Design in practice

Theme B · SL and HL

5127 prototypes

> Good products come from many small tests, not one perfect drawing.

- Dyson changed one feature at a time, about five years.
- Most prototypes failed, and each taught something.
- This unit: models $\rightarrow$ materials $\rightarrow$ processes $\rightarrow$ quality.

Kinds of model

Model	**Typical use**
Sketch **model**	Explore form and size quickly
Mock-up	Full size, check ergonomics and looks
Scale model	Too big or small to make full size
Prototype	Test function with real users

Low or high fidelity?

Low fidelity

Paper, card, foam.

Quick, cheap, easy to discard.

High fidelity

Looks and works almost real.

Slow, costly, reliable evidence.

Iteration with evidence

1. **First prototype.** 8 mm deflection
2. **Revision.** 5 mm deflection
3. **Reduction.** $(8 - 5) \div 8 \times 100 = 37.5\ \%$

Decision

Evidence of **stiffness** in this test only

CAD and virtual testing

Advantages

Precise, easy to edit, check **fit**.

Files go straight to machines.

Limitations

Cost and training.

Cannot show feel or weight.

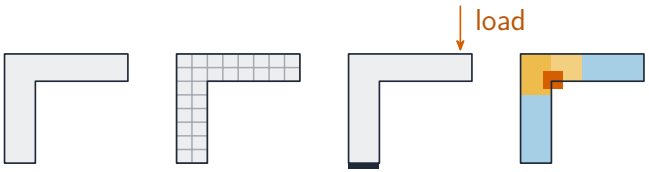
From sketch to working prototype



Common mistake: building high fidelity before the idea has been explored

> Match the **model** to the question it must answer

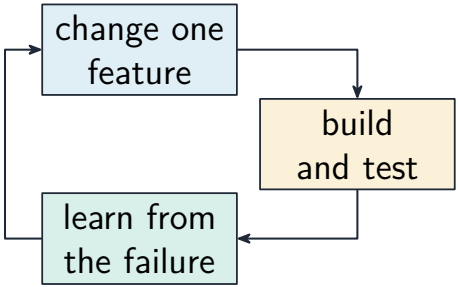
Finite element analysis



1. CAD model
2. mesh of elements
3. load and fixing
4. stress map: hot spot at the corner
5. confirm key results with a physical test

FEA predicts where a part will fail; a physical test confirms it

Iterating to a working design

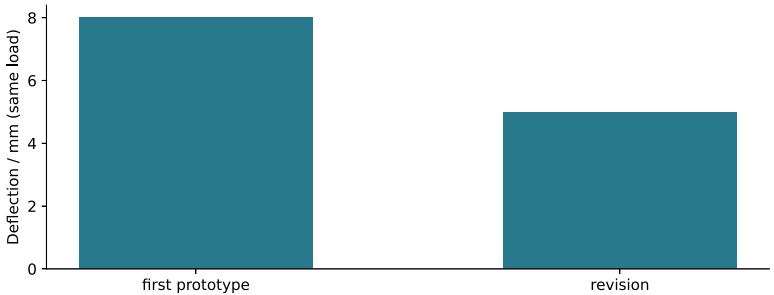


cone angle, inlet size,
number of cyclones ...

about 5127 loops, five years

> Each failure narrows the design

Testing a revision



A fair test shows the improvement

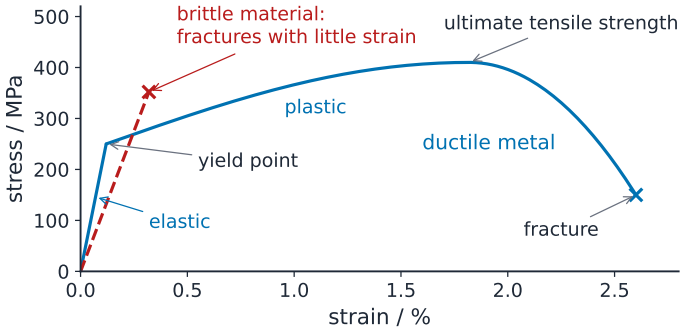
Material groups

Group	**Example**
Ferrous metal	Mild steel
Non-ferrous metal	Aluminium, copper
Thermoplastic	Polypropylene, acrylic
Thermosetting polymer	Melamine, epoxy
Composite	Carbon-fibre reinforced polymer

Mechanical properties

Property	**Meaning**
Strength	**Stress** before it breaks
Stiffness	Resists elastic bending
Toughness	Absorbs energy, resists cracks
Hardness	Resists scratches and wear

Stress-strain graphs



- Elastic, yield, plastic, ultimate **tensile strength**, fracture.
- Brittle materials break with no warning.

