Maintaining our Grasp on Reality - Are Design Processes and CAD Models fit for purpose?

Queen's University Belfast

Professor Mark Price

12th June 2014

School of Mechanical and Aerospace Engineering

Overview

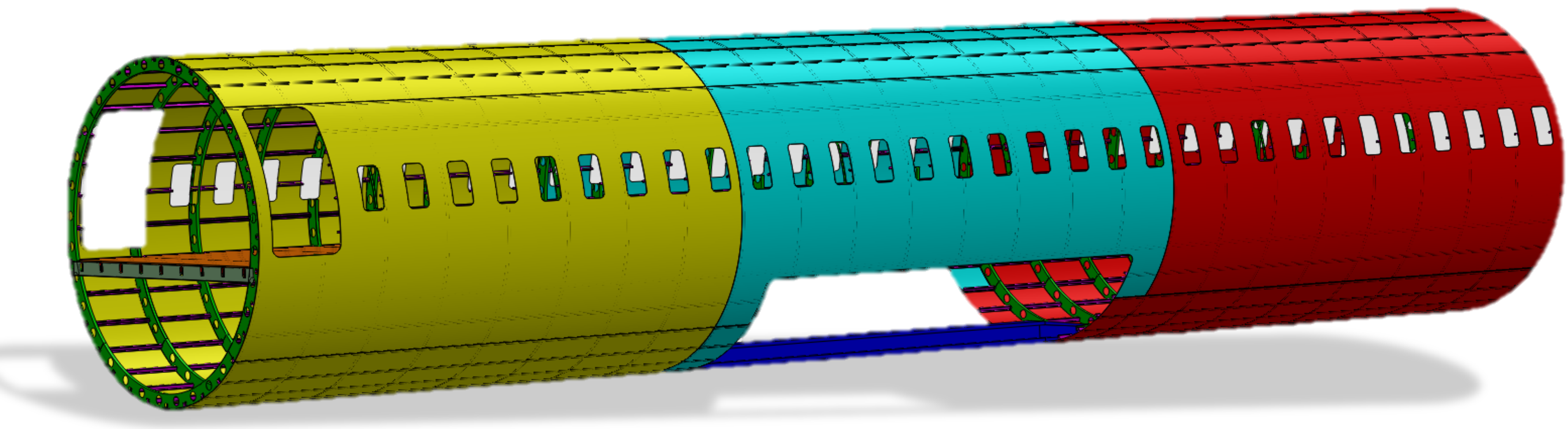
- Context and Background
  - Why is this an issue?
- Features and Parameters
  - What is the difference and why does it cause problems?

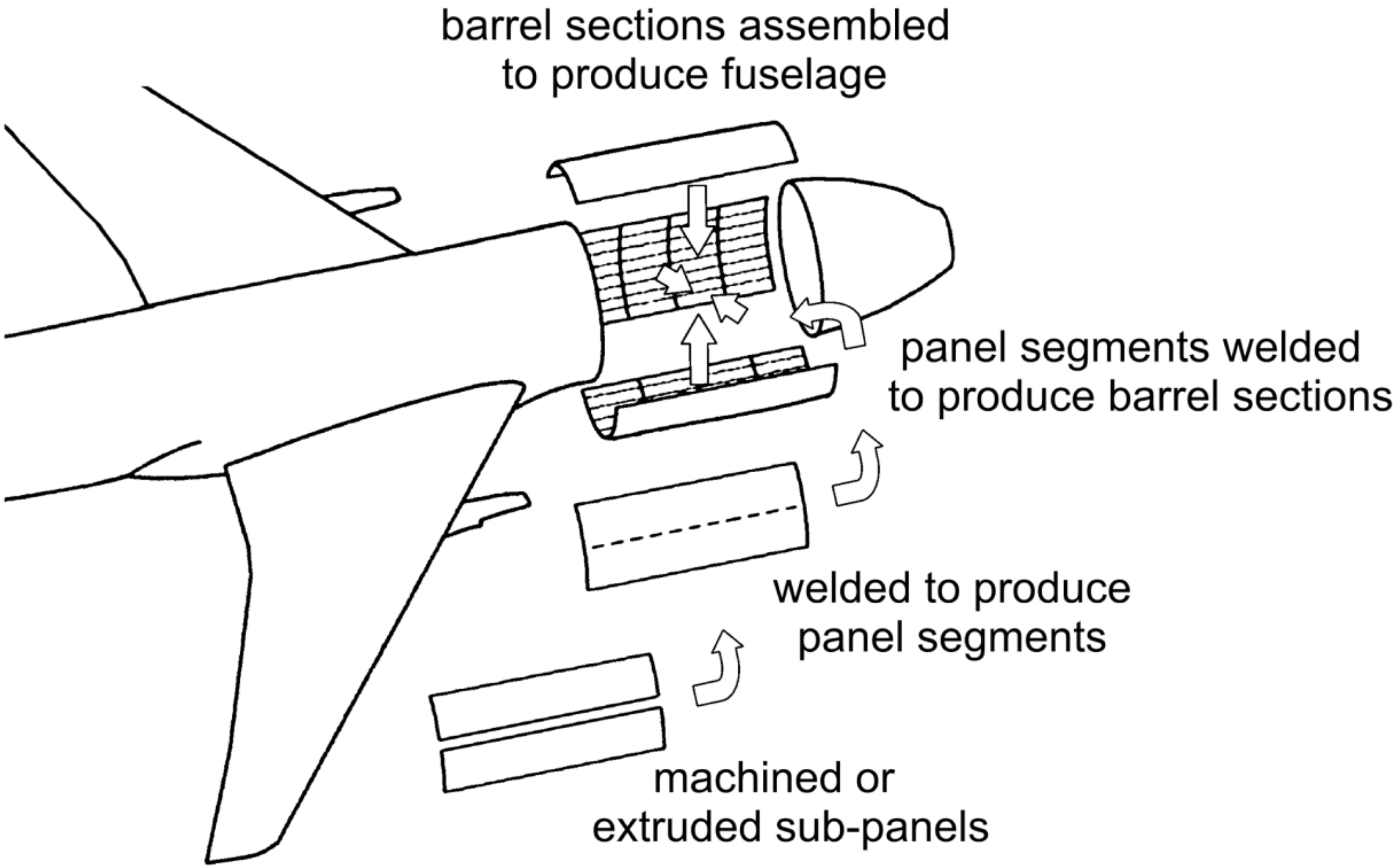
Begin at the beginning," the King said, very gravely, "and go on till you come to the end: then stop."
— Lewis Carroll, *Alice in Wonderland*

Context & Background

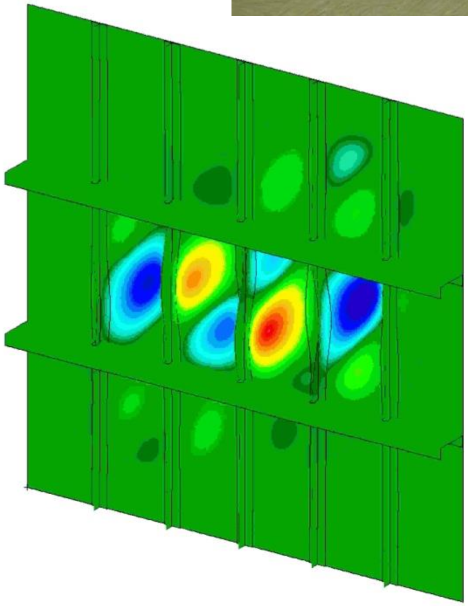
Complex Machines – Complex Decisions

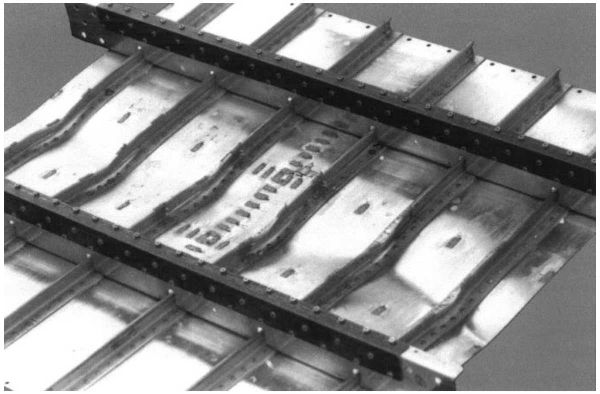
Fuselage Structure

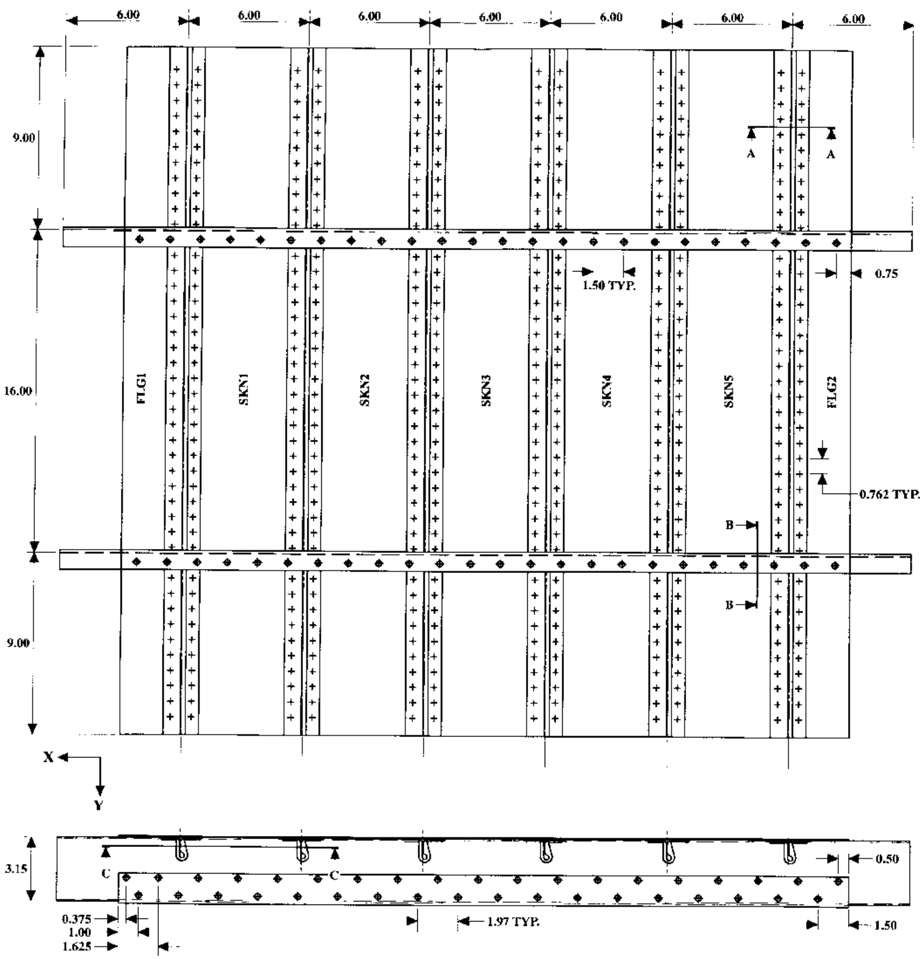


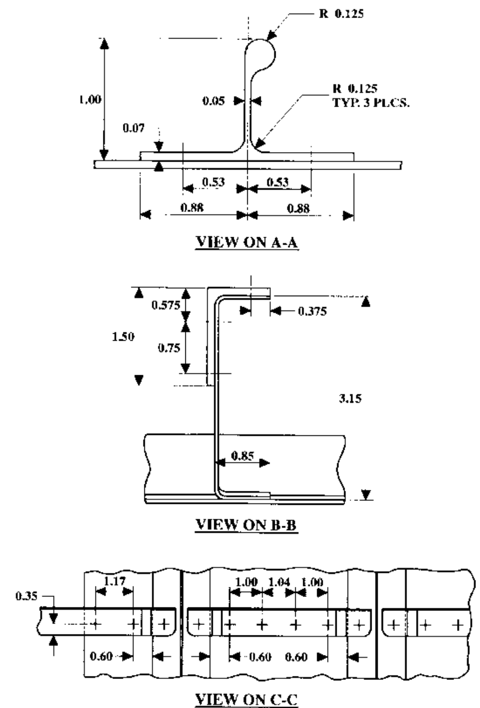

barrel sections assembled
to produce fuselage
panel segments welded
to produce barrel sections
welded to produce
panel segments
machined or
extruded sub-panels

Structures









NOTES

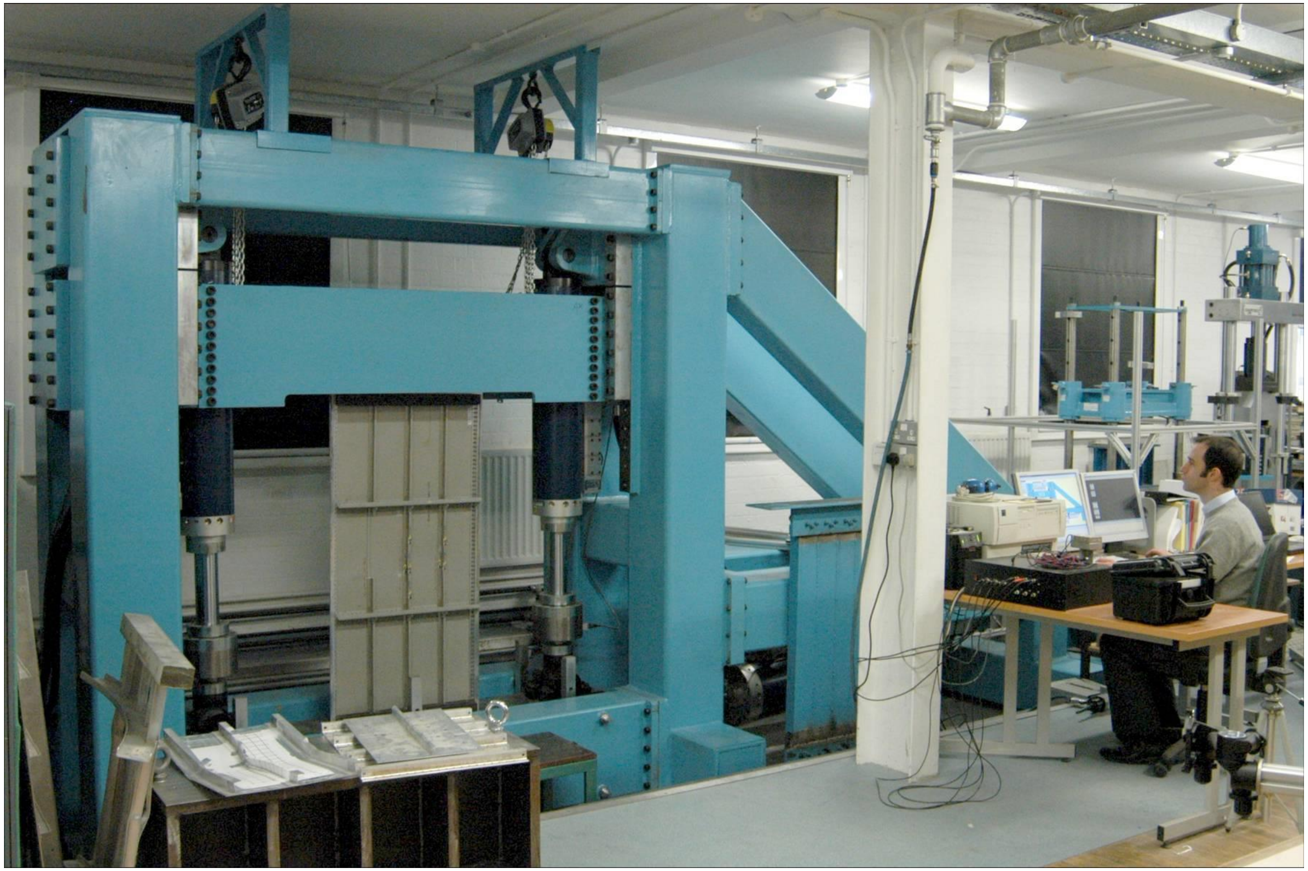
1. ALL DIMENSIONS IN INCHES
2. + = MS20426 100 DEG CSK RIVET
3. ⊕ = 2BA BOLT
4. SKIN - 2024-T3 0.063 THK
5. FRAME SECTIONS - 7075-T6 0.05 THK
6. STRINGERS - 2024-T8511 EXTRUSIONS
7. FRAME REINFORCING ANGLES - MILD STEEL 0.118 THK

