given length equalities indicated by the colored pointy end cylinders, prove that the yellow cylinder is the perpendicular bisector of the purple and red cylinders?
    - Never be afraid to add your own sketching to a problem that is given you
      - The thin red and blue lines and vertex labels were added!
    - If you do not rapidly see how to move forward, try going backwards!

As given:

After user inflicted clarifying features:

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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 (90%-10% Rule)**
    - “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!
  - “If you board the wrong train, there’s no use running along the corridor in the opposite direction” Dietrich Bonhoeffer
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Deterministic Design: Play!

- Engineering is often a tactile, visual, verbal, cerebral, and physical activity:
  - Play with the table and the kit parts
  - Sketch ideas
  - Create physical & 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!

“Personal self-satisfaction is the death of the scientist. Collective self-satisfaction is the death of the research. It is restlessness, anxiety, dissatisfaction, agony of the mind that nourish science”  
Jacques-Lucien Monod
Experimentation with Prototype/Model

- Playing With Parts
- Sketch Models
- Bench Level Experiments
- Bench Level Prototypes
- Identifying Risky Ideas

QKC Error in Sensitive Direction

<table>
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<th>Trial #</th>
<th>JL</th>
<th>JR</th>
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<tbody>
<tr>
<td>7</td>
<td></td>
<td></td>
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<tr>
<td>1</td>
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</tr>
</tbody>
</table>

Groove Seat
Side Reliefs
Spherical Protrusion
Axial Cap Probe
Bedplate Fixture
1st Block Fixture
JL Cap Probe
2nd Block Fixture
1st Block Fixture
JL Cap Probe
Bedplate Fixture
Bedplate
CMM Head

0_init = 0_final
O_initial
O_final
Experimentation: Playing with Parts

- Lay out all the materials you have (physically or information sheets) in front of you and play with them, let them talk to you, what are their limits, how have others used them…?
  - Place components amongst each other on the contest table to obtain a physical feel for how they might work and fit…..
  - Move the table and feel its motions….
- With a “competing” partner “drive” imaginary machines with your hands to feel how things might move in competition
  - Mock competitions can help create and evolve strategies
Experimentation: Sketch Models – Rapid Prototyping

- **Sketch models are made from simple materials** (e.g., cardboard, foam, hot-melt glue, tape, string – 3D Printing) and **they allow you to literally “play” with potential strategies**
  - Later, when you have a concept developed, they enable you to “test drive” your machine concept around the table
    - In the “real world” where designs are often very complex, sketch models are still often important “proof of concept” aids
      - They can be invaluable sales tools!
- A Sketch-Model-Derby is an invaluable way to test ideas, with minimal risk of time and materials
  - See [http://me.mit.edu/lectures/sketch-modelling/2.2-examples.html](http://me.mit.edu/lectures/sketch-modelling/2.2-examples.html)
  - Evolution of The MIT and the Pendulum:
Experimenting: Bench Level Experiments of Physical Models

- **Experiments to test function, force, friction, and speed, are a vital part of the design process**
  - *Analysis is potentially the quickest way to verify an idea*
  - *Remember, to be thorough! However, ....*
  - *Analysis inexperience or uncertainty can lead to analysis paralysis*
    - Analysis paralysis is most often relieved by a simple experiment

Example:

- **Idea:** Use a winch to pull the pendulum back and forth?
- **Experiment:** Tape a motor to the beam and tie a string around the pendulum and see if the motor shaft can wind the string up and pull the pendulum over. Does the motor’s distance from the pendulum affect how far over it can pull the pendulum?
Experimenting: Bench Level Prototypes

- Once you get to the **concept** phase, you may have a risky idea, which if it works, would be awesome
  - **A Bench Level Experiment** is performed to prove the principle of an idea, **but it is not a potentially functional part of the machine**
- **A Bench Level Prototype** is designed to ideally be an actual **module** to test a **risky concept**
  - Design it well, and if it works, it could be a ready-to-use **module** for your machine!
  - It often shows what works and what must be fixed in a **module** (like the software!)
  - A robot contest BLP would be to create a vehicle to test its speed and controllability
    - Use modular **components**, so you can change them to optimize performance
    - E.g., change the gear ratio on a vehicle’s drive train

Oops! Software crashed it again!

