Simulations in Astroengineering: from FEA to Multiphysics PDE's

How Astronomers and Engineers interact

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Outline

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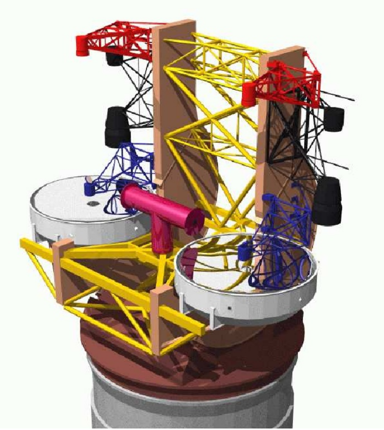
How the Specs are Fulfilled.

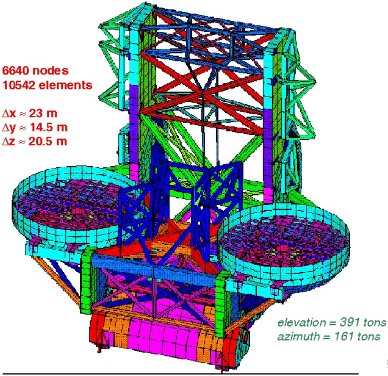
The Translation of the Error Budget for the Structural Engineer.

- As the most relevant disturbances are dynamic (wind and drivers), the input parameter is the global stiffness.
- Such a stiffness is evaluated by the *locked rotor frequency* and the *free rotor frequency*, respectively.
- The *measure* of such a stiffness is set by the specifications at 8 Hz.
- If such a stiffness is reached, . . .
  - leave static response as a consequence;
  - let it work as the basis for the (high frequency, low amplitude) active optics, and, possibly, adaptive (very high frequency, very low amplitude) optics.

Discretization: from CAD to FEM.

Each Sub-Component must have a known elastic response.





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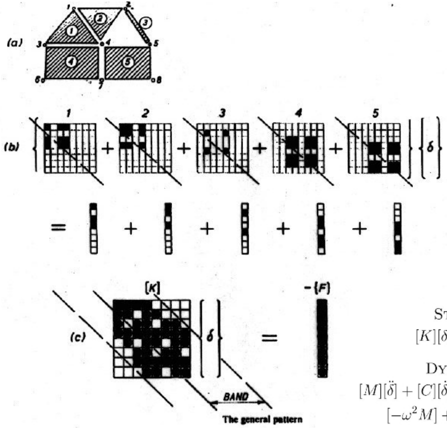
Splitting a complex Structure in “Simple” Elements.

Each Element is fully described. All Element Stiffness Sub-Matrices are Assembled.



STATIC

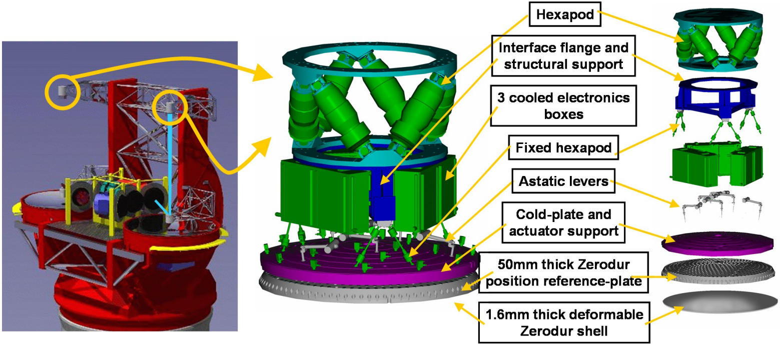
$$[K][\delta] = -[f]$$

DYNAMIC

$$[M][\ddot{\delta}] + [C][\dot{\delta}] + [K][\delta] = -[f]$$

$$[-\omega^2 M] + [K][\delta] = [0]$$

Adaptive Optics on board the Telescope.
System Overview.



[Riccardi et al., 2004]

Outline

Theory Background.

Strain-Displacement Relationship: the Tensor ϵ.

$$\epsilon_x = \frac{\partial u}{\partial x}$$
$$\epsilon_y = \frac{\partial v}{\partial y}$$
$$\epsilon_z = \frac{\partial w}{\partial z}$$
$$\epsilon_{xy} = \frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)$$
$$\epsilon_{yz} = \frac{1}{2}\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)$$
$$\epsilon_{xz} = \frac{1}{2}\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)$$

Theory Background.