Shear-Compression Test Rig

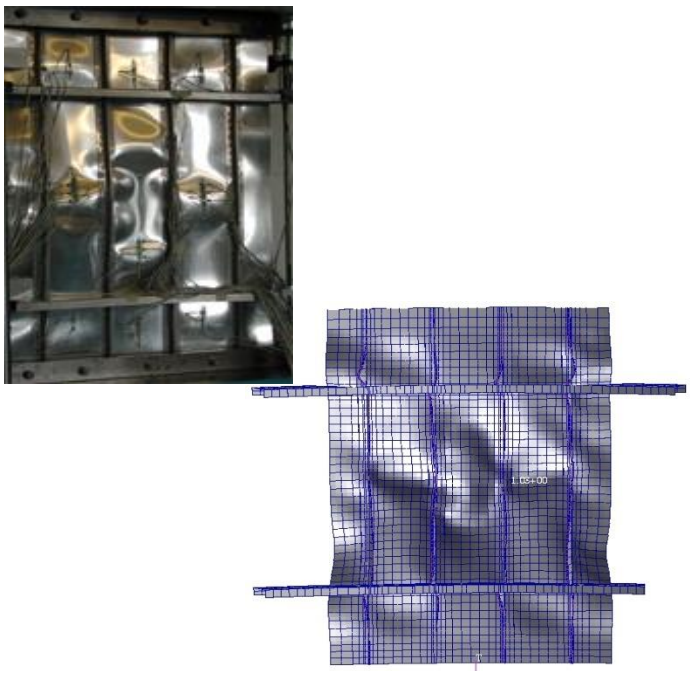
500kN
Compression

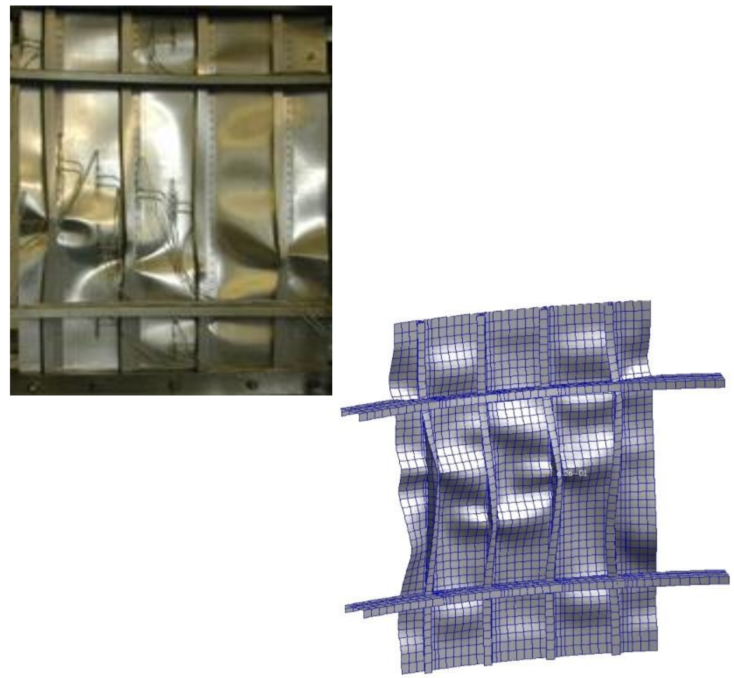
400kN
Shear

Panels
1.5mx1.5m



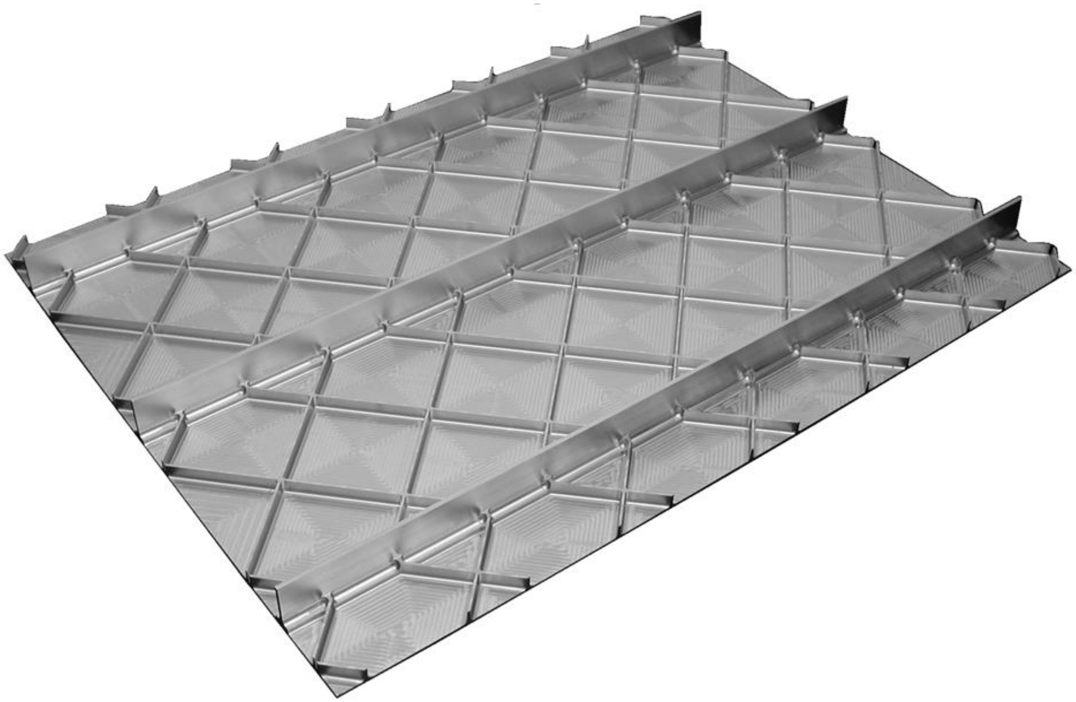
Virtual Testing



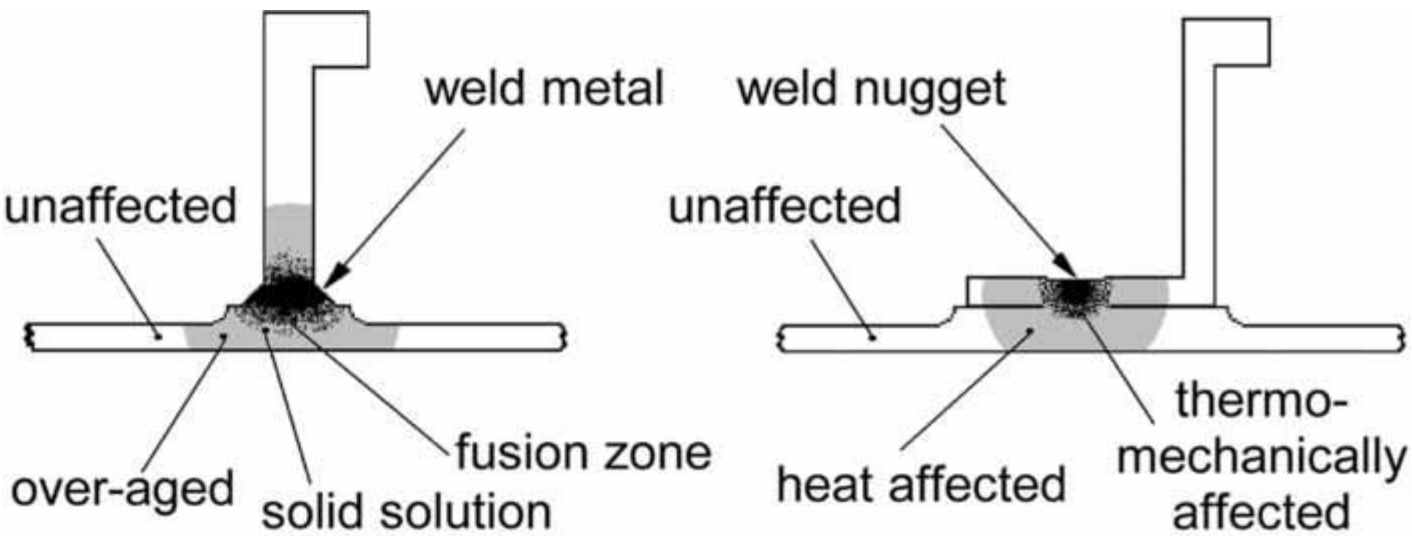


Advanced computer simulation allows virtual testing of the new concepts to quicken the selection of the most promising.

Integrated Design and Manufacturing

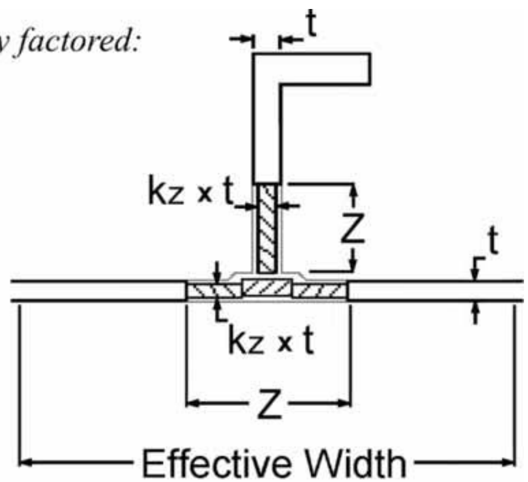


New manufacturing concepts such as laser beam and friction stir welding, and panel profiling, can result in lighter, cheaper airframes. (with Alcan France)

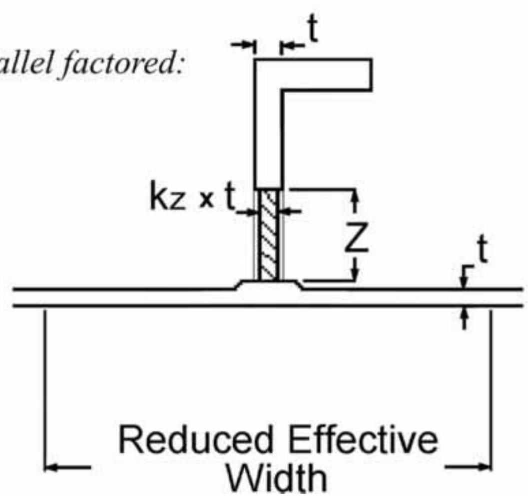


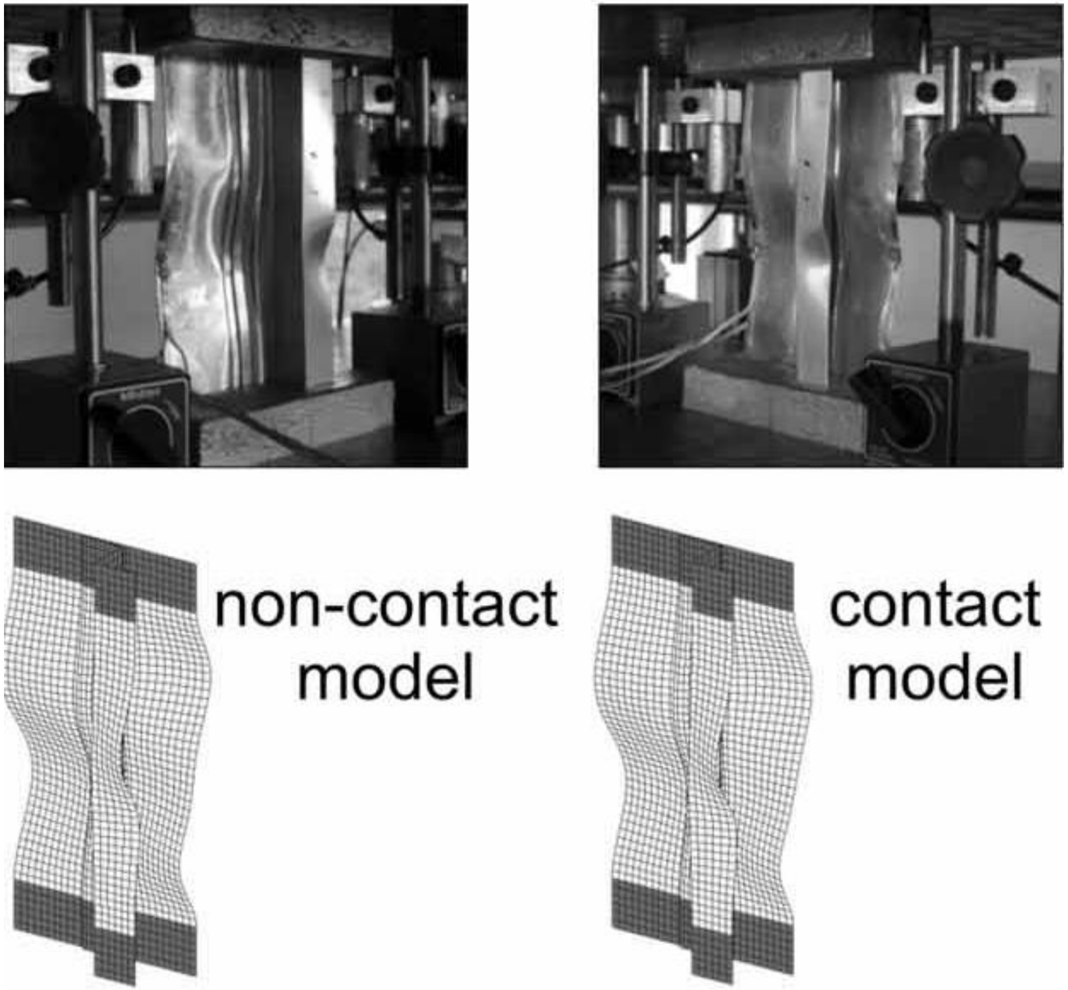
a) Laser beam welded section. *b) Friction stir welded section.*

a) Fully factored:



