6

FEM Modeling: Introduction

FEM Terminology

degrees of freedom (abbrv: DOF)

state (primary) variables: displacements in mechanics

conjugate variables: forces in mechanics

stiffness matrix

master stiffness equations

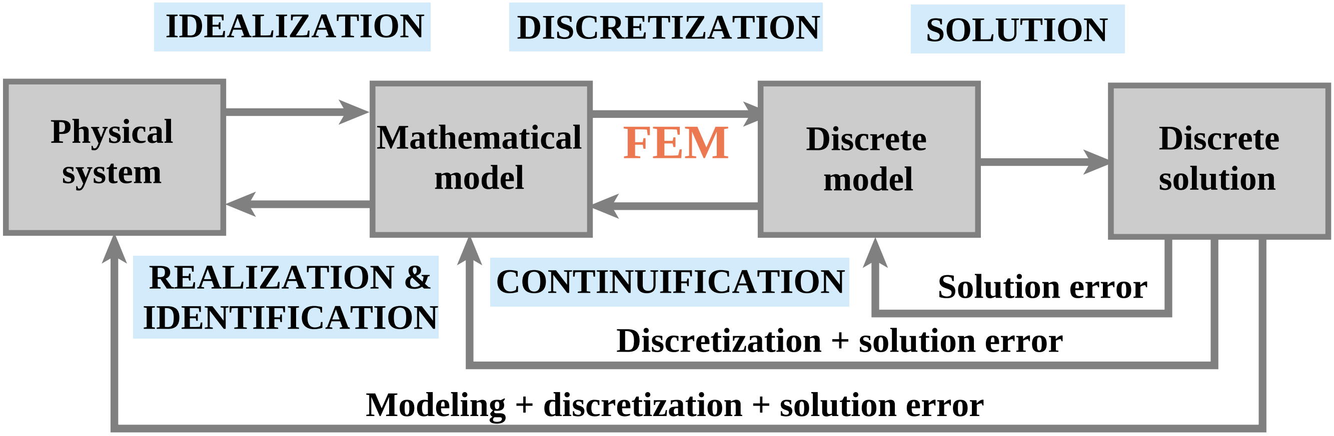
$$\mathbf{K}\,\mathbf{u} = \mathbf{f}$$

$$\mathbf{K}\,\mathbf{u} = \mathbf{f}_M + \mathbf{f}_I$$

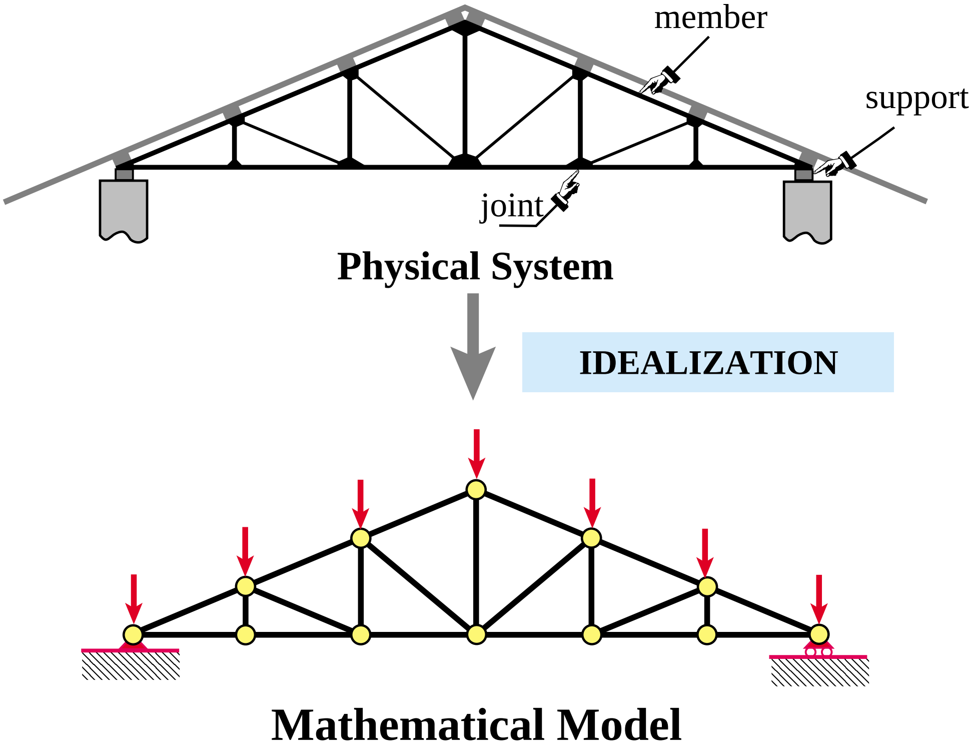
Physical Significance of Vectors u and f in Miscellaneous FEM Applications