Programmers are not that innocent!
Creating Ideas
Concepting

Topics

- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- **Drawing**
- Research
- Writing
- Analysis
- Evolving Ideas

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Drawings

- **Motion, Force, & Free-Body Diagrams**
- Sketches & Mock Battles
- **Solid Models**
Drawing: Motion & Force Diagrams
Free Body Diagram (Statics & Dynamics)

• It is important to sketch the idea of a strategy without including any mechanical detail:
  – Just use arrows to indicate directions of motions
    • Illustrating the motion with mechanism implies a concept
    • Use different colors!
  – You do not want to start implying specific concepts because this could lead you to spend time developing it before you explore enough strategies
    • Time is precious
    • For an illustrative reference, read If You Give a Mouse a Cookie
  – Use your motion and force diagrams to help create a preliminary power budget!
**Drawing: Sketches**

- **Strategies (Design)** are sketched with simple arrows to indicate motions
- **Concepts (Brain Storming)** are sketched showing overall design intent via possible mechanisms and blocks representing modules
- **Modules (Subsystems)** are sketched showing basic types of components
- **Sub-assemblies** and **Components** capture detail and design intent
- Pit your sketches against each other in mock competitions (DMMs)!
- Good sketches and a not so good sketch:
  - Try to sketch in 3D!
Drawing: **Solid Models**

- Creating a solid model of the environment (e.g., Contest table!) helps you build a solid model of your machine, to make sure it will fit!
  - A solid model of the environment lets you make measurements outside of the lab, to make sure your mechanism will fit
- A solid model of a concept starts with simple parametric shapes, that will essentially define volumes into which modules must fit
  - Detail is added as the design progresses
  - Use Tools/Equations to add relations between dimensions
    - When you change a primary dimensions, all other dimensions related by equations automatically change too!
      - The design "morphs" automatically
    - The true power of solid modeling: You do not have to track down and change umpteen different dimensions in different parts!
- **Analysis of a solid model can serve as a Bench Level Experiment, to illuminate problems and help guide sensitivity**
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Research

Go to your local museum of science, as they likely have a neato mechanisms room!

www.bobcat.com

- **Books, journals, trade magazines** …
- **Past events**
  - Show guides, competitor catalogs
  - Previous contests!
- **The Internet**
  - Popular search engines
  - Engineering and scientific databases!
  - University technical library

Google

SELECT DATABASE
- All [ ] Compendex [x] Inspec [x] NTIS [ ]

SEARCH FOR
- induction motor and torque

search in All fields

MIT Libraries

RefWorks
Patents & Standards

Patent searches can be done online:
- Library databases
- www.uspto.gov
- www.freepatentsonline.com

Standards contain information on “how to do things right”!
- www.nssn.org
- www.ansi.org
- www.astm.org
- www.iso.org

Publication Types

Patents at MIT

Where to Search
- Utility and design patents
- Biotechnology and chemistry patents
- Aggregate analysis of patents

How to Search
- Search strategy
- Guides for searching

Specification for motors for battery operated vehicles
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Writing

• Putting it in your own words….
• Lists, Figures, and Tables
• Narratives
• Poems, raps, ballads…

PROJECT STATUS UPDATE: NOFER TRUNIONS

Work has been proceeding in order to bring to perfection the crudely conceived idea of a machine that will consistently refractate Nofer Trunions. The current design concept, known as a Turbo Encabulator, supplies inverse reactive current to unilateral phase detractors and thus is capable of automatically synchronizing its internal Cardinal Grammeters.

