

# 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**

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

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

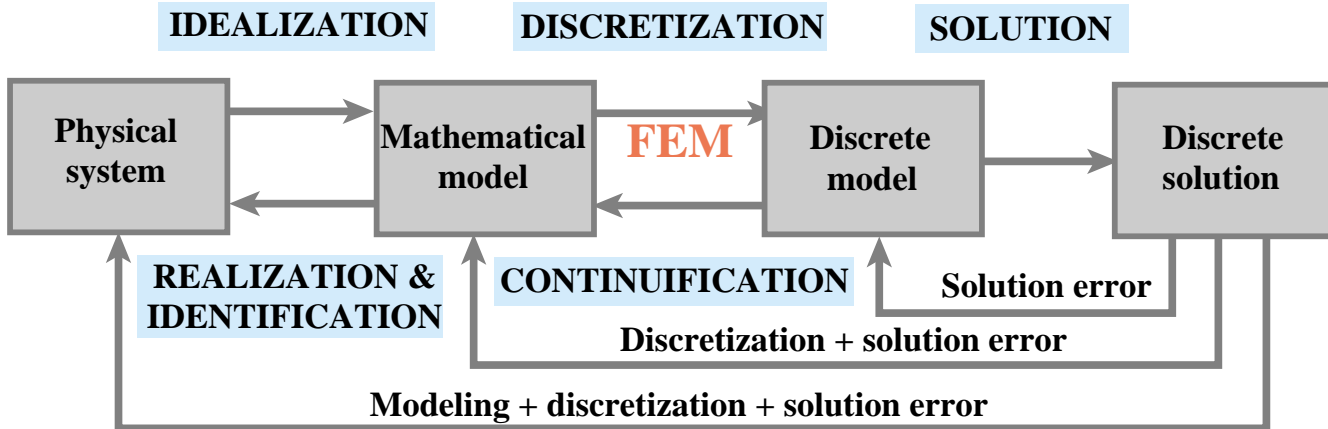
# Physical Significance of Vectors $\mathbf{u}$ and $\mathbf{f}$ in Miscellaneous FEM Applications

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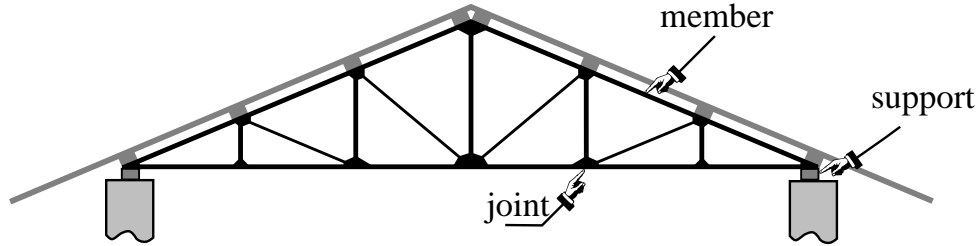
<i>Application Problem</i>	<i>State (DOF) vector <math>\mathbf{u}</math> represents</i>	<i>Forcing vector <math>\mathbf{f}</math> represents</i>
Structures and solid mechanics	Displacement	Mechanical force
Heat conduction	Temperature	Heat flux
Acoustic fluid	Displacement potential	Particle velocity
Potential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

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# Where FEM Fits (from Chapter 1)



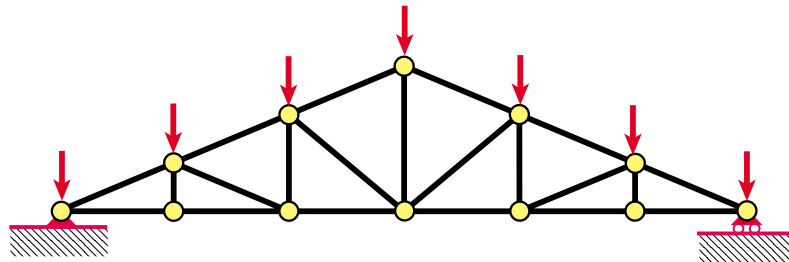
# Idealization Process (from Chapter 2)