Application Problem	*State (DOF) vector* **u** *represents*	*Forcing vector* **f** *represents*
Structures and solid mechanics	Displacement	Mechanical force
Heat conduction	Temperature	Heat flux
Acoustic fluid	Displacement potential	Particle velocity
Potential flows	Pressure	Particle velocity
General flows	Velocity	Fluxes
Electrostatics	Electric potential	Charge density
Magnetostatics	Magnetic potential	Magnetic intensity

Where FEM Fits (from Chapter 1)



Idealization Process (from Chapter 2)



Mathematical Model Definition

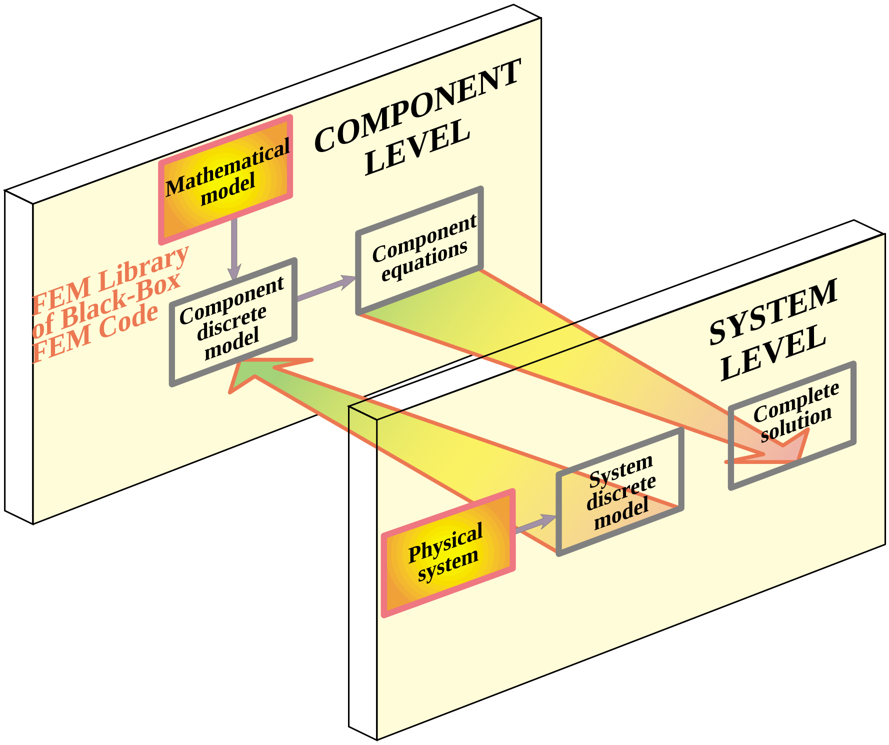
Traditional definition

Scaled fabricated version of a physical system (think of a car or train model)

Simulation oriented definition

A model is a symbolic device built to simulate and predict aspects of behavior of a system

Implicit Modeling



Recall the "Breakdown" DSM Steps

Breakdown
- **Disconnection**
- **Localization**
- **Member (Element) Formation**
  - **-> generic elements**

Let Stop Here and
Study Generic Elements next

... Because Most of the Remaining DSM Steps

Globalization
Merge
Application of BCs
Solution
Recovery of Node Forces

are Element Independent

Attributes of Mechanical Finite Elements

Dimensionality

Nodes serve two purposes:

geometric definition

home for DOFs (connectors)