The original machine has a base plate of pre-fabulated amalthee surmounted by a malleable logarithmic casing in such a way that the two spinning bearings are co-linear with the pentrametric fan. The main winding is of the normal Lotus-O-Delta type, placed into pateredmic semi-blade slots in the stator with every seventh conductor being connected by a non-reversible tremio pipe to the differential gridle spring at the upper end of the grammer. 41 (yes, 41!) manesitically spaced groating brushes are arranged to feed into the rotor slip stream a mixture of high $S$ value phenol-bisubol benzene and 5% luminous tetraethylol hexamine. Both these liquids have a specific pericosity given by:

$$P = 2.5 \text{ Cn 6.5}$$

where $n$ is the diesthetical retribue of temperature phase disposition, and $C$ is Colomondola's annual grilling constant. Initially, $n$ was measured with the aid of a metapolar diffusive pilifrometer, but to date nothing has been found to equal the transcendental hopper dactroscope.

Undoubtedly, the Turbo Encabulator has reached a high level of technical development. It has been successfully used to produce successively modified Nofer Trunions in large volumes. In addition, whenever a bardensk scoon motion is required, it may be employed in conjunction with a drawn reciprocating dingle arm to reduce sinusoidal deploration in the Nofer Trunions' bifurcangled hippocorn.

Believed to be written decades ago by a long-forgotten scul at Phi Kappa Tau fraternity, Rensselaer Polytechnic Institute
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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 (i.e., Risk Mitigation)
  – 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!

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• Appropriate Analysis
  – *Ratiocinator emptor*
• Scoring Sensitivity
• Geometry, Time & Motion
• **Energy, Momentum, Mass, & Strength**

Sir Isaac Newton (1642 - 1727)

**Analysis**

Tim Zue

1997’s *Pass The Puck!*

Will Delhagen & Alex Jacobs

2001’s *Tiltilator!*

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Analysis: Scoring Sensitivity

• What gives the greatest score for the least effort:
  – Pendulum?
  – Hockey pucks?
  – Balls?

• What variables affect the score?
  – Ball and puck weight
  – Pendulum travel?
  – ?

• Answer these questions by writing the equations, and then investigating which are the most sensitive parameters
  – Ask yourself: How can I affect each of these parameters?

• Physics is an AWESOME catalyst to help your brain generate ideas
• Analysis is an awesome lens for focusing effort!

• The MOST critical thing you can do in a robot design contest, is study the scoring algorithm and determine which are the most sensitive parameters!
  – This will direct your efforts for the development of strategies and concepts!
Analysis: Appropriate Analysis

- Appropriate Analysis is a CRITICAL part of defining a problem’s bounds and generating creative concepts!
  - If \( F = ma \) will answer the question, do NOT bother with relativity!
  - Spreadsheets, MATLAB, FEA…use whatever works best for you to yield an informative and insightful answer in the least amount of time
  - Remember to use analysis to design experiments, and run experiments to answer questions when analysis is too difficult
    - If you spend your time pushing on a rope, you will buckle from the strain!
  - “Back-of-the-envelope” calculations are a critical part of the early conceptual design phase!
    - Kinematic constraints
    - Beam stresses
    - Power required
    - Ttractive force
    - Tipping angle
    - ...

- Too many designers put-off analysis until its too late. Detailed Analysis must be done prior to “Freezing the Design”
- Always check your solutions to see if they pass the “Sanity Check”, using your Engineering Sense & Knowledge

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Analysis: Geometry, Time, & Motion

- The contest only lasts for N seconds, so do you have the time (and the power!) to do what is needed?
  - Maximum motor power is generated at ½ the motor’s no-load speed!
- A simple spreadsheet can help answer these questions
- Check out gearmotor_move.xls and its discussion in Topic 7
  - Those who succeed in design are usually explorers…!