**Physical System**



**IDEALIZATION**



**Mathematical Model**

# Mathematical Model Definition

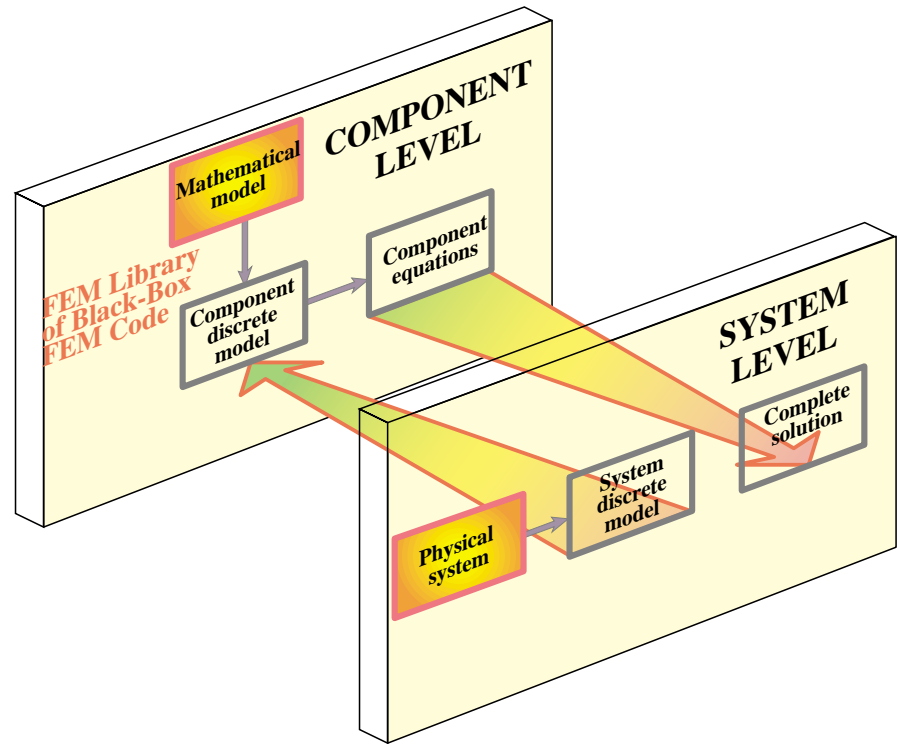
## Traditional definition

*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"**

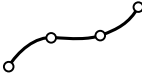
**Conjugate node forces**

**Material properties**

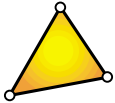
**Fabrication properties**

# Element Geometry Is Defined by Node Locations

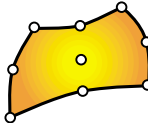
1D



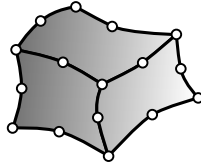
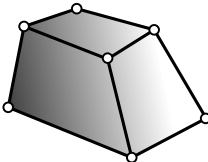
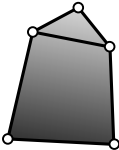
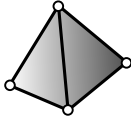
2D



2D



3D



# **Classification of Mechanical Finite Elements**

**Primitive Structural**

**Continuum**

**Special**

**Macroelements**

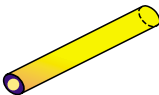

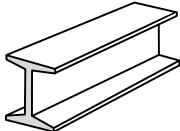

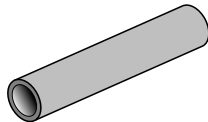

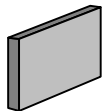

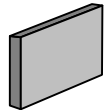
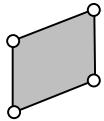
**Substructures**



**Superelements**

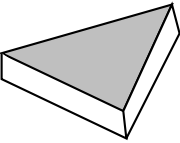
# Primitive Structural Elements

(often built from MoM models)