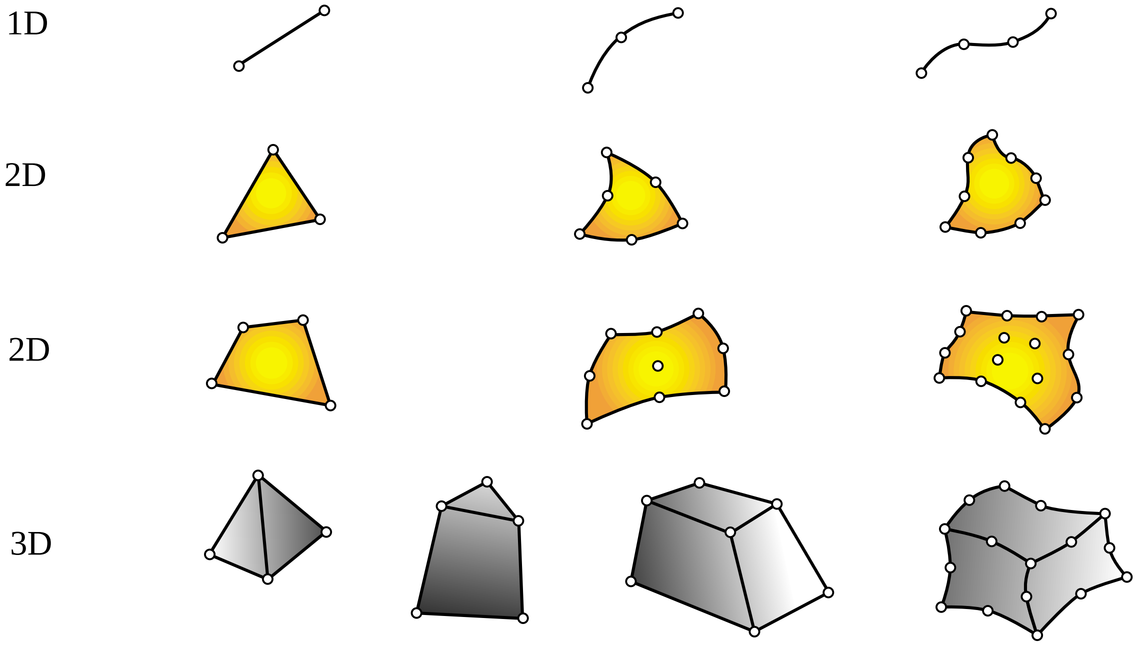
Degrees of freedom (DOFs) or "freedoms"

Conjugate node forces

Material properties

Fabrication properties

Element Geometry Is Defined by Node Locations



Classification of Mechanical Finite Elements

Primitive Structural

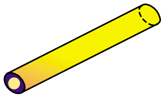
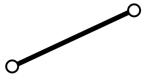
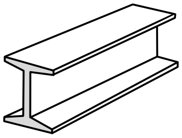
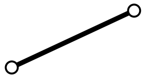
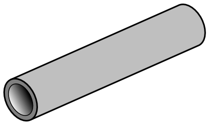
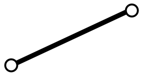
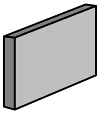
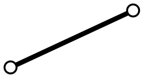
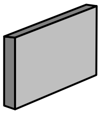
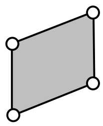
Continuum

