Reverse Engineering

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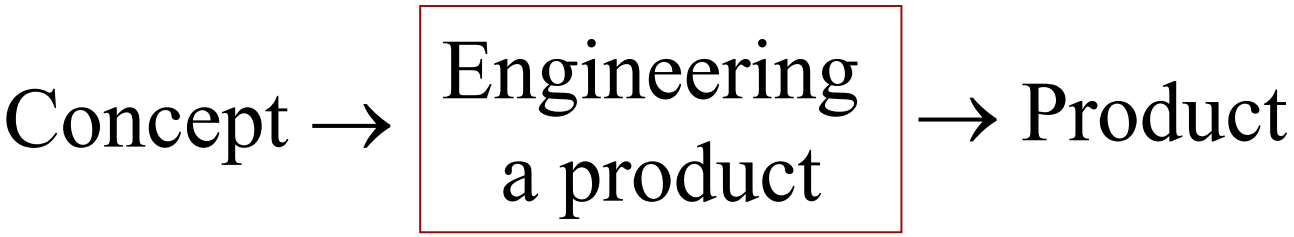
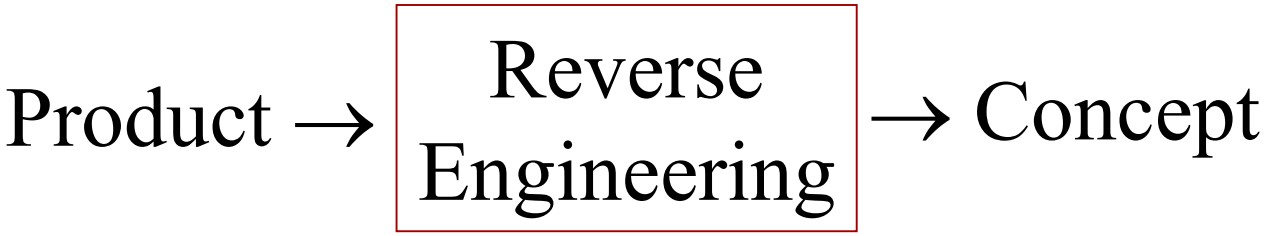
Khul Ja Sim-Sim

Forward Engineering



Reverse Engineering



Reverse Engineering

"Examining competitive or similar or prior products in great detail by dissecting them or literally taking them apart."

- Dym & Little

"How does it do that?"

"Why would you want to do that?"

Why Reverse Engineering?

“Sometimes, the best way to advance is in reverse,” By Eldad Eilam

What is a Product?

In general, the product is defined as

- a "*thing produced by labor or effort*" or
- the "*result of an act or a process*"

Example: Fan, Computers, Software, Pen, Clock, Bottle etc.

Who make product?

- Entrepreneurs
- Engineers
- Designers
- Students
- …

Why make product?

- Earn money
- Get recognition
- Social service
- Personal satisfaction
- …

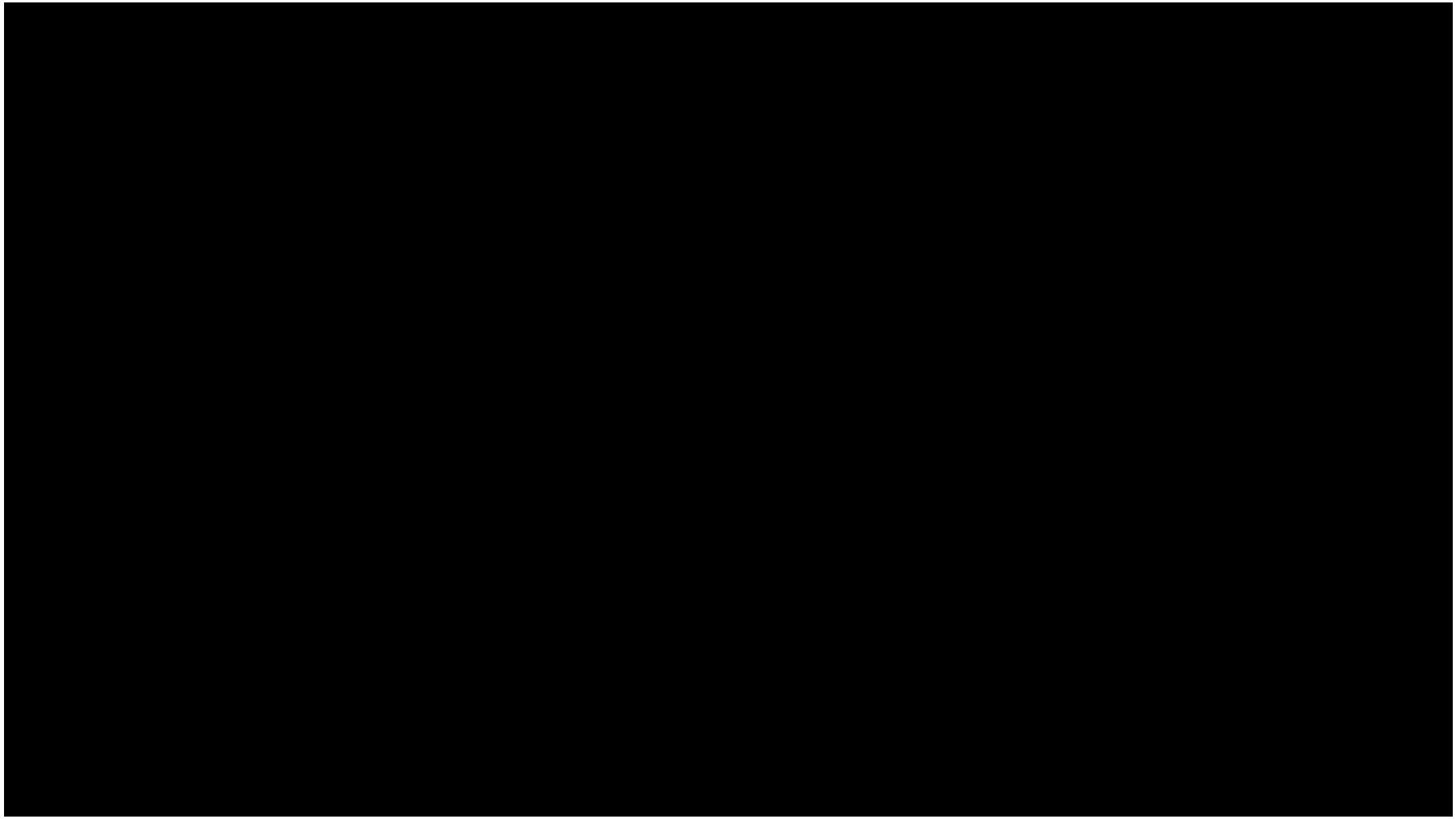
Startup company by IIT students

- Company name: IdeaForge
- NETRA is a completely autonomous Unmanned Aerial Vehicle – for Intelligence, Surveillance and Reconnaissance of moving and fixed targets.
- NETRA streams you real time video of the target area with spotless clarity.
- Helped Nepal during Earthquake, saved many life
- Initially struggled, lots of failure in designs

Unmanned aerial vehicles are the best way to access risky terrain, especially cracked buildings during an earthquake. Here rescue officials are inspecting a ramshackled building in the 2015 Nepal earthquake. Image: ideaForge

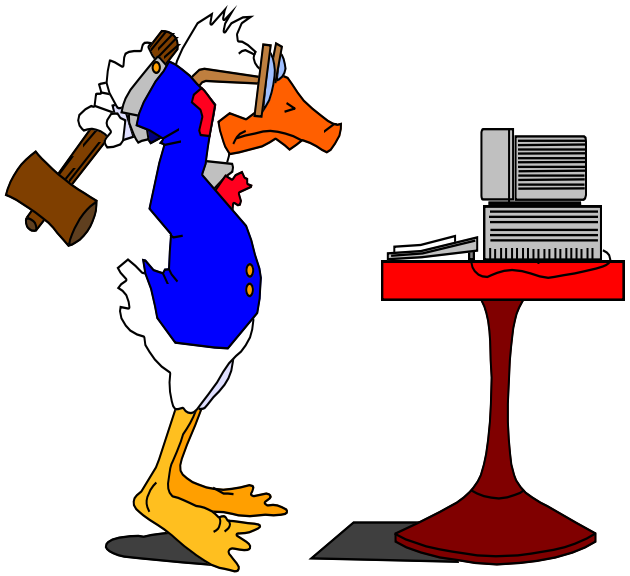
Video

If you want to design a bird like machine, you have to study the bird first



Reverse Engineering

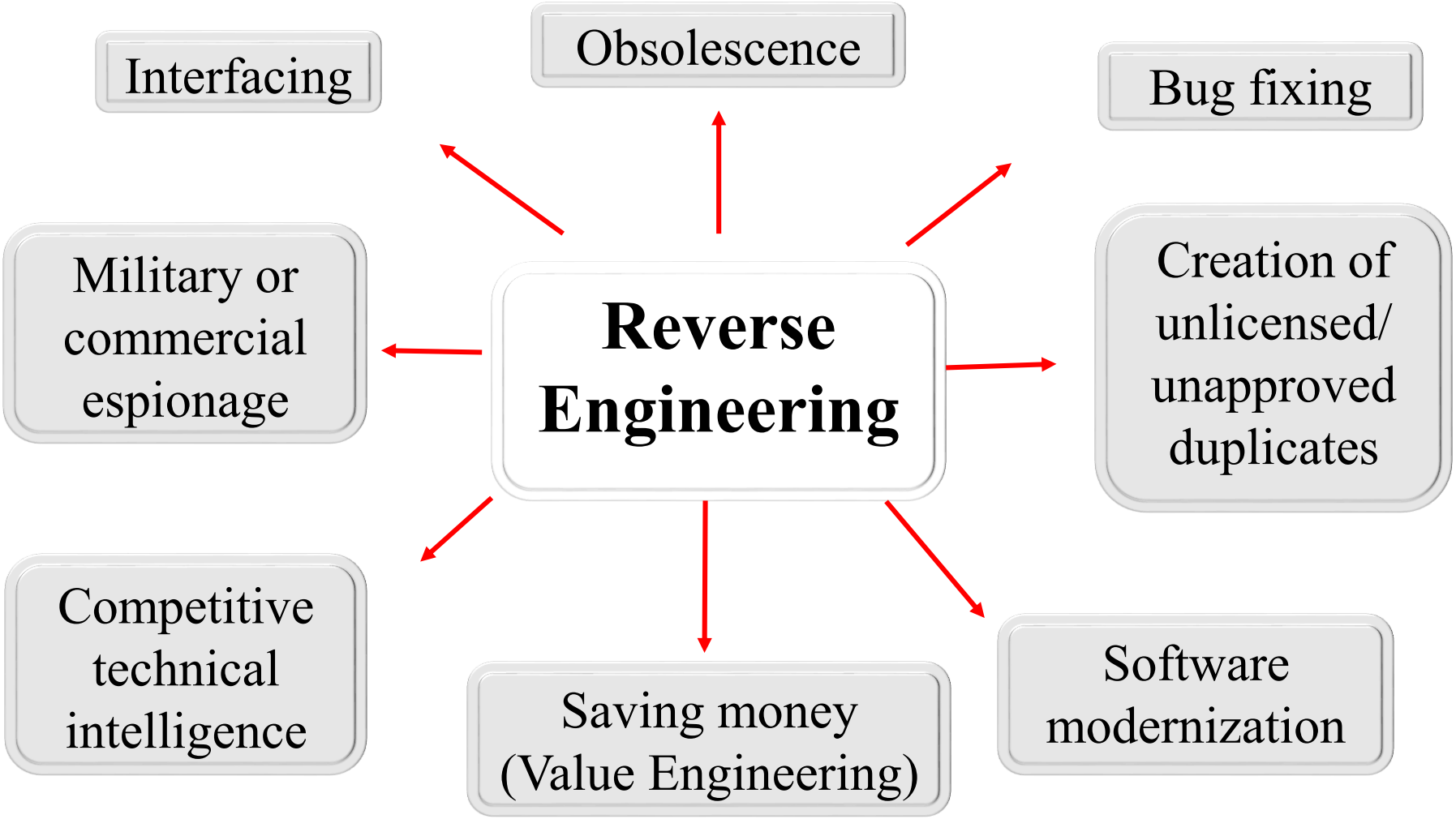
Gain insight into our own design problem by looking at how other people have addressed the same issues.



Restrictions:

- Expensive designs
- Protected by copyrights and patents
- May be the competitor's design
- Design may not work very well
- Design may be copied, difficult to copy knowledge

Reasons for reverse engineering



Reasons for reverse engineering a part or product:

1. The original manufacturer of a product no longer produces a product
2. There is inadequate documentation of the original design
3. The original manufacturer no longer exists, but a customer needs the product
4. The original design documentation has been lost or never existed
5. Some bad features of a product need to be designed out. For example, excessive wear might indicate where a product should be improved
6. To strengthen the good features of a product based on long-term usage of the product
7. To analyze the good and bad features of competitors' product
8. To explore new avenues to improve product performance and features
9. To gain competitive benchmarking methods to understand competitor's products and develop better products
10. The original CAD model is not sufficient to support modifications or current manufacturing methods
11. The original supplier is unable or unwilling to provide additional parts
12. The original equipment manufacturers are either unwilling or unable to supply replacement parts, or demand inflated costs for sole-source parts
13. To update obsolete materials or antiquated manufacturing processes with more current, less-expensive technologies

Reverse Engineering for military applications

World war II: **Jerry can**

- British and American forces noticed that the Germans had gasoline cans with an excellent design.
- They reverse-engineered copies of those cans

Reverse Engineering for military applications

World war II: **Panzerschreck**

- The Germans captured an American Bazooka during World War II, and reverse engineered it to create the larger Panzerschreck.
- See how the need of mask removed in improved design

Original design: American

Improved design: German

Reverse Engineering for military applications

World war II: **Tupolev Tu-4**

- Three American B-29 bombers on missions over Japan were forced to land in the USSR.
- The Soviets, who did not have a similar strategic bomber, decided to copy the B-29.
- Within a few years, they had developed the Tu-4, a near-perfect copy.

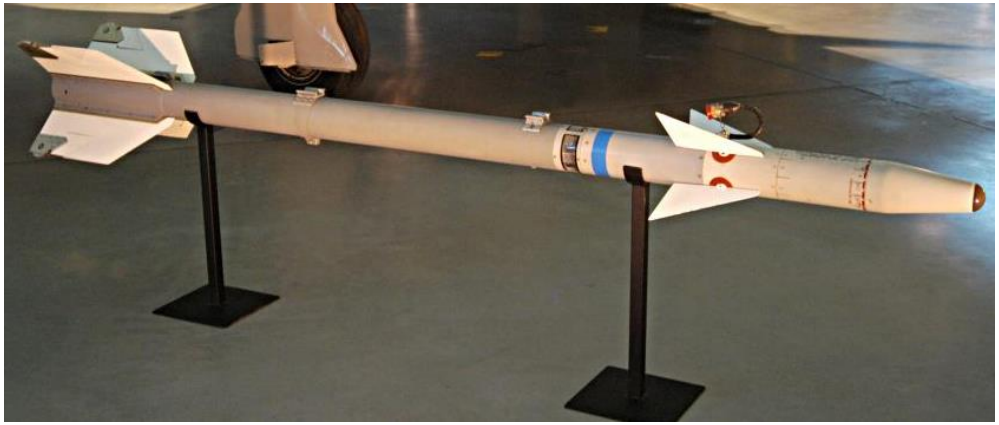
B-29 bombers: American

Tupolev Tu-4: Russian

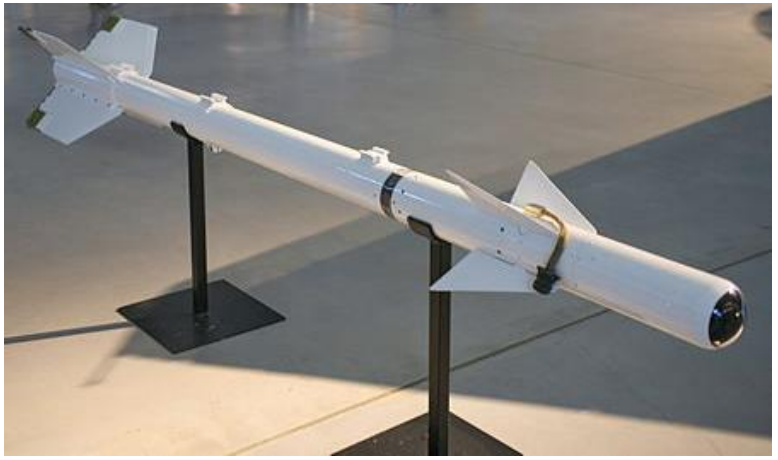
Reverse Engineering for military applications

World war II: **K-13/R-3S missile**

- Soviet reverse-engineered copy of the AIM-9 Sidewinder, was made possible after a Taiwanese AIM-9B hit a Chinese MiG-17 without exploding. The missile became lodged within the airframe, and the pilot returned to base with what Russian scientists would describe as a university course in missile development.

