Thermal Cooling Design of an Electronic Component using Coupled Conduction, Three Dimensional Convection (CFD), and Radiation Heat

Transfer Finite Element

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Abstract

- This paper attempts to explain the concurrent thermal design of an electronic component assembly, involving coupled conduction convection, and radiation analysis
- I-DEAS/TMG/ESC software is used to demonstrate the technique

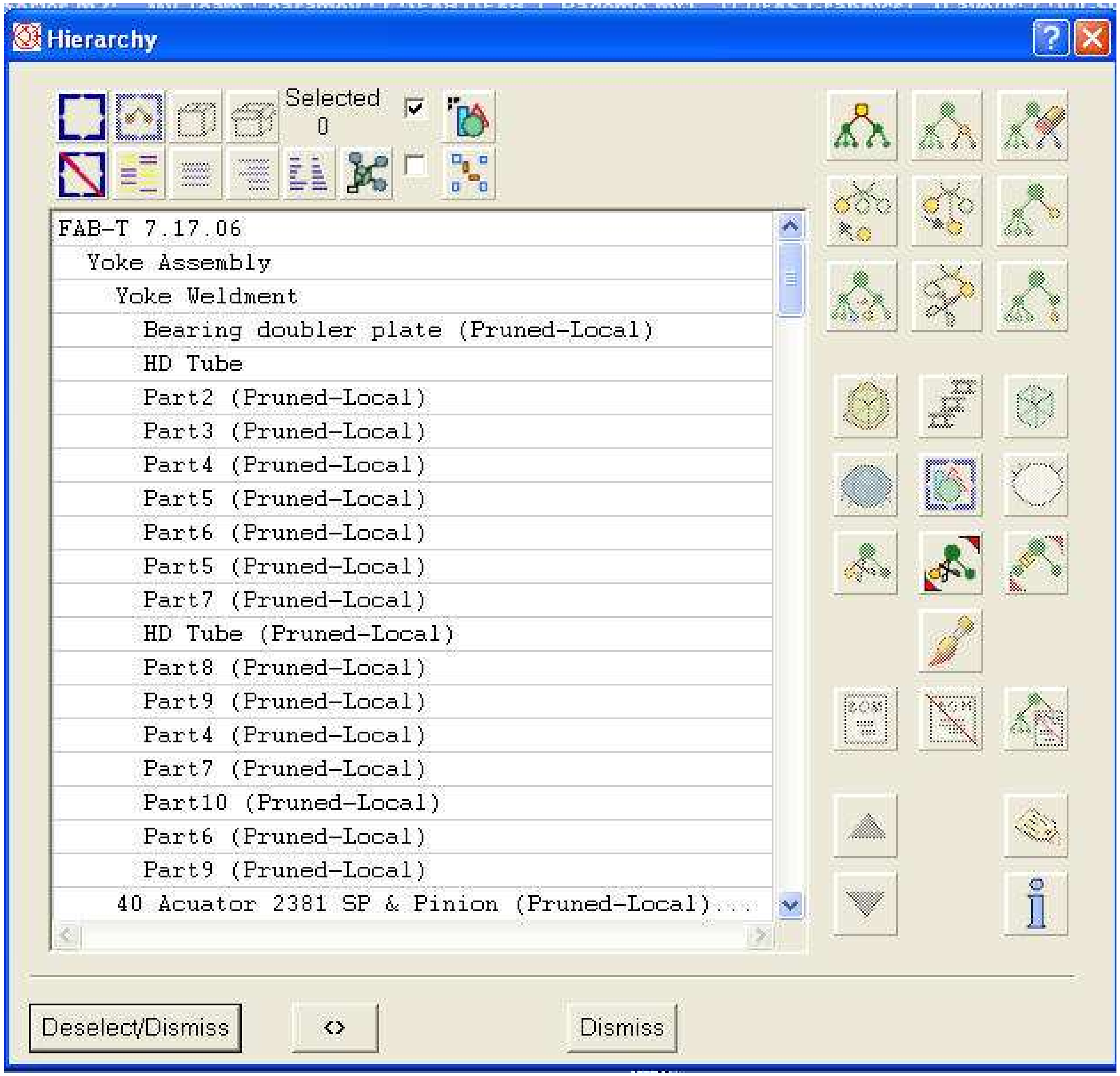
Concurrent Engineering

- **In concurrent engineering, various engineering disciplines work together in unison to come up with an optimum design**
- **This eliminates redesigns and waste.**
- **Generally designs are created and owned by mechanical design organizations based on compromises among various engineering disciplines**