Special

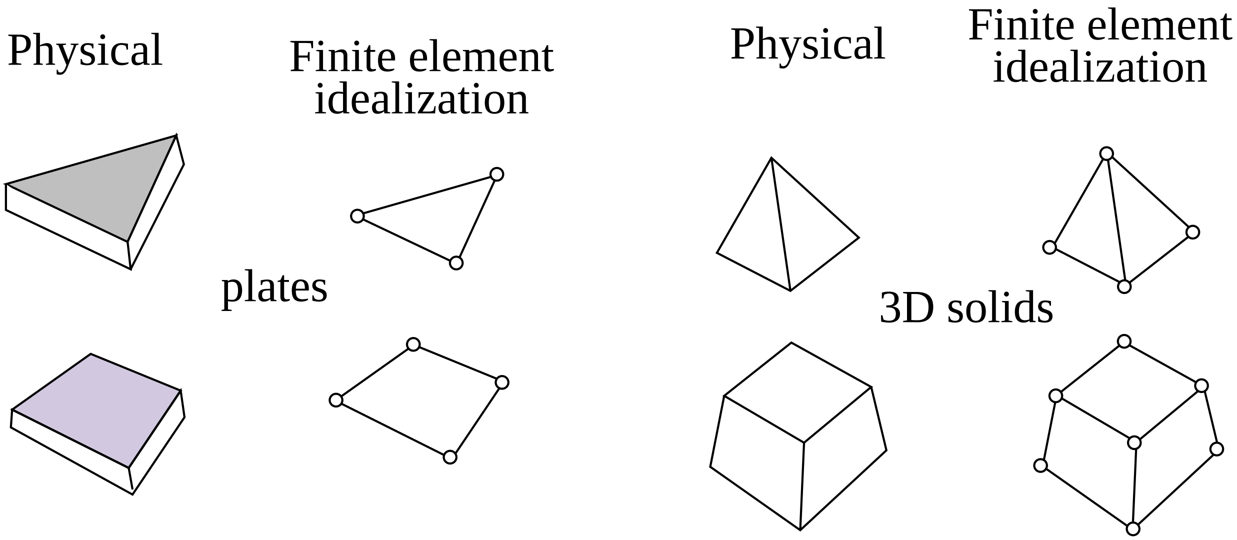
Macroelements } **Superelements**

Substructures }

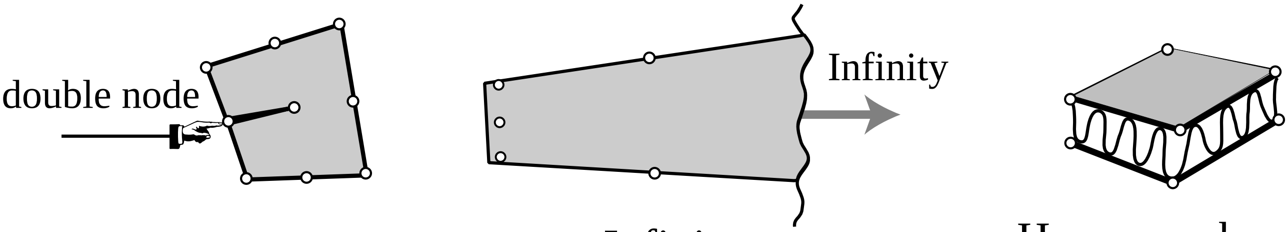
Primitive Structural Elements
(often built from MoM models)

Physical Structural Component	Mathematical Model Name	Finite Element Discretization
	**bar**	
	**beam**	
	**tube, pipe**	
	**spar (web)**	
	**shear panel (2D version of above)**	