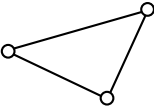
Physical Structural Component	Mathematical Model Name	Finite Element Discretization
	<b>bar</b>	
	<b>beam</b>	
	<b>tube, pipe</b>	
	<b>spar (web)</b>	
	<b>shear panel</b> (2D version of above)	

# Continuum Elements

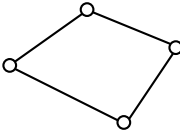
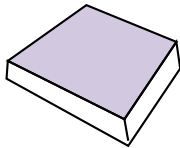
Physical



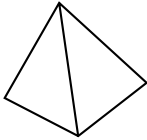
Finite element idealization



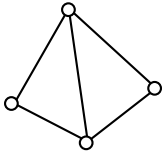
plates



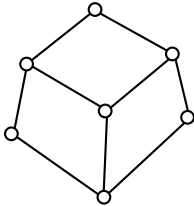
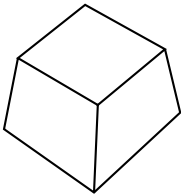
Physical



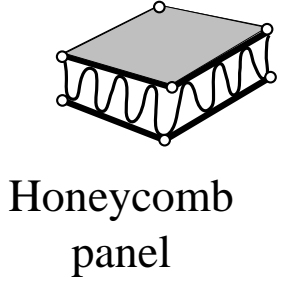
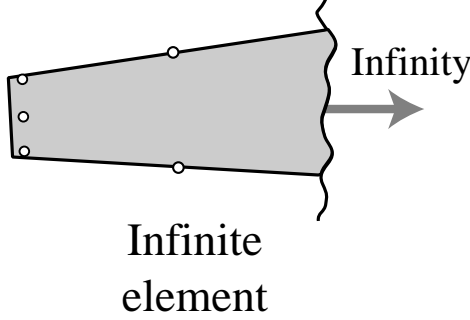
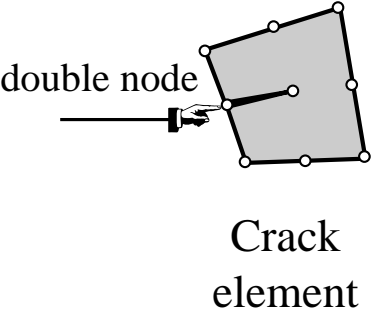
Finite element idealization