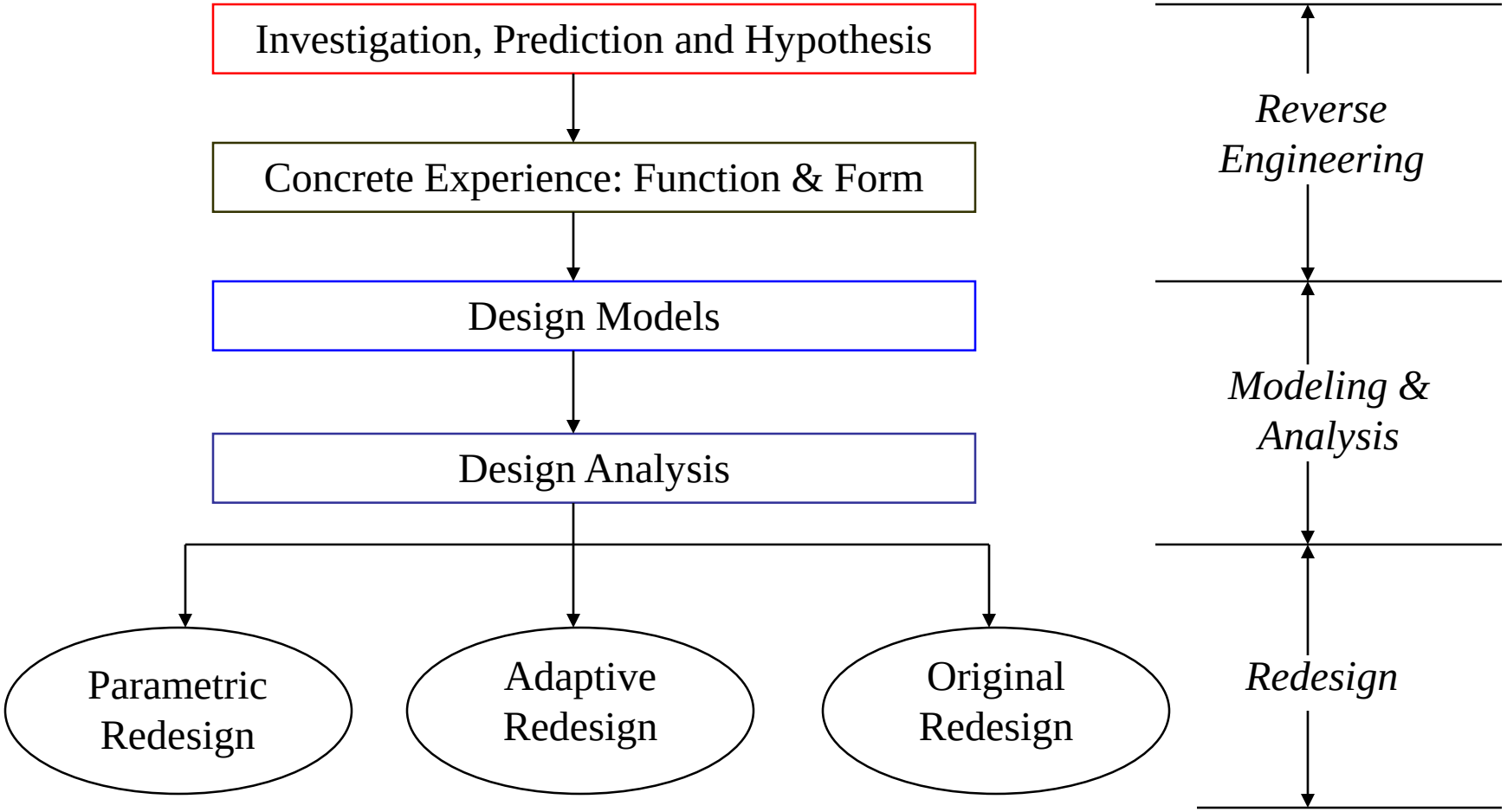


An AIM-9E Sidewinder missile on display at the National Air and Space Museum



K-13: Short-range, infrared homing air-to-air missile developed by the Soviet Union

Product (re)design begins with Reverse Engineering Methodology



Adapted from Otto and Wood's "Reverse Engineering and Redesign Methodology" UT Austin

Reverse Engineering Methodology

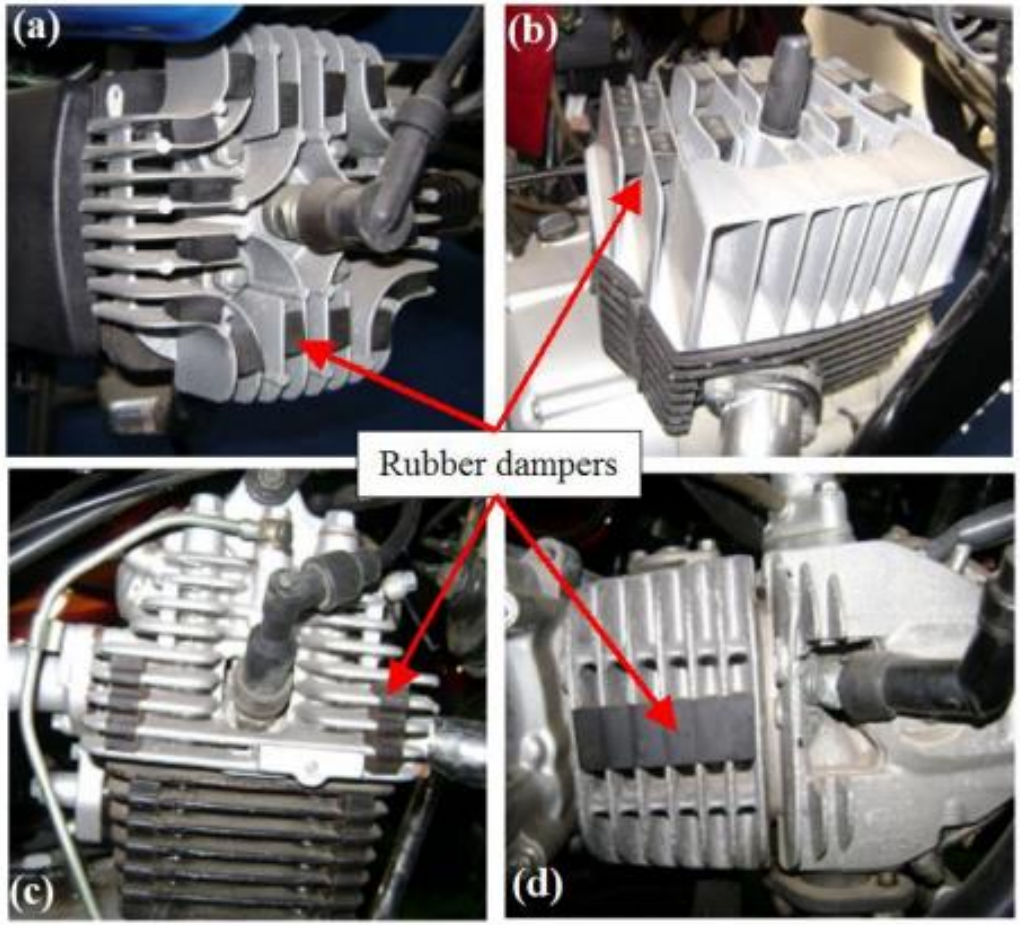
1. Investigation, Prediction and Hypothesis

- Develop black box model
- Use / Experience product
- List assumed working principles
- Perform economic feasibility of redesign
- State process description or activity diagram

Segment 1:

Selected crash tests

Example

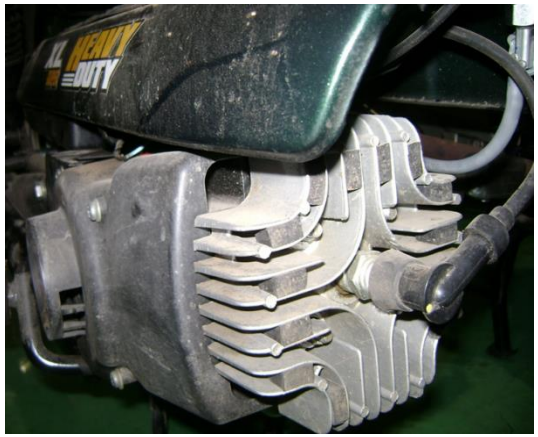


XL Super, heavy duty, 95% market share, 15 year old engine

Engines from different automotive companies

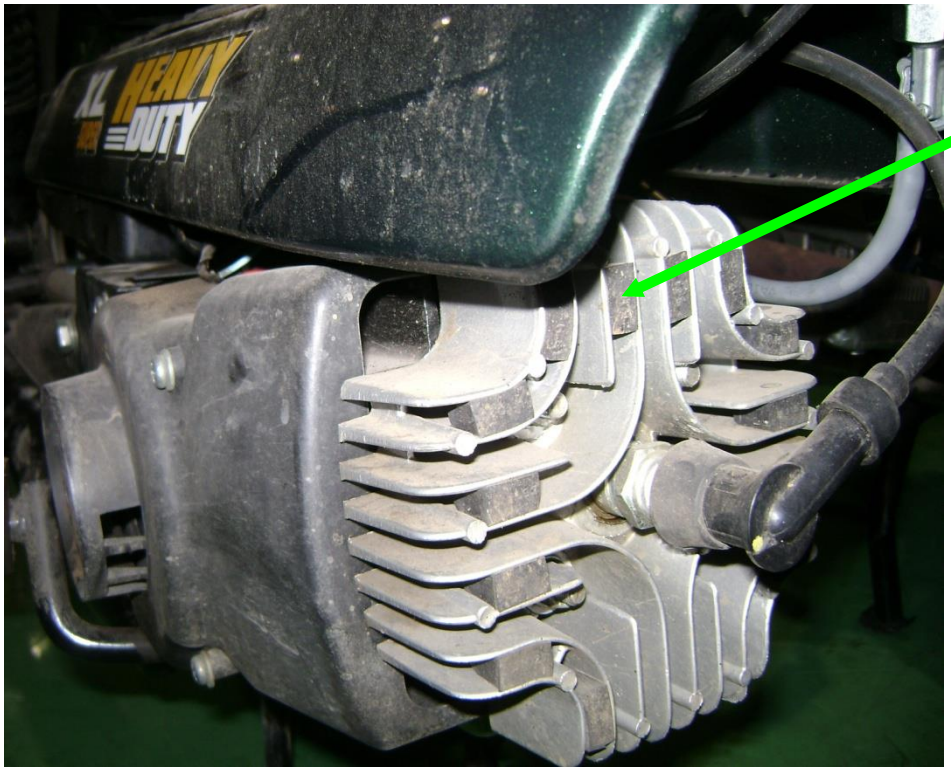
Rubber dampers

- Rubber dampers are provided between the fins to reduce their vibration
- High vibration of fins produces undesirable noise.
- Undesirable noise leads to customer dissatisfaction.
- Proper design of the fins are necessary
- Rubber dampers add extra cost to the vehicle



Two-wheeler engine head

TVS Moped Engine

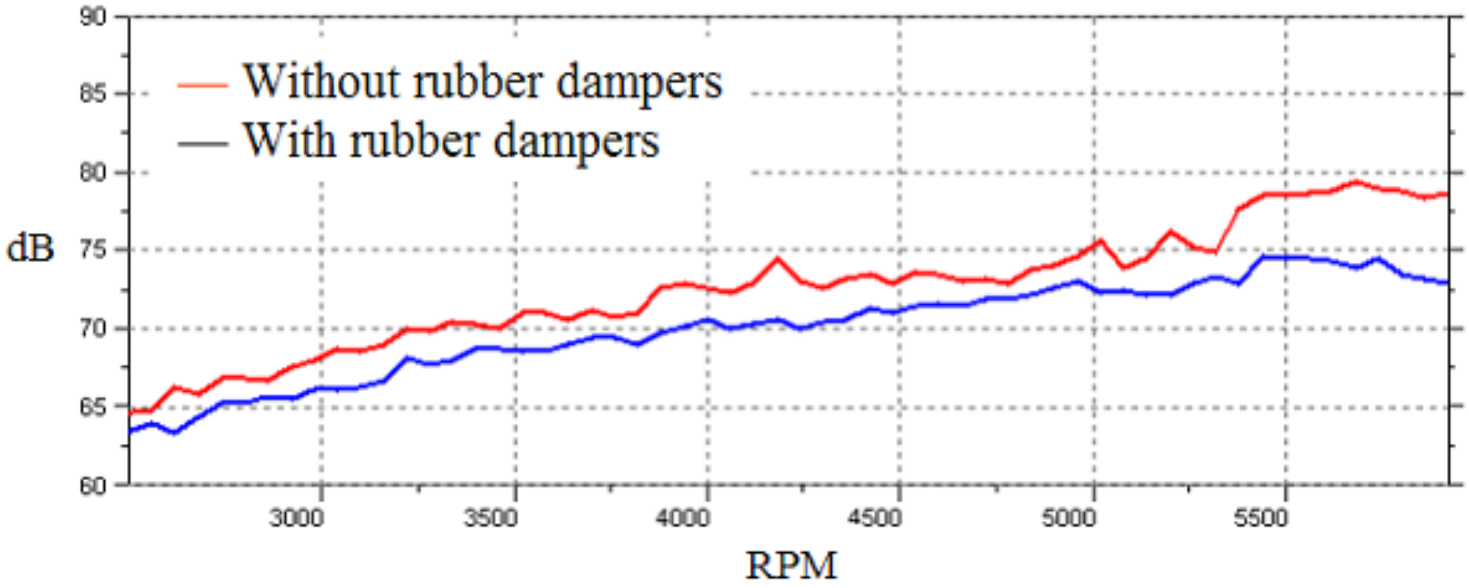


Rubber dampers

- Reliable engine: > 15 years in the market
- Holds 95% market share in moped class
- Lakhs of satisfied customers
- 16 dampers on the cylinder head.

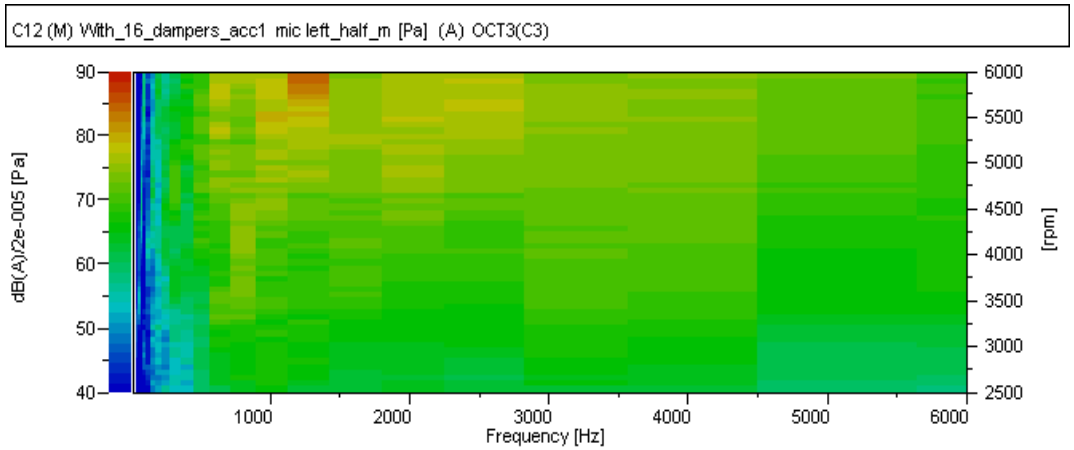
If dampers are removed, the new cylinder head should have noise level equal to or better than the existing cylinder head !!!

Radiated noise with and without rubber dampers

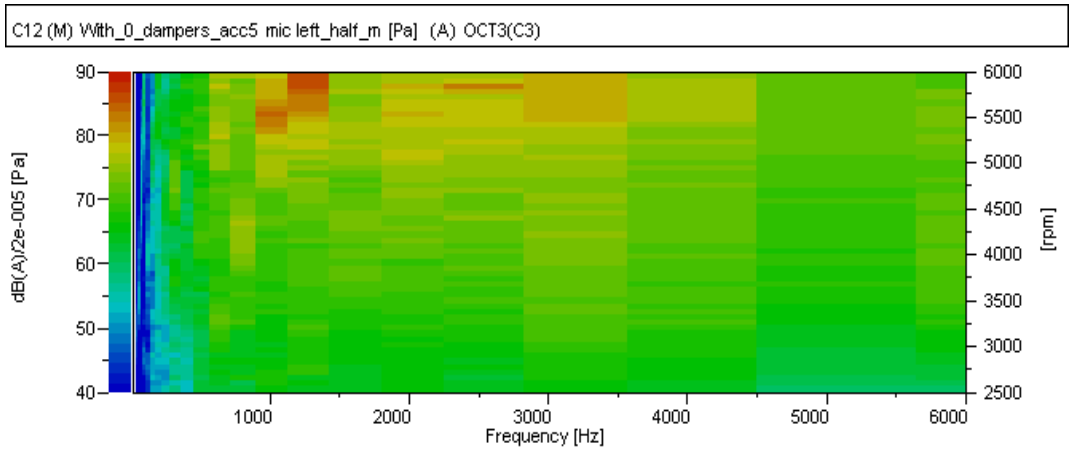


Comparison of noise radiated from the engines with and without rubber dampers on the cylinder head at 3150 Hz.