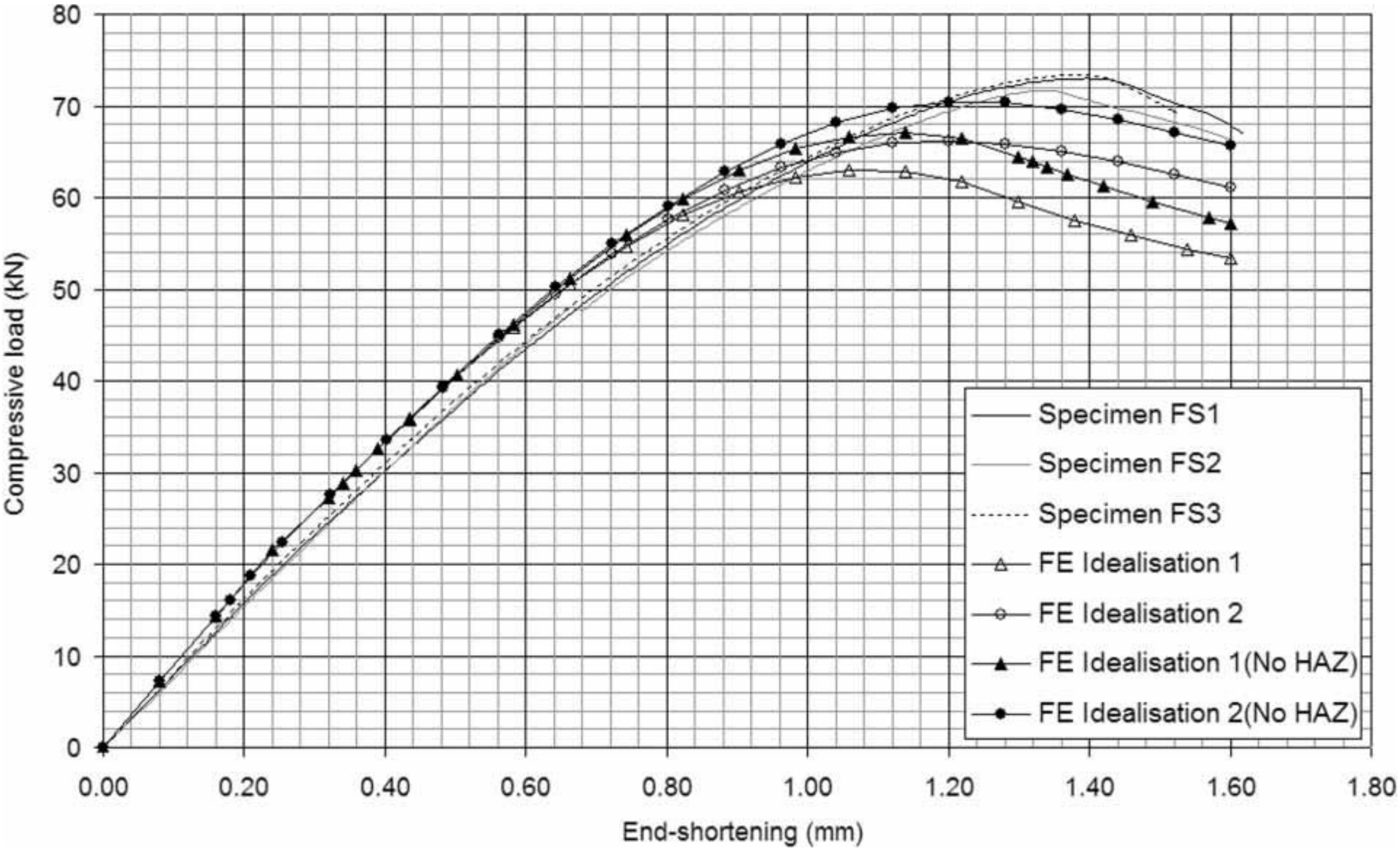
b) Parallel factored:

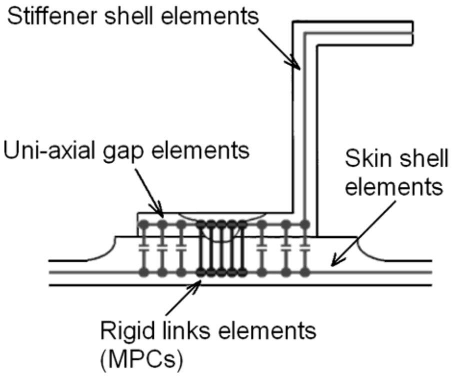


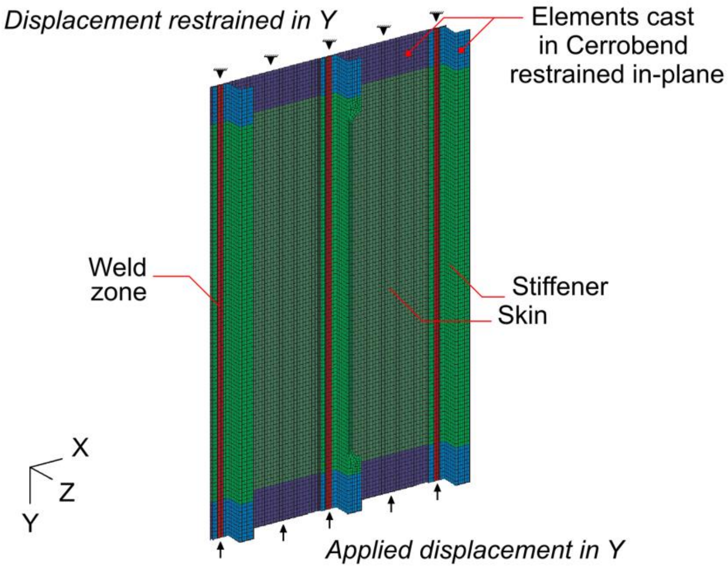


b) Friction stir welded (Specimen FS2)

Load-Displacement Curves

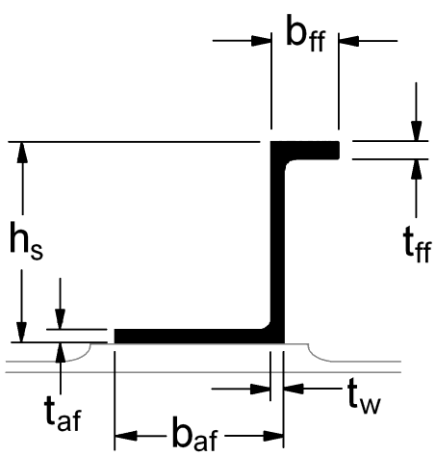


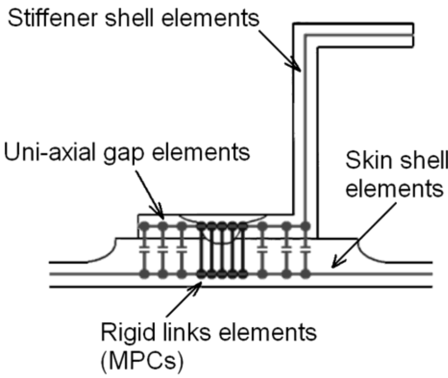

Stiffener shell elements
Uni-axial gap elements
Skin shell elements
Rigid links elements (MPCs)


Displacement restrained in Y
Elements cast in Cerrobend restrained in-plane
Weld zone
Stiffener
Skin
X
Z
Y
Applied displacement in Y

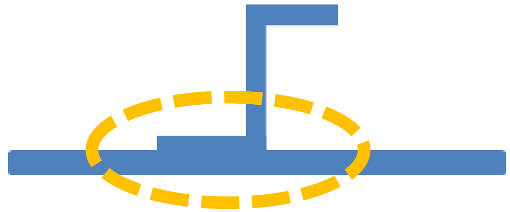
The devil in the detail!

Single frame bay specimen		
	Edge stiffeners [welded] (mm)	Central stiffeners [welded] (mm)
$\mathbf{h_s}$	25.4	25.4
$\mathbf{b_{ff}}$	20.3	7.3
$\mathbf{b_{af}}$	22.9	22.9
$\mathbf{t_w}$	1.6	1.6
$\mathbf{t_{ff}}$	1.6	1.6
$\mathbf{t_{af}}$	1.6	1.6
$\mathbf{t_{skin}}$	1.2	

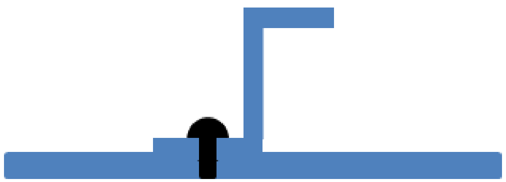




Key Issue: Stiffener-Skin Interface

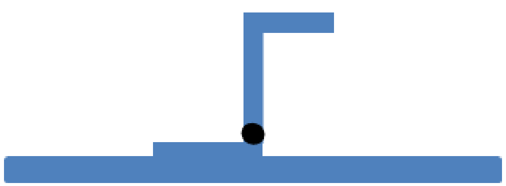


(a) Idealised Stiffener on plate

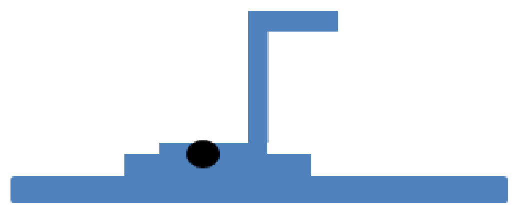


(b) Riveted Stiffener
(assembled)

(c) Integral Stiffener
(extruded or machined)

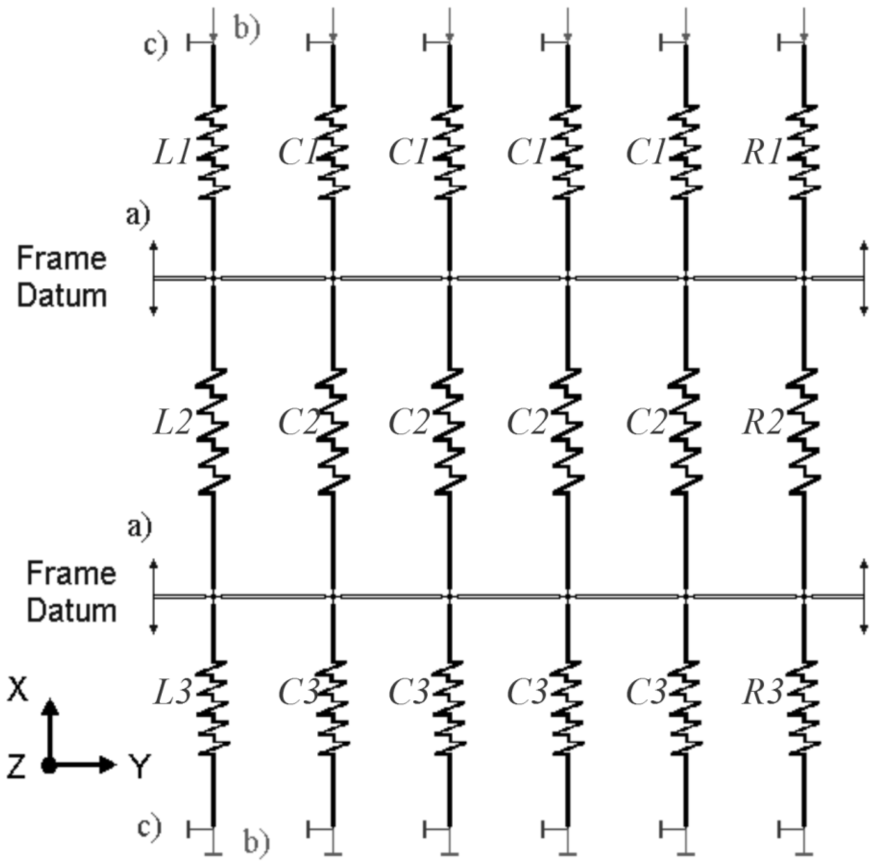


(d) Laser welded Stiffener
(assembled)