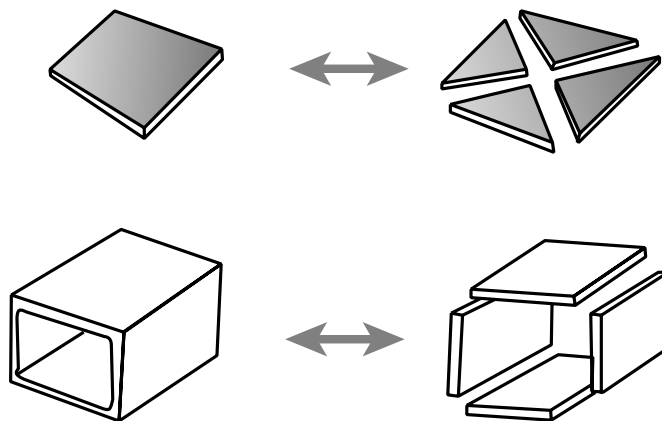
3D solids



# Special Elements

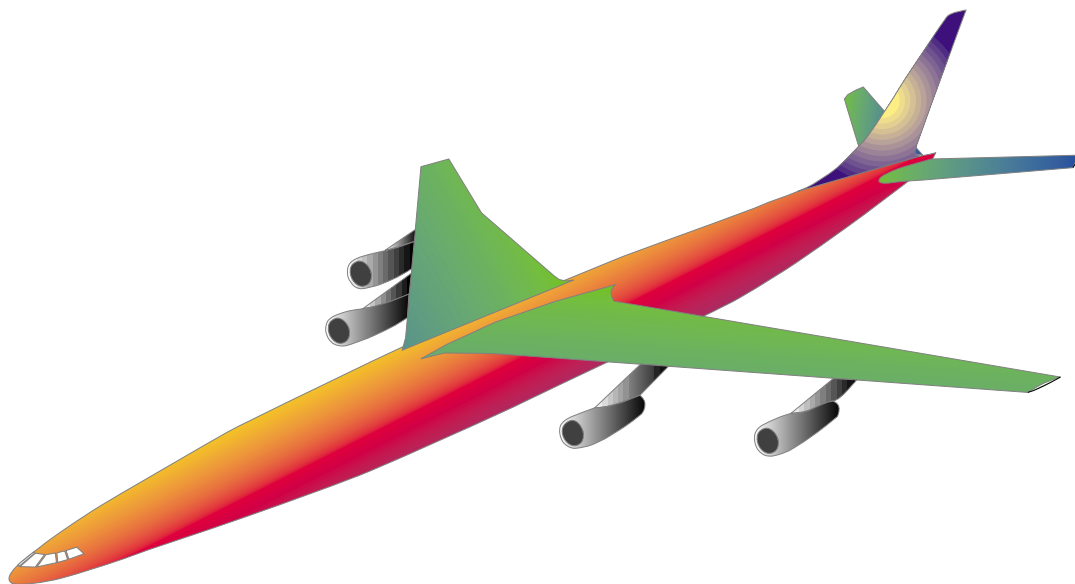


# MacroElements

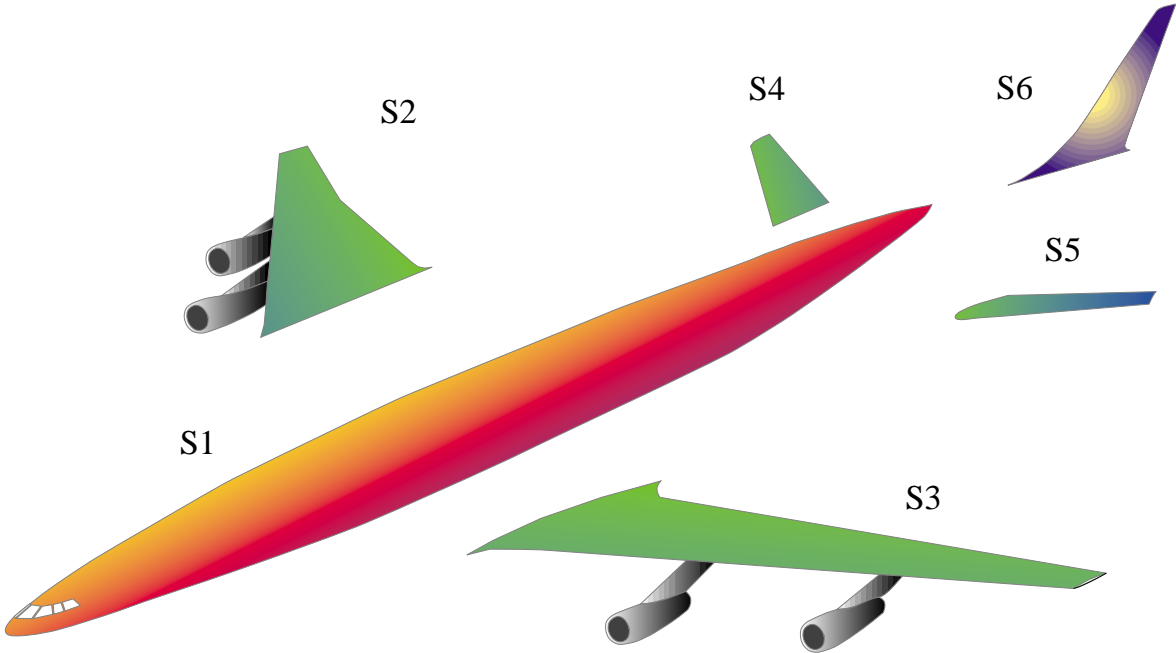




# Substructures

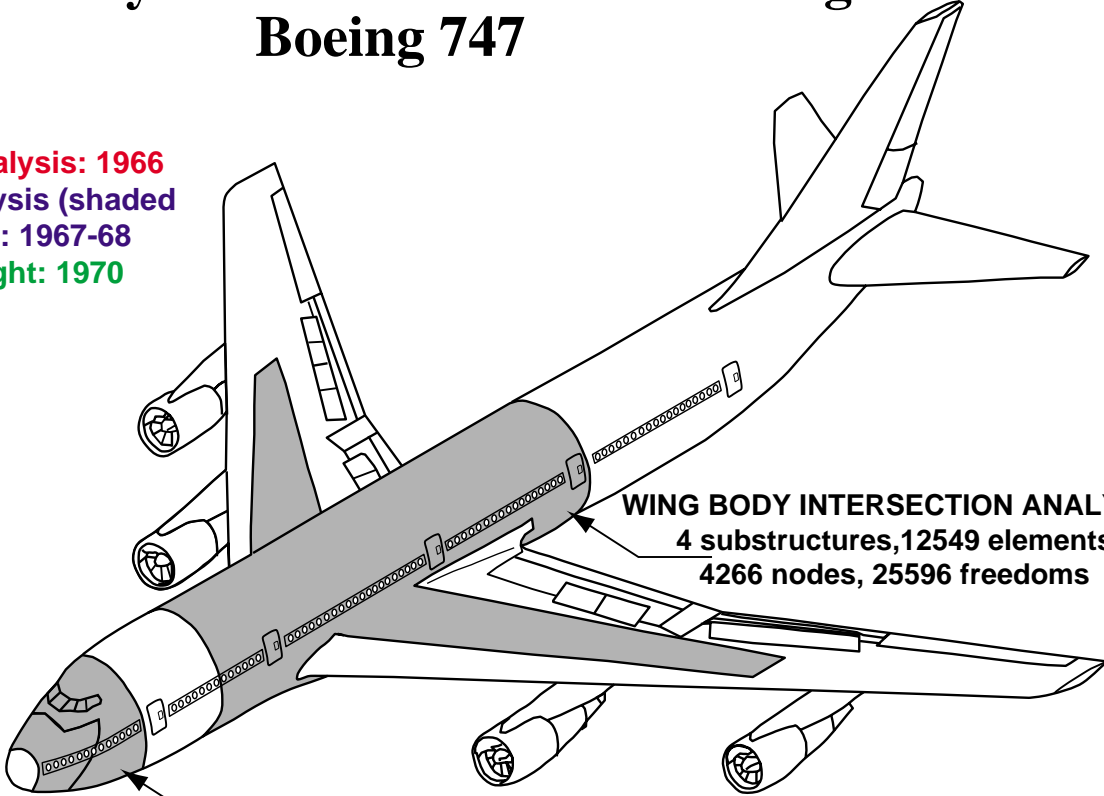


# Substructures (cont'd)



# An Early Use of FEM