Experimental verification…



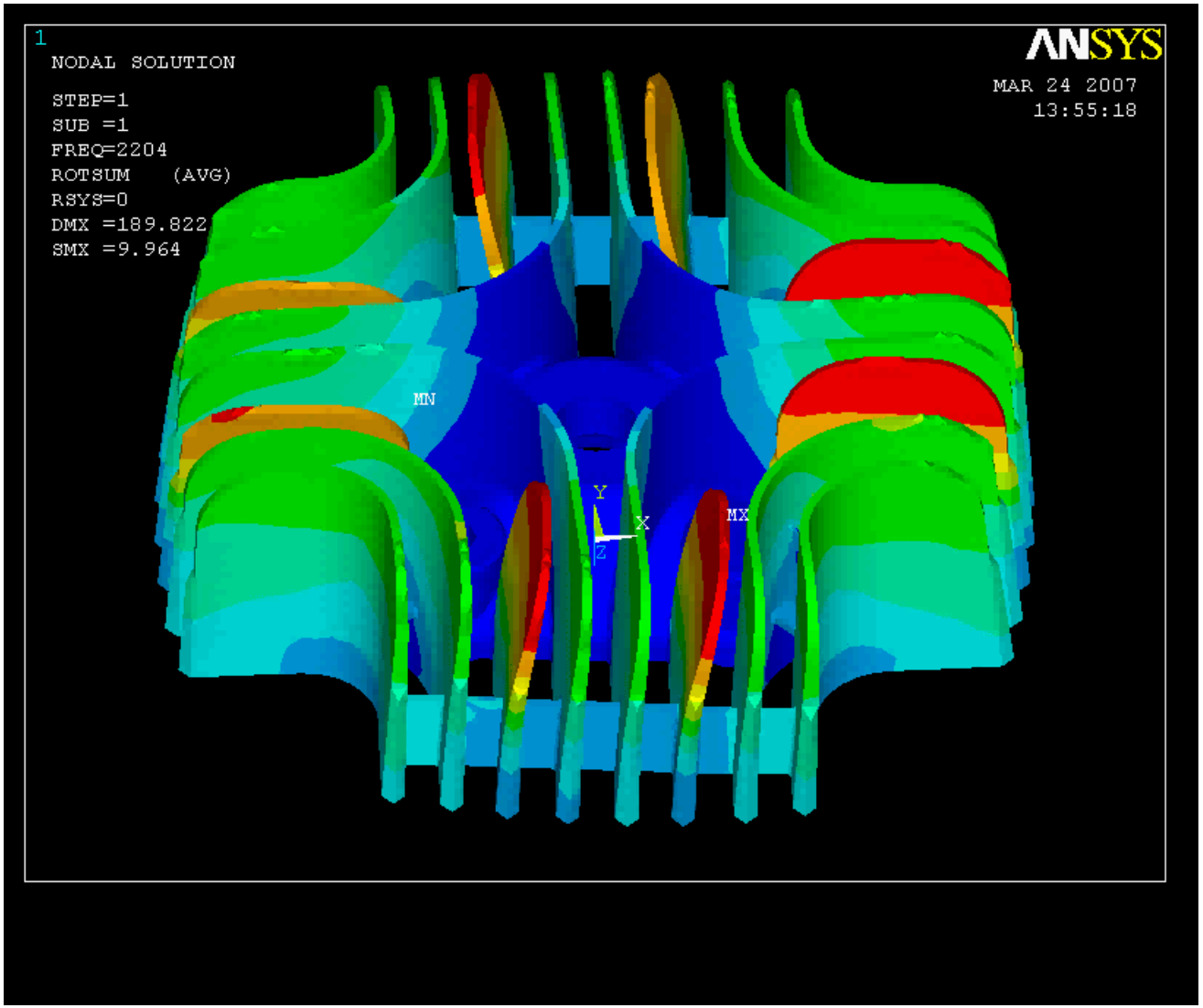
All 16 dampers in place



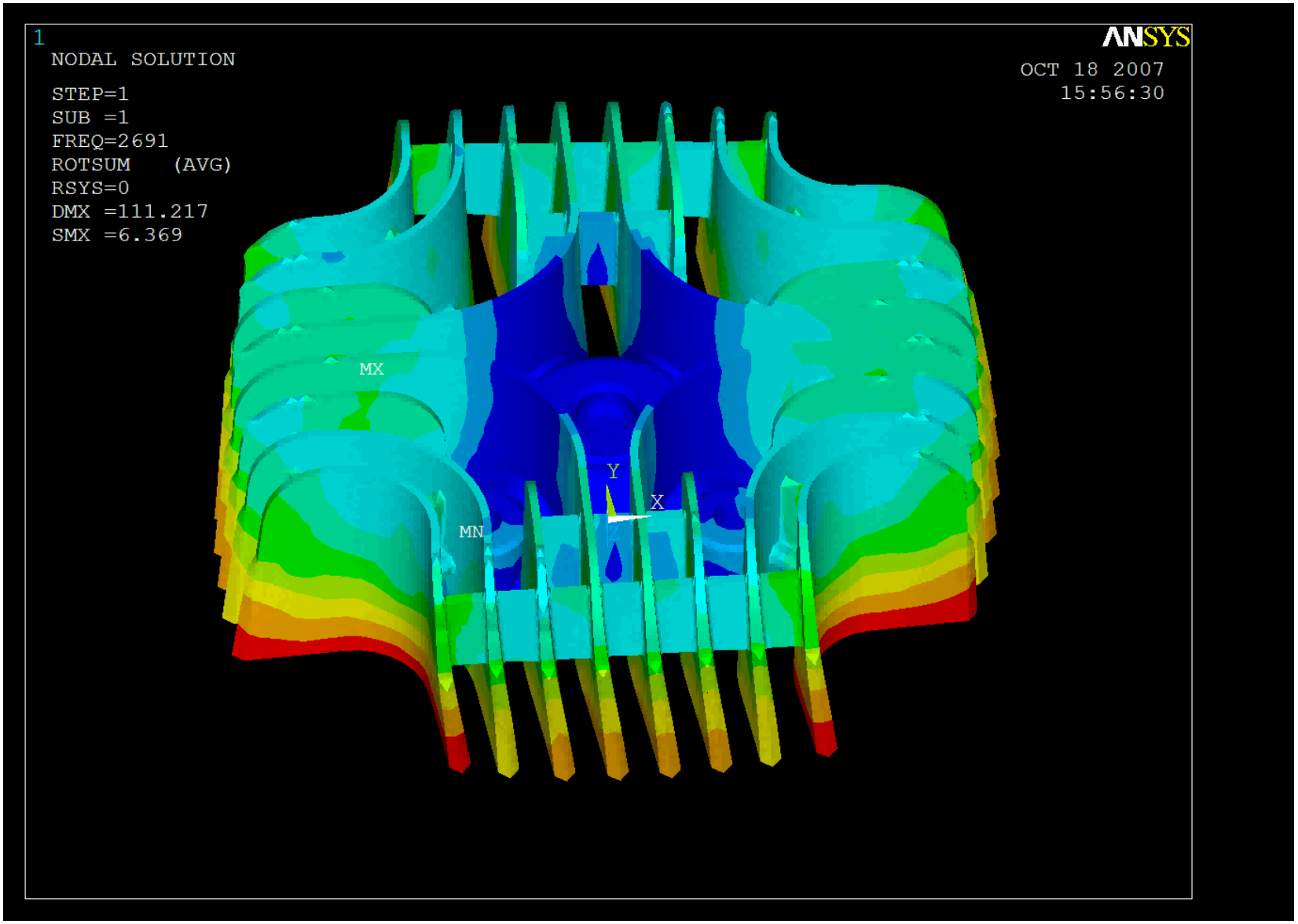
All 16 dampers removed

- Campbell diagram during gradual acceleration
- Noise levels have spread and are higher in magnitude in the 2nd case

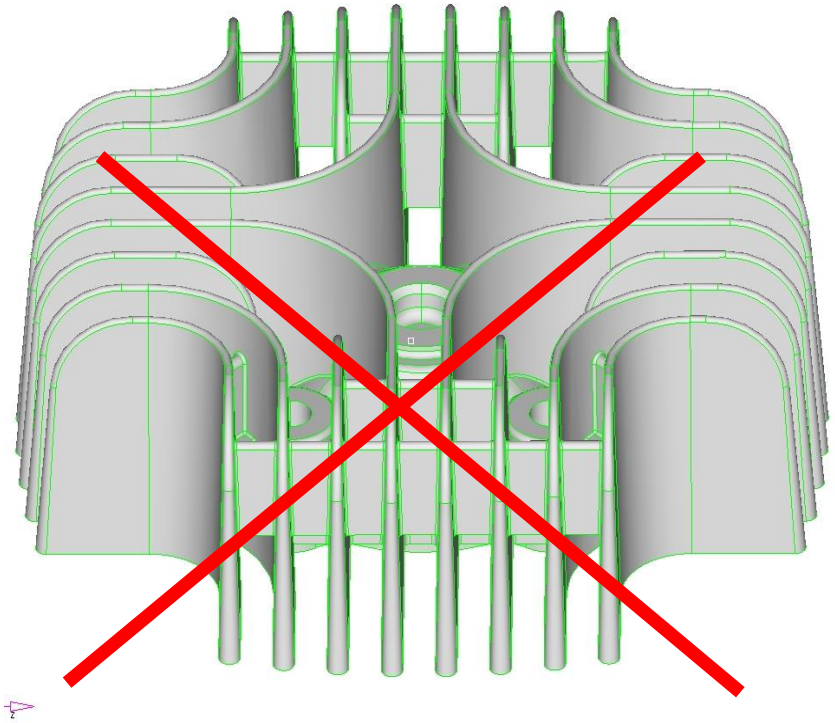
Existing cylinder head



Modified cylinder head

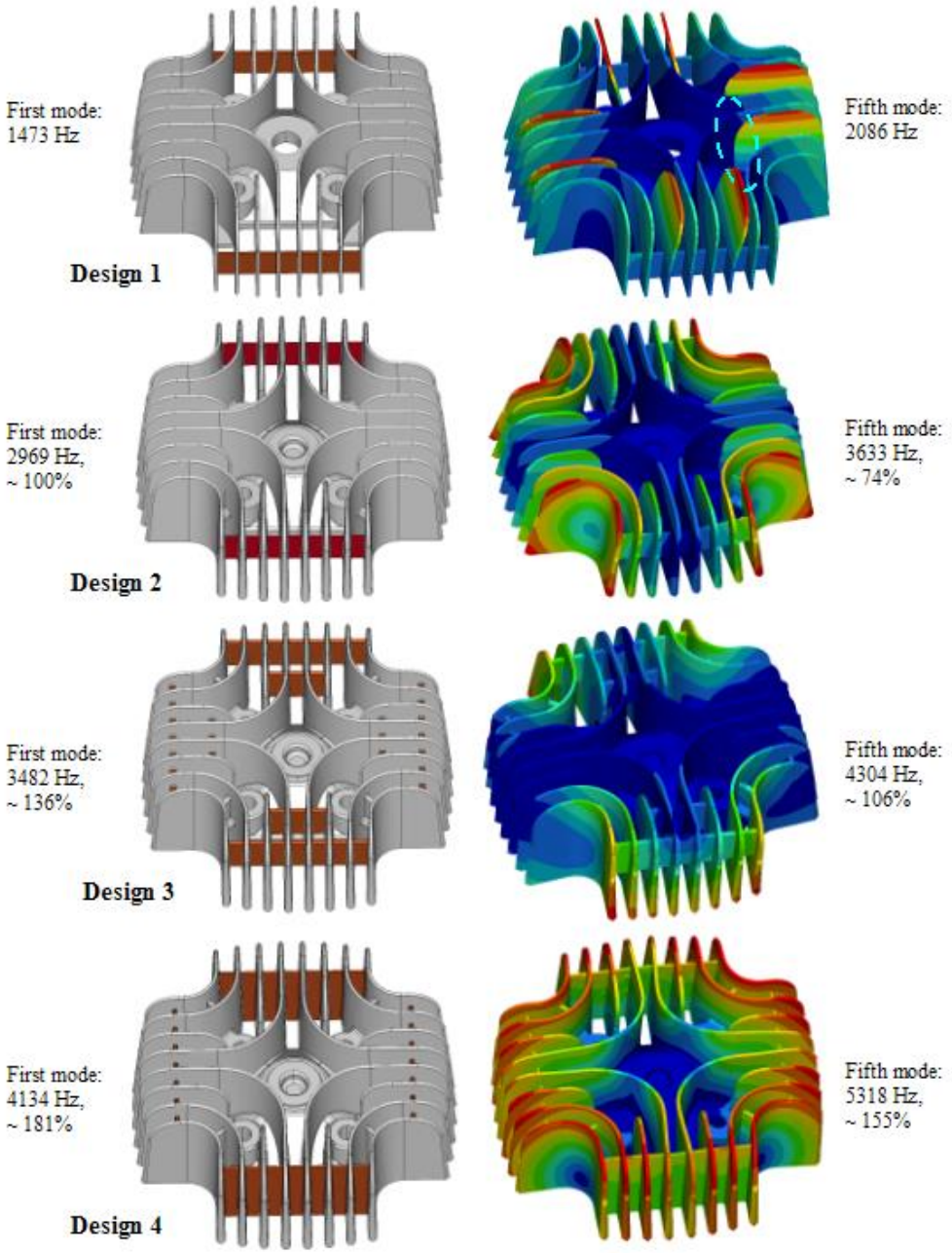


It was observed that the new head design may not be feasible from manufacturing point of view



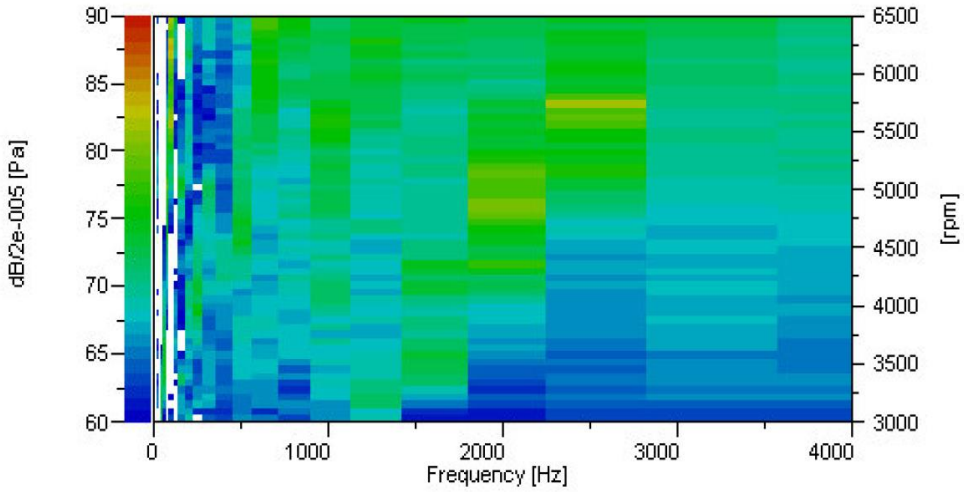
2nd stage cylinder head

Further design changes and analysis

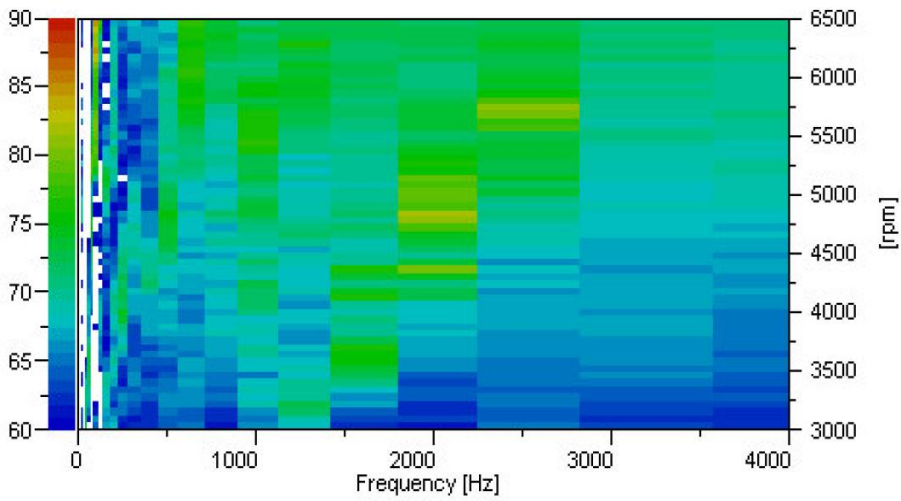


Experimental verification: Campbell diagram

Existing head with rubber dampers

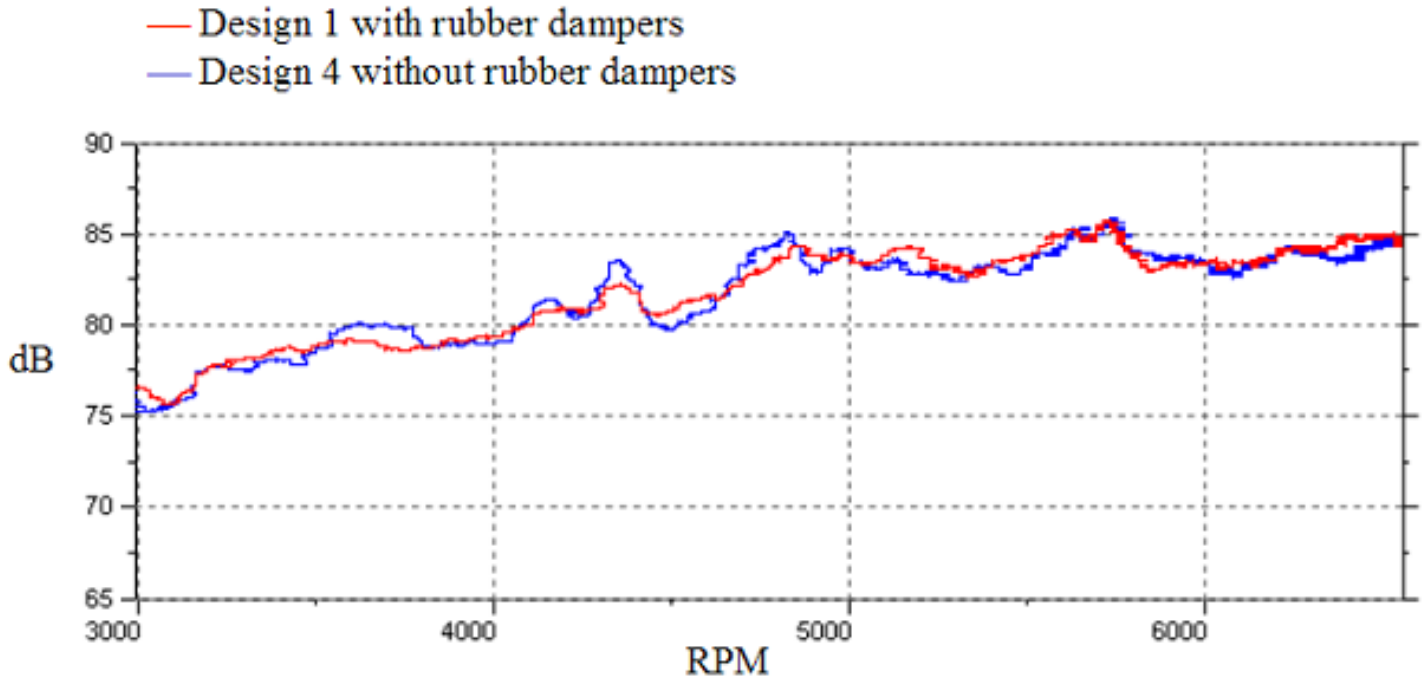


3rd stage head without rubber dampers



- Similar Campbell diagram in both the cylinder head
- 3rd stage cylinder head can replace the existing cylinder head