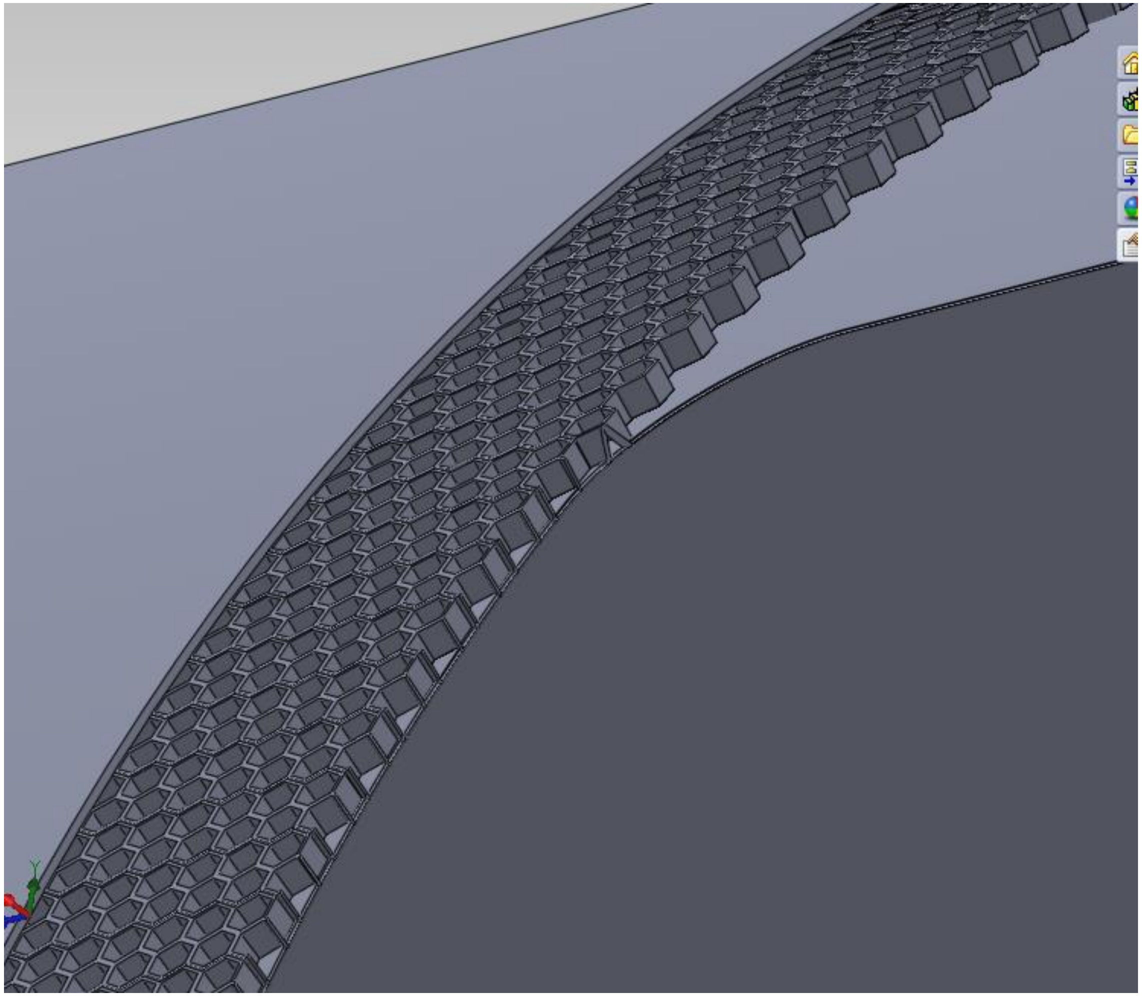


(e) Friction Stir Welded Stiffener
(assembled)

Different minimum weight solutions are found for each of these.



a) → Frame datums allow to translate axial in-plane
b) → Model axial loading & restraints
c) → Model rigid body motion restraints



Problem

- Design is about creating real products
  - Things that get made!
- Fundamentally it is defining geometry for manufacture
  - Of course also operations etc
- Sophisticated processes and tools
  - Systems engineering, CAD, CAE CAM…..
  - Powerful feature based modelling systems

- Design Intent

“..a set of geometric and functional rules that the final product has to satisfy.”

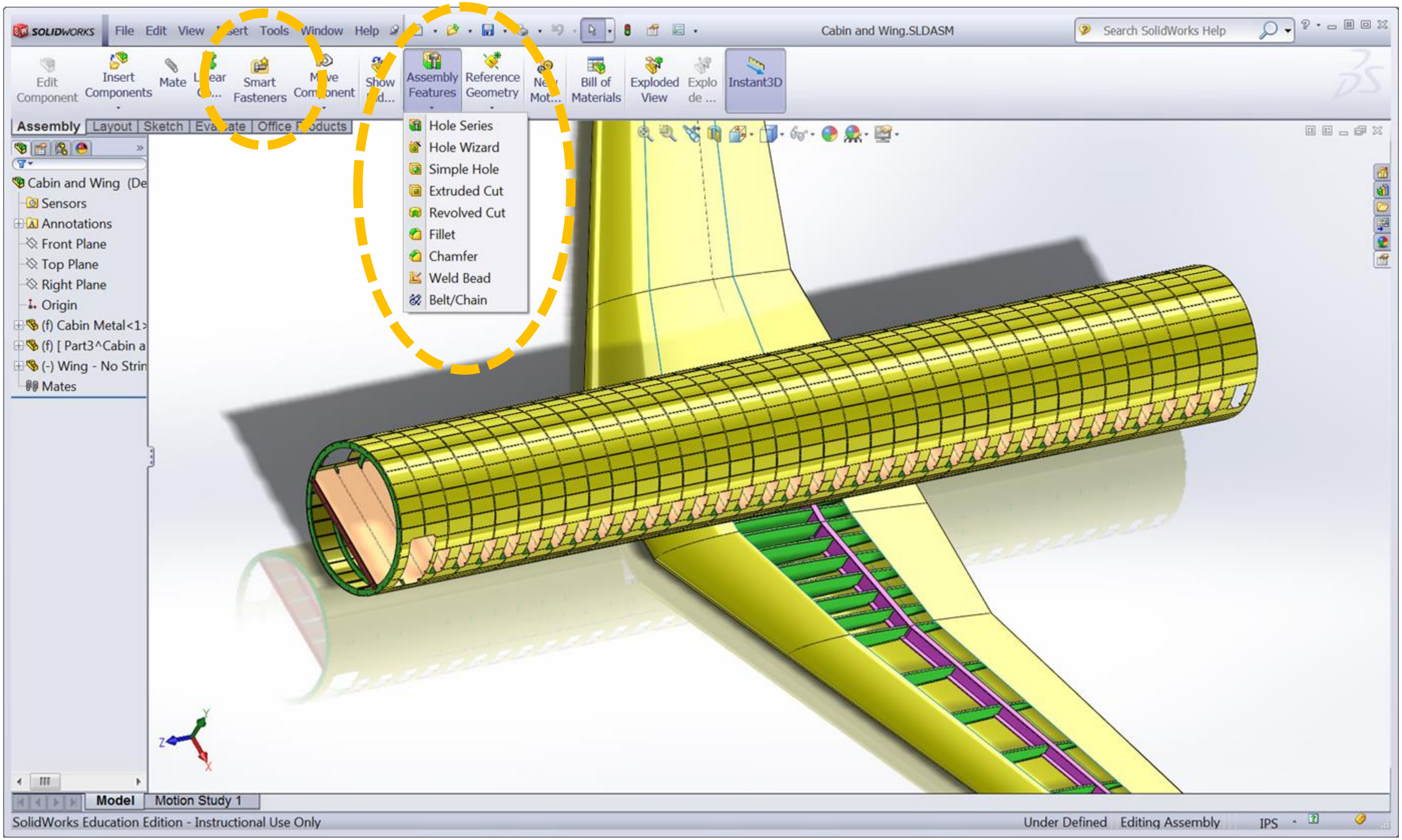
(Mun)

or

“The set of functions which the system was designed to deliver in the anticipated operating environment”

(QUB)

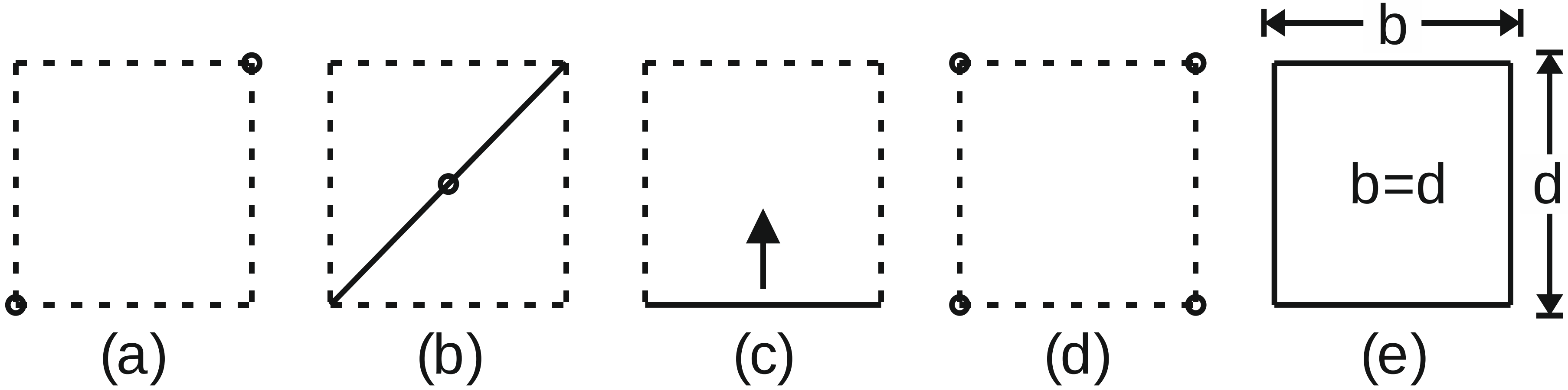
Features and Parameters



SolidWorks
File
Edit
View
Tools
Window
Help
Cabin and Wing.SLDASM
Search SolidWorks Help
Edit Component
Insert Components
Mate
Smart Fasteners
Show
Assembly Features
Reference Geometry
Bill of Materials
Exploded View
Instant3D
Assembly
Layout
Sketch
Hole Series
Hole Wizard
Simple Hole
Extruded Cut
Revolved Cut
Fillet
Chamfer
Weld Bead
Belt/Chain
Cabin and Wing (De
Sensors
Annotations
Front Plane
Top Plane
Right Plane
Origin
(f) Cabin Metal<1>
(f) [Part3^Cabin a
(-) Wing - No Strin
Mates
Model
Motion Study 1
SolidWorks Education Edition - Instructional Use Only
Under Defined
Editing Assembly
IPS

The Face Off

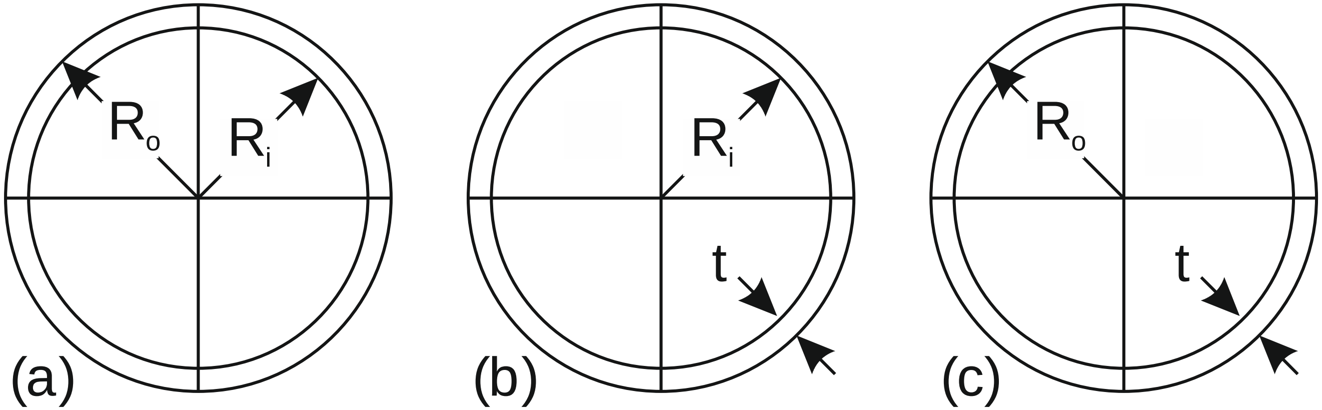
- The Process vs the Product
  - How the model is built
  - How it looks in it’s final form



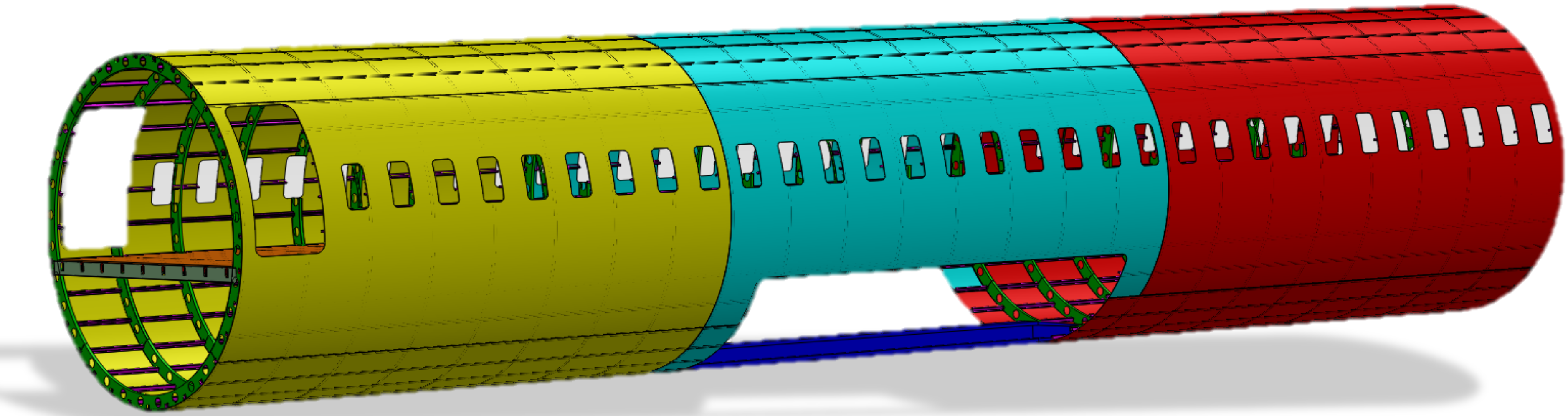
- Parameters….