A steel tie rod

1. **Stress.** $10\,000 \div 50 = 200$ MPa
2. **Strain.** $0.5 \div 500 = 0.001$
3. **Young's modulus.** $200 \text{ MPa} \div 0.001 = 200\,000 \text{ MPa} = 200$ GPa

Decision

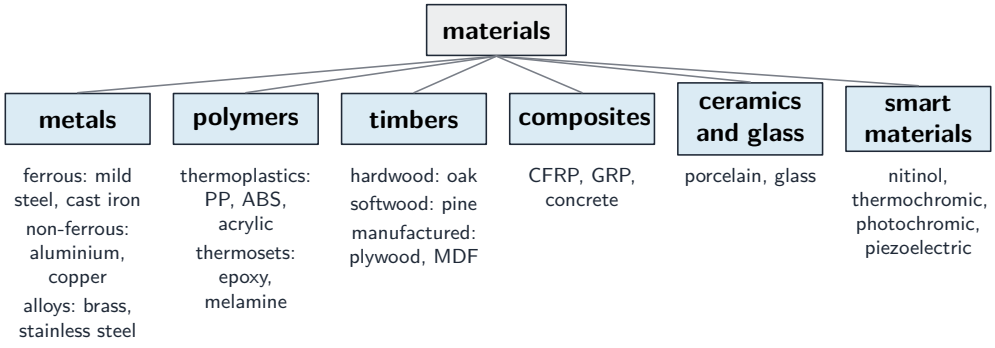
Yield at 250 MPa gives a factor of safety of only 1.25

Strength-to-weight

> Choose by function, manufacture, cost, looks and environment, never one property.

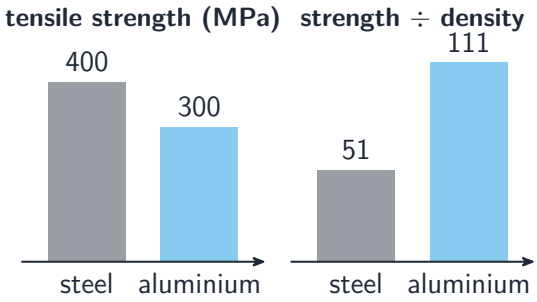
- Aluminium 300 MPa $\div$ 2.7 $\approx$ 111.
- Steel 400 MPa $\div$ 7.85 $\approx$ 51.

Six material groups



> Name the group, then the family, then the material

Stronger, or stronger for its weight?



density 7.85 vs 2.7 g/cm^3: aluminium carries about twice the load for the same mass

Specific strength decides when weight matters

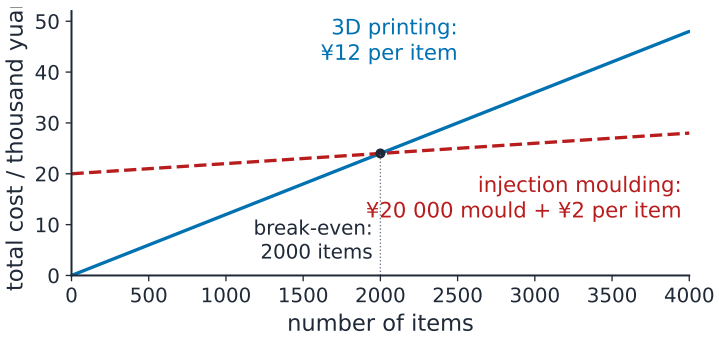
Four families of process

Family	Examples
Wasting	Drilling, turning, laser cutting
Forming	Casting, **injection moulding**, vacuum forming
Additive	FDM and resin printing, sintering
Joining	Screws, adhesives, welding

Scales of production

Scale	**Example**
One-off	A bridge, a **prototype**
Batch	Bread, school furniture
Mass	Cars, phones
Continuous flow	Oil, steel, paper

Break-even



- Printing ¥12 per item, no tooling.
- Moulding ¥20 000 mould, then ¥2 per item.

Solving for break-even

1. **Equation.** $12n = 20\,000 + 2n$
2. **Solve.** $n = 20\,000 \div 10 = 2000$
3. **10 000 items.** ¥120 000 against ¥40 000

Decision

Print fewer than 2000, mould more

Just in time or just in case?

Just in time

Little stock, little space.

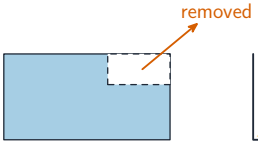
One late delivery stops the line.

Just in case

Reserve stock is safer.

Costly to store.

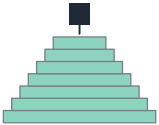
Four process families



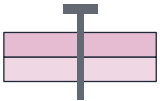
wasting (subtractive)
saw, drill, mill,
lathe, laser cut