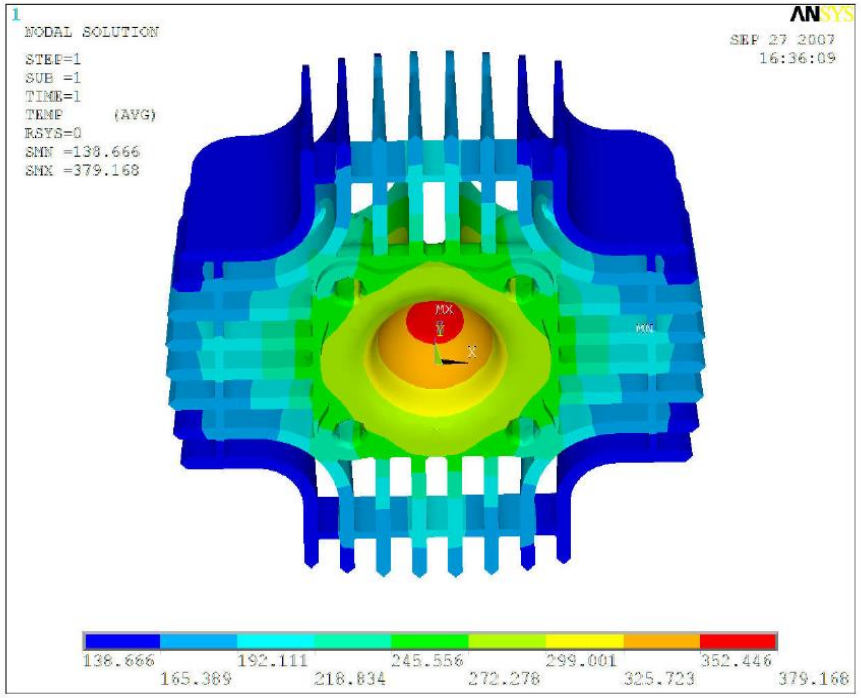
Noise level comparison



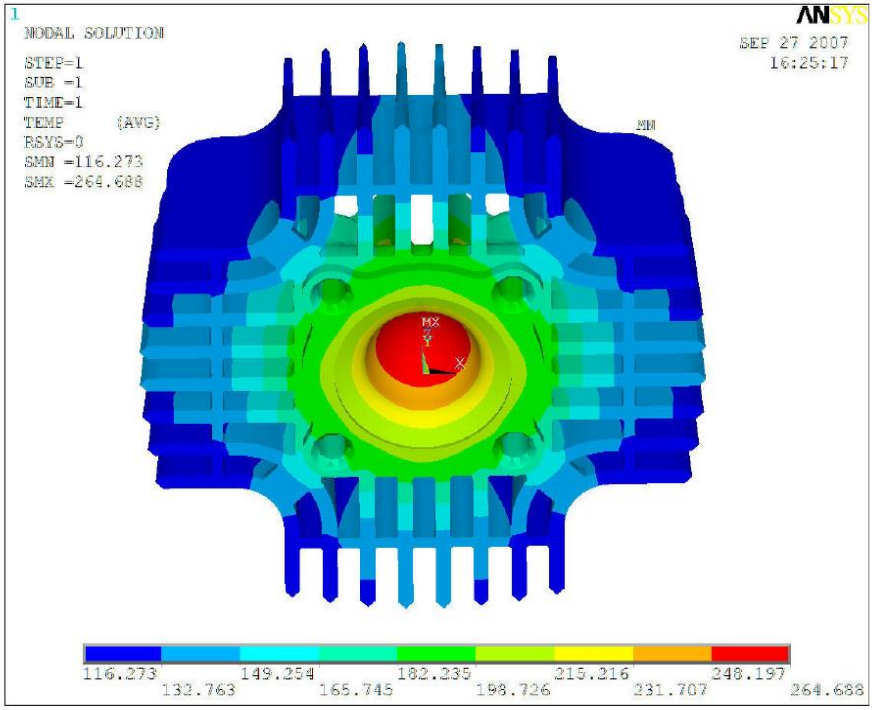
Computational Fluid Dynamic analysis

Temperature distribution

1st stage cylinder head



3rd stage cylinder head



- 3rd stage cylinder head shows lower temperature on the fins and in the
- combustion chamber compared to the 1st stage design of the head
- This is experimentally verified
- 3rd stage design without rubber dampers is implemented on the vehicle for mass production

Costs and environmental impact

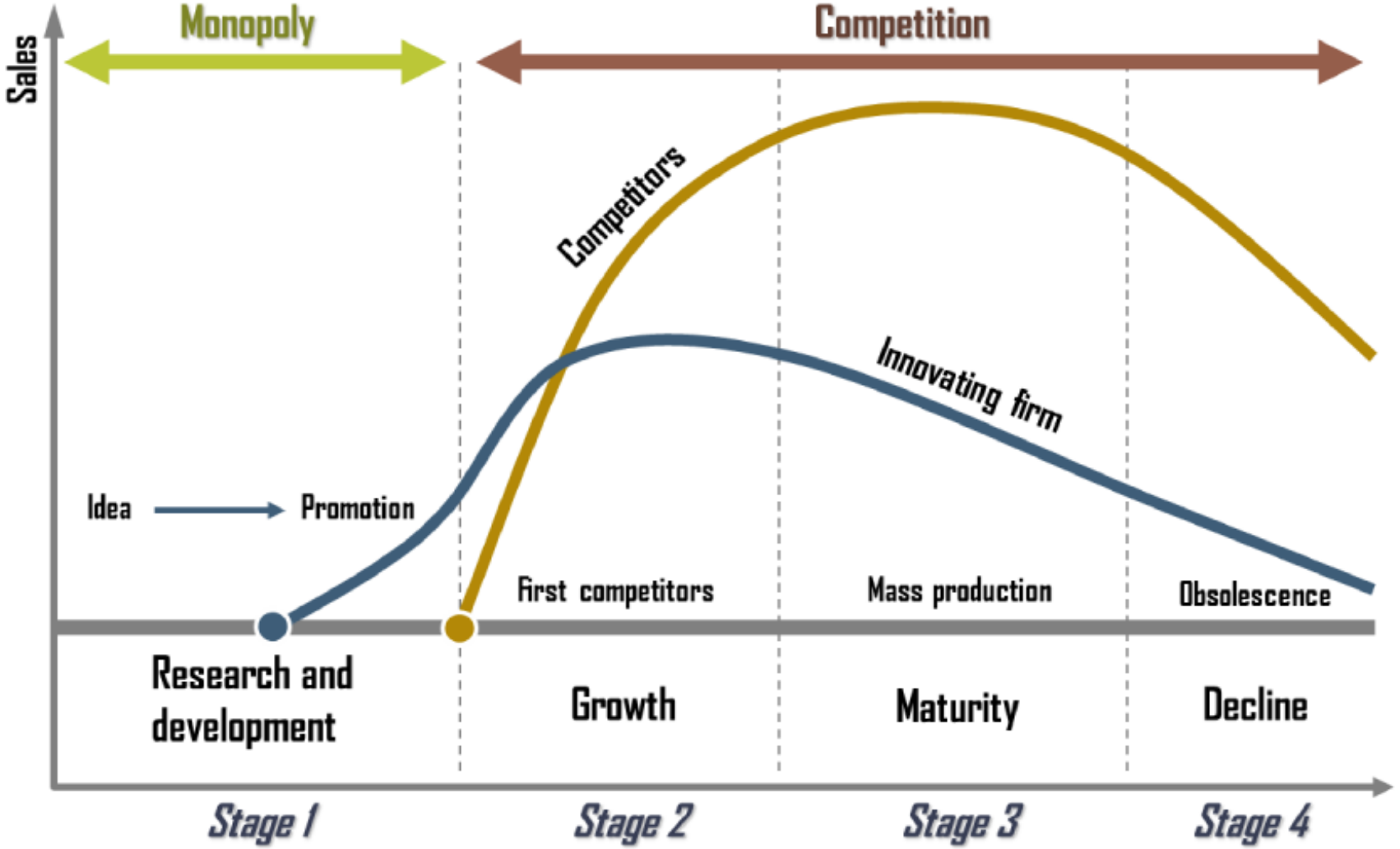
- **Among many benefits, few advantages are listed below**

1. Rubber damper manufacturing process is eliminated completely; rubber production is harmful to the environment
2. Long term benefits; over a period of time typically after six months of use, rubber dampers properties deteriorates and it becomes brittle due high temperature of the fins. The initial grip between the dampers and fins reduces and finally these dampers come off the engine. The noise radiated from the engine increase again. Hence, putting rubber dampers on engines does not provide long-term benefits,
3. Logistics and inventory reduction; logistics of dampers involves the integration of information, transportation, inventory, warehousing, material handling, and packaging,
4. Man power saving; since rubber dampers are not an integral part of the engine, additional workman are needed to hammer down the rubbers between the fins
5. Part count reduction; rubber dampers are additional parts that needs to put on the engine before integrating on the vehicle and hence increases the number of part count of the engine,
6. Improves engine cooling; rubber dampers restricts the free flow of air around the engines and hence increases the overall engine temperature.

Life cycle cost benefit

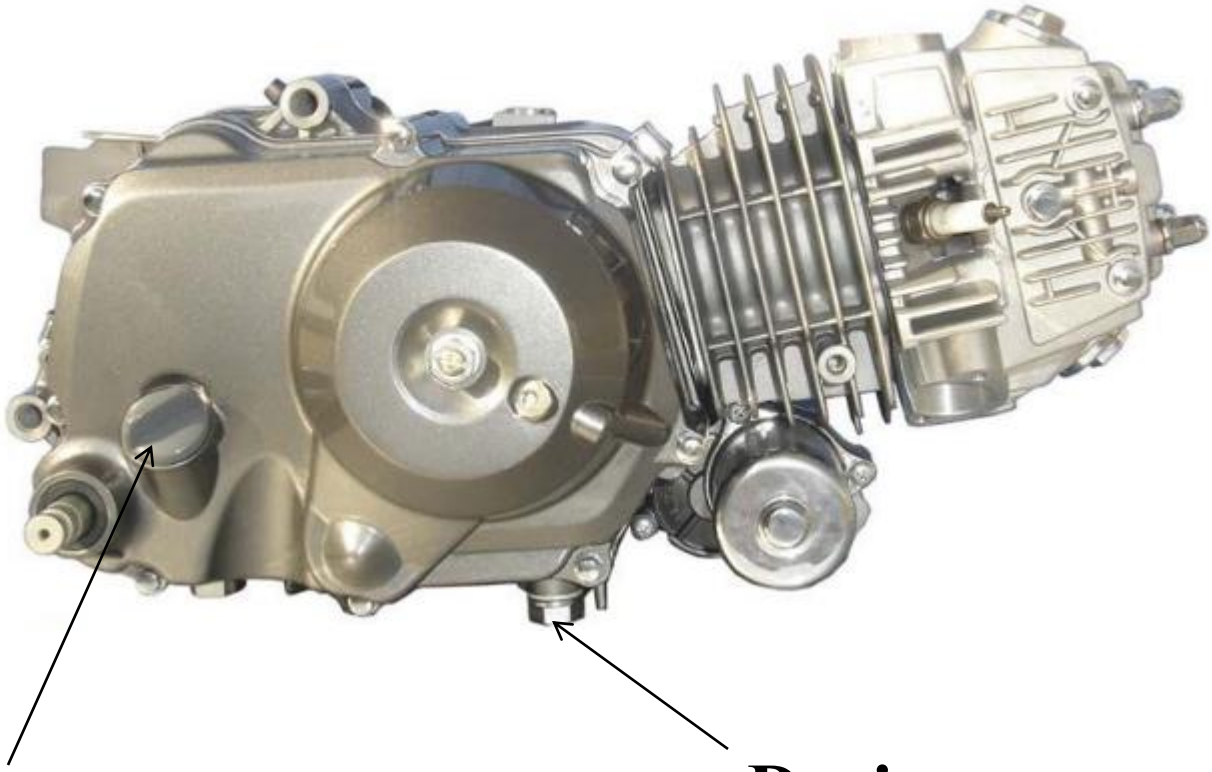
Each rubber damper cost	= Rs. 1
Total cost dampers	= 16 x 1 = Rs. 16
Additional benefit	= Rs. 4
Total saving	= Rs (16 + 4) = Rs. 20/vehicle
Sales	= 70,000 vehicles/month
Benefit/month	= Rs 20 x 70,000 = 14 Lakh/month
Benefit/year	= 12 x 14 lakh = 1.68 Crore/year
Life cycle benefit	= 10 x 1.68 crore = 16.8 crore

Product life cycle: Competitors upper hand



Example

Engine Oil consumption measurement

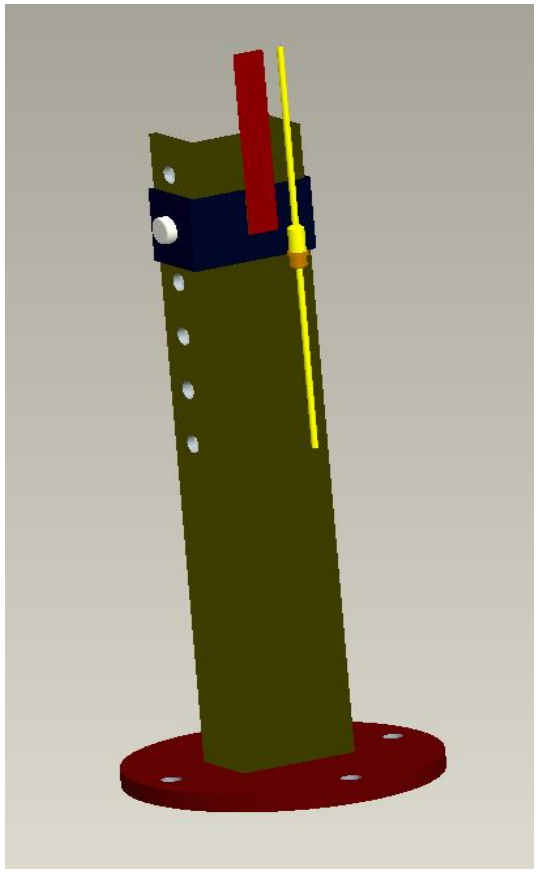


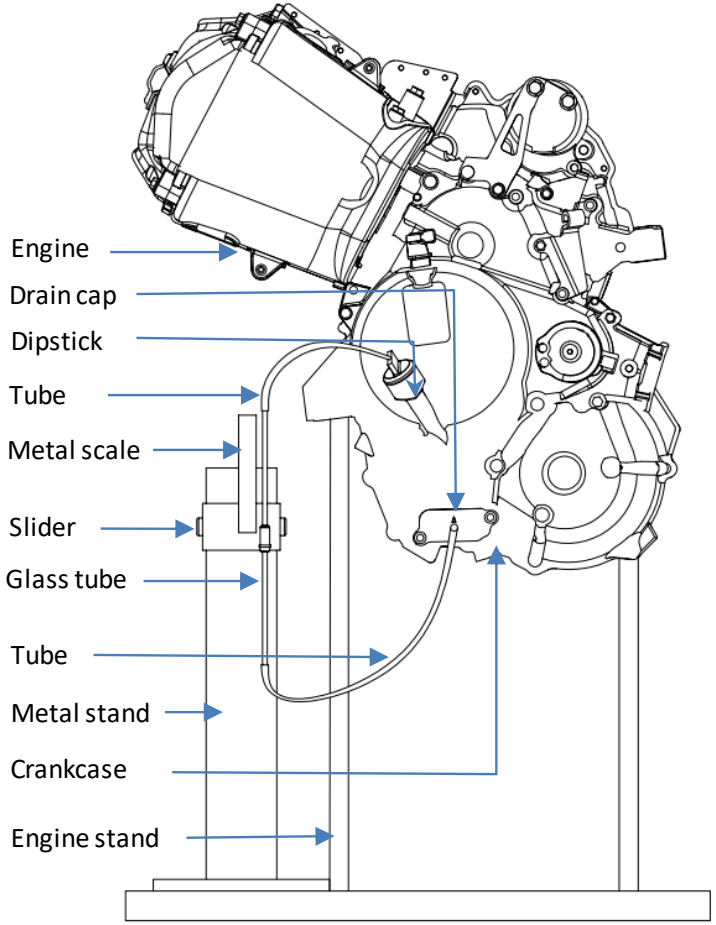
Engine Oil consumption measurement methods

Method	Advantages	Disadvantages
Drain & measure	• Simple and economical • No complicated equipment required • No skilled labor required	• Error in measurement • Approx 25 hrs to run • Impossible to drain all oil practically • Increase in viscosity due to degradation increases time of drain
***Tracer* Radioactive Sulfur**	• Measurement time – order of minutes • Transient effects can be measured	• Very costly equipment and special handling procedures for radioactive material • Secondary measurements and calibration of air and fuel flow • Oil deposited on piston, valves, and exhaust after treatment devices not accounted for in final measurement
Smart Oil Consumption Meter	• Level sensor to gauge level of oil in crankcase • Measurement time of the order of hours	• Accuracy of level sensor is of concern • Requires addition of new oil • Suitable for diesel engines • Transient effects cannot be measured
New Method	• Cheap to build and use • Portable • Run time of the order of hours • Pump flow characteristics can be studied • Addition of new oil not required	• Accuracy of the scale • Vibrations need to be handled better • Leakages have to be monitored

Comparison of various oil consumption measurement techniques.