Substructuring Boeing 747

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



**WING BODY INTERSECTION ANALYSIS**  
4 substructures, 12549 elements  
4266 nodes, 25596 freedoms

**CARGO DOOR CABIN ANALYSIS**

■ 747 Regions Analyzed with FEM-DSM at Boeing

## **Boundary Conditions (BCs)**

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

**Two types**

**Essential**  
**Natural**

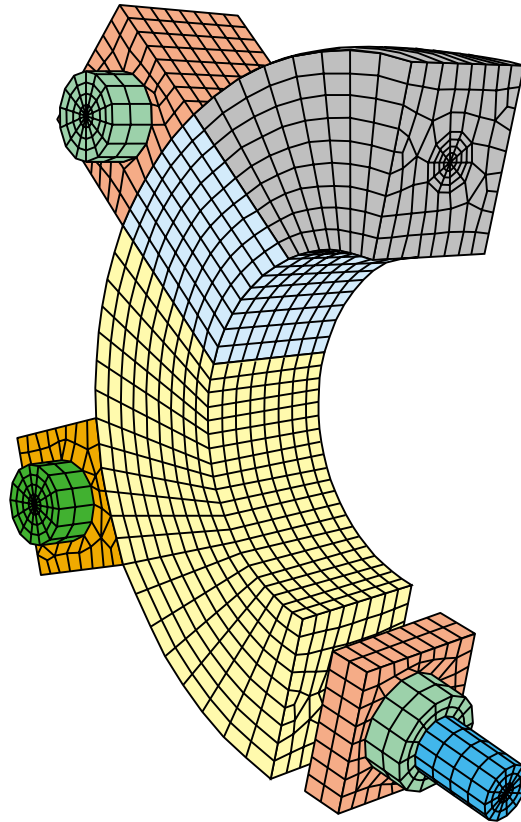
# Boundary Conditions

## Essential vs. Natural

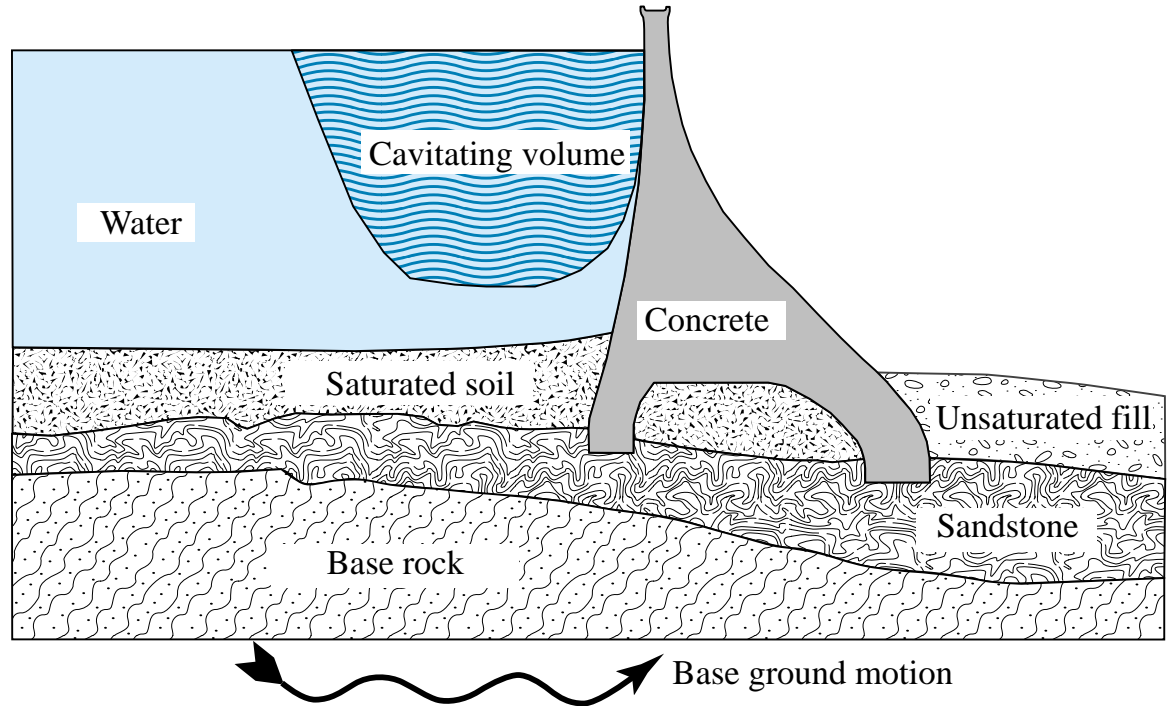
### Recipe:

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)