Implementation

- Designs are assemblies, sub-assemblies, or LRUs, and parts created in a CAD design tool
- This is then imported into the analysis tool suite
- Only parts, sub-assemblies that are deemed to be important for thermal analysis are selected
- Such parts can be selected by the use of prune features in IDEAS from the assembly hierarchy
- This involves the use of assembly tree structure

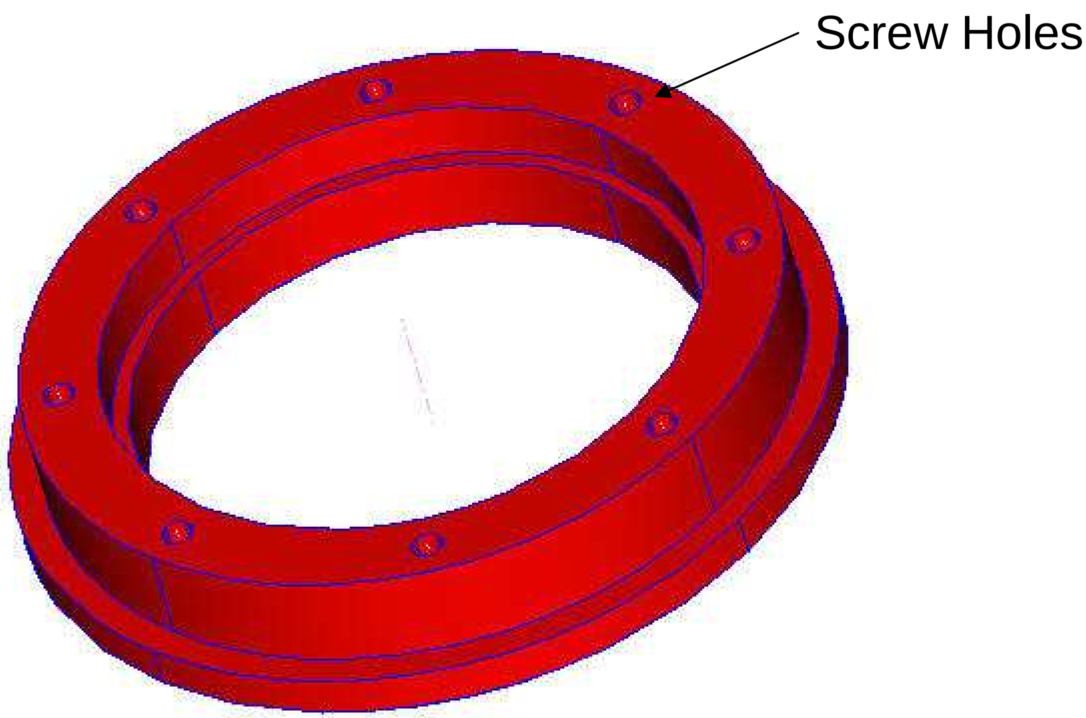
Parts Selection



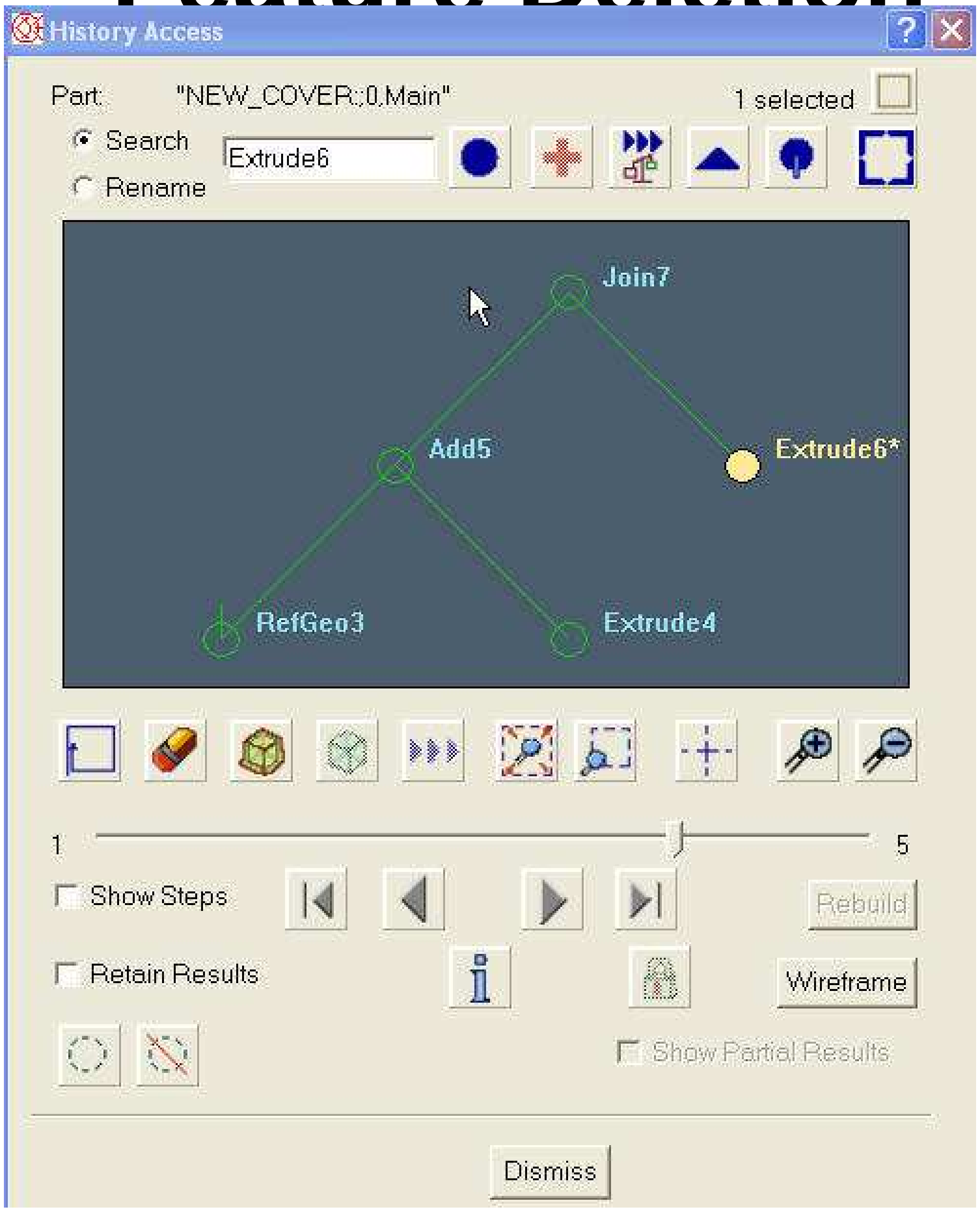
Idealized part

- After parts are selected unwanted featured are removed
- Chamfers, holes, fillets and minor details are removed

Part Features



Feature Deletion



Meshing and Analysis

- The parts are then meshed, checked and all the FEMs are combined
- Analysis is run, results examined
- If it does not meet requirements, modifications made and re-run and recommendations provided

Solution

- Most thermal involves conduction, convection, and radiation.
- In many problems use of most commonly used empirical correlations for convection are inadequate
- Flow field may be complex and can not be approximated by one dimensional flow field
- Thus use of empirical correlations may yield incorrect results

Governing Equations

- **3-D Transport equations in fluid:**
  - Energy $\partial(\rho h)/ \partial t + \partial(\rho U_j h)/ \partial x_j = \partial(k/C_p \, \partial(T)/ \partial x_j - \underline{\rho u_j h'})/ \partial x_j + S_h$