Continuum Elements



Special Elements

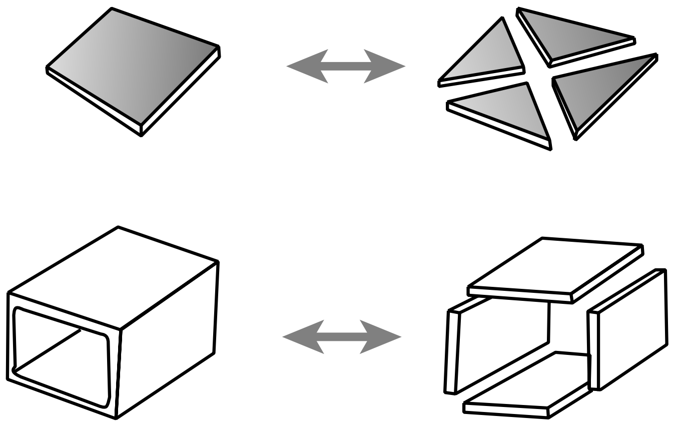


Crack element

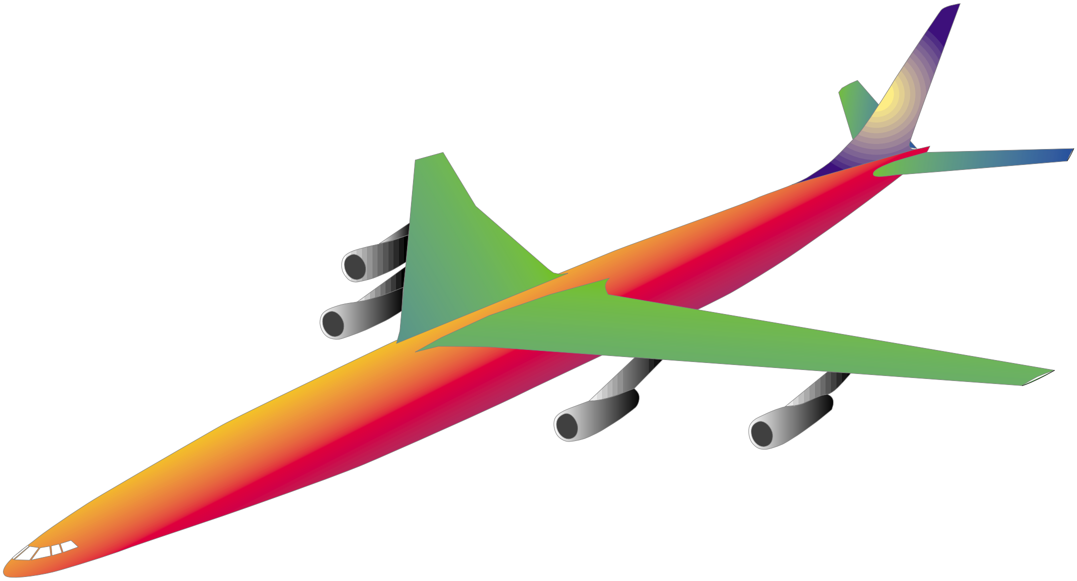
Infinite element

Honeycomb panel

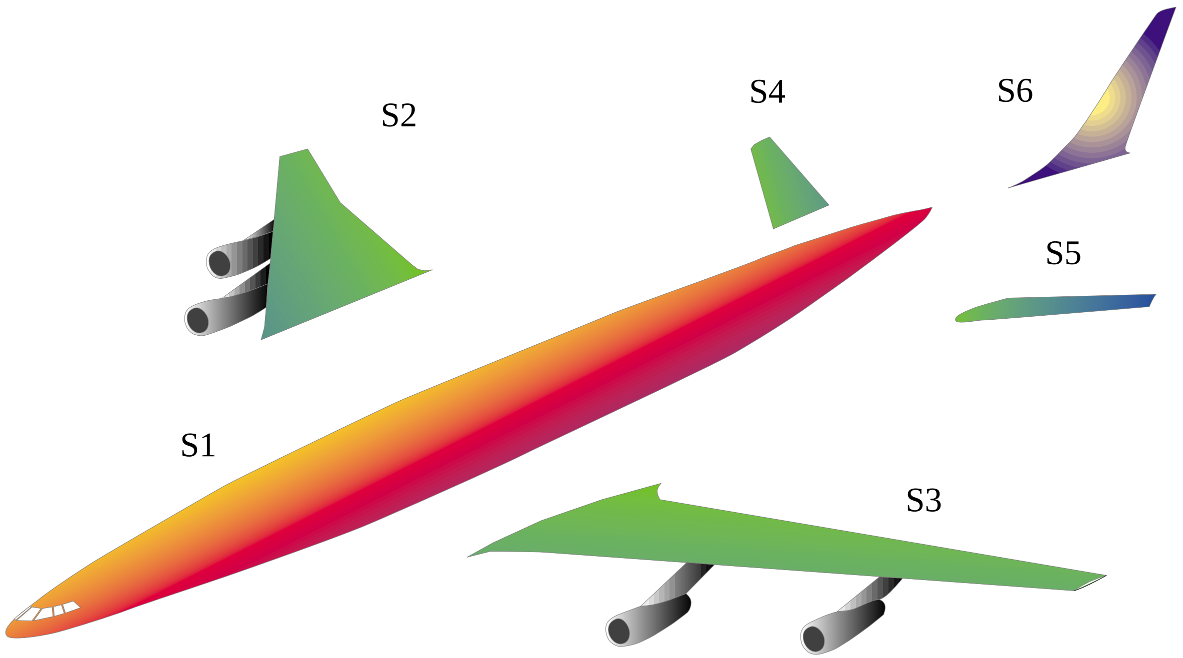
MacroElements



Substructures

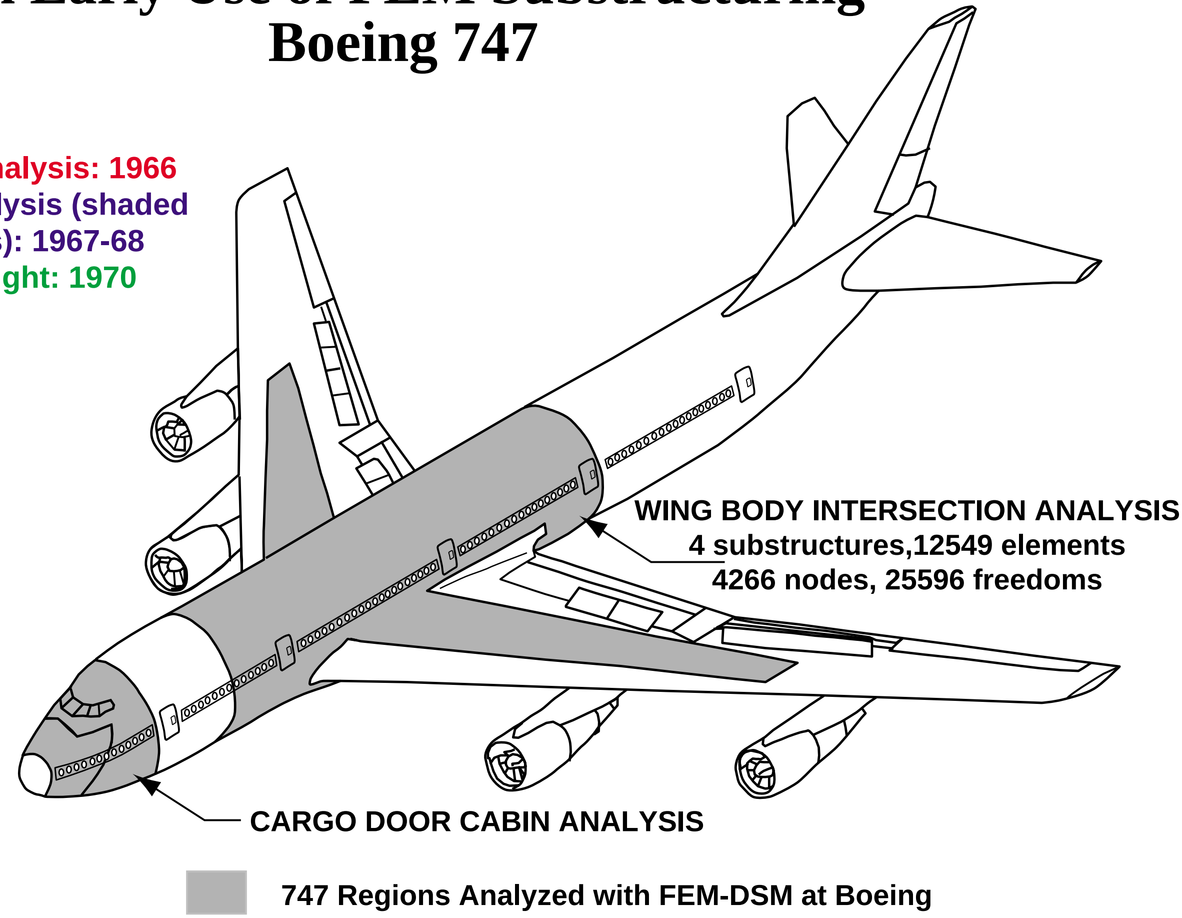


Substructures (cont'd)



An Early Use of FEM Substructuring