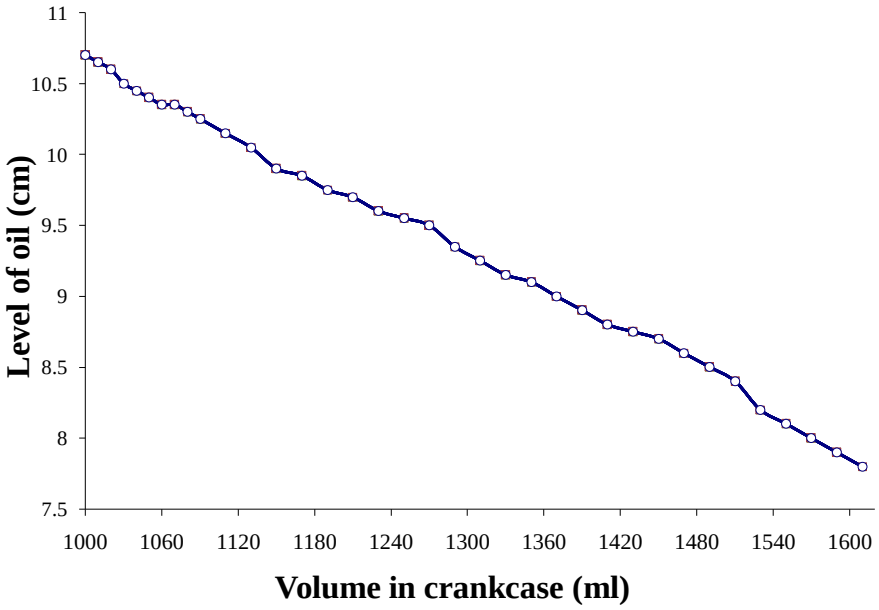
Example: Engine oil measurement

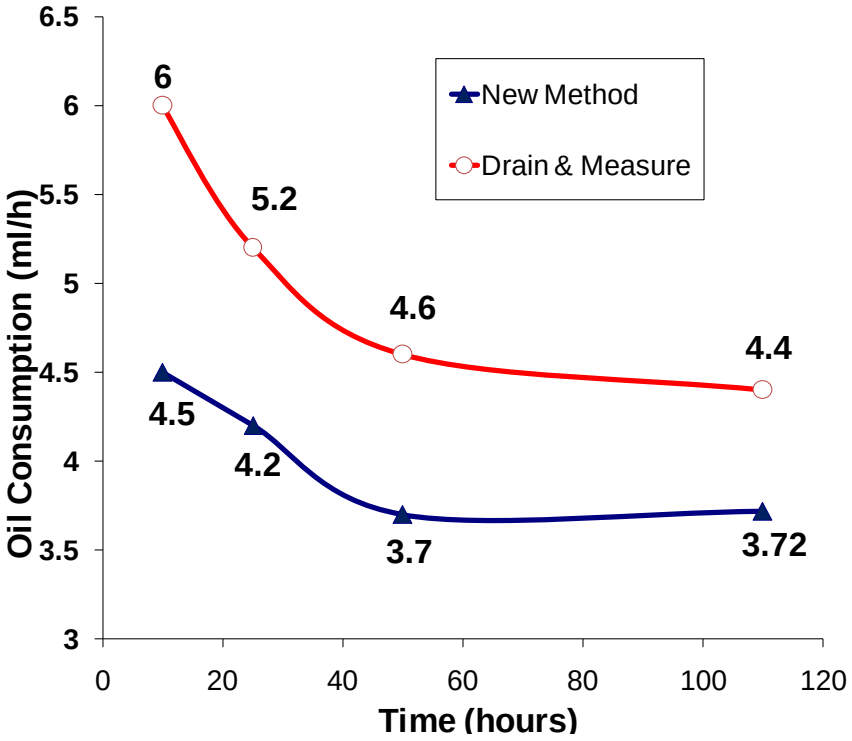




1. Investigation, Prediction and Hypothesis

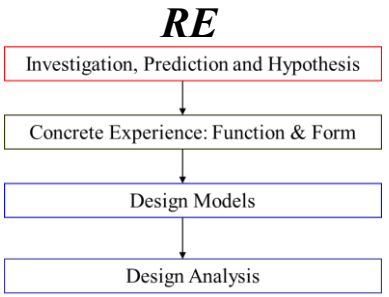
Example: Engine oil measurement





Calibration and measurement

Reverse Engineering Methodology



2. Concrete Experience: Function and Form

- Plan and execute product disassembly
- Group defined systems and components together
- Experiment with product components
- Develop free body diagrams
- Identify function sharing and compatibility
- Transform to engineering specs and metrics

Car Assembly Plant

Reverse Engineering Methodology

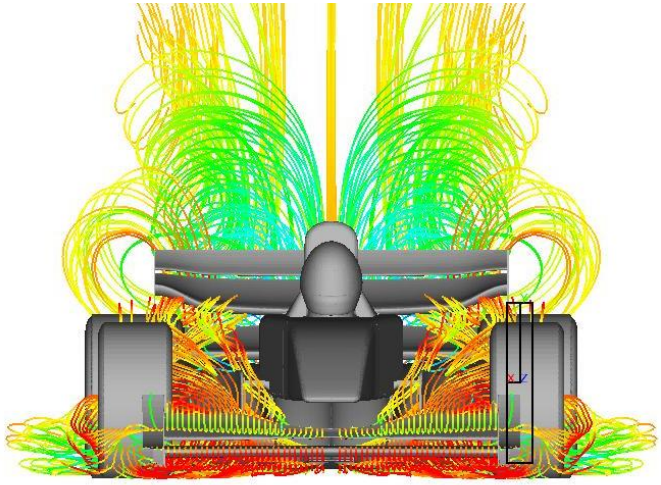
3. Design Models

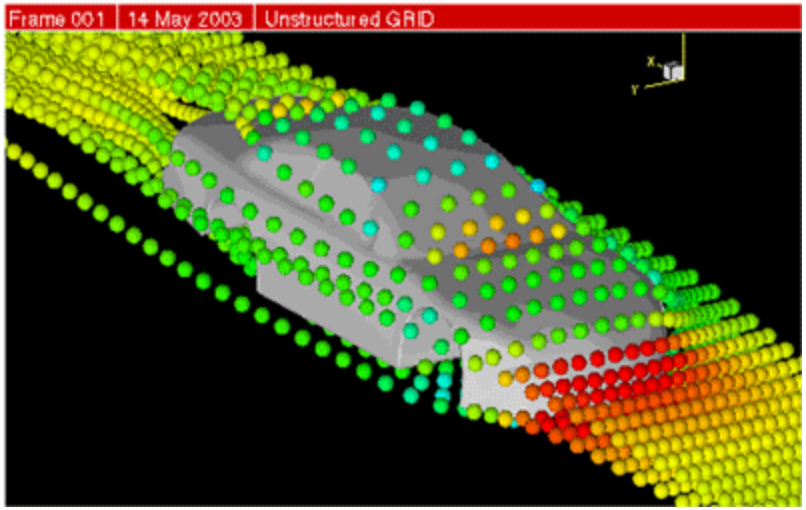
- Identify actual physical principles
- Constantly consider the customer
- Create engineering models and metric ranges
- Alternatively or concurrently build prototype to test parameters
- Ethical issues
- IPR issues

Reverse Engineering Methodology

4. Design Analysis

- Calibrate model
- Create engineering analysis, simulation or optimization
- Create experiment and testing procedures

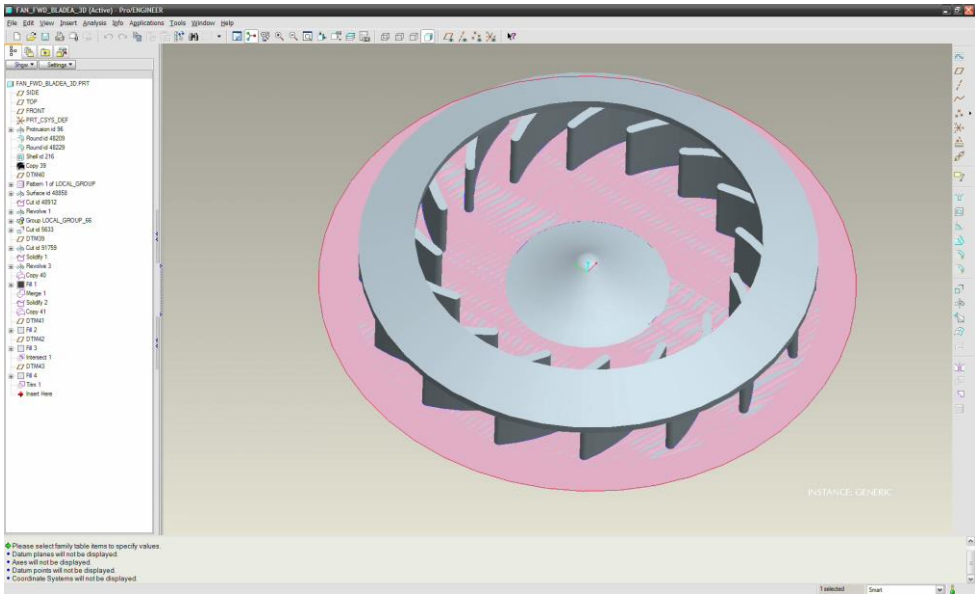




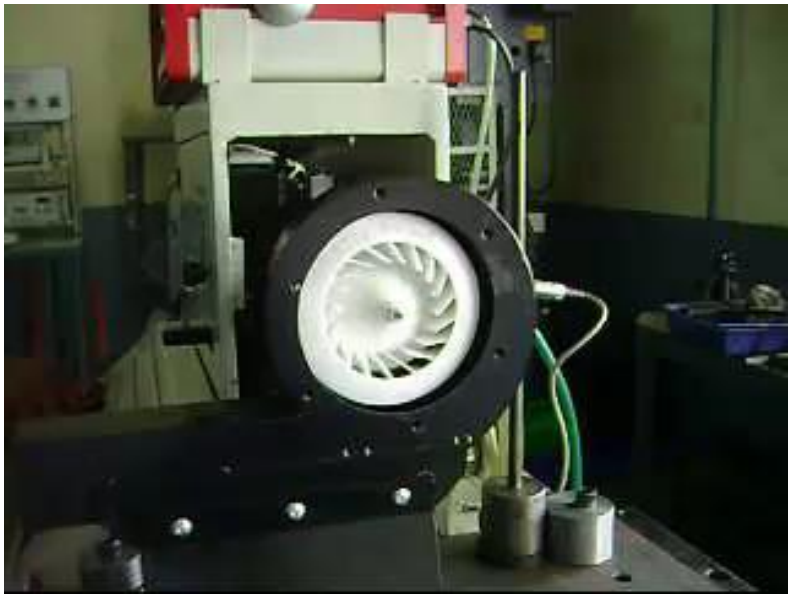
Reverse Engineering Methodology

5. Parametric Redesign

- Optimize design parameters
- Perform sensitivity analysis and tolerance design
- Build and test prototype



Parametric design



Prototypes testing

Reverse Engineering Methodology

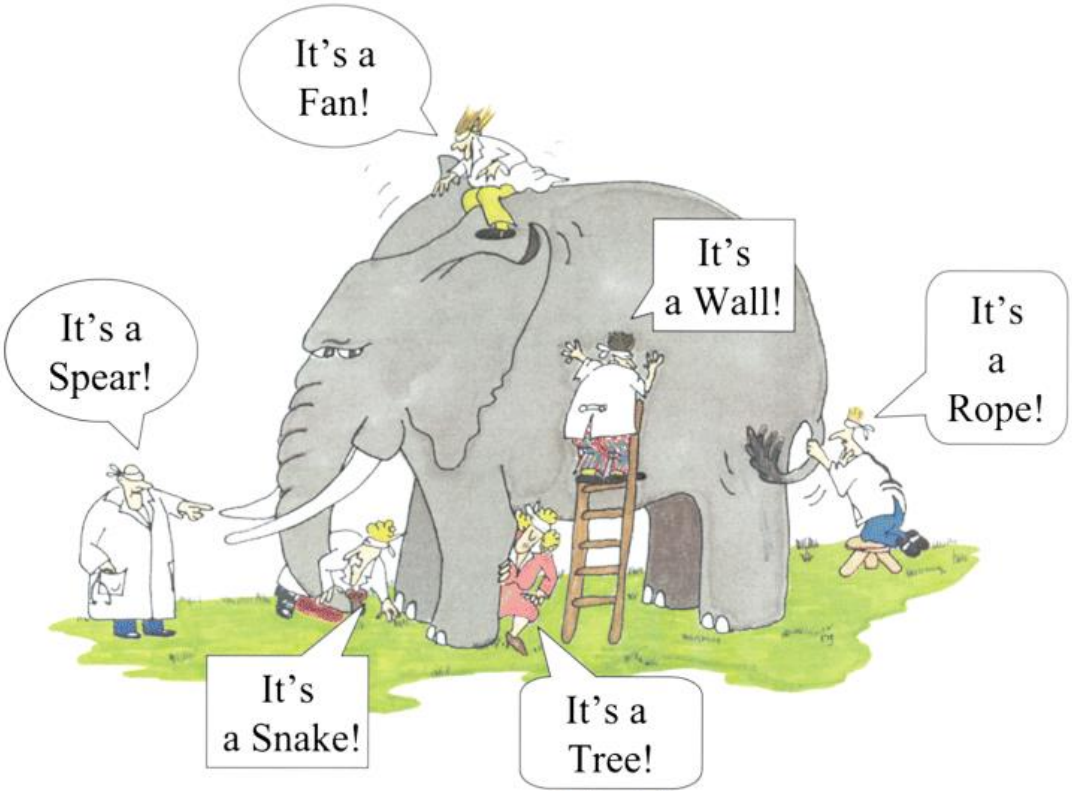
6. Adaptive Redesign
   - Recommend new subsystems
   - Search for inventive solutions
   - Analyze force flows and component combinations
   - Build and test prototype

Reverse Engineering Methodology

7. Original Redesign
   - Develop new functional structure
   - Choose alternatives
   - Verify design concepts
   - Build and test prototype

System Level Design

- Reverse Engineering requires understanding the product or design as a system or set of systems that work and interact together.
- This concept is known as System Level Design.

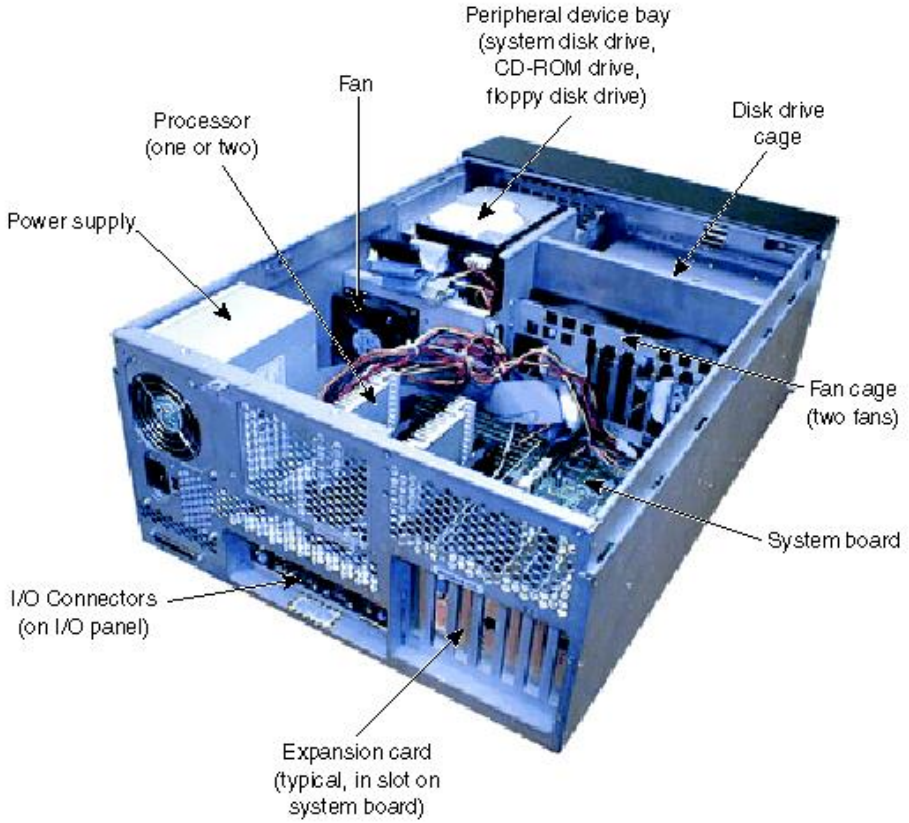


System Level Design

System = Components + Connections

- **Components**
  - Physical - pick-up, measure, draw on CAD
  - Functional - flowcharts, difficult to define
- **Connections**
  - Fundamental - intended design
  - Incidental - created by physical proximity of components (vibration, heat transfer, etc.)

