EK210: Engineering Design

Lecture notes for Engineering Design

Giacomo Cappelletto

Published: October 06, 2025
Last updated: October 06, 2025

Contents

List of Tables

* * *

Chapter 1: Engineering Design Definition

Engineering Design — Definition 1.1

A systematic, intelligent process in which designers generate, evaluate, and specify designs for devices, systems, or processes whose form and function achieve clients' objectives and users' needs while satisfying a specified set of constraints.

Key Concepts

Objectives vs Functions vs Specifications

Objectives Note 1.1

Attributes that a client or user would like in a product.

- Example: “Make a brown frying pan”, “Make it cheap”, “Make it transparent”
- Often vague and require clarification through proper questioning

Functions Note 1.2

Things the product is supposed to do (verb-noun pairs).

- Example: “Measure temperature”, “Withstand impact”, “Resist breakage”
- Engineering perspective of what must be achieved
- Active form vs. objectives as “states of being”

Specifications Note 1.3

Engineering statements of functions that must be exhibited and can be measured.

- Example: Coefficient of thermal expansion < X value
- Example: Fracture toughness > Y value
- Example: Thermal conductivity specification

Other Key Terms

Metrics Definition 1.2

A scale upon which achievement of design objectives can be measured.

Constraints Definition 1.3

Restrictions or limitations on a product’s performance.

- Example: "Cannot be metal", "Must cost under $5"
- Can be explicit or implicit

Chapter 2: Problem Statements

Good Problem Statement Requirements Note 2.1

1. Clear statement of WHO, WHAT, and WHY
2. General - doesn’t constrain specific means/solutions
3. Specific enough to guide design decisions

Examples

Poor Problem Statement Example 2.1

“The goal of our project is to design an infrared thermometer”

Issues:

- Constrains means (infrared)
- Doesn’t explain what/who/why

Good Problem Statements — Example 2.2

"The goal is to design a device to measure the temperature of everyone walking through the front door at Boston Medical Center as a preliminary indicator of either COVID-19 or influenza."

"The goal is to design a device to measure temperature in a home setting for use with telemedicine tracking of elderly patients."

Why these work:
- Clear WHO, WHAT, WHY
- No specific means mentioned
- Sufficient detail for design direction

Chapter 3: Functional Analysis: Glass Box Method

Glass Box Analysis — Definition 3.1

A systematic method for determining functional requirements by analyzing inputs, outputs, and the functions needed to transform them.

Glass Box Components

All glass boxes have three possible inputs and outputs:
- Energy
- Information
- Material

Example: Screwdriver Glass Box

Table 1: Glass box functional analysis for a screwdriver

INPUTS	FUNCTIONS	OUTPUTS
Energy (supplied by user)	Enable grip (plastic cylinder, rubberized handle, wood, rectangular)	Energy (torque)
Information (location, object)	Attach to object (wood, metal, flathead, phillips, interchangeable)	

Worked Example: Lead Pencil Glass Box

Let's work through a complete glass box analysis for a lead pencil.

Step 1: Define the objective
- Product: Lead pencil
- Objective: Create marks on paper for writing/drawing

Step 2-5: Complete Glass Box Analysis

Table 2: Glass box functional analysis for a lead pencil

INPUTS	FUNCTIONS	OUTPUTS
Energy (user pressure & motion) Information (content, location) Material (paper)	Hold graphite (wood casing, mechanical housing, plastic tube, metal ferrule) Enable user grip (hexagonal shape, round shape, textured surface, rubber grip)	Material (graphite marks on paper) Information (written content)

Step 6: Analysis and selection For a traditional wooden pencil:

- Hold graphite: Wood casing ⟶ inexpensive, easy to sharpen, natural grip
- Enable grip: Hexagonal shape ⟶ prevents rolling, comfortable hold, easy manufacturing

Key Steps for Glass Box Analysis

1. Set boundaries - define what's inside vs outside your system
2. Identify inputs - what Energy/Information/Material enters?
3. Identify outputs - what Energy/Information/Material exits?
4. Determine functions - what must happen to transform inputs to outputs?
5. List means - brainstorm ways each function could be achieved

Chapter 4: Engineering Design Process

The five-stage systematic process:

1. Problem Definition - Frame problem, clarify objectives, identify constraints, establish functions
2. Conceptual Design - Generate alternative concepts, evaluate and select best approach
3. Preliminary Design - Size and estimate attributes, model and analyze chosen design
4. Detailed Design - Refine and optimize, build prototype, fix design details
5. Communication - Document specifications, justification, and design decisions

Important Principles Note 4.1

- Cross-functional teamwork required
- No single "best" answer to design problems
- Communication skills (oral & written) are critical
- Don't jump to final solution too quickly - explore alternatives