Boeing 747

Global Analysis: 1966
Local Analysis (shaded regions): 1967-68
First flight: 1970



Boundary Conditions (BCs)

The most difficult topic for FEM program users ("the devil hides in the boundary")

Two types
- **Essential**
- **Natural**

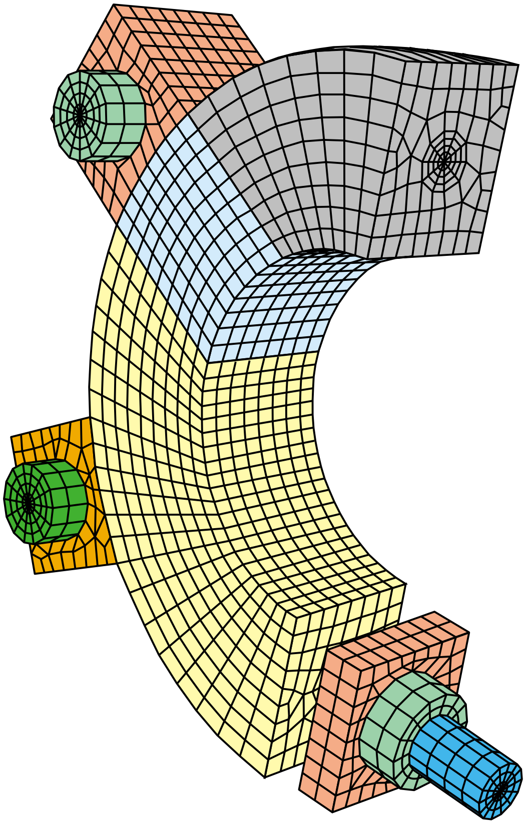
Boundary Conditions
Essential vs. Natural