Stress-Strain Relationship.

$$\sigma = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{bmatrix} \quad \sigma = D\epsilon$$

$$D^{-1} = \frac{1}{E}\begin{bmatrix} 1 & -\nu & -\nu & 0 & 0 & 0 \\ -\nu & 1 & -\nu & 0 & 0 & 0 \\ -\nu & -\nu & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2(1+\nu) & 0 & 0 \\ 0 & 0 & 0 & 0 & 2(1+\nu) & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(1+\nu) \end{bmatrix}$$

D is the elasticity matrix, D^{-1}, the inverse of D, is the flexibility or compliance matrix. The above definition is for an isotropic material.

Theory Background.

Implementation.

The equilibrium equations expressed in the stresses for 3D are

$$\begin{aligned} F_x &= -\frac{\partial \sigma_x}{\partial x} - \frac{\partial \tau_{xy}}{\partial y} - \frac{\partial \tau_{xz}}{\partial z} \\ F_y &= -\frac{\partial \tau_{xy}}{\partial x} - \frac{\partial \sigma_y}{\partial y} - \frac{\partial \tau_{yz}}{\partial z} \\ F_z &= -\frac{\partial \tau_{xz}}{\partial x} - \frac{\partial \tau_{yz}}{\partial y} - \frac{\partial \sigma_z}{\partial z} \end{aligned} \quad \rightsquigarrow \quad -\vec{\nabla}\sigma = \vec{F}$$

($\vec{F}$ denotes the volume forces)

Substitution of the stress-strain relationship and the strain-displacement relationship into the static equilibrium equation produces Navier's equation of equilibrium expressed in the displacements. For static conditions, Navier's equation reads

$$-\vec{\nabla} \cdot (c\vec{\nabla}\vec{u}) = \vec{F}$$

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The Multiphysics Definition.

Available Relationships and User-Defined functions.

- HT, SM, EM, and NS PDE's are Built-in but . . . The User can Write his/her own Equations.
- "Classical" FE Elements/Nodes are Available but . . . Every Model is Defined through Domains/Boundaries/Edges.
- "Classical" FE Methods are Available but . . . Every Kind of Load/Restraint can be supplied.
- A Built-in Drawer Exists but . . . CAD Models are importable.

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Opto-Mechanics.

Running the FEM/PDE Secondary Units Models.

- Dynamic:
  - MMT336 Adaptive Secondary Mirror eigenmodes/eigenvectors
  - LBT672 Adaptive Secondary Mirror eigenmodes/eigenvectors
- Static
  - (Reduced) MMT336 Stiffness Matrix (Influence functions)
  - (Reduced) LBT672 Stiffens Matrix (Influence functions)
  - Dust Grain in the LBT672 DM/RF Gap
  - Silvering Load on the LBT672 DM
  - Wind Load on the LBT672 DM

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Magnetostatics.
E/M Actuator Models.

- MMT336 and LBT672 Magnetic Circuit Design . . . Good Agreement with previous Ansys Results.
- ELT/LIDAR Magnetic Circuit Design . . . 2D Optimization has been Defined.

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Coupled Analyses.

Running two or more PDE's.

- Structural Mechanics + Heat Transfer:
  - Giano (S. Gennari et al.)
- Structural Mechanics + Navier-Stokes:
  - Floating ("Ball") Telescope (P. Salinari et al.)
- Structural Mechanics + Electrostatics:
  - Gravitational Waves Experiment (R. Stanga et al.)
  - LIDAR DM (F. Lisi)

Summary

- Multiple coupled-field analyses can be run in the same process:
  - 1. Thermal-induced + generic load deformations/stresses
  - 2. Fluid-dynamics computations with deformable boundaries
  - 3. Electromagnetic/Electrostatic computations with deformable domains
- FEA calculations can be embedded in the Matlab workspace:
  - 1. Pre- and Post-Processing of data is a component of the computational process
  - 2. Any user-defined functions can be internally implemented
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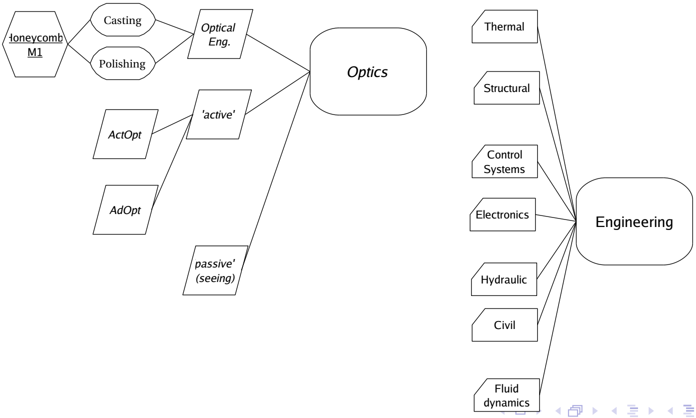
Astroengineering is a Complex Interaction.



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