  - Momentum $\partial(\rho h)/ \partial t + \partial(\rho U_j h)/ \partial x_j = \partial(\mu \{\partial U_i / \partial x_j + \partial U_j / \partial x_i \} - \underline{\rho u_i u_j})/ \partial x_j + S_{Uj}$
  - Mass conservation $\partial \rho / \partial t + \partial \rho U_j / \partial x_j = S$
  - Turbulence k-e Model with wall function
  - The above are integrated over a finite control volume and difference equations are obtained at various volume centers.
  - Requires boundary conditions of surface temperature or flux, which is unknown to be obtained from conduction solution

Governing Equations

- **Conduction Equation:**
  - $\partial(\rho C_p T)/\partial t = q + (\partial/\partial x(k\partial T/\partial x) + \partial/\partial y(k\partial T/\partial y) + \partial/\partial z(k\partial T/\partial z))$
- **Boundary Condition: Radiation, Convection**
  - Radiation defined in terms of a view-factor, emissivity, and enclosure temperature
  - Convection in terms of a heat transfer coefficient, and fluid temperature, which is unknown and has to be obtained from solution of transport equations

Turbulence

- The turbulence quantities are related as follows:
  - Momentum $\rho \underline{u_i u_j} = \mu_t(\partial U_j / \partial x_j + \partial U_j / \partial x_i)$
  - Energy $\rho \underline{u_i h'} = \mu_t / Pr_t \, (\partial T / \partial x_j)$
  - Viscosity $\mu_t = C_\mu k / \varepsilon$