Recipe:

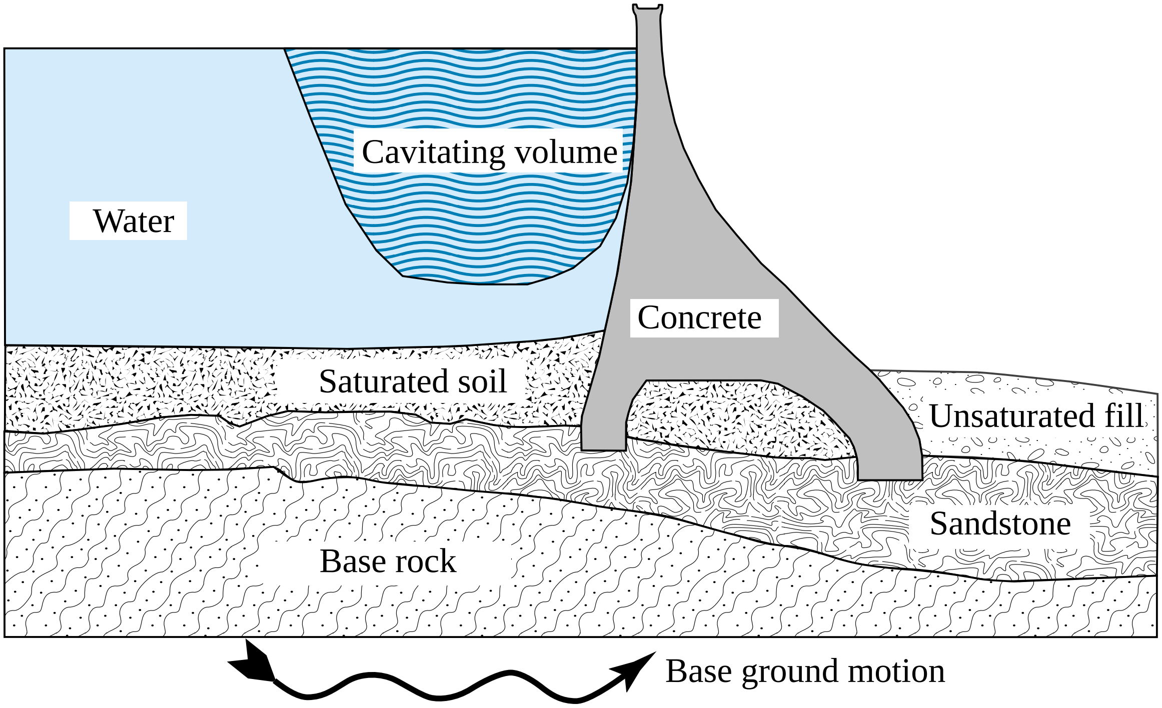
1. **If a BC involves one or more DOF in a** *direct* **way, it is** *essential* **and goes to the Left Hand Side (LHS) of Ku = f**

2. **Otherwise it is** *natural* **and goes to the Right Hand Side (RHS) of Ku = f**