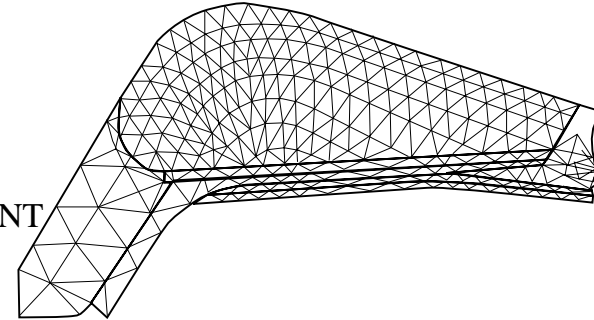
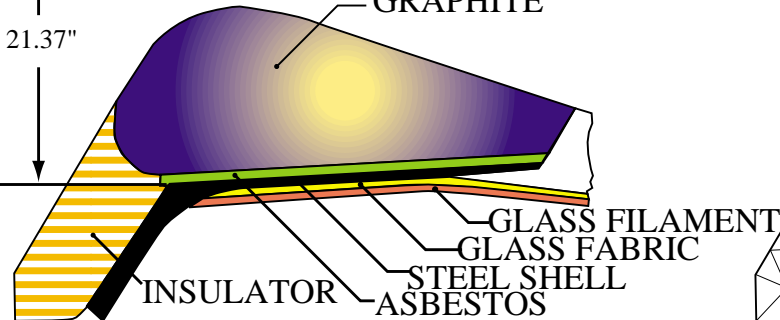


# Examples of Structural Models: Rocket Nozzle (Aerospace Engrg)

Rotational axis



21.37"

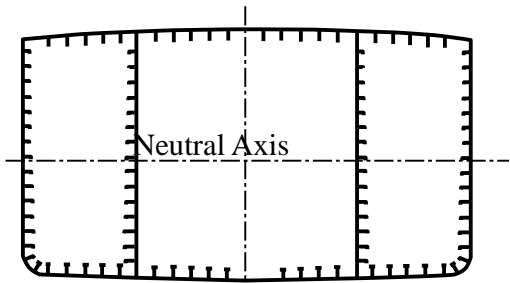
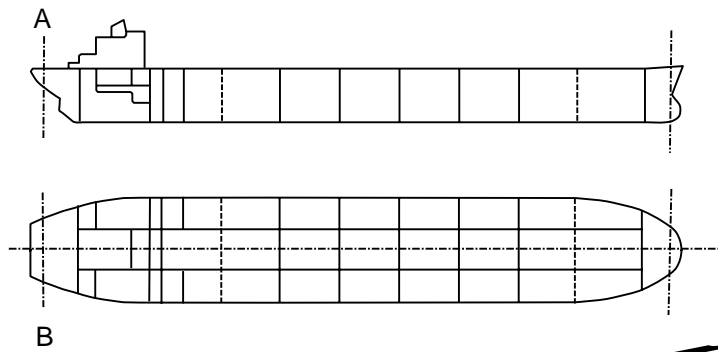


(a) Typical solid rocket nozzle  
(Aerojet Corp., 1963)

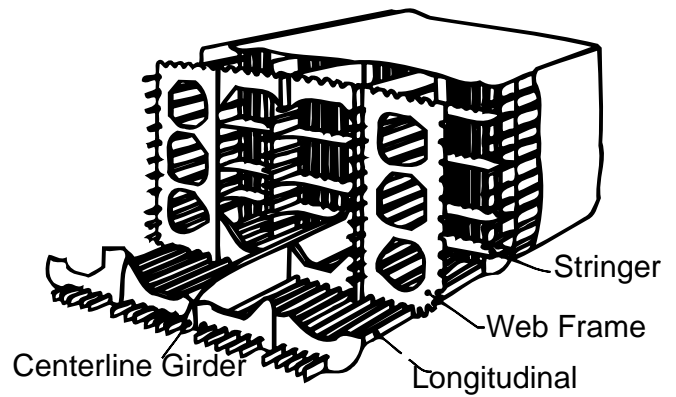
(b) Finite element idealization



# 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)