Wall Relationship

- Near wall relationship
  - $y^+ = \rho\ u_* y/\mu$, $\tau_w = \rho u_*^2$
  - Log law $u^+ = u_f / u^* = 1/\kappa \log(y^+ E)$
  - The above defines wall shear
  - The wall flux $q_w = k(T_w - T_f)/y_f$
  - Defining $T^+ = \rho C_p u^* (T_w - T_f)/ q_w$, $R = Pr\ y^+$, $Tau = 0.01(Pr\ y^+)^4 /(1+5\ Pr^3\ y^+)$
  - $T^+ = R e^{-Tau} + (1/\kappa \log R + C) e^{-Tau}$

Wall Relationship

- Van Driest damping factor is used for nodes close to the wall

Boundary Condition

- For an infinitesimal control volume around the solid/liquid interface the energy flux should balance
- Q = kdT/dn (solid) = KdT/dn(Liquid)
- The above formulation couples the conduction convection transport and generally written as h(Tw – Tf), where Tw is the surface temperature and Tf the fluid temperature

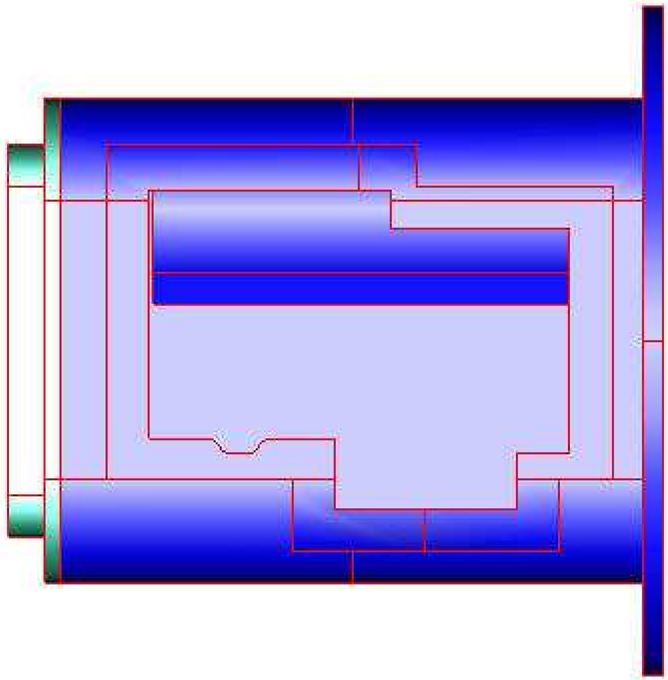
Example

- The following examples demonstrates the principle
- It does not represent any real component, used for illustration only

Result

- Helps designing the air intake, outlet for optimum performance
- Automatically calculates the heat transfer without relying on empirical formulation