“..the designer’s choice of parameterisation and constraint schemes constitutes an important part of what is known as design intent”

(Anderson)

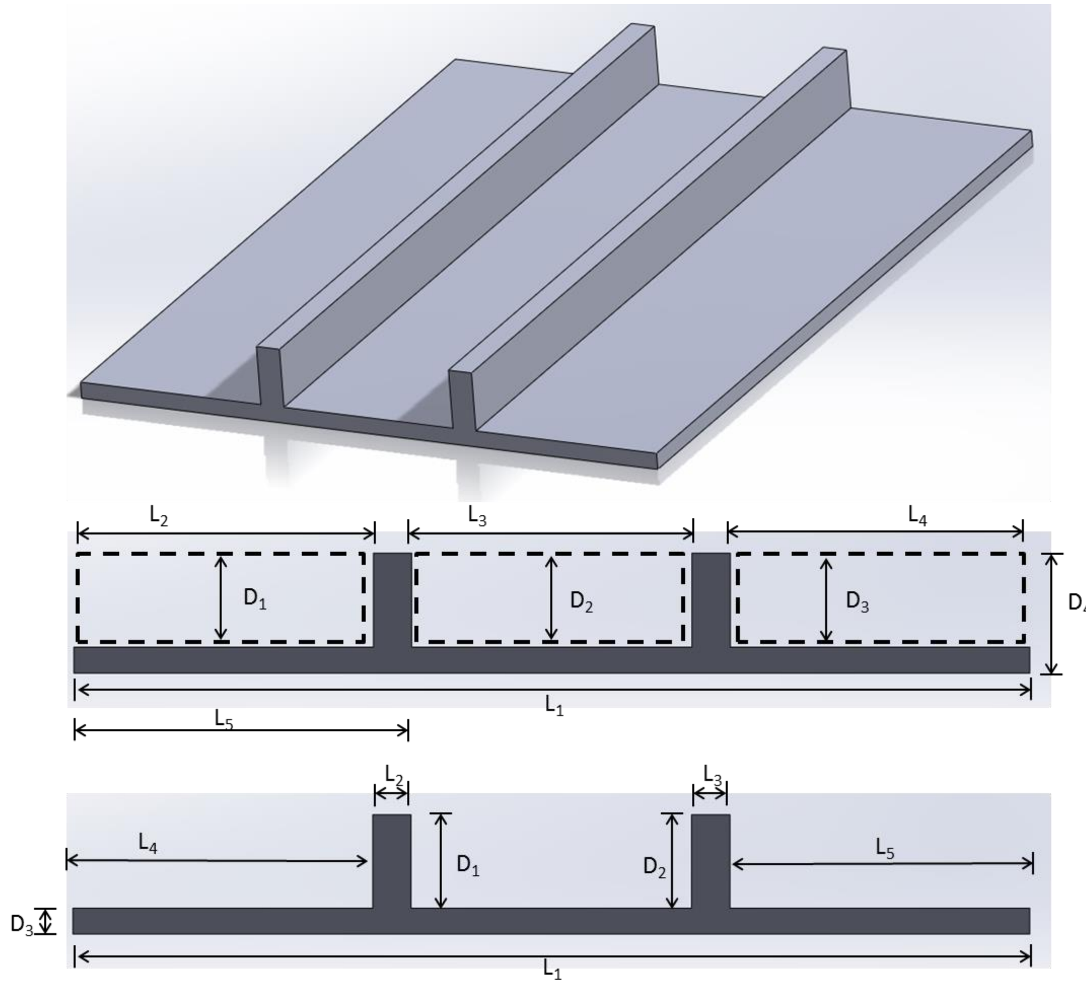


Back to the Fuselage

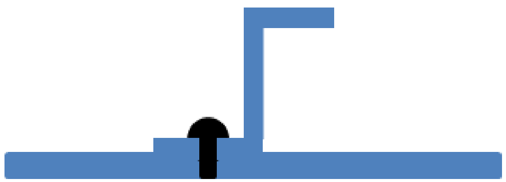


- CAD Feature tools help the designer to create geometry (and features) quickly

- No account taken how it is to be manufactured…..

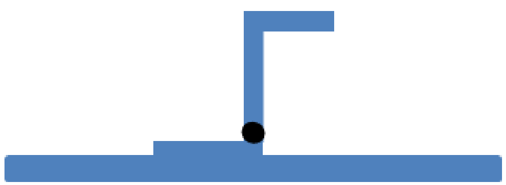

L2
L3
L4
D1
D2
D3
D4
L1
L5
L2
L3
L4
D1
D2
L5
D3
L1

(a) Idealised Stiffener on plate

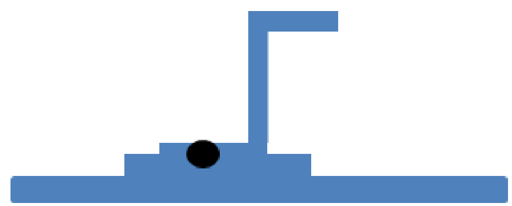


(b) Riveted Stiffener
(assembled)

(c) Integral Stiffener
(extruded or machined)

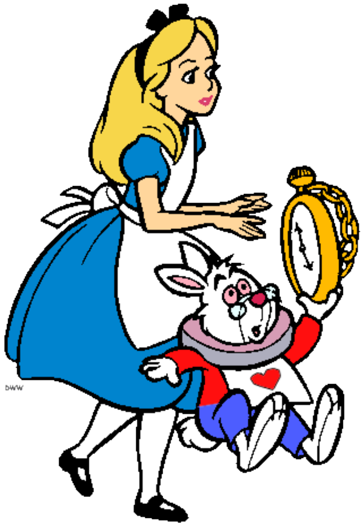


(d) Laser welded Stiffener
(assembled)



(e) Friction Stir Welded Stiffener
(assembled)

Why, sometimes I've believed as many as six impossible things before breakfast.”
— Lewis Carroll, *Alice in Wonderland*



Where does this all fit in a design process?

- Prediction using Newton…..

$$\sum F_y = 0$$

- But formula become more complex as we look deeper into problems
  - E.g. beams

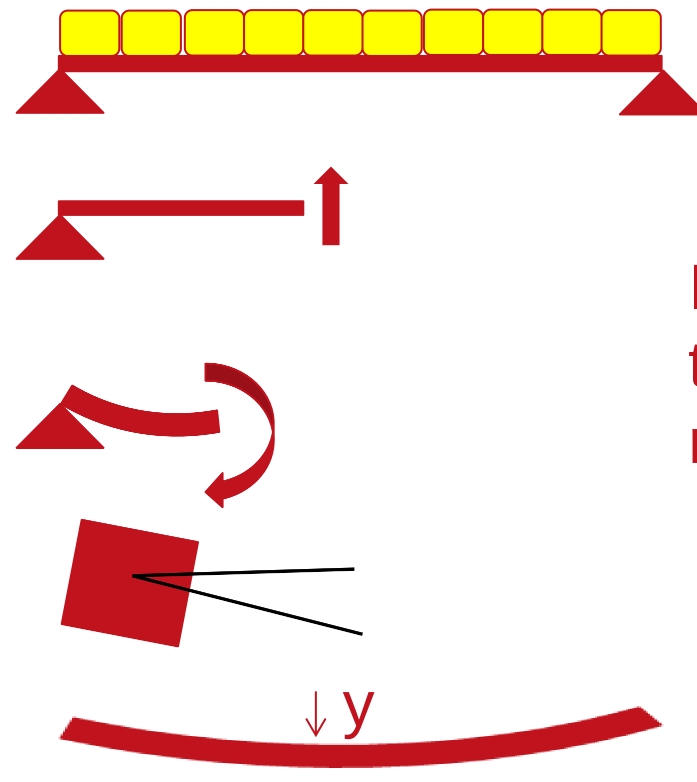
$$Load = W(x)$$

$$S = \int W dx$$

$$M = \int S dx$$

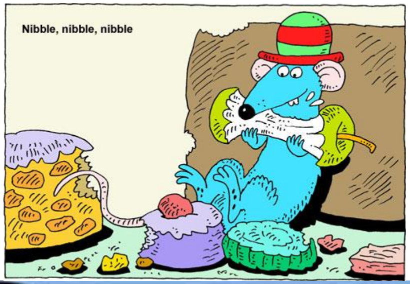
$$\theta = \int M dx$$

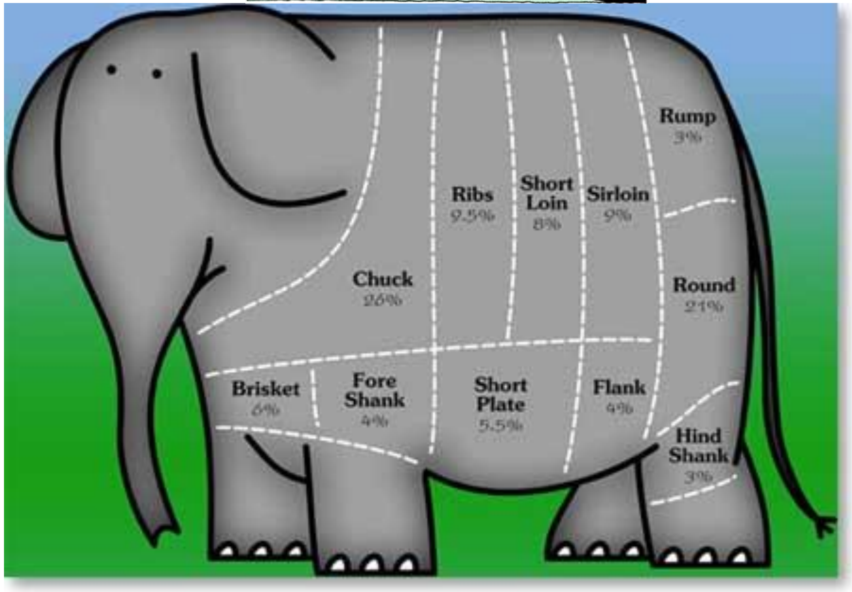
$$y = \int \theta dx$$



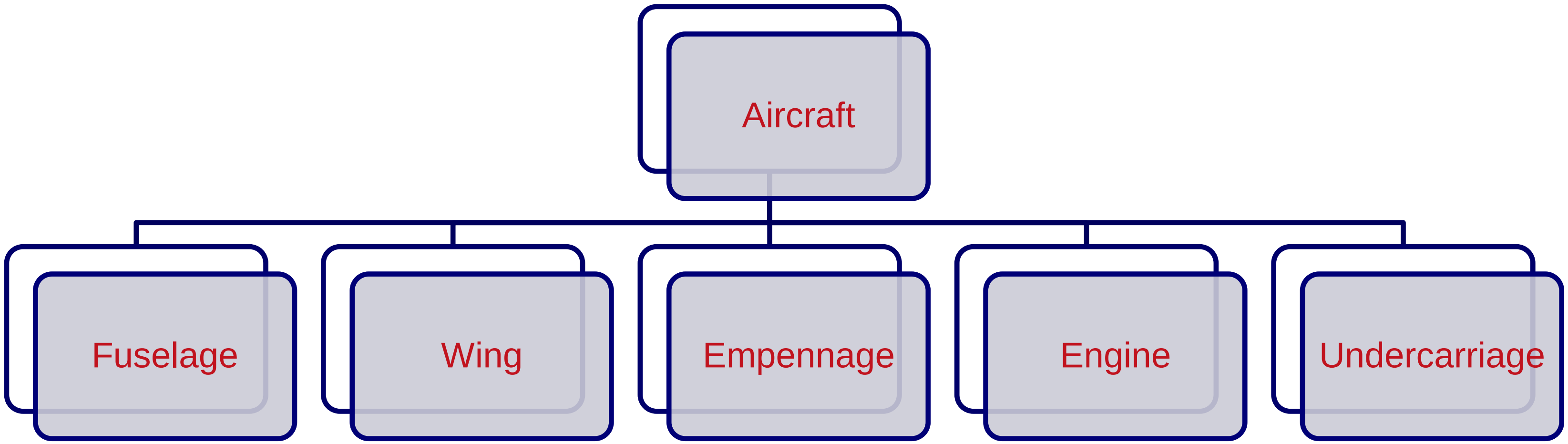
Inside the material!

How do you eat an elephant?