forming
cast, injection
mould, vacuum
form, bend



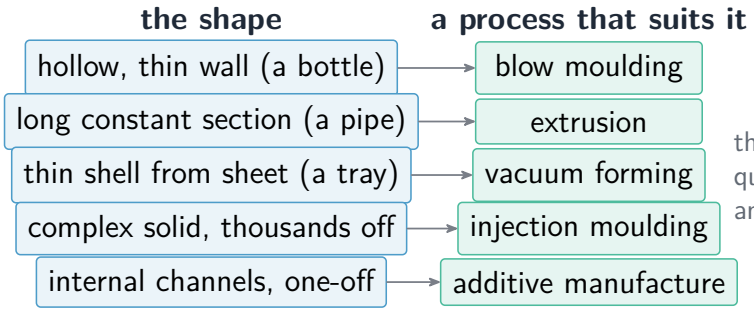
additive
FDM, resin,
laser sintering



joining
screws, rivets,
adhesive, weld

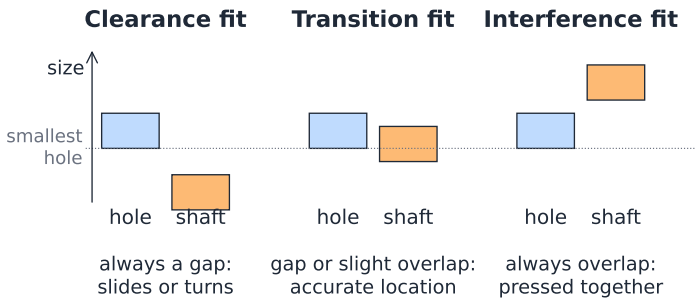
> Every process removes, shapes, adds or joins

Choose the process from the shape



The shape and the quantity choose the process

Three kinds of fit



- **Accuracy**, close to the true value.
- **Precision**, results close to each other.

Clearance from tolerances

1. **Minimum.** $9.8 - 9.6 = 0.2$ mm
2. **Maximum.** $10.2 - 9.4 = 0.8$ mm
3. **Fit.** Always a gap, a **clearance fit**

Decision

Says nothing about strength

Tolerances stack

> Every part can be in **tolerance** and the assembly still not **fit**.

- Three spacers 25.0 ± 0.1 mm make 75.0 ± 0.3 mm.
- Tighter tolerances cost more, use them only where needed.

Quality and testing

Quality control

Inspects and rejects.

Finds faults.

Quality assurance

Procedures, training, calibration.

Prevents faults.

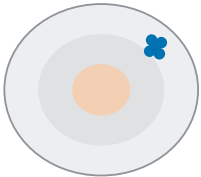
Check: which fit?

Your turn

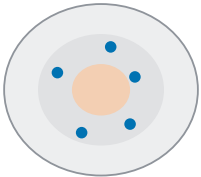
What kind of fit do these limits give?

A. Clearance fit
B. Transition fit
C. Interference fit
D. It depends on the material

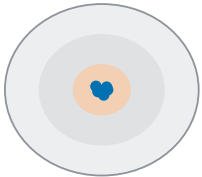
Accurate, precise, or both



precise, inaccurate



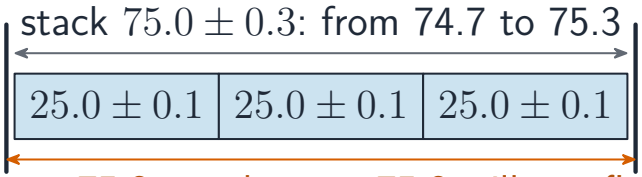
accurate, imprecise



accurate and precise

Precision is repeatability; **accuracy** is closeness to the true value

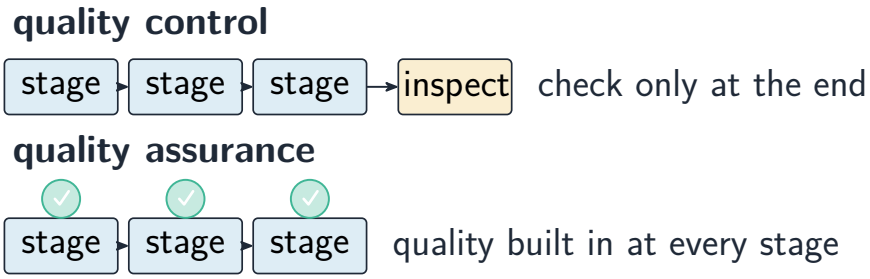
Tolerances add up



every part in tolerance, yet some assemblies fail

> A 75.2 mm gap will not take every stack

Inspect at the end, or build it in



> Assurance prevents faults; control only finds them

Four kinds of testing

destructive
load to failure; samples only

non-destructive
dye, ultrasound, X-ray: keeps the part

performance
each spec point: holds 100 N?

user and field
real people, real conditions

> Performance testing and user trials

Exam tips

> Minimum **clearance** = smallest hole − largest shaft.

- $\mathrm{N/mm^2}$ is the same as MPa; **strain** has no units.
- Justify materials and processes with several factors.
- QC finds faults, QA prevents them.

Check yourself

Try these

A wire of area 2 mm^2 and length 1500 mm carries 400 N and stretches 1.5 mm. Find stress, strain and Young's modulus.

Jigs cost ¥9000, then ¥150 per chair; a workshop charges ¥450 per chair. Find the break-even.

A hole is 12.0 to 12.4 mm and a shaft 11.5 to 11.8 mm. Find the clearances.