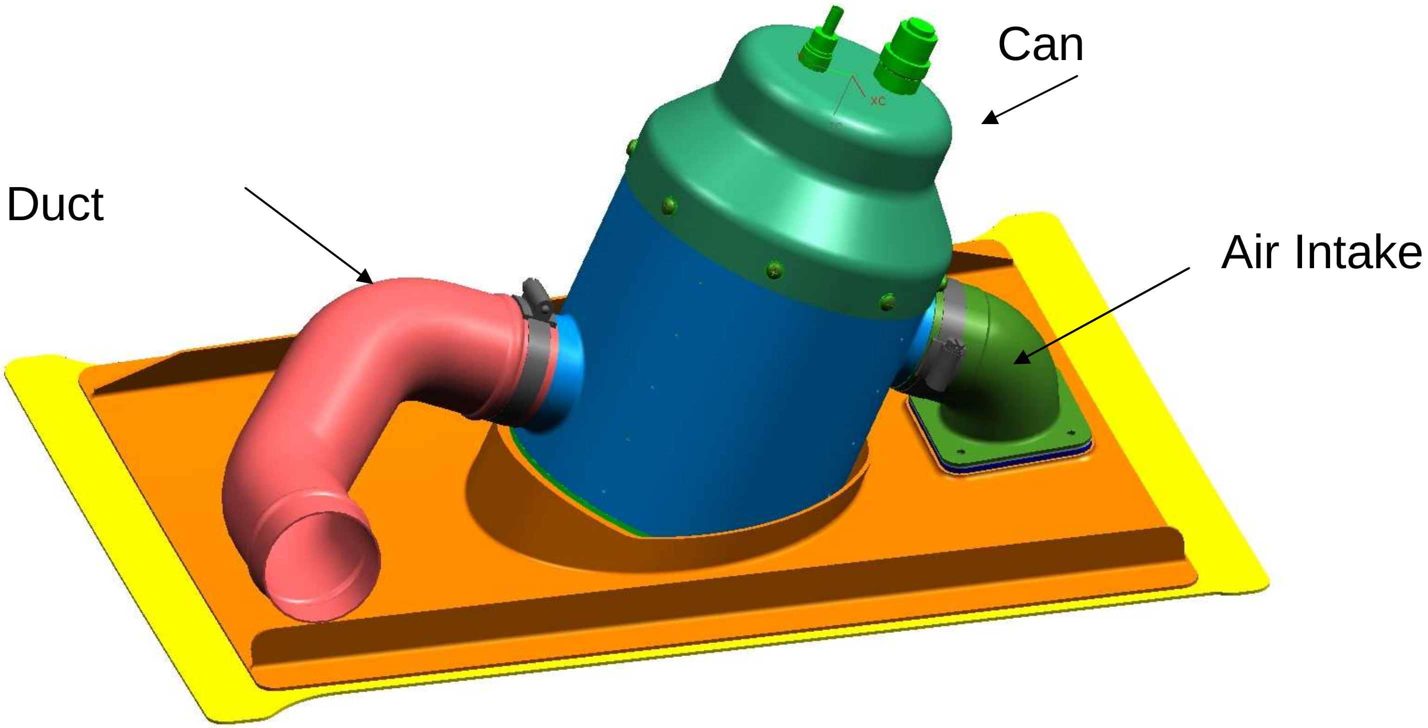
Component



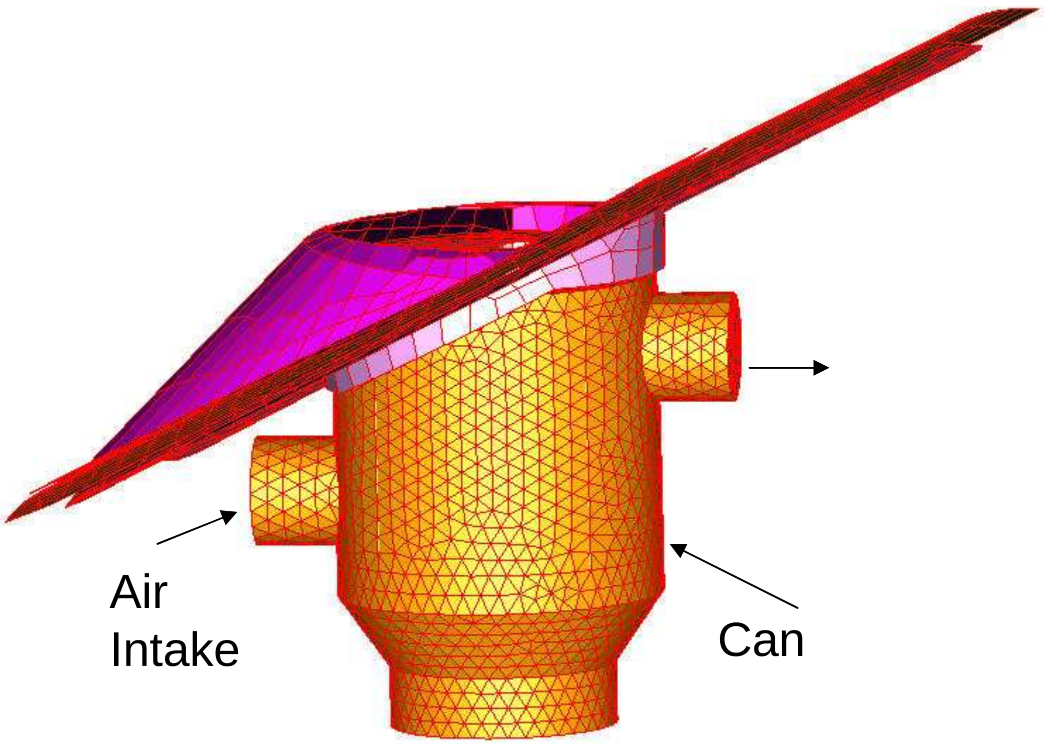
Challenges in Design

- Component has parts dissipating heat at various locations
- Subjected to solar load
- Internal air convection whose temperature distribution is unknown
- External air convection with a known temperature
- Sensor should cool to a mount temperature < required limit
- Low DT