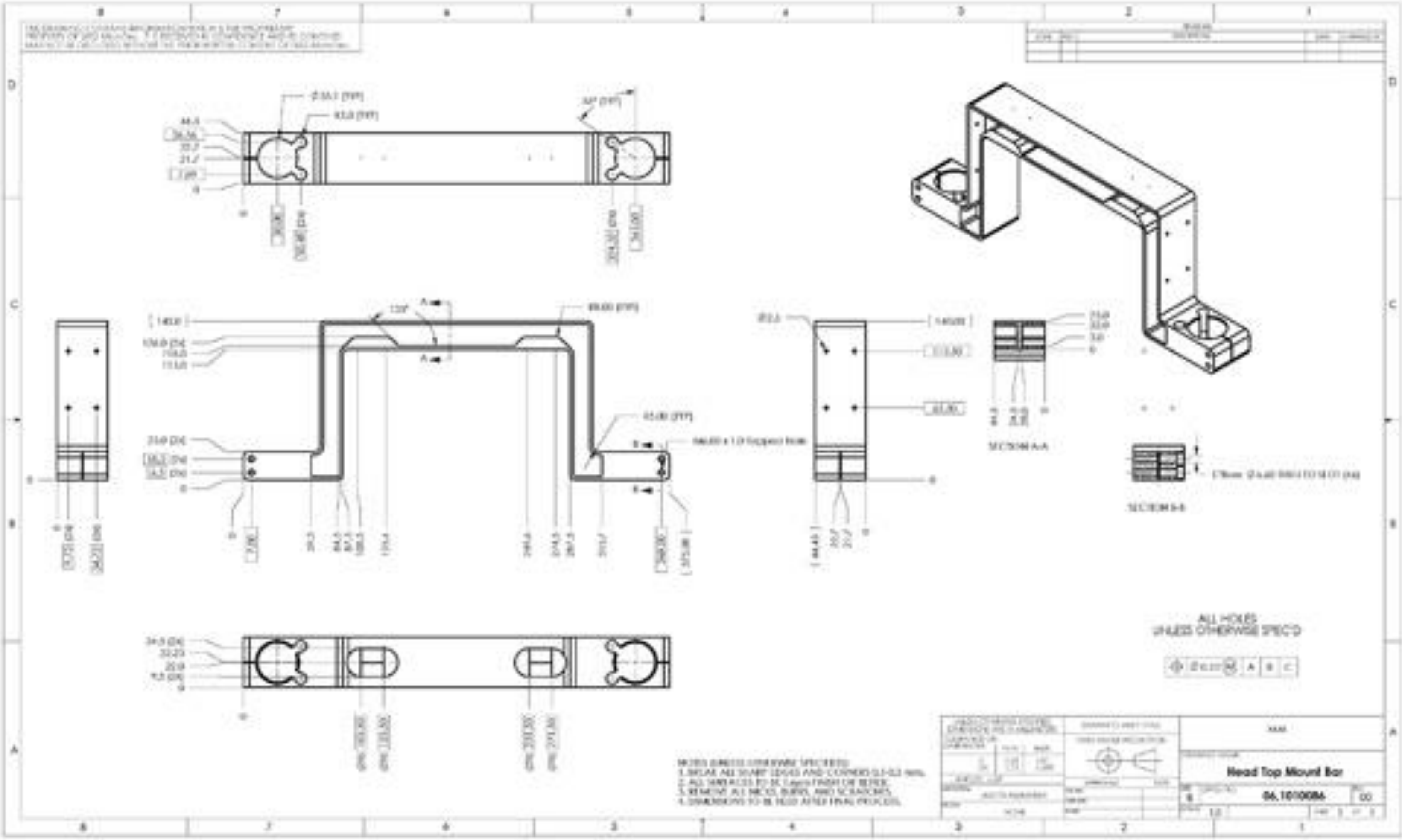


Same for Complicated Machines

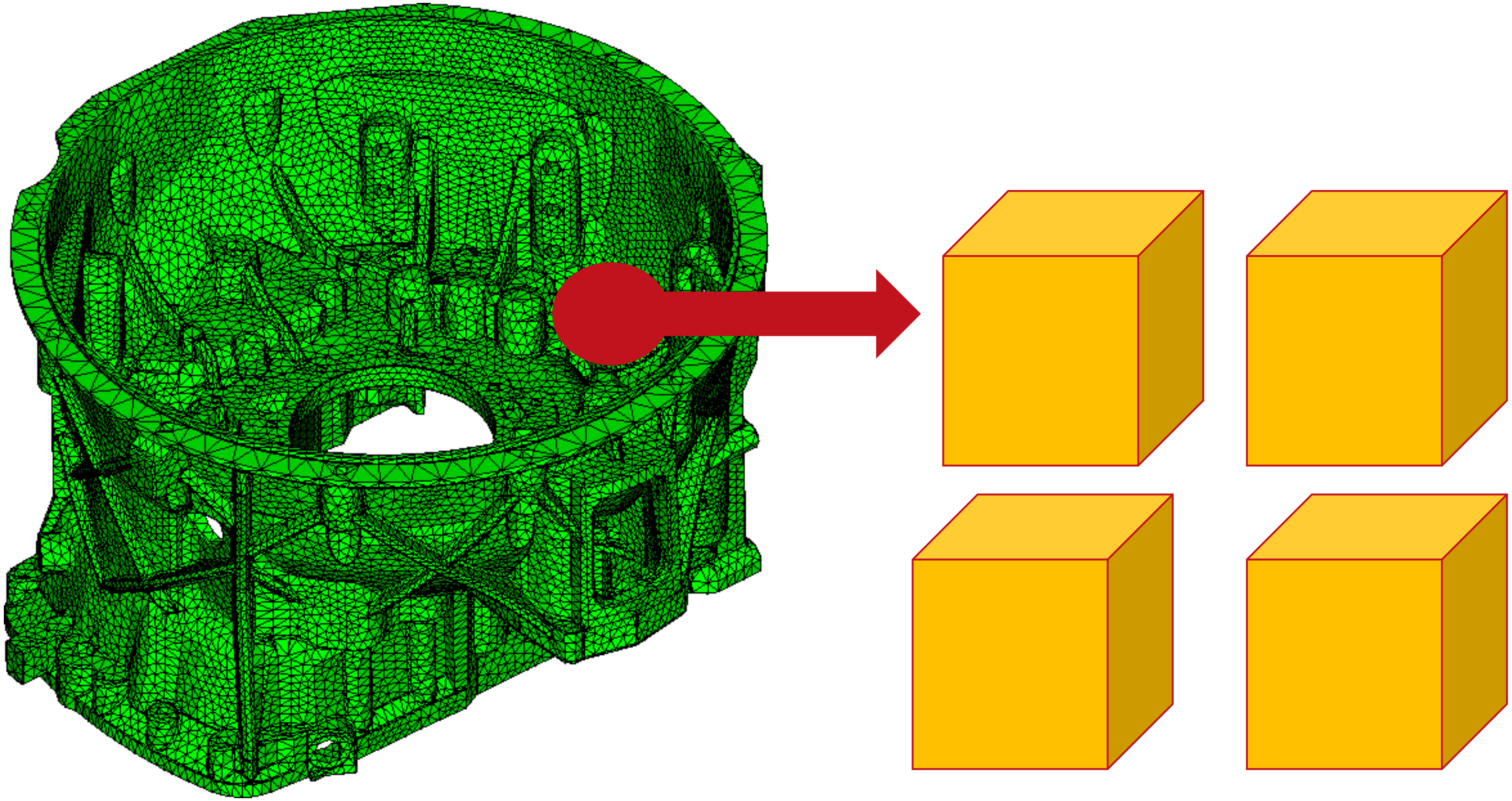


Components can be complex in shape

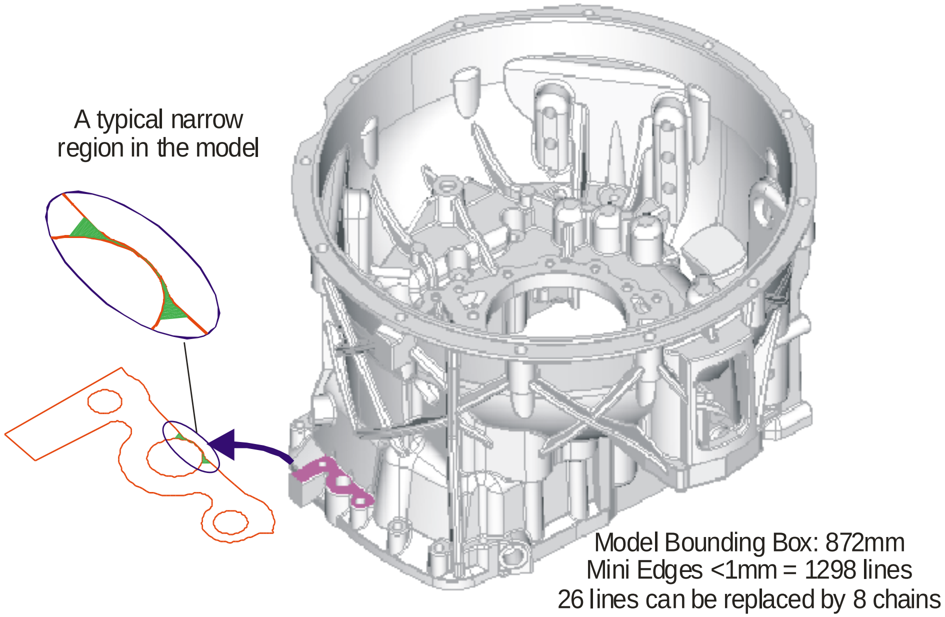
Detailed Manufacturing Drawings

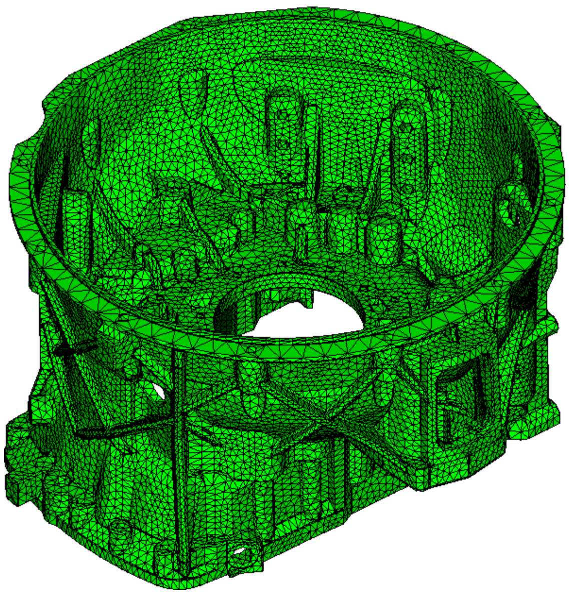


Very challenging for complex shapes



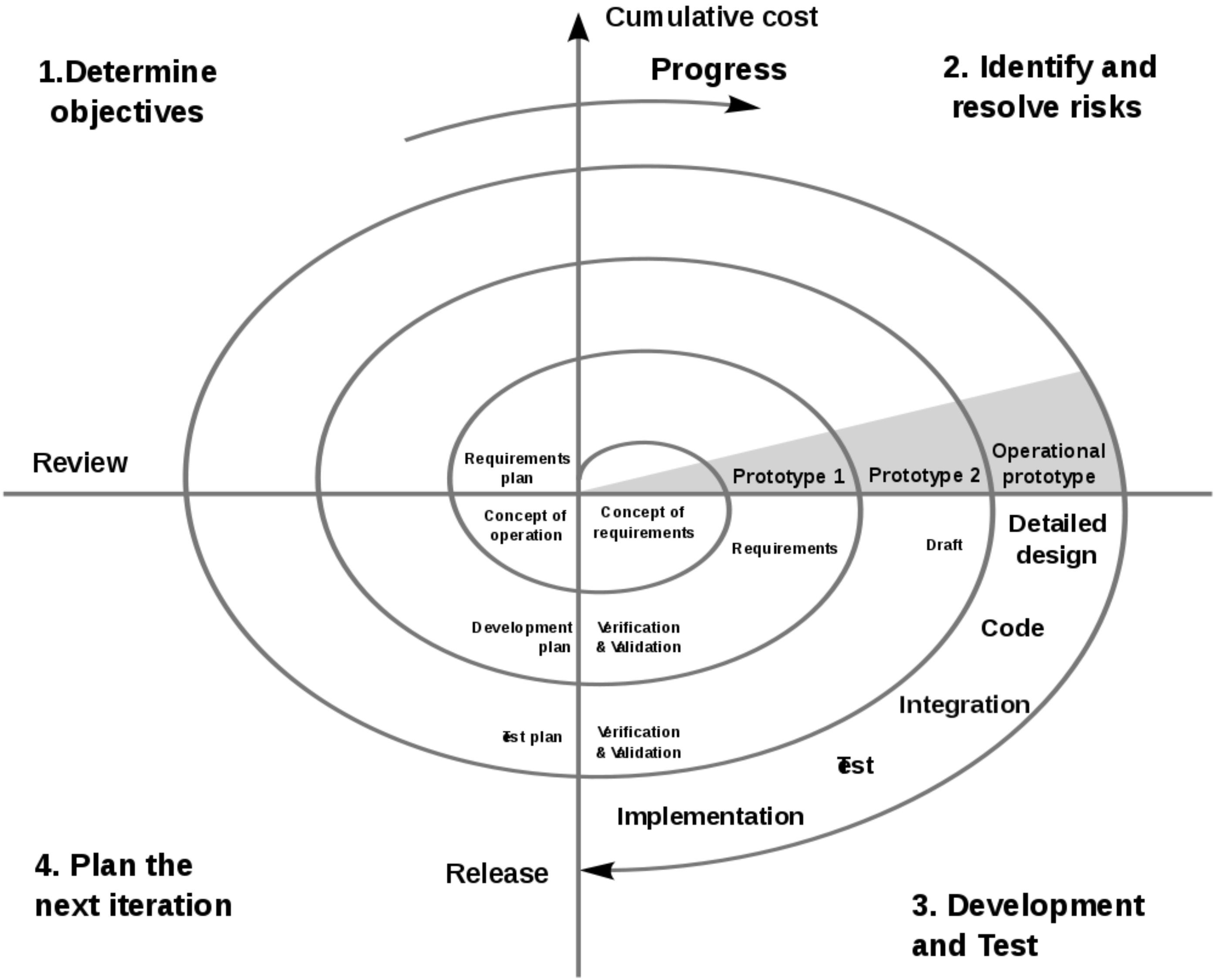
Idealisation & Model Simplification

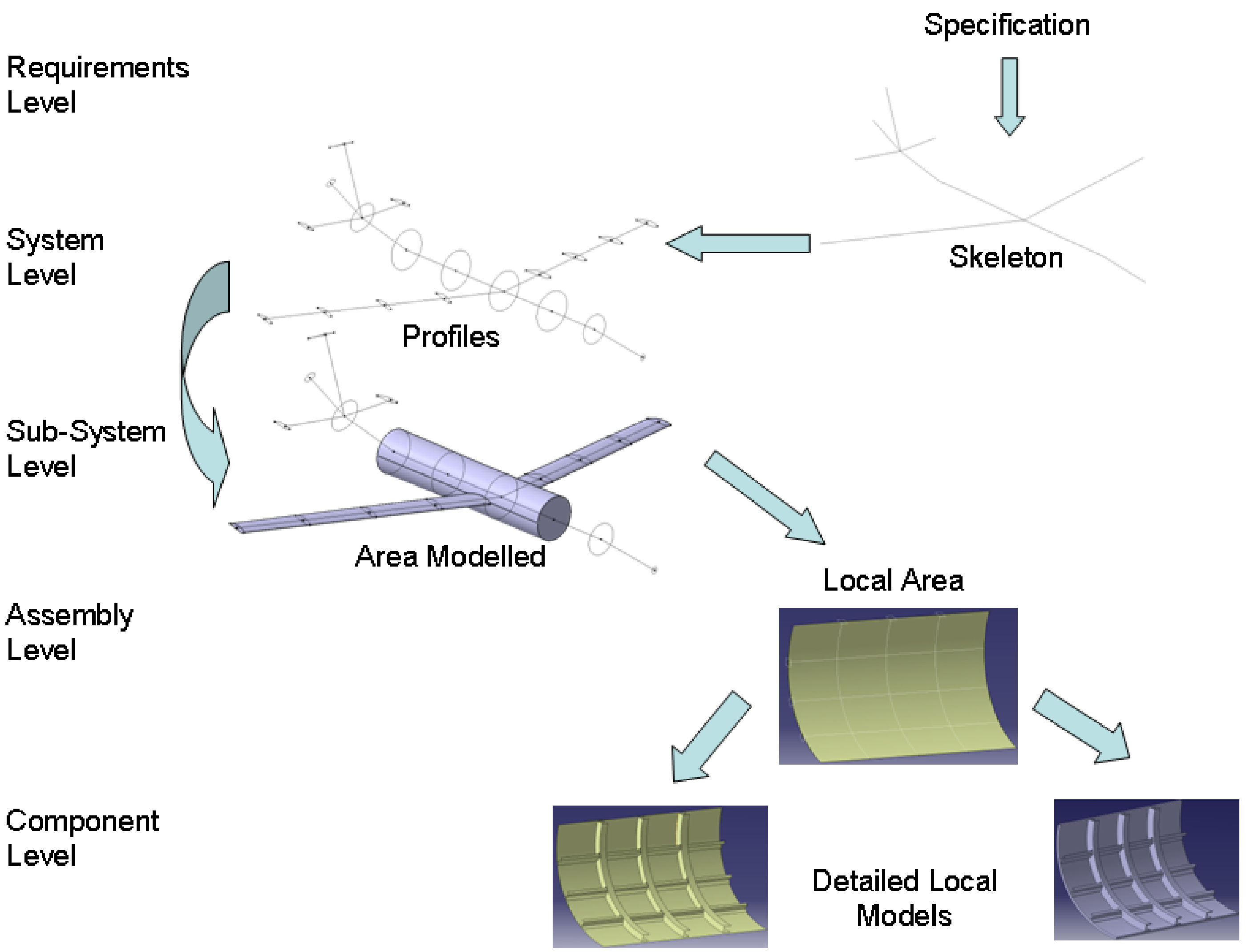




“What I cannot create, I do not understand. *Know how to solve every problem that has been solved.”*