\[ D = \frac{a_{\text{max}}}{2} \left(\frac{t_a}{3}\right)^2 + \left(\frac{a_{\text{max}} t_c}{3}\right) \left(\frac{2 t_c}{3}\right) + \frac{a_{\text{max}}}{2} \left(\frac{t_d}{3}\right)^2 \]

\[ a_{\text{max}} = \frac{9D}{2t_c^2} \], maximum acceleration (m/s² or rad/s²)

\[ v_{\text{max}} = \frac{3D}{2t_c} \], maximum velocity (m/s or rad/s)

Curves based on voltage control to motor

Thermal duty cycle (TDC)

Most useful operating region

Maximum power

Maximum efficiency

Power

Efficiency

\[ X_{\text{car}} = F_{\text{max}} \left( \frac{M}{t} \cdot \frac{1}{2} \right) + \frac{s}{M}^2 + \frac{s}{M}^3 + \frac{1}{3!} \cdot \frac{s}{M}^4 + \ldots + \frac{1}{s^2} \cdot \frac{M}{t} \]

\[ X_{\text{car for } a/M << 1} \approx \frac{2M}{F_{\text{max}}} \]
Analysis: *Energy, Momentum, Mass, & Strength*

- **1st check for the feasibility of a design: Is available Power\textsubscript{available} > Power\textsubscript{required}?**
  - Example: Can I raise the pendulum through a 30 degree arc in 1 second using energy stored in constant force springs?

- **2nd check for the feasibility of a design: Is \( \sigma\_\text{yield} > \text{applied stress} \) i.e., is FOS > 1 ?**
  - Example: Can I hold M kg extended out L m on a telescoping truss with H m cross section made from D mm welding rod?

- It is a good idea to be aware of the physical capabilities of the kit materials, and the physical requirements of the scoring methods…

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Creating Ideas

Concepting

Topics

• Creation: Coarse-to-Fine
• Thought Processes
• Experimentation
• Drawing
• Research
• Writing
• Analysis
• Evolving Ideas

“Curiosity is one of the permanent and certain characteristics of a vigorous mind” – Samuel Johnson
Evolving Systems

- Individual Thought
- Peer Review
- Brainstorming
- Comparing Designs

1998’s Ballcano!

Colin Bulthap
Evolving Systems: Individual Thought

- **Individual thought is often the most creative**
  - Do leisurely things (e.g., long walks) that inspire creative thought
  - Look at what other people have created
    - Look in your home, stores, www, patents
  - Get out of traffic and take alternate routes
  - Sketch ideas and the ideas’ principal components
  - Cut out the principal components and pretend they are modular elements
    - Like toy building blocks, try different combinations of components to make different products
  - Pit one idea against another and imagine strategies for winning
    - Take the best from different ideas and evolve them into the best 2 or 3 ideas

- **Group Brainstorming is often the most effective for Concepting Alternatives**

- **Update the FRDPARCC table and create a Milestone Report or Press Release for your favorite ideas**
  - The FRDPARCC Table (ONE DP per FR) and a large annotated sketch makes an effective infomercial
    - A random person should be able to read your press release and fully understand your idea without your having to explain it to them
    - These sheets will be shared with your teammates in the next stage…
Peer Review Evaluation Process:

- There is no such thing as just an individual/teams are made up of individuals
- Any design process must make the best use of resources: individuals and teams:
  - Give individuals pride of ownership:
    - Privately (think & create on their own, AND constructively evaluate the work of others)
  - Maximize the efficiency and effectiveness of teams and reduce apathy:
    - Do not have brainstorming meetings unless everyone is PREPared
      - Individuals must have thought of ideas and reviewed each other’s ideas beforehand
      - Peer pressure will help correct non-performers and nay-sayers and reduce apathy
Evolving Systems: Group Brainstorming

- Brainstorming helps teams solve personal creativity deadlocks and help to ensure something hasn't been overlooked
- Initially let everyone voice their suggestions, then distill ideas
- Group personality factors must be considered:
  - Shy individuals getting run over
  - Aggressive individuals always driving
- An individual's personality often has nothing to do with creativity
  - Careful to avoid conflicts over the issue of who first thought of the idea
  - The people in the group must be willing to take praise or scolding as a group
  - NO pure negatives, only observations with suggestions for improvement:
    - “That design sucks!”
    - “I see a low pressure region that can be alleviated by making it blue”
Evolving Systems: *Comparing Designs (DMMs)*