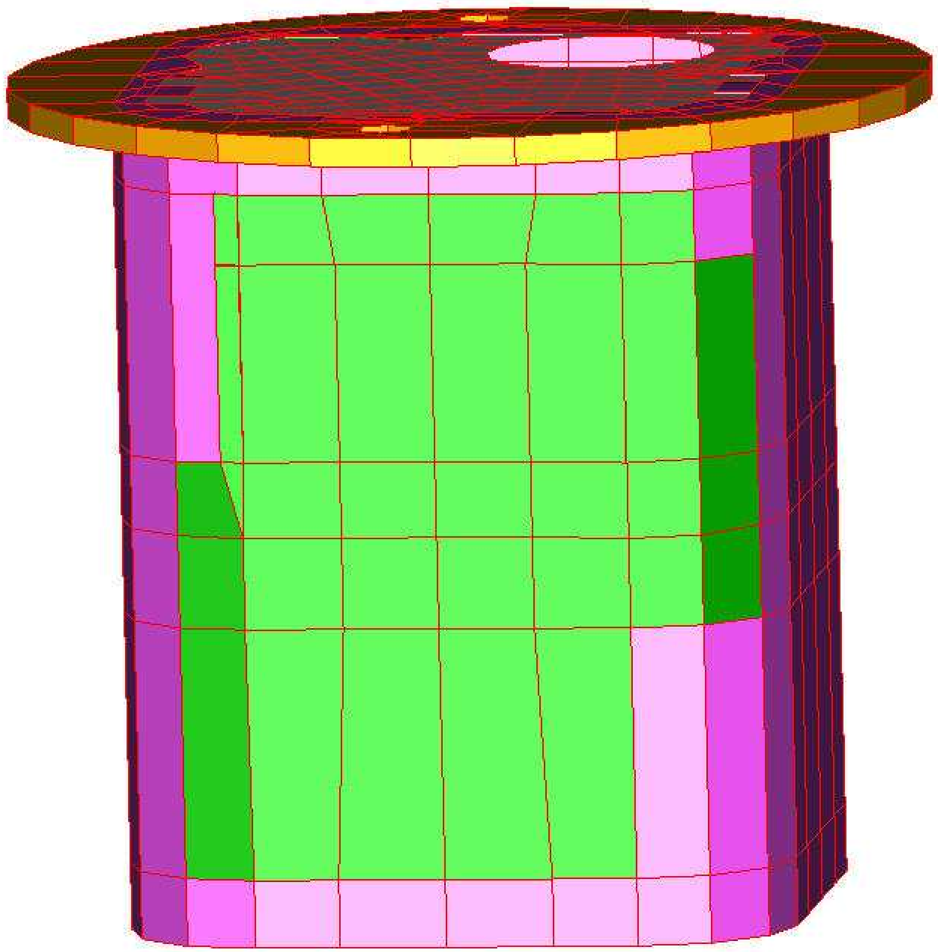
Cooling Configuration

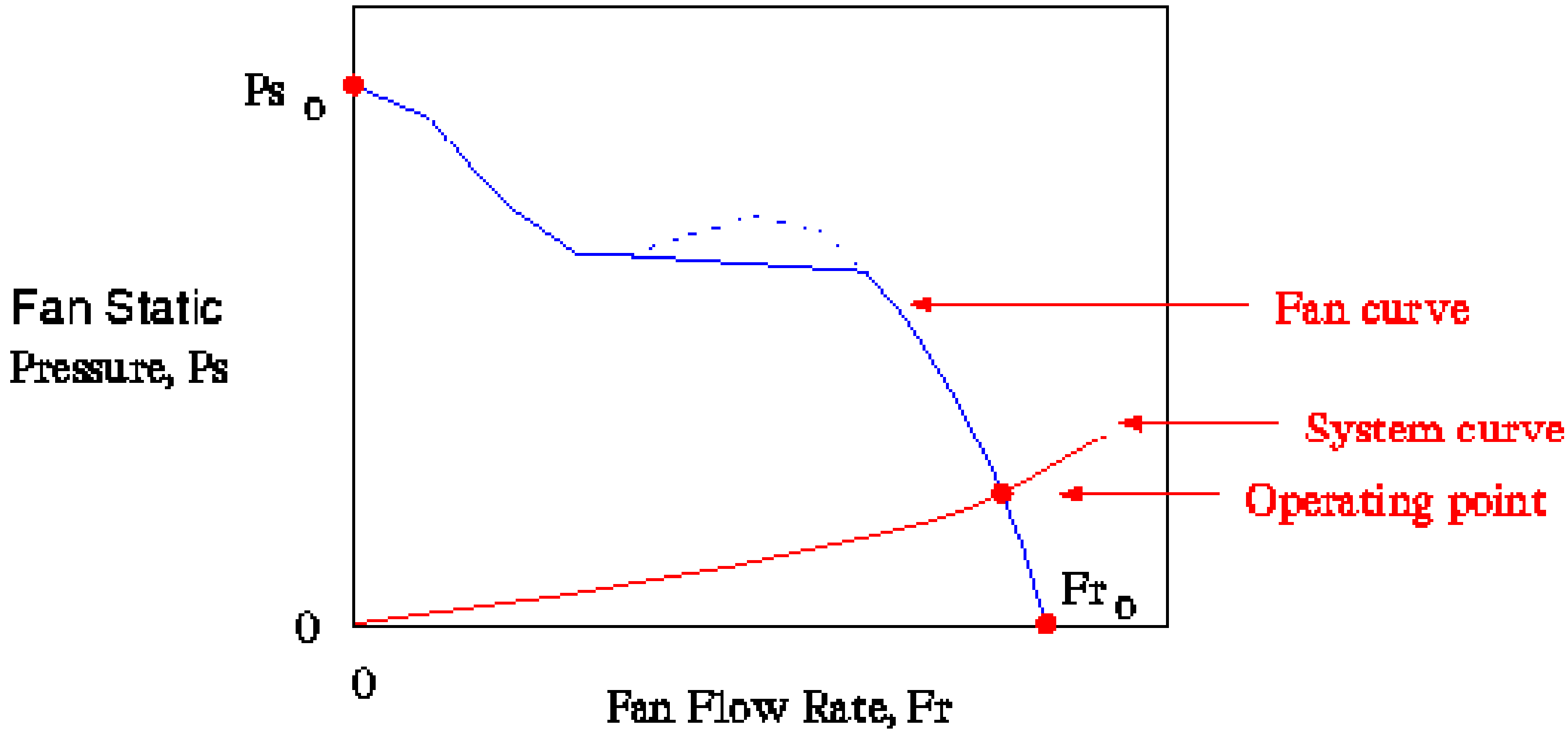


Finite Element Model