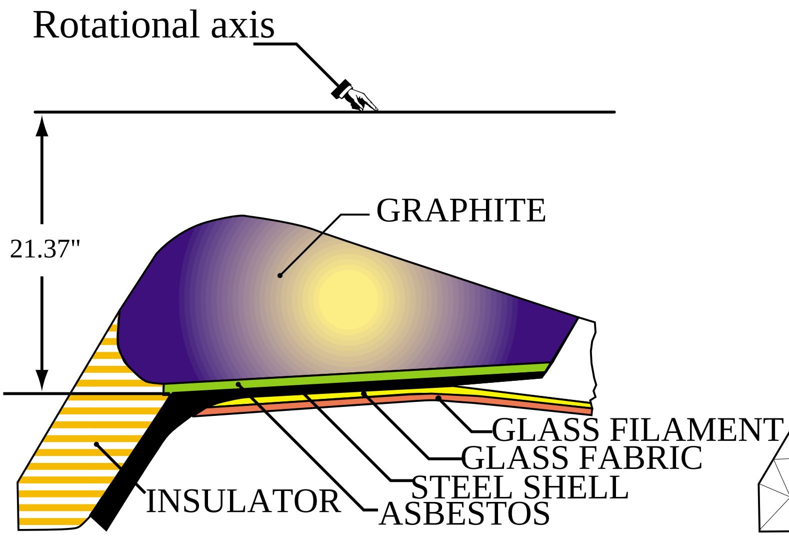
Examples of Structural Models: Machine Component (Mech. Engrg)



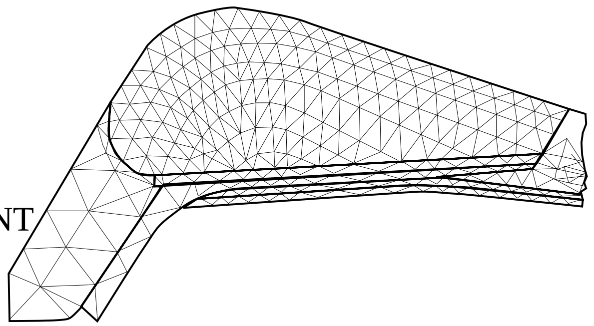
Examples of Structural Models: Dam under Ground Motion (Civil Engrg)



Examples of Structural Models: Rocket Nozzle (Aerospace Engrg)

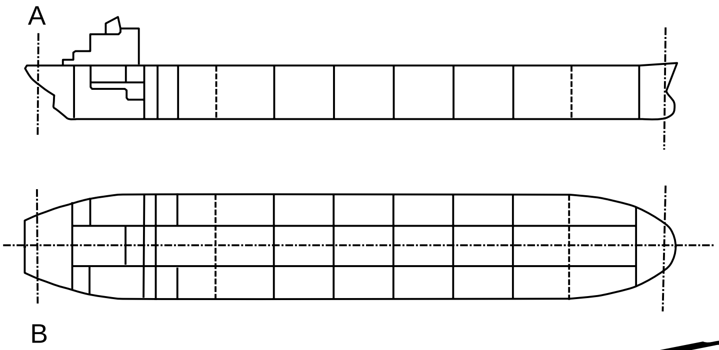


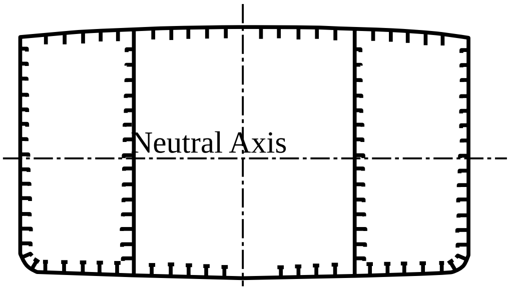
(a) Typical solid rocket nozzle (Aerojet Corp., 1963)



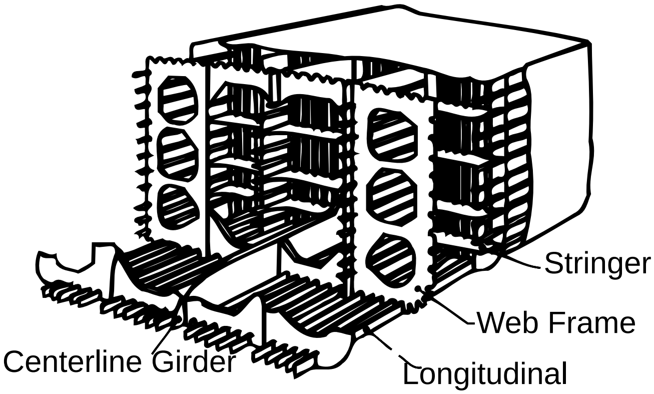
(b) Finite element idealization

Examples of Structural Models: SuperTanker (Marine Engrg)





Cross section of tanker



Typical internal structure of tanker

Examples of Structural Models: F16 External View (Aero)

Examples of Structural Models: F16 Internal Structure (Aero)