Chapter 5: Team project

Objectives

- Fit within a 12″ × 12″ footprint and weigh < 750 g
- Operate autonomously with no tethered power or manual control
- Start via a touchless mechanism (e.g., clap or proximity sensor)
- Cover the entire 4×4 ft desk area in 2 minutes or less
- Include reliable edge detection to prevent falling off the desk
- Incorporate a student-built vacuum or suction mechanism for cleaning
- Collect visible and particulate debris into a removable or viewable container
- Pick up both light debris (paper scraps) and heavier particles (e.g., rice grains)

- Run untethered for at least 5 minutes continuously
- Signal cleaning completion with a clear indicator (LED, buzzer, etc.)
- Remain within the EK210 project budget constraints
- Prioritize core functionality over aesthetic appearance

Material Flow

- Collect debris
- Entrain air
- Pick up paper scraps
- Pick up rice grains
- Transport debris/air
- Prevent clogging

Energy Flow

- Store electrical energy
- Convert electrical energy to motion
- Convert electrical energy to suction
- Indicate low battery

Information Flow

- Detect start gesture
- Detect edge
- Detect obstacle
- Measure runtime
- Indicate completion

Morph Chart

Autonomous Desk Cleaner — Morph Chart

H[FUNCTION]	H[MEANS 1]	H[MEANS 2]	H[MEANS 3]	H[MEANS 4]	H[MEANS 5]	H[MEANS 6]
H[Initiate on gesture], [MEMS mic + Goertzel clap], [IR prox (VCNL/ToF) wave], [UWB tap-zone start], [BLE beacon start pkt], [Time-gate + first motion], [Dual-confirm (audio ∧ prox)],	H[Propel & steer to cover area], [Boustrophedon lanes], [Spiral-in/out + lanes], [Random + wall-follow], [SLAM-lite: gyro + bump map], [Lissajous sweep], [Frontier fill],	H[Sense & avoid edges], [IR “cliff” array], [ToF mini-lidar (drop)], [Optical-flow ground-loss], [IMU pitch spike → retreat], [Drop whisker (mech)], [Fusion vote (2-of-N)],	H[Sense & avoid obstacles], [Front ToF strip (10–60 cm)], [Ultrasonic pair (backup)], [Tactile bumpers], [Optical-flow looming], [Hall/odom slip check], [Bayes fusion → slow/re-route],	H[Generate suction & entrain debris], [50–80 mm radial + ESC (2–3S)], [Dual-stage centrifugal (high ΔP)], [Vortex nozzle], [Agitator brush (foam/bristle)], [Nozzle skirt seal], [PWM suction (cruise save)],	H[Convey, separate & store debris], [Cyclonic cup], [Mesh + HEPA slice], [Labyrinth path (quiet, anti-re-entrain)], [Anti-clog grate + purge], [Clear bin + mag latch], [ΔP clog sensor → boost/stop],	H[Manage power & communicate status], [2S 18650 pack + BMS + LVC], [Buck-boost rails (isolated)], [Fuel-gauge (INA219/LC709)], [LED ring + buzzer], [Auto-sleep after done], [Budget watchdog (BOM counter)],

Brief notes on selected means

- strong[Goertzel clap detector] — band-energy detect for clap; low-cost.
- strong[Boustrophedon coverage] — lane sweep for fast, full coverage.
- strong[“SLAM-lite”] — gyro/odom + bump map; avoids gaps without vision.
- strong[Optical-flow cues] — ground-flow vs wheel speed flags drop/loom.
- strong[Cyclonic separation] — spins air to drop debris before filter.
- strong[ΔP clog sensing] — pressure rise triggers purge/alert.
- strong[Fuel-gauge + LVC] — runtime estimate; cell protection.

Chapter 6: Project

Modelling in Pairs

- List your product’s requirements for the sensor/actuator.
- With possible product means identified, look up the component’s specification sheet and report any relevant values (i.e. values one might test to understand real world performance) Note if these values can meet your requirements.
- If necessary, provide calculations of relevant component specifications with regards to how your product would use it. (i.e. motor torque and wheel size, sensor range/FOV…)
- Calculate/model/test at least 2 aspects of the component’s capability or compare one aspect for at least 2 means or components. Test things relevant to your product design. (i.e. Test one motor’s lifting torque and it’s wattage vs speed, or test two different distance sensors accuracy vs distance.)
- Describe the quantitative experiment you are conducting to test the aspect. Consider how the component behaves under a varied condition. (i.e. what is the independent vs dependent variables)
- Provide sketches with dimensions for the experiment.
- Report the data. Plots, Graphs, Tables…
- Discuss whether it fits the need

* * *

References