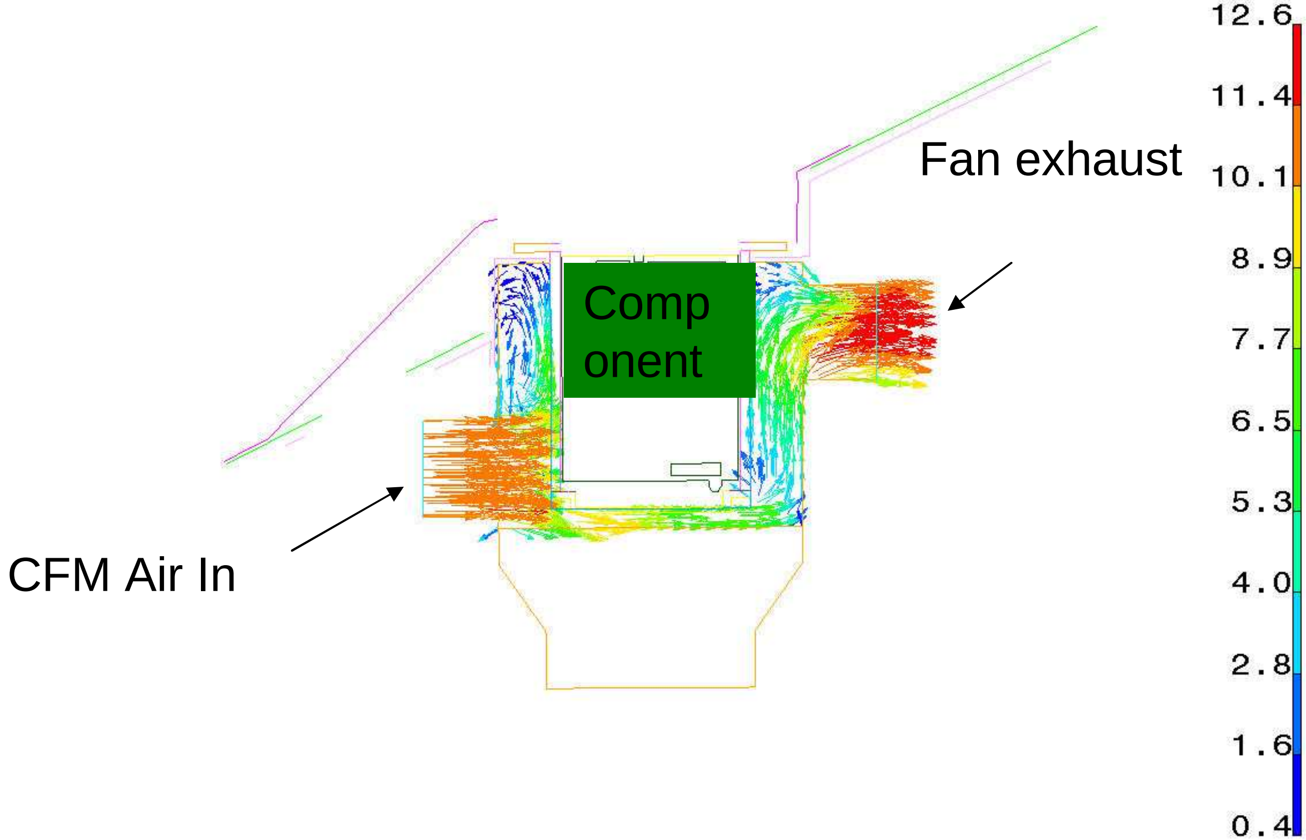
FE Meshing





Ps o
Fan Static
Pressure, Ps
0
0
Fan Flow Rate, Fr
Fr o
Fan curve
System curve
Operating point