- There are many methods available for evaluating design alternatives
  - The simplest method is a linear weighting scheme:
    - You may want to use the list of FRs as the evaluation parameters
      - Apply a relative importance weight to each evaluation parameter
    - Pick one design as a “baseline” (all zeros), and compare the rest (+ or -)
      - Easiest to use provided user bias can be minimized
    - When you find the “best” design, look at other designs and see how the + characteristics can be transferred to the “best” design to make it better!
      - A “Pugh” chart is similar, except that it does NOT use the weighting column!
  - A linear weighting scheme (+, -, 0 wrt a baseline design) will give equal weighting to attributes

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Intellectual Property

- **www.uspto.gov** has lots of useful information, e.g.,:
  - Under the Paris Convention for the Protection of Industrial Property, a treaty that provides a number of important rights for innovators, a patent applicant may file an application in one Paris Convention member country (the priority document), and within 12 months, file corresponding applications in other member countries, while obtaining the benefit of the first application’s filing date. This 12-month period allows applicants to make important decisions about where to file subsequent applications to seek protection for their inventions. Paris Convention filings are a critical component in many applicants’ global business and patenting strategies and represent a substantial portion of worldwide patent activity.
Professional & Personal Ethics and Moral Standards

• Professional ethics:
  – Work hard and try to help create an environment where others can also do their work
  – Practical jokes and humor at the expense of others are never in good taste
  – If you see a problem, try to offer help and do not turn a blind eye
  – Always try to offer constructive criticism: end each statement with a +
  – Document what you do, and if a problem is discovered, keep raising it until it is addressed.

• Personal ethics and Moral Standards
  – Assume what you do and your name will be on the front page of the newspaper…
  – Treat others with the same respect as you would like to receive
    • Brush your teeth, beware others’ personal space…
  – Romance in the office can work, but ask what will happen if it ends…
    • Be discrete, perhaps ask a friend to enquire…NO means NO!
  – There should be no direct supervisory role, and not working on the same project
    » Check company policy and tell your boss ASAP!

Look for happiness all around, and if you do not find it, create it!
Safety

• It should be obvious:
  – WEAR EYE AND EAR PROTECTION!
  – We each only have one set of body parts and one life to live
  – We all need to look out for each other

• The RISK column of FRDPARRC is also used to identify potential safety issues

• Humans are often defensive, and people will often make up what sounds like a reasonable excuse to justify their poor decision
  – It starts with kids:
    • “Dude, isn’t it dangerous to hold the pipe and fill it with match heads?”
    • “Nah, if the match heads start to go off, I will just throw the pipe away before it explodes”
  – It does not always end with adults:
    – “I am going to help my kid and his friends build a PVC potato canon like they saw on TV”

• Do for others as you would have them do for you
Evolution: *It Never Stops*

- Physically experimenting with the hardware while thinking about all possible variations can produce many creative ideas
  - Sketching, drawing, and solid modeling are powerful creativity catalysts
  - Much has been done by others: Learn from others’ failures and successes
  - Writing down your thoughts and dreams can help you to see solutions
  - Analysis can identify areas of high (low) sensitivity and rapidly ascertain feasibility
  - Ideas can evolve rapidly when they are compared to others

- **Stay Psyched and Passionate!**
- **Never Stop!**
Deterministic Design: Disruptive Technologies

- 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

Hyoseok Yang

1995’s Pebble Beach!
Sami Busch

1996’s Niagara Balls!

1997’s Pass The Puck!
Tim Zue

1998’s Ballcano!
Colin Bulthap

2001’s Tiltillator!
Kevin Lang

2000’s Sojourner This!
David Arguellis

1999’s MechEverest!

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