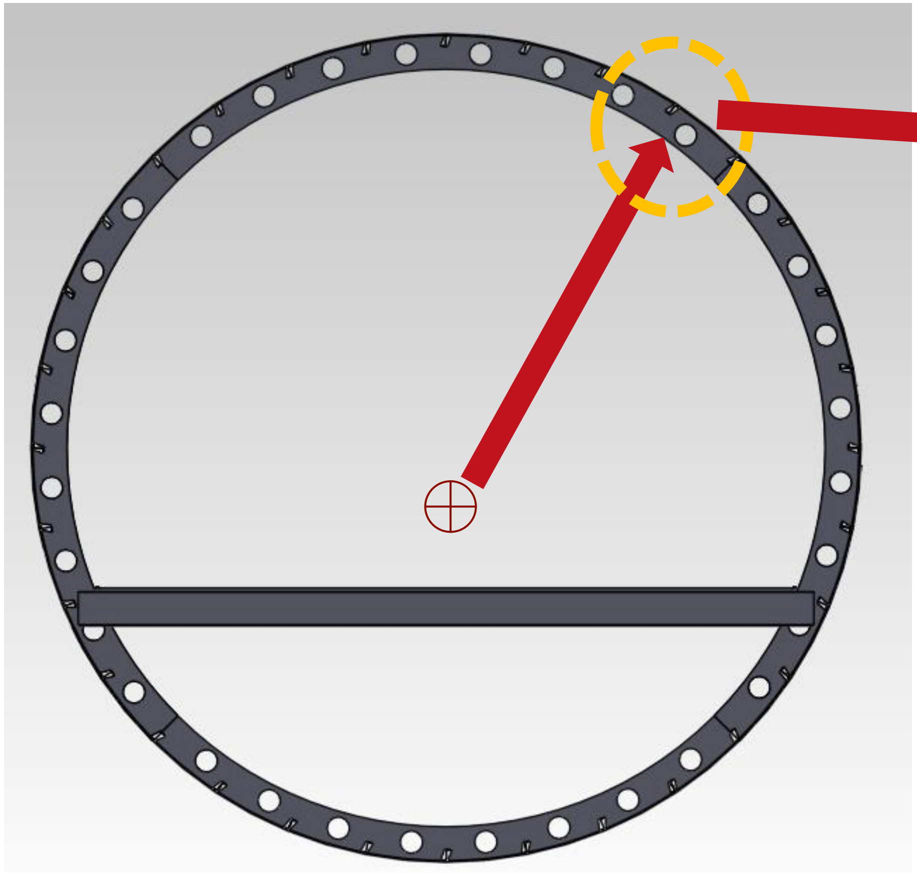
Richard Feynman

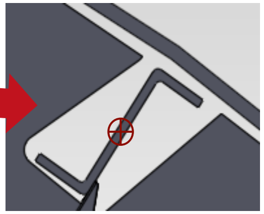

Cumulative cost
Progress
1.Determine objectives
2. Identify and resolve risks
Review
Requirements plan
Concept of operation
Concept of requirements
Prototype 1
Prototype 2
Operational prototype
Requirements
Draft
Detailed design
Development plan
Verification & Validation
Code
Integration
Test plan
Verification & Validation
Test
Implementation
Release
4. Plan the next iteration
3. Development and Test


Specification
Requirements
Level
System
Level
Skeleton
Profiles
Sub-System
Level
Area Modelled
Local Area
Assembly
Level
Component
Level
Detailed Local
Models

Correct placing & relationships

The fuselage is reinforced with frames and stiffeners

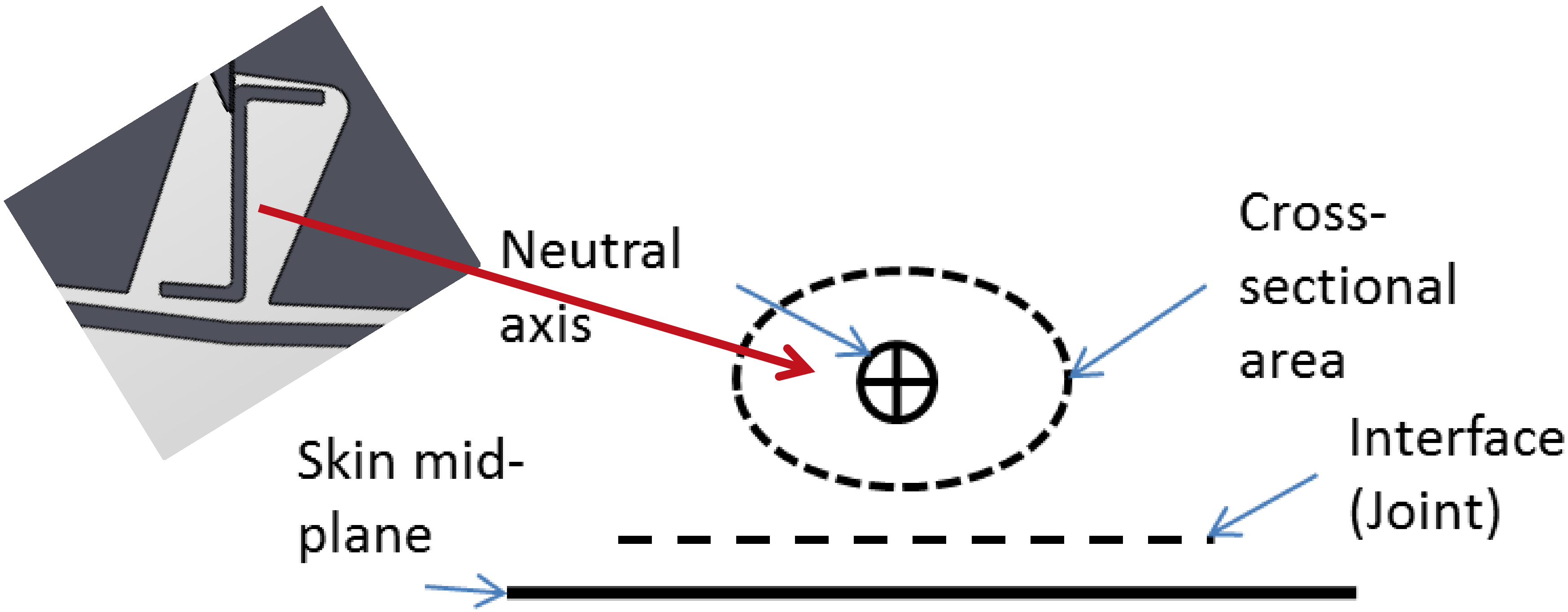




The stiffeners are placed relative to the neutral axis of the fuselage.

Designers sketch & analysts idealise

Function (Intent) of the stiffener is to carry end load and a little (but preferably no) bending, supporting the skin.



Implications of assemblies

- Implies integration of manufacturing processes in design
- Consideration of cost, resourcing, planning, maintenance etc
- It is a problem with many dimensions