Air Flow in the Can

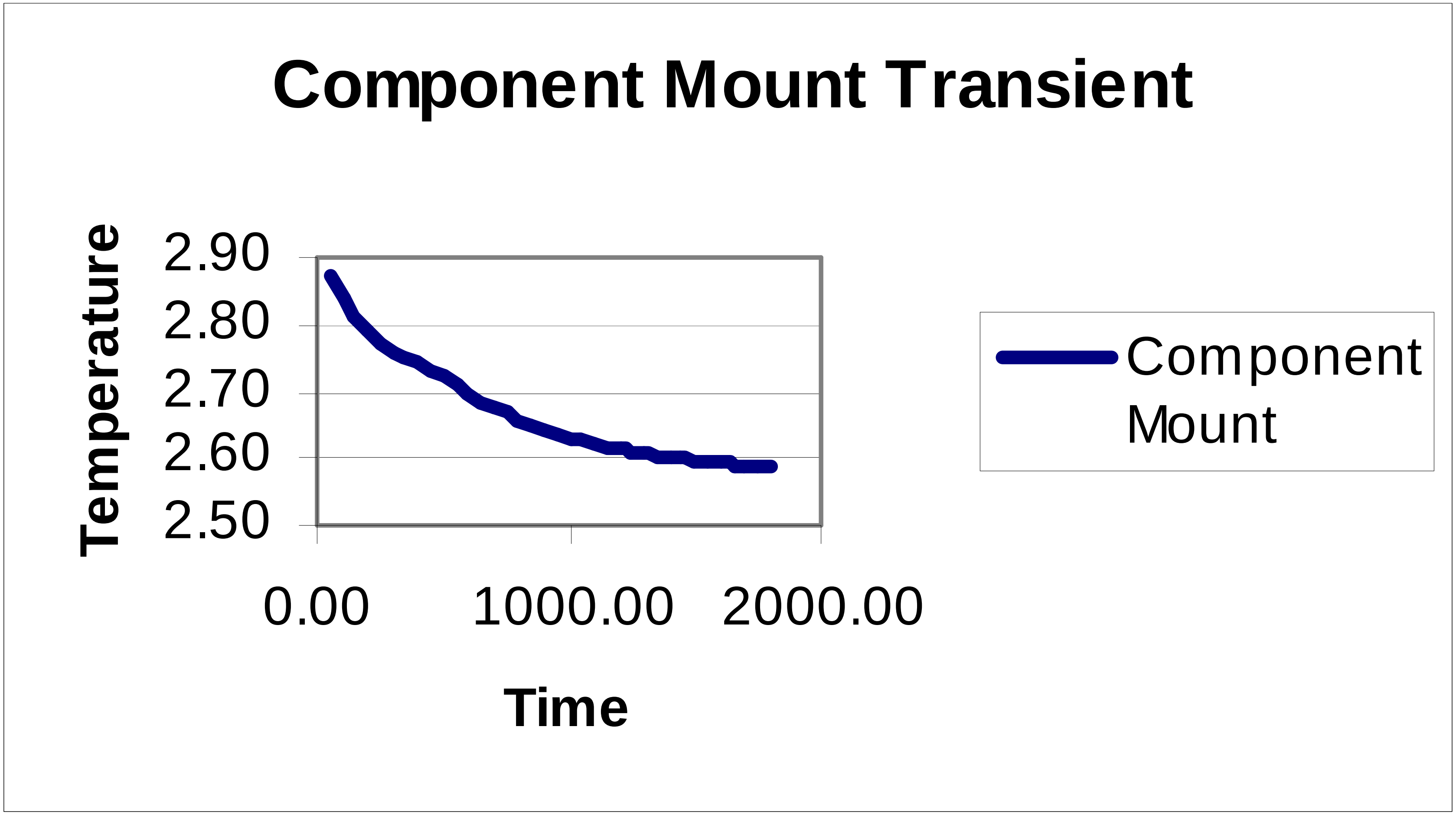


Velocity

Design Issues

- Space constraints
- Weight
- Fan
- Placement of inlet and outlet
- Reliability, availability, maintenance
- Baffling in the can
- Environments

Temperature Transient



Conclusion

- **Concurrent thermal design of component, parts , assemblies and sub-assemblies, and large assemblies can be very effectively performed using I-DEAS/TMG/ESC tool suite**