Thermal Cooling Design of an Electronic System using Coupled Conduction, Three Dimensional Convection (CFD), and Radiation Heat Transfer Finite Element Analysis with PID-Control System

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Overview

- Purpose
- Background
- The 3 axis system
- FE Modeling
- The Control System
- Results
- Conclusion

Abstract

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

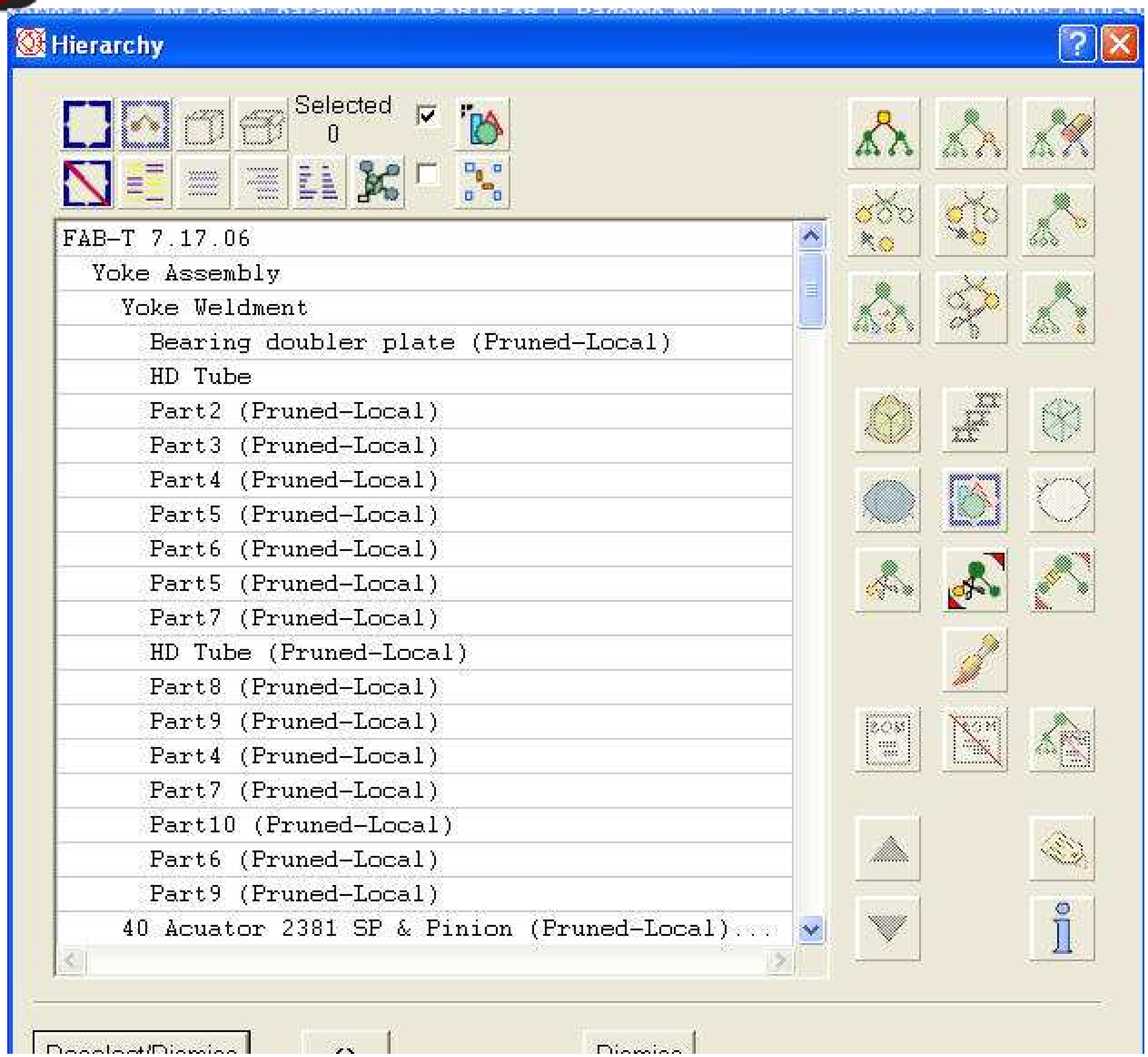
Concurrent Engineering

- **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 organization 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

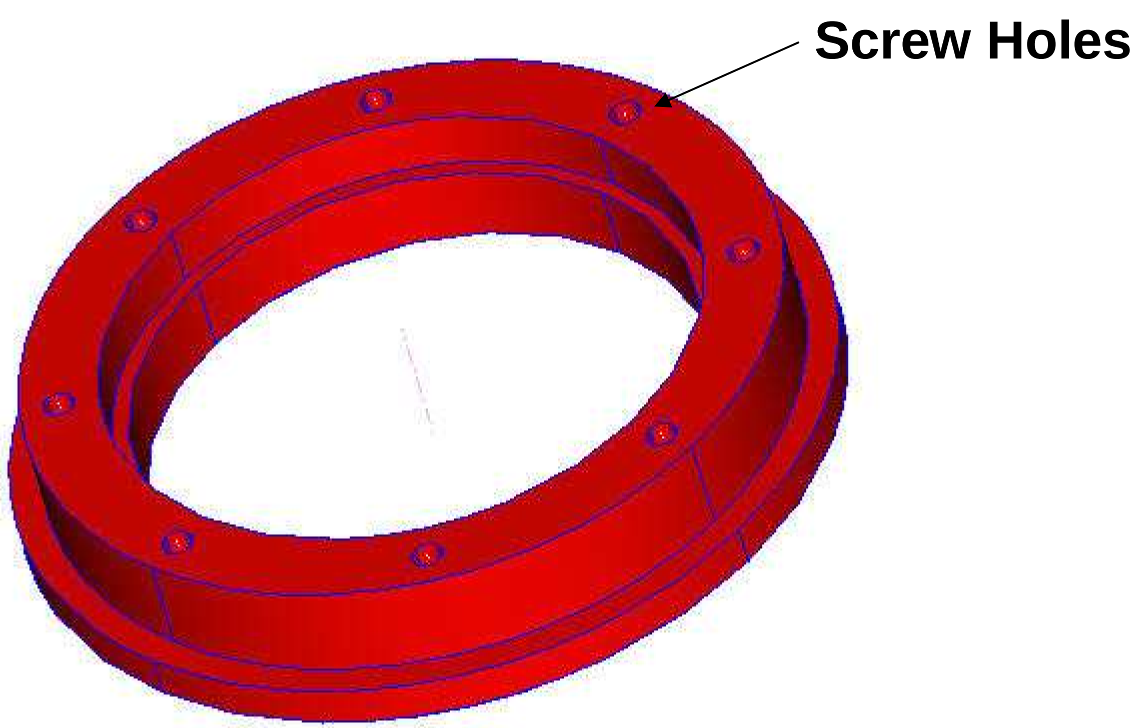
Parts Selection