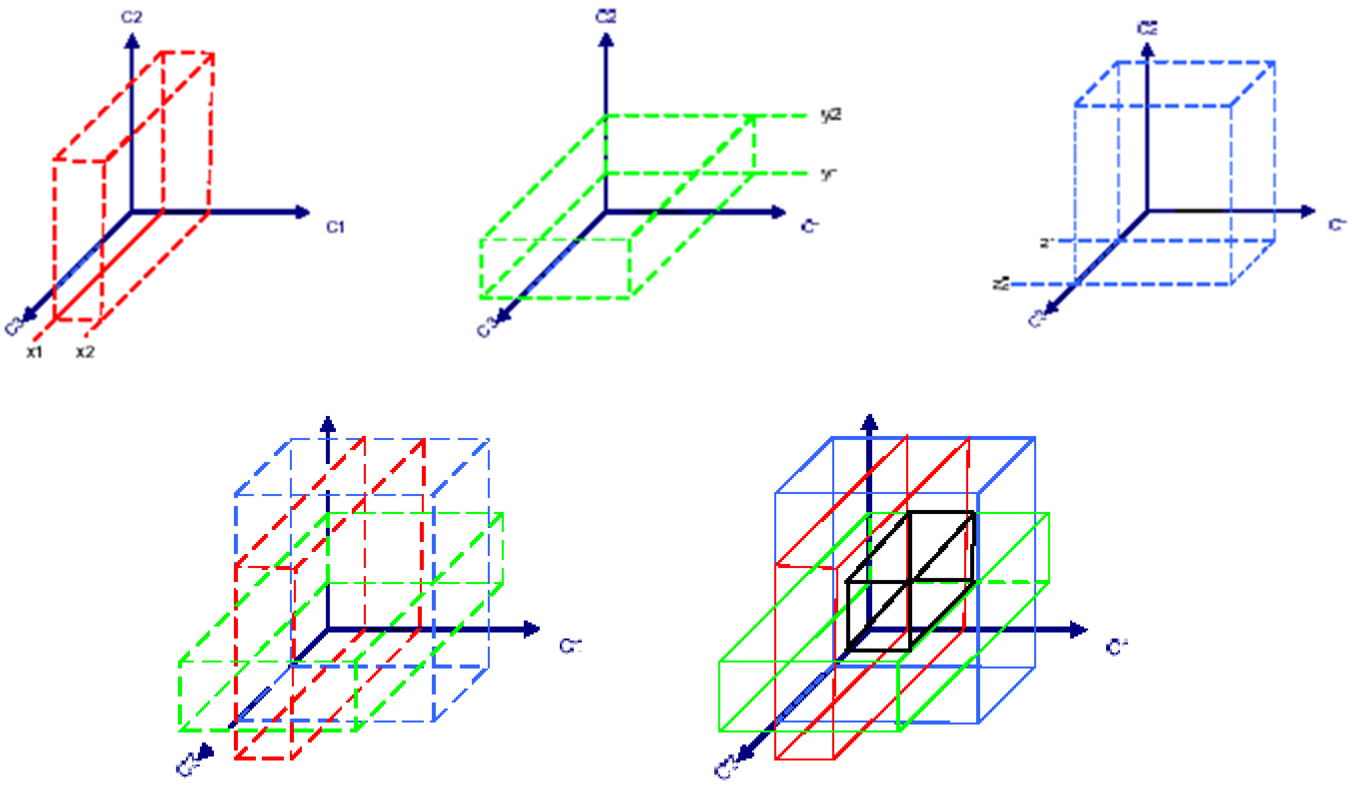
Integrated System Functions

$$F(x, y, z, t, \text{cost}, \text{material}, \text{process}\ldots)$$

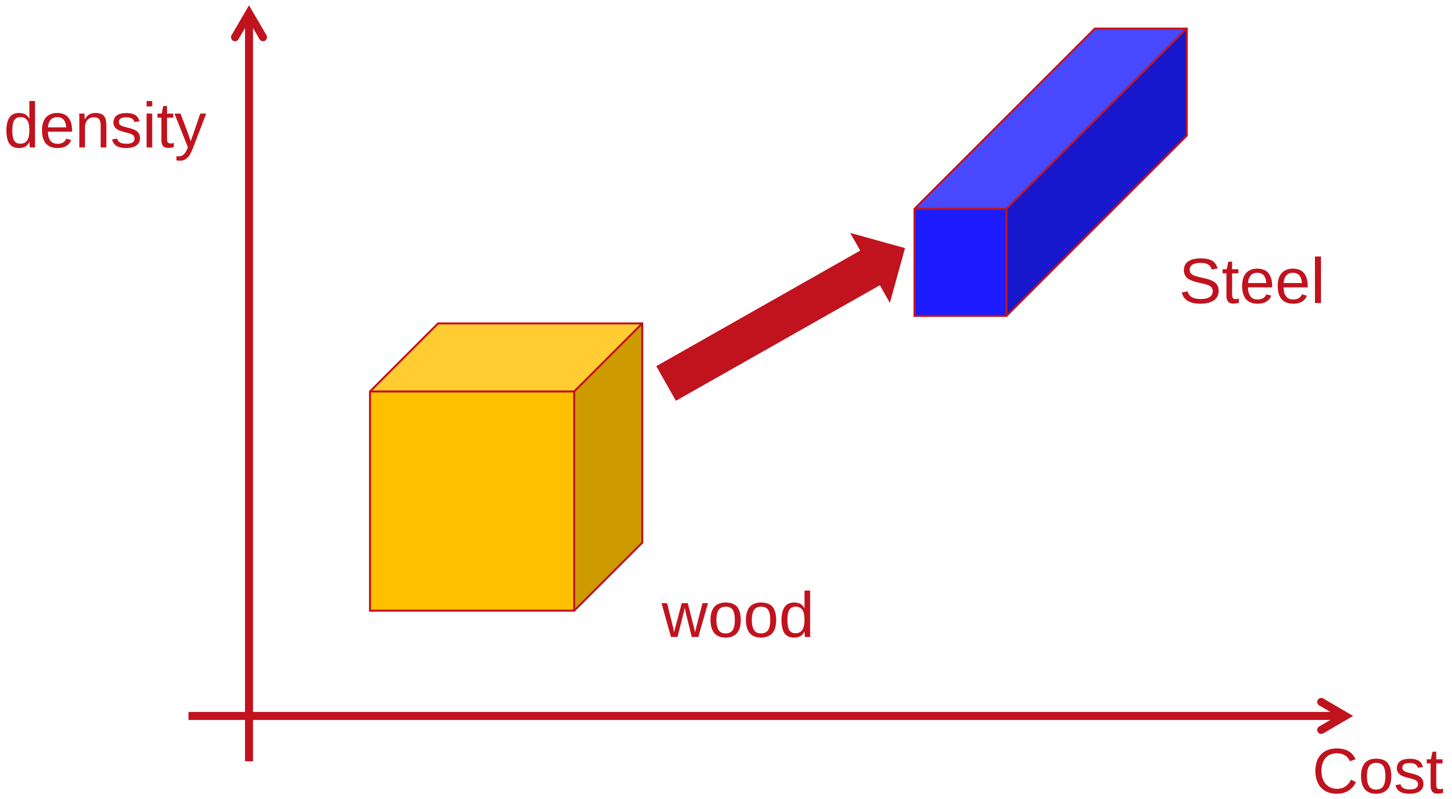
What we can see in 3D

N-dimenions

Constraints limit the size & shape in 3D

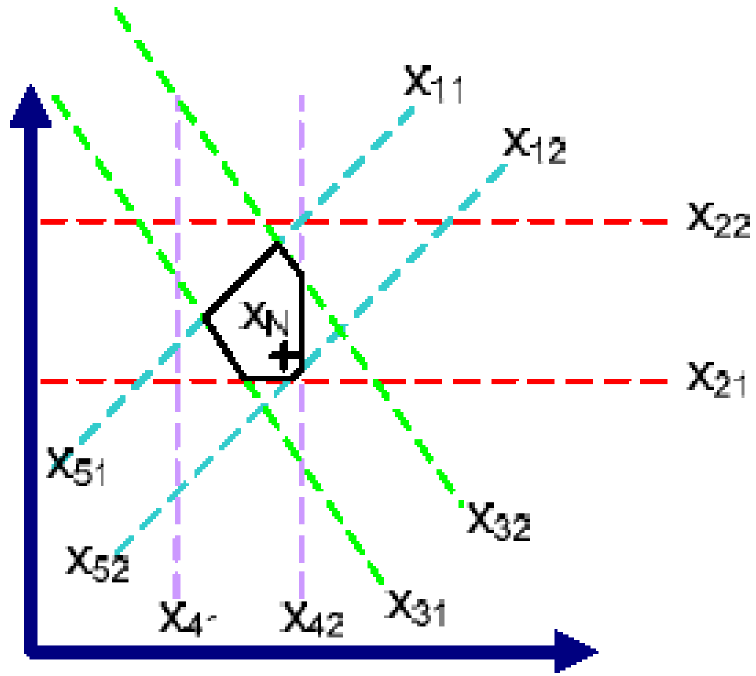


Example of square showing cost & size in different areas



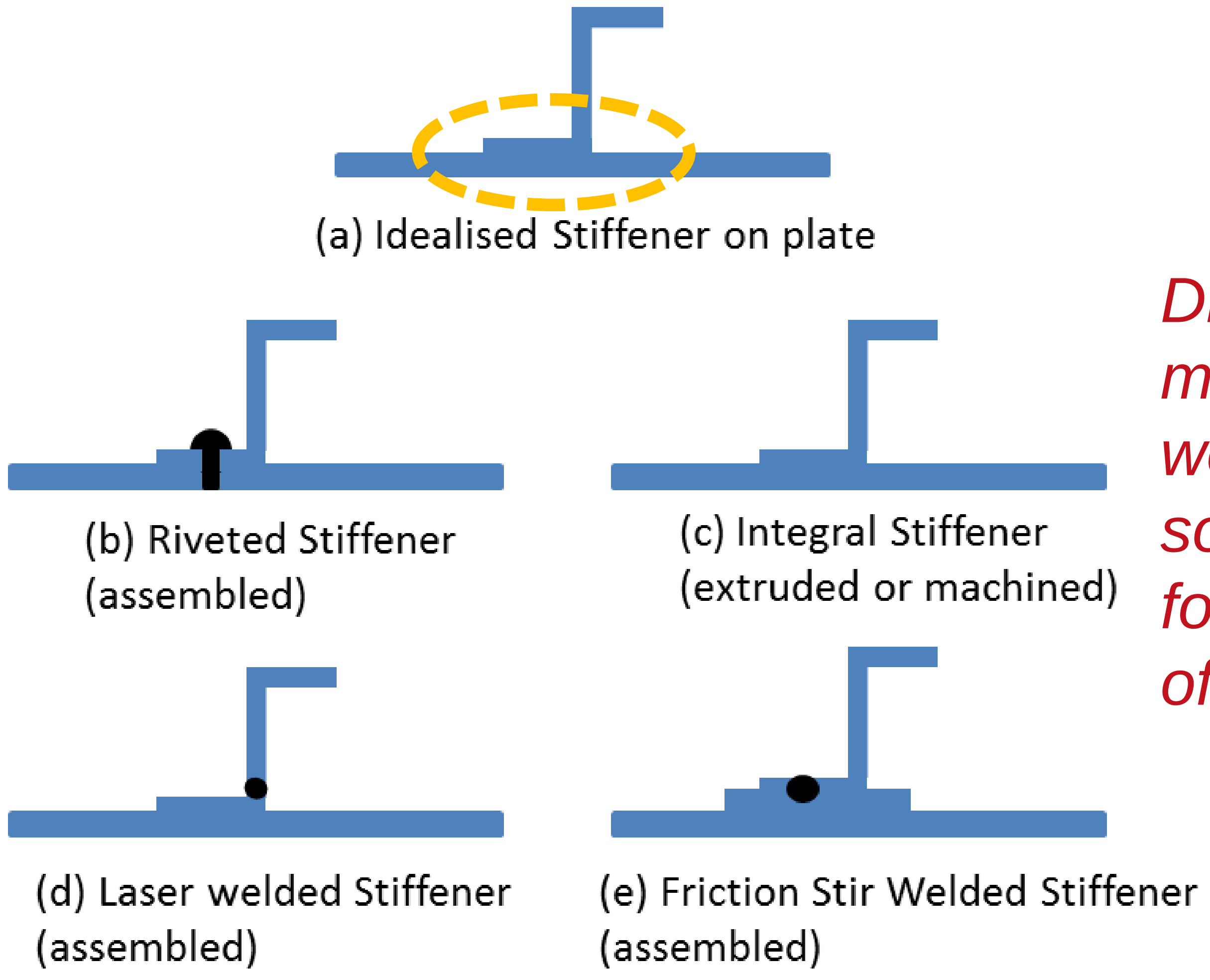
The physical shape may change due to other parameters, such as cost & weight

Constraints impact shape



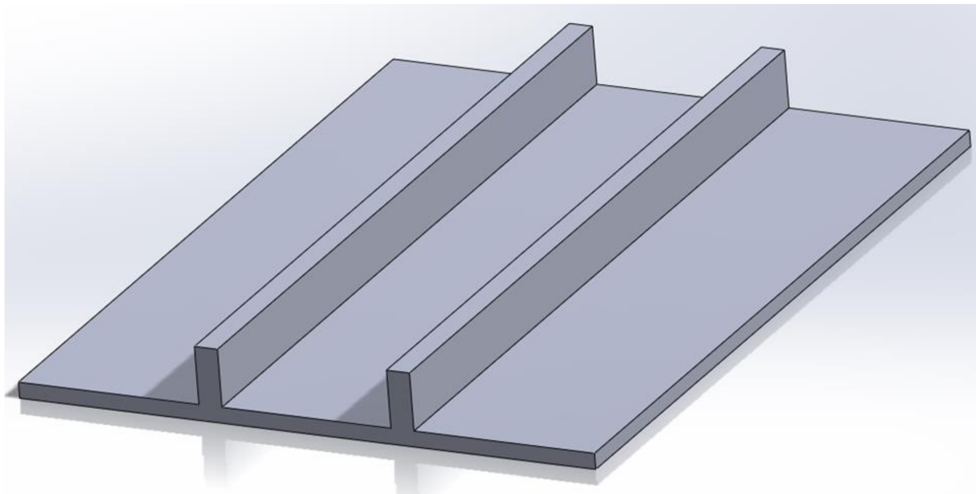
Projection of 5-D design space in 2D with and without uncertainty factor applied to constraints

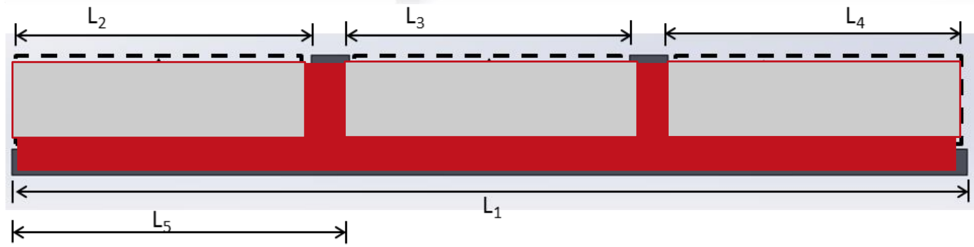
Now think about manufacturing



Different minimum weight solutions are found for each of these.

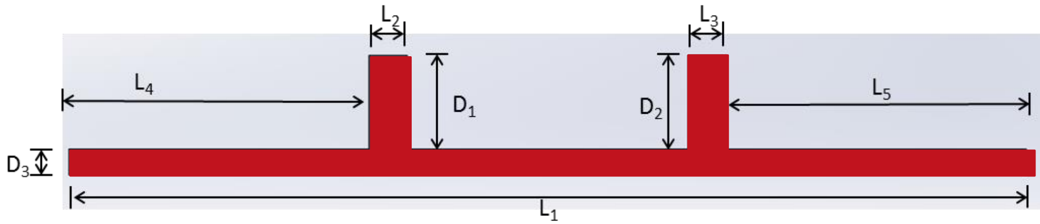
Plate - Parameterisations



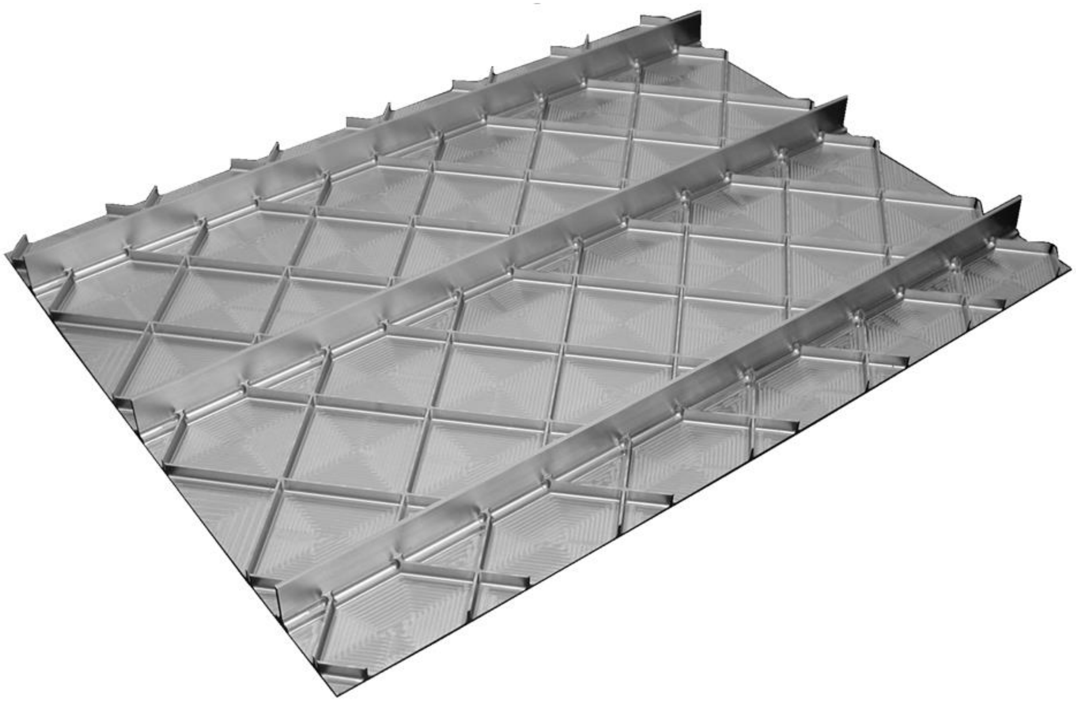


Machine from a block

Weld



Integrated Design and Manufacturing



New manufacturing concepts such as laser beam and friction stir welding, and panel profiling, can result in lighter, cheaper airframes. (with Alcan France)

C-Series Wing ~13,000 tests!
-> 1 vehicle, small number of material configurations

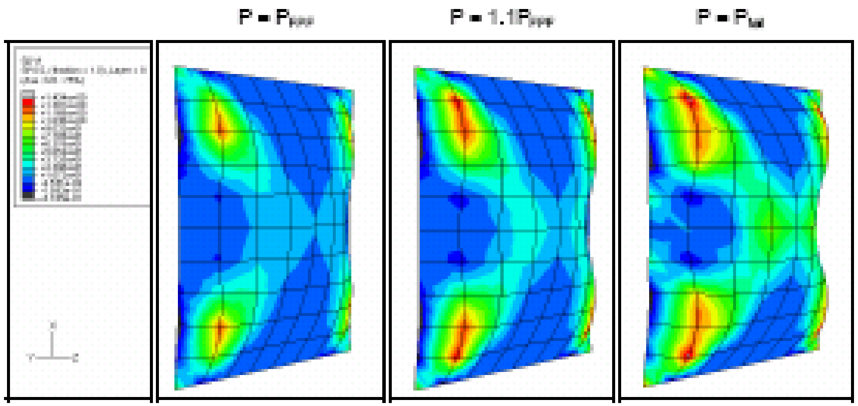


Figure 4-27 Contours of matrix failure index of crossply laminate, AR = 1.2

Failure locations are not always obvious

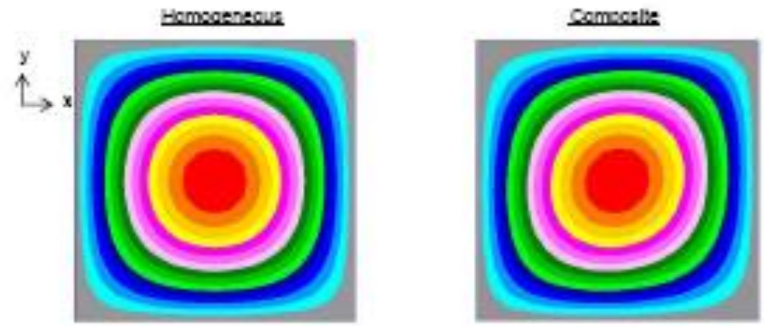


Figure 4-7 First buckling mode shapes for quasi-isotropic laminate

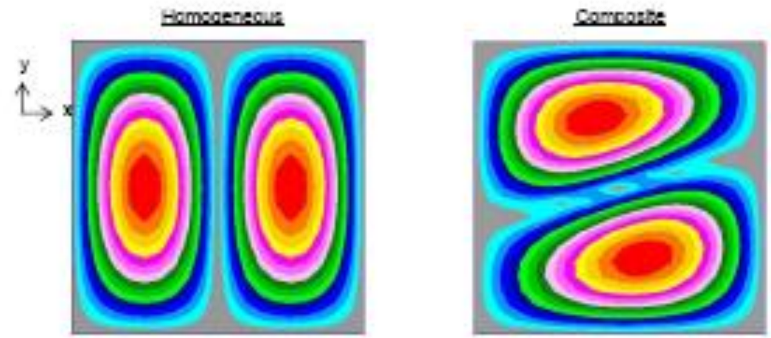


Figure 4-8 Second buckling mode shapes for quasi-isotropic laminate

Stress and displacement patterns

are different in composites

Questions!

- Identify the limitations of the CAD technology and integration of additional problem dimensions?
- A consistent parameter set representing the appropriate capability for design, analysis and manufacturing?
- A consistent modelling process for design, analysis and manufacturing?
- What is our confidence that validation testing is genuinely validating operational behaviour?
- What is the cost/confidence trade-off for testing new materials and structures in complex machines?

Would you tell me, please, which way I ought to go from here?“

"That depends a good deal on where you want to get to.“

"I don't much care where –"

"Then it doesn't matter which way you go.”

— Lewis Carroll, *Alice in Wonderland*

Thank You for Listening

And remember…….

Imagination is the only weapon in the war against reality."
— Lewis Carroll, *Alice in Wonderland*