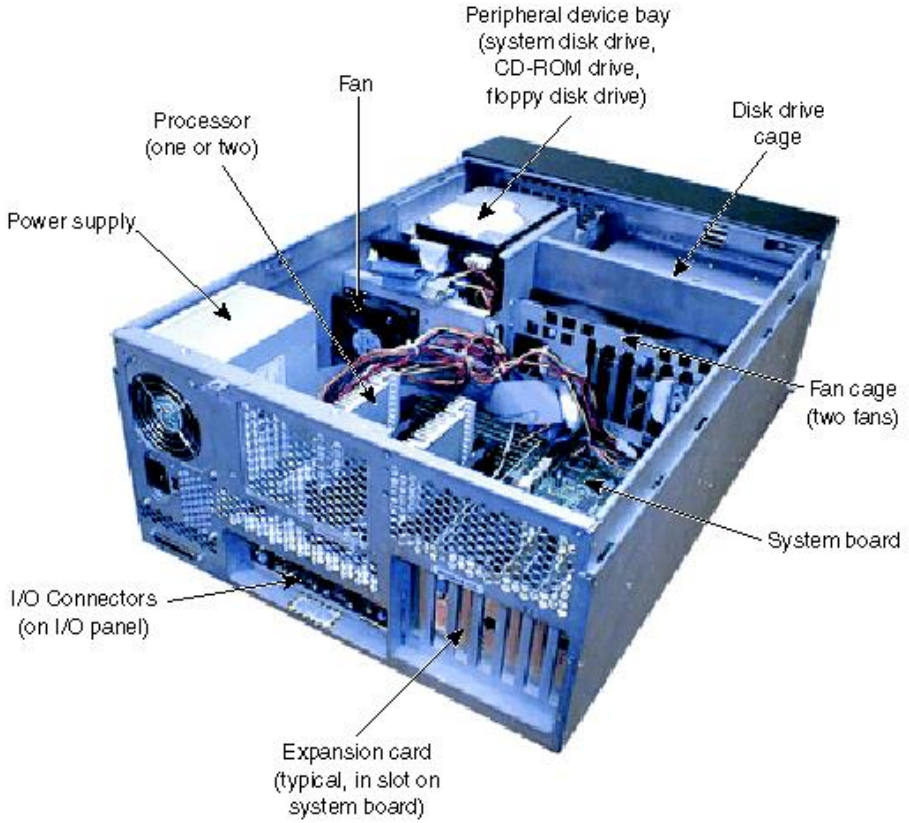
System Level Design



Approaches to reverse engineering

- **Black Box Analysis**
  - Analyzing a running product by probing it with various inputs and outputs
- **White (or Glass) Box Analysis**
  - Analyzing and understanding sub-system components
  - Connections between components
- **Gray Box Analysis**
  - A combination

System and sub-systems



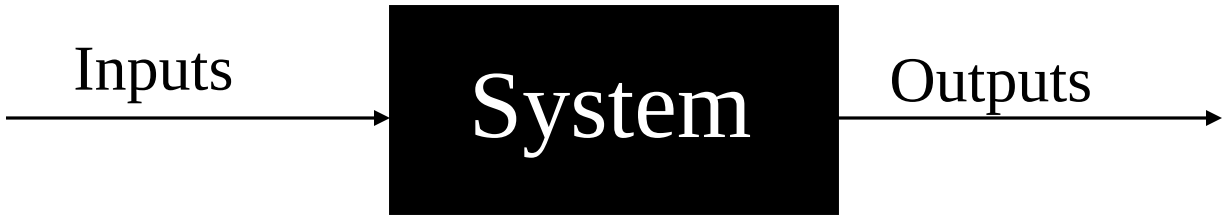
Black box analysis

Glass box analysis

System Level Design

Develop black box model avoiding bias.

Graphic representation of the system or object being designed, with inputs shown entering on the left and outputs leaving on the right.



Black box

System Level Design

Example: Radio

RF=radio frequency

System Level Design

Example: Motorcycle

- **Price**
- **Fuel**
- **User choices**

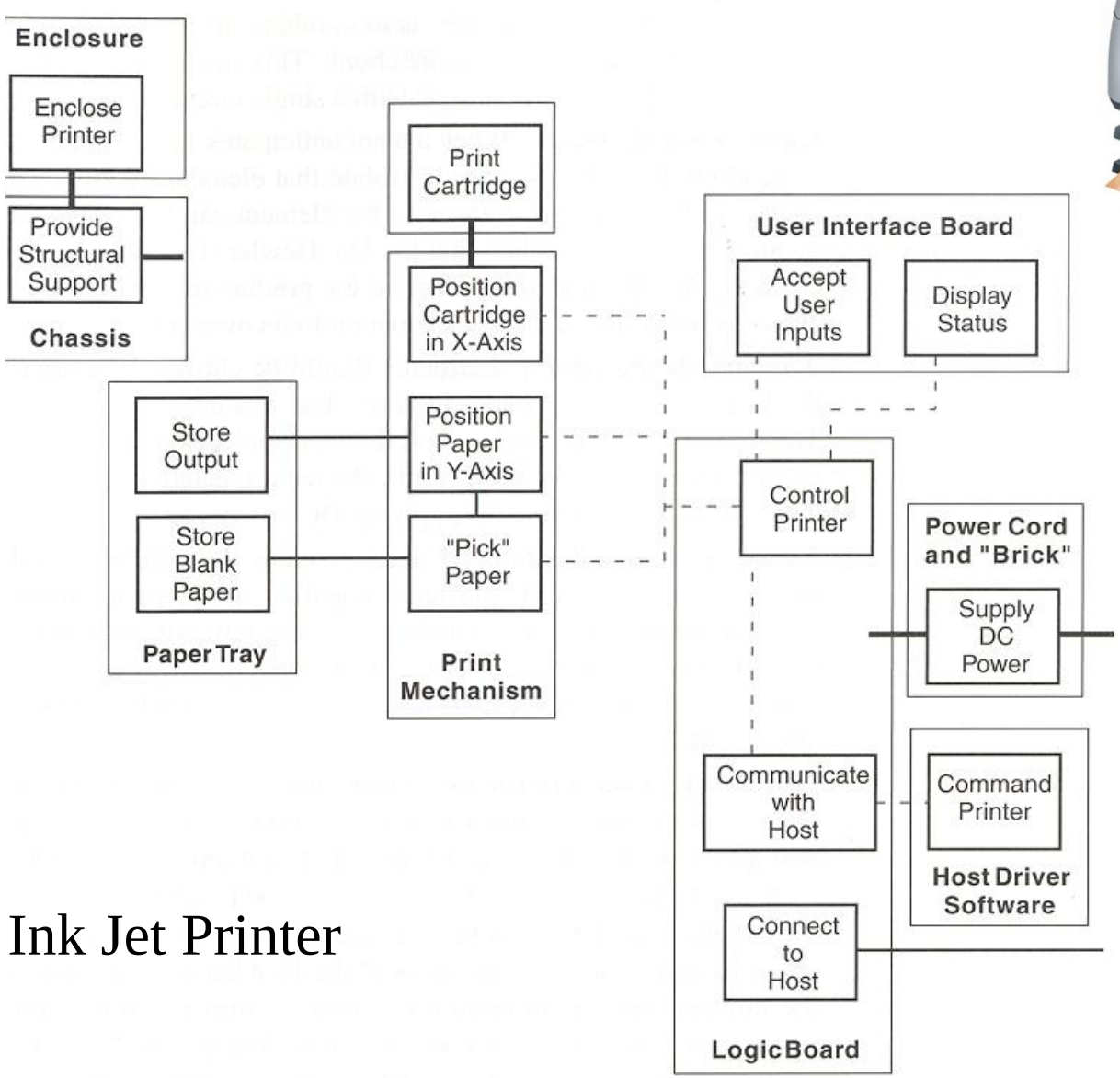
- **Mileage**
- **Comfort**
- **Sound**
- **Durability**
- **…**

System Level Design

Continue with the glass box approach.

- Identify sub-systems
  - Electrical
  - Mechanical
  - Task oriented
- Define interactions and flow of forces
  - Intentional
  - Unintentional
  - Wires, signals, material, data, etc.

‘Glass Box’ Example



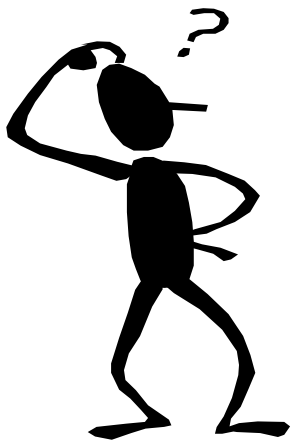
Ink Jet Printer

System Level Design

Final Breakdown

For every piece or component of interest, discuss:

1) How was it made
2) Why it was made this way
3) Design issues
4) The material it is made out of
5) Complexity and cost
6) Ergonomic issues
7) Interaction with other components



Reverse Engineering Example

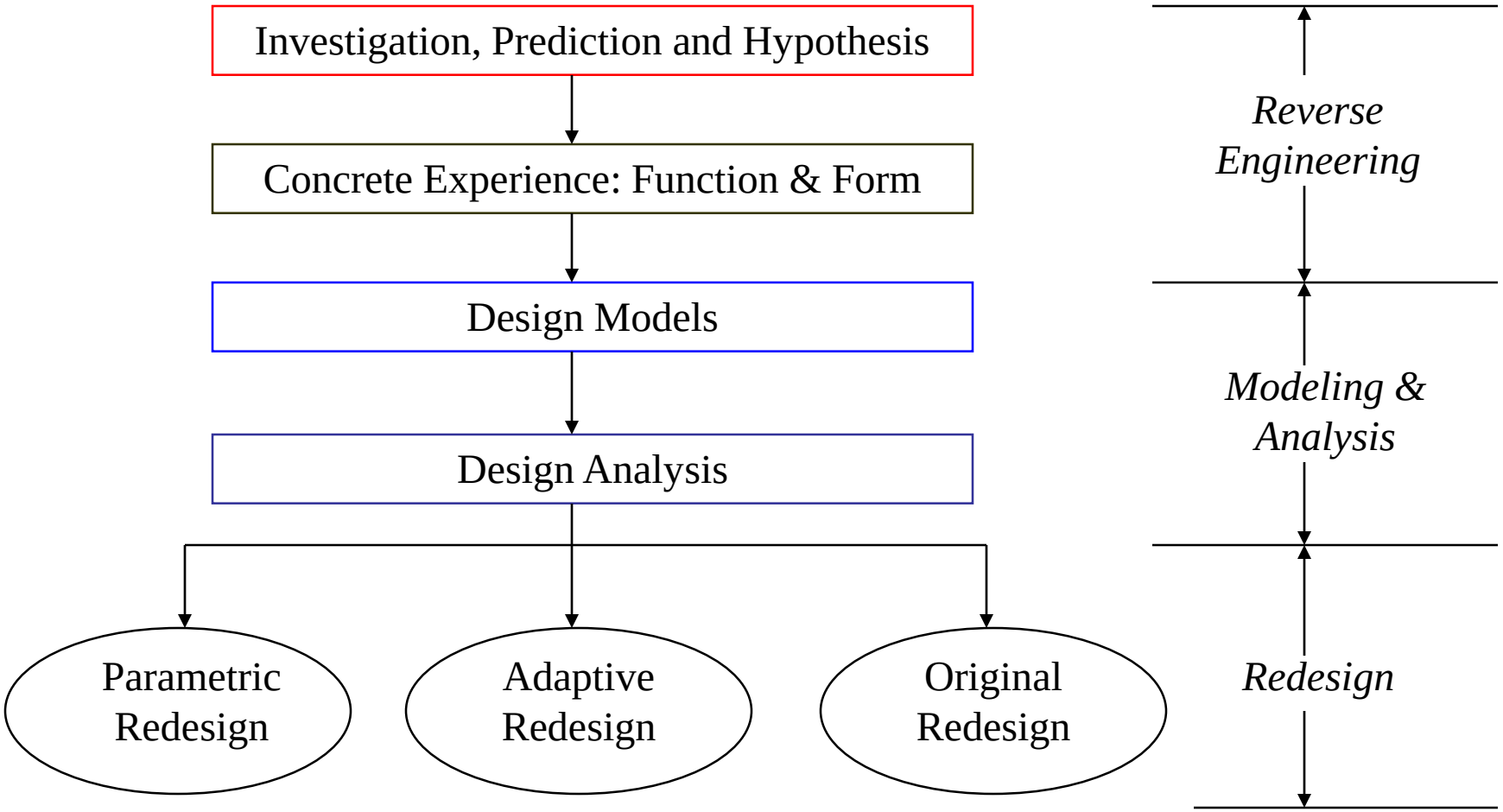
Example Project

Hedge/Bush Trimmer

Hand trimmer

Electrical trimmer

Reverse Engineering Methodology



Adapted from Otto and Wood's "Reverse Engineering and Redesign Methodology" UT Austin

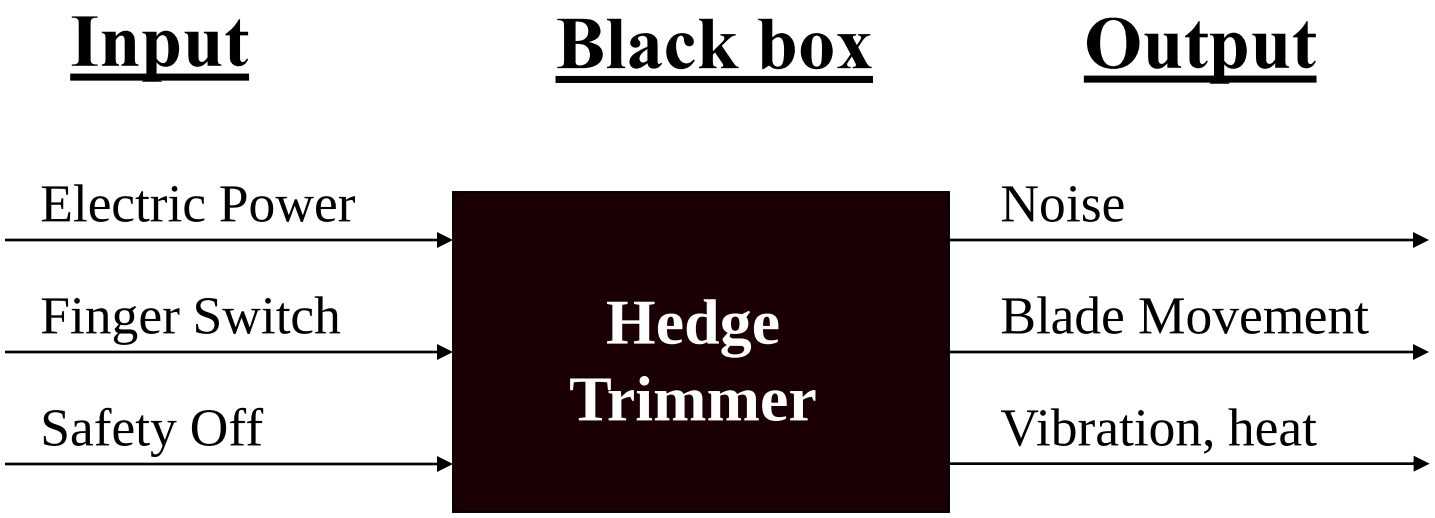
Reverse Engineering Example Project

1. Investigation, Prediction and Hypothesis

Develop Black Box Model

» Assemble product and conduct a test

» What goes in? What comes out? (i.e. power, noise, heat, vibration)



Reverse Engineering Example Project

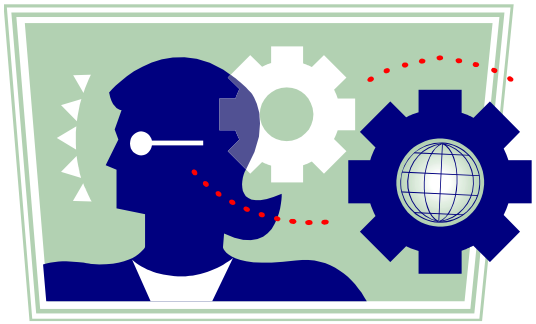
Conduct a single test of the performance of the product:

- Record product performance attributes

  –Shearing speed

    –3300 strokes/min

    –5:1 Gear reduction = 16,500 RPM for the motor



Reverse Engineering Example Project

What is the market for this product?

- » “Suitable for small shrubbery” –Product Catalog
- » Homeowners with small yards and limited budget
- » For use only 3-4 times a year

What are the costs associated with this product?

- » Design - Manufacturing - Assembly – Packaging
- » Resale ($40.00)

Reverse Engineering Example Project

How long will this product last?

- » Assumed durability of each component (outdoor use, dirt)
- » Availability of replacement parts and service shops

What features does this product have that are important?

- » Molded-in cord retainer
- » Lock off switch prevents accidental start-up
- » Lock on switch for continuous running
- » Lightweight design for less fatigue (4.5 lbs.)

Market Research

- I bought my first hedge trimmer at WalMart because it was very inexpensive compared to most other trimmers

- It has has an excellent reputation.

- The 13" seemed a little too small… The 18" seemed heavier

- I also wanted electric rather than gas because being a busy woman, I had no time to learn about mixing gas.

- Durability: Excellent
- Noise Level: Average
- Purchase Price: $25.00

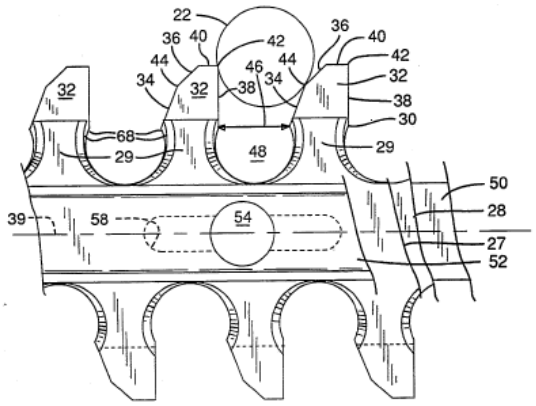
Market Research…

- While it may be a good trimmer it also has it's downside!
- The second problem is that since it is electric and you use it outside, you run the risk of being electrocuted! Remember most people doing lawn work are also running sprinklers to water the lawn. *I have had good friends killed simply by using these trimmers on wet grass.*
- Over all this tool does a great job of trimming but the hazards to your personal safety far out weigh the pros of this tool.

Patent Search on Hedge Trimmers

After completing a search on the U.S. Patent and Trademark website:

http://www.uspto.gov



Patent # 5,778,649 (1998)

Power Driven Hedge Trimmer

Patent # 5,581,891 (1996)

Hedge Trimmer with Combination Shearing and Sawing Blade Assembly

US005412873A

United States Patent [19]
Gibson

[11] **Patent Number: 5,412,873**
[45] **Date of Patent: May 9, 1995**

[54] **RECIPROCATING HEDGE TRIMMER TOOL HAVING CUTTING TEETH WITH ASYMMETRICAL GUARD PORTIONS**

[75] Inventor: **Duane M. Gibson**, Milwaukie, Oreg.
[73] Assignee: **Blount, Inc.**, Portland, Oreg.
[21] Appl. No.: **95,600**
[22] Filed: **Jul. 21, 1993**

[51] **Int. Cl.**[6] **B26B 9/02**
[52] **U.S. Cl.** 30/355; 56/DIG. 17; 56/DIG. 20; 56/297; 56/158; 30/196; 30/216
[58] **Field of Search** 56/158, 232–236, 56/255, 257, 264, 297, 296, 295; 30/216–220, 225, 228, 196, 355; 83/855, 854

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Primary Examiner—Michael Powell Buiz
Assistant Examiner—Pamela O'Connor
Attorney, Agent, or Firm—Robert L. Harrington

[57] **ABSTRACT**

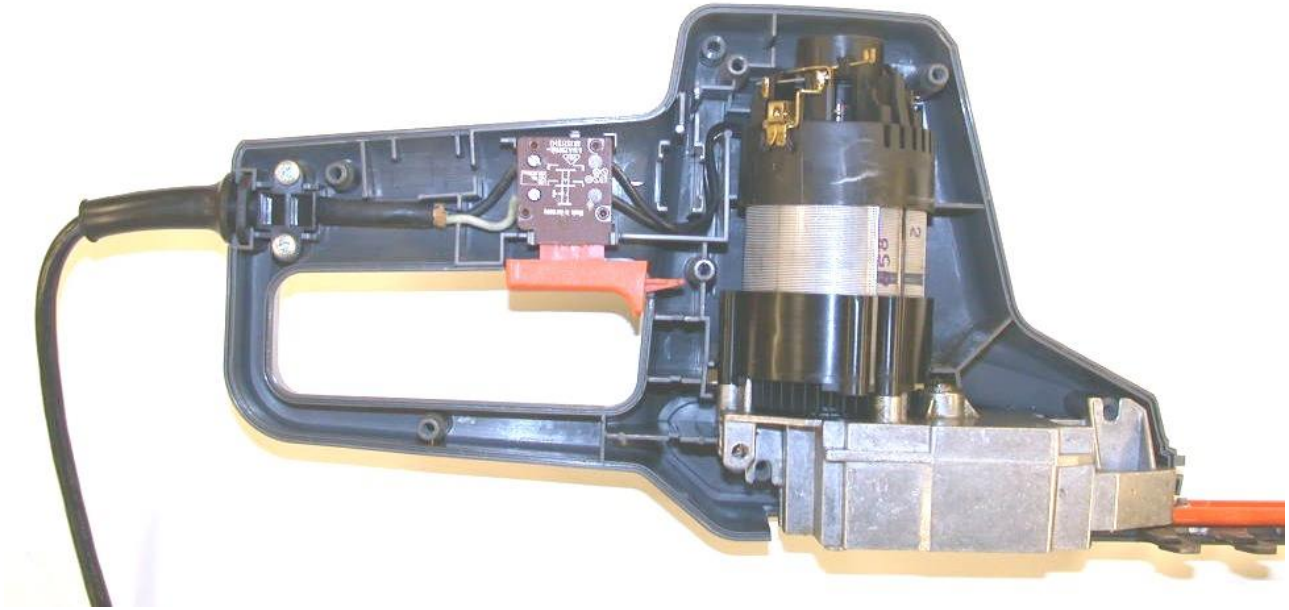
A hedge trimmer blade assembly preferably a double acting assembly having upper and lower reciprocating blades. Superimposed cutting teeth extend laterally from the sides of the assembly from each of the blades. Guard portions extend from the teeth of the upper blade only on one side and from the teeth of the lower blade only on the other side. The guard portions are asymmetrical with a straight side and a tapered side, the taper preferably including a shallow bevel near the base and a sharper bevel near the tip of the guard portion. The cutting teeth of both upper and lower blades on both sides form oval shaped cutting chambers with cooperative hook configurations at the entry to the cutting chambers. The upper and lower blades are preferably identical in configuration but inverted one relative to the other in the assembly. The straight sides of the guard portions are all faced toward the power head of the trimmer to produce a hooking action as the user sweeps the trimmer during operation.

6 Claims, 3 Drawing Sheets

Function and Form

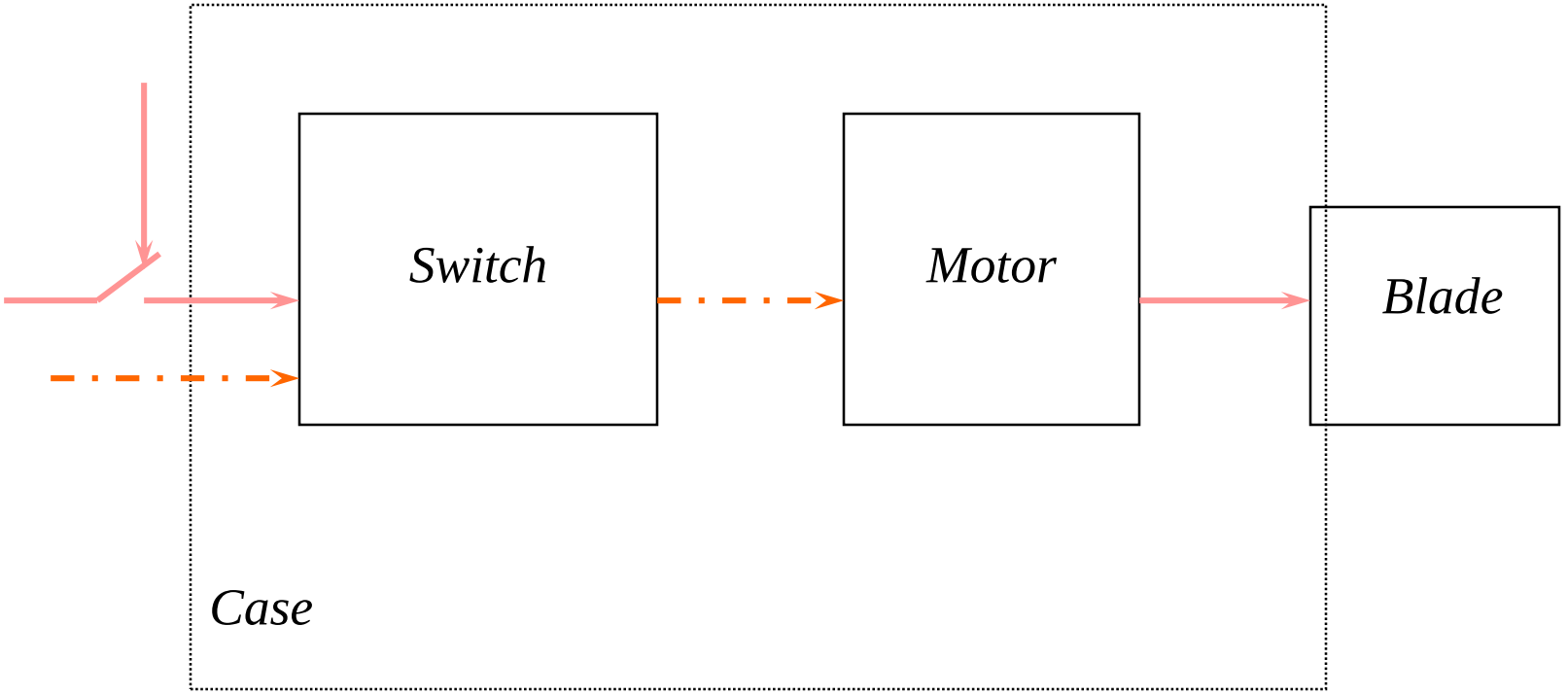
2. Concrete Experience: Function and Form

- Carefully begin Disassembly
- Document steps and components with photographs, sketches or video



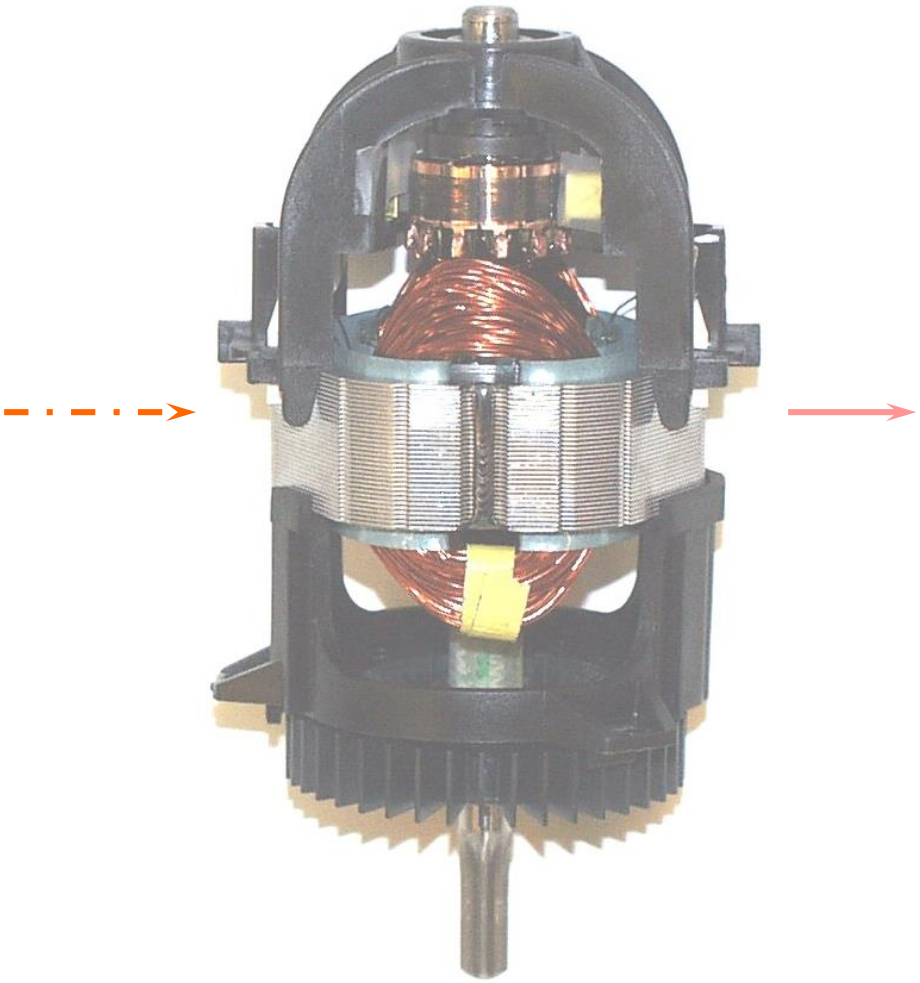
Hedge Trimmer Sub-Systems and Interactions

- Group defined systems and subsystems together.



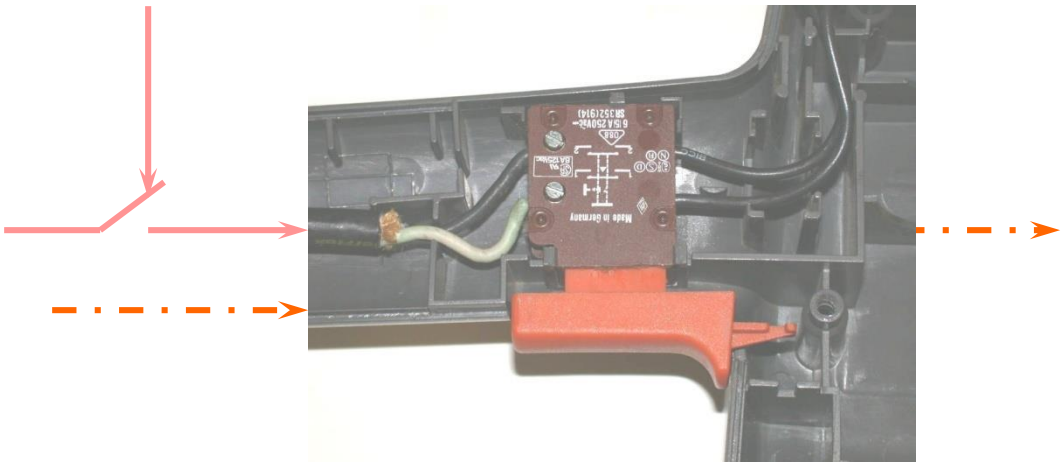
Motor

- 120 V - 8 Amp Motor
- 350 RPM
- Why not batteries?
- How important is size, speed?
- Was weight a consideration?

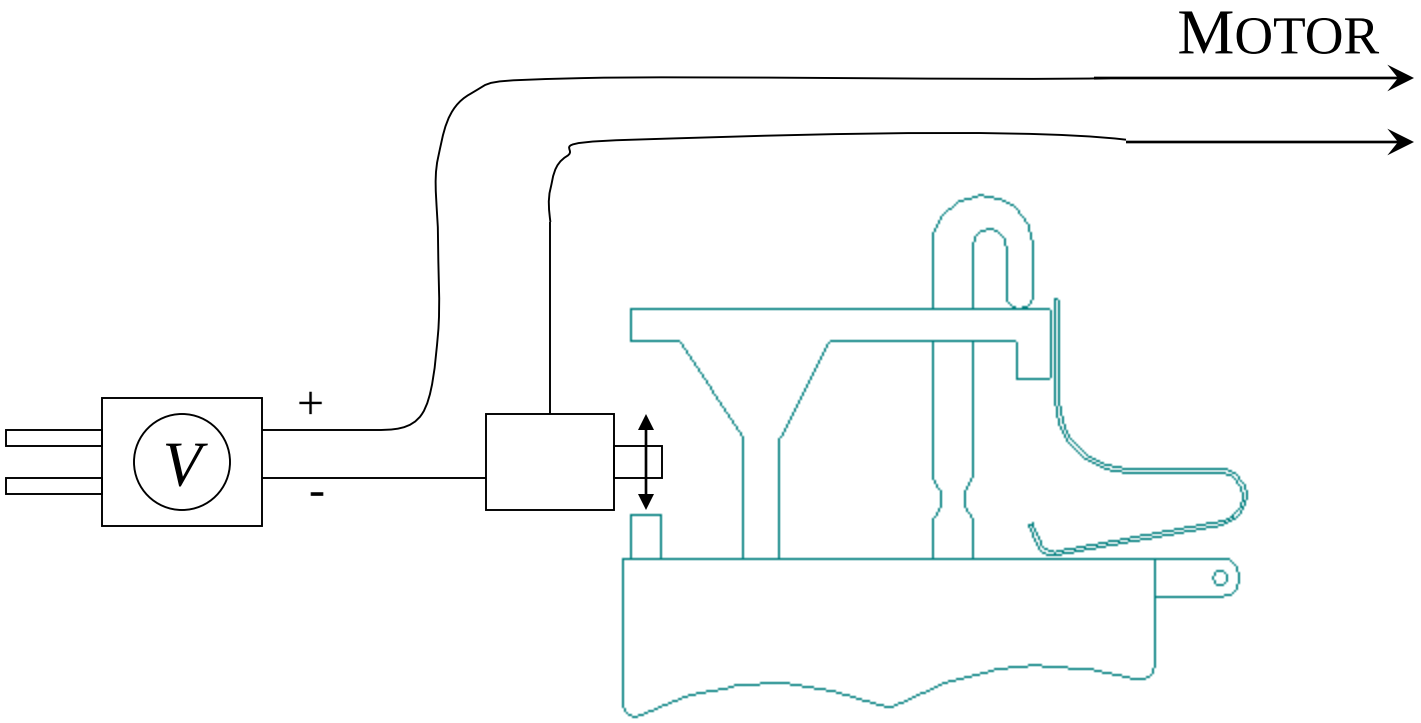


Switch

- Safety lock allows trigger action.
- Is this a regulatory requirement?
- Ergonomic issues of size and lever force
- What type of spring mechanism is used?



Switch



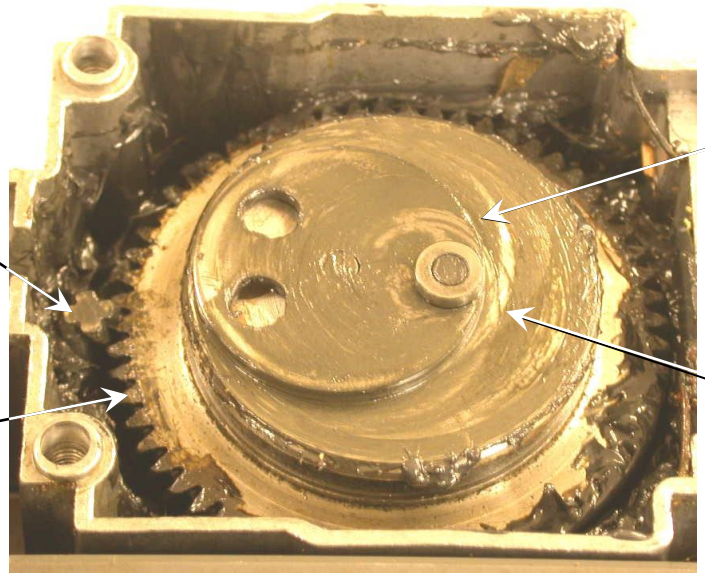
Sketch of Switch

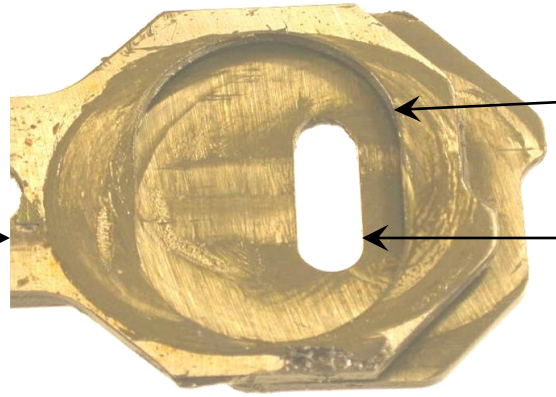
Blades

- How fast do the blades need to move? Force?
- Are the blades sharp?
- What are the blades made of ?
- Can we replace the blades?

Excavator

Transmission





Case

- How was the case made?
- Was the case designed to be esthetically pleasing?
- Why isn't the case made out of metal?
- What sort of costs are involved in the manufacturing of this case?

Feature List

- Switch - Plastic Injection Molded
- Gear – Die Cast Steel
- Case – Plastic Injection Molded
- Handle – Plastic Injection Molded
- Guard – Plastic Injection Molded

Reassemble Product

Engineering Specifications

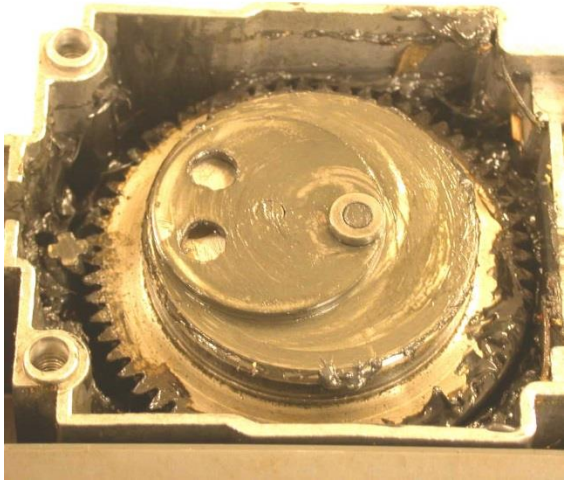
Transforming to engineering specifications

Example - Motor-Blade Kinematics

Helical gears

Number of teeth: input = 4

output = 60



Motor speed = 22800 rpm

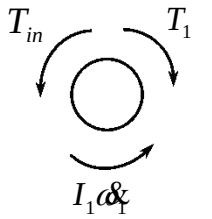
Output speed $= \frac{4}{60}\omega_{in} = \frac{1}{15}(22800\,\text{rpm})$

= 1520 rpm = 159 rad/s

Maximum blade speed = 1 m/s

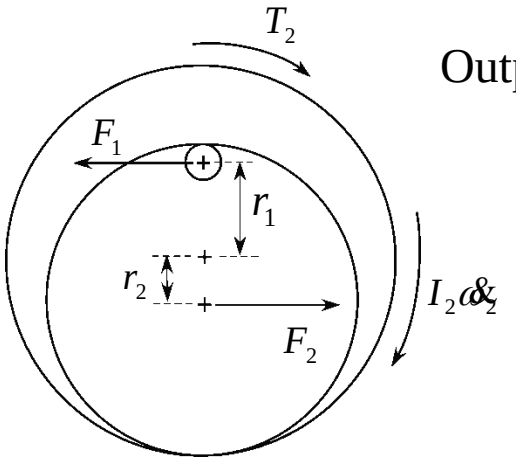
Engineering Specifications

Transforming to engineering specifications



Input gear from motor

$$T_{in} - T_1 = I_1\alpha_1 \qquad T_1 = F_t\frac{d_1}{2} \qquad T_2 = F_t\frac{d_2}{2}$$



Output gear to blades

$$T_2 - F_1 r_1 - F_2 r_2 = I_2\alpha_2$$

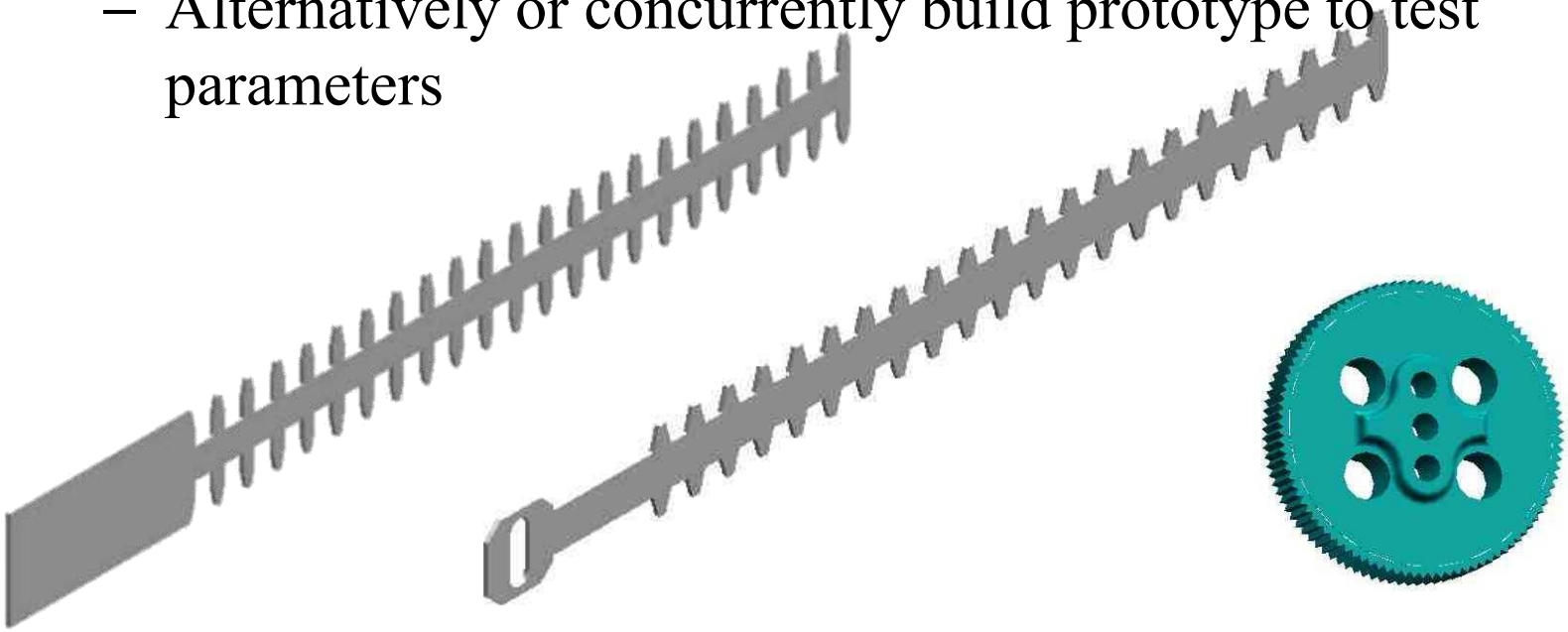
$$F_1 = m_1\left(r_1\alpha_2 \sin\phi - r_1\omega_2^2 \cos\phi\right)$$

$$F_2 = m_2\left(-r_2\alpha_2 \sin\phi + r_2\omega_2^2 \cos\phi\right)$$

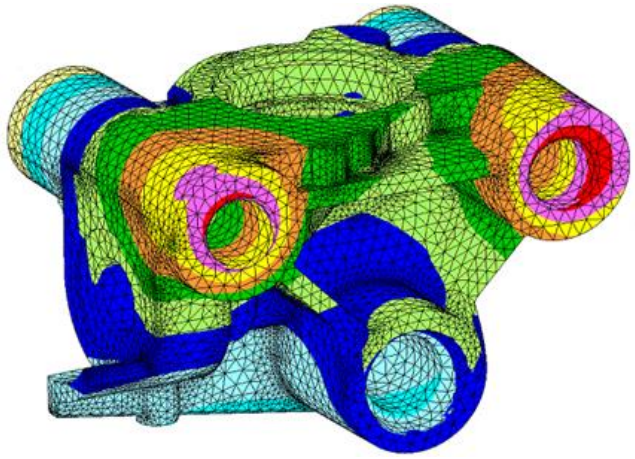
Design Models

3. Design Models

- Identify actual physical principles
- Create engineering models and metric ranges
- Alternatively or concurrently build prototype to test parameters



Design Analysis



4. Design Analysis

- Calibrate model
- Create engineering analysis, simulation or optimization
- Create experiment and testing procedures

Parametric Redesign

5. Parametric Redesign

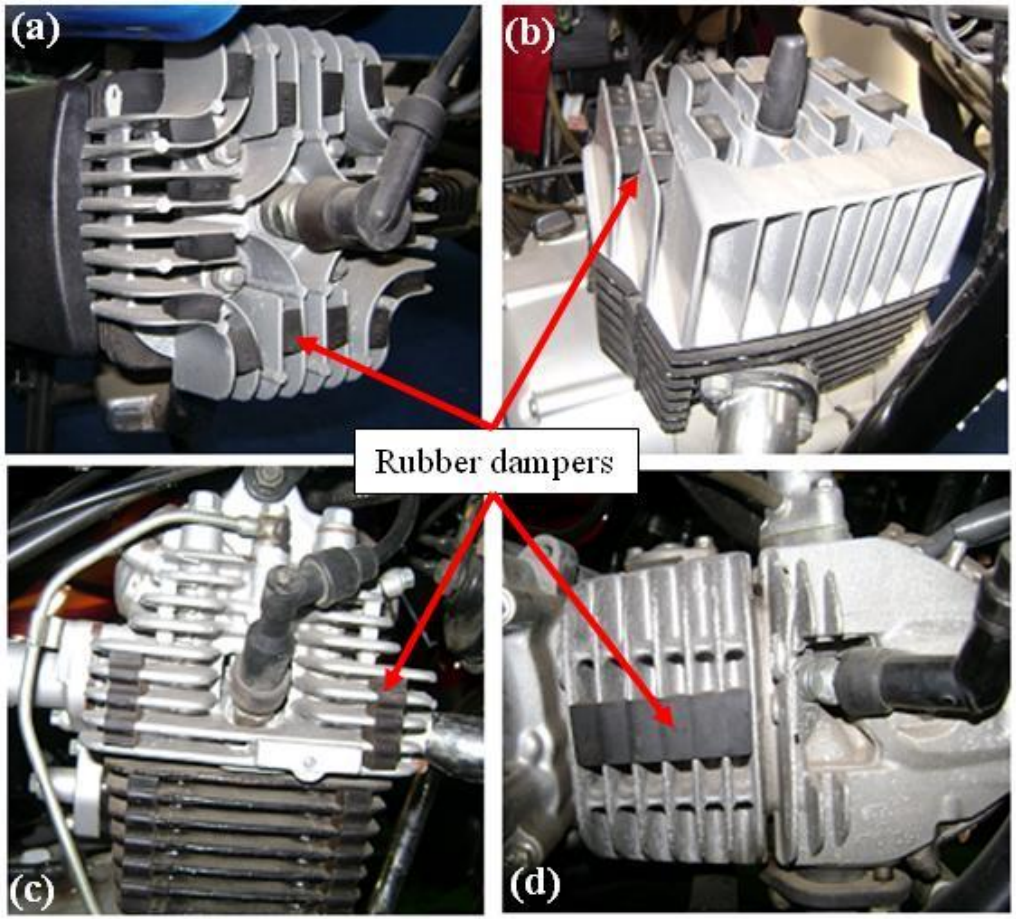
- Optimize design parameters
- Perform sensitivity analysis and tolerance design
- Build and test prototype

Adaptive Redesign

6. Adaptive Redesign

- Recommends new subsystems
- Searches for inventive solutions
- Analyzes force flows and component combinations
- Builds and tests prototype

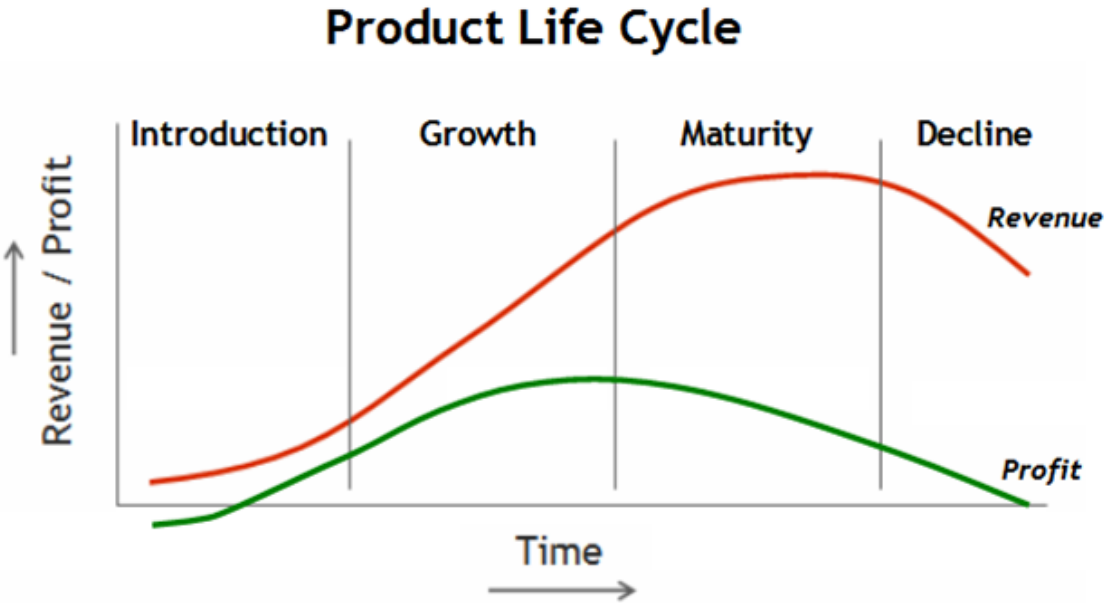
Environmental Impact



Environmental Impact

To determine the environmental impact of the existing design evaluate each step of the Product Life Cycle

- Pre-production
- Manufacturing Process
- Product Life
- The After Life



Pre-production

- Replaceability of natural resources
- Availability of an alternative resource
- Energy required to obtain
- Energy to process
- Amount of waste created during processing
- Waste disposal method

Manufacturing Process

- Energy to produce
- Waste created during production
- Type of waste- solvents, emissions?
- Reuse of in-process material waste?
- Material yield

Product Life

- Energy consumption
- Waste production
- Length of product life

The After Life

- Reuse
- Recycle- design for disassembly?
- Neither- harmful pollutants?

Think: Reuse vs. Recycle

Summary

Reverse engineering

- Tool to understand current design solutions and technology
- Use dissection, experimentation and analysis
- Save time and gain insight on current design challenges and solutions

Products

- Printer/Scanner
- Electric fan
- Steam iron
- Television set
- Laptop
- Desktop computer
- Microwave Oven
- Air Conditioner
- Refrigerator
- Mobile
- Tea & Coffee maker

Groups

- Make groups consisting of 6 members
- Members: 2 ME, 2 SC & 2 EE
- Max. 3 girls students in group

Evaluation

- Quality of documentation
- Product knowledge
- Disassembly and assembly
- Presentation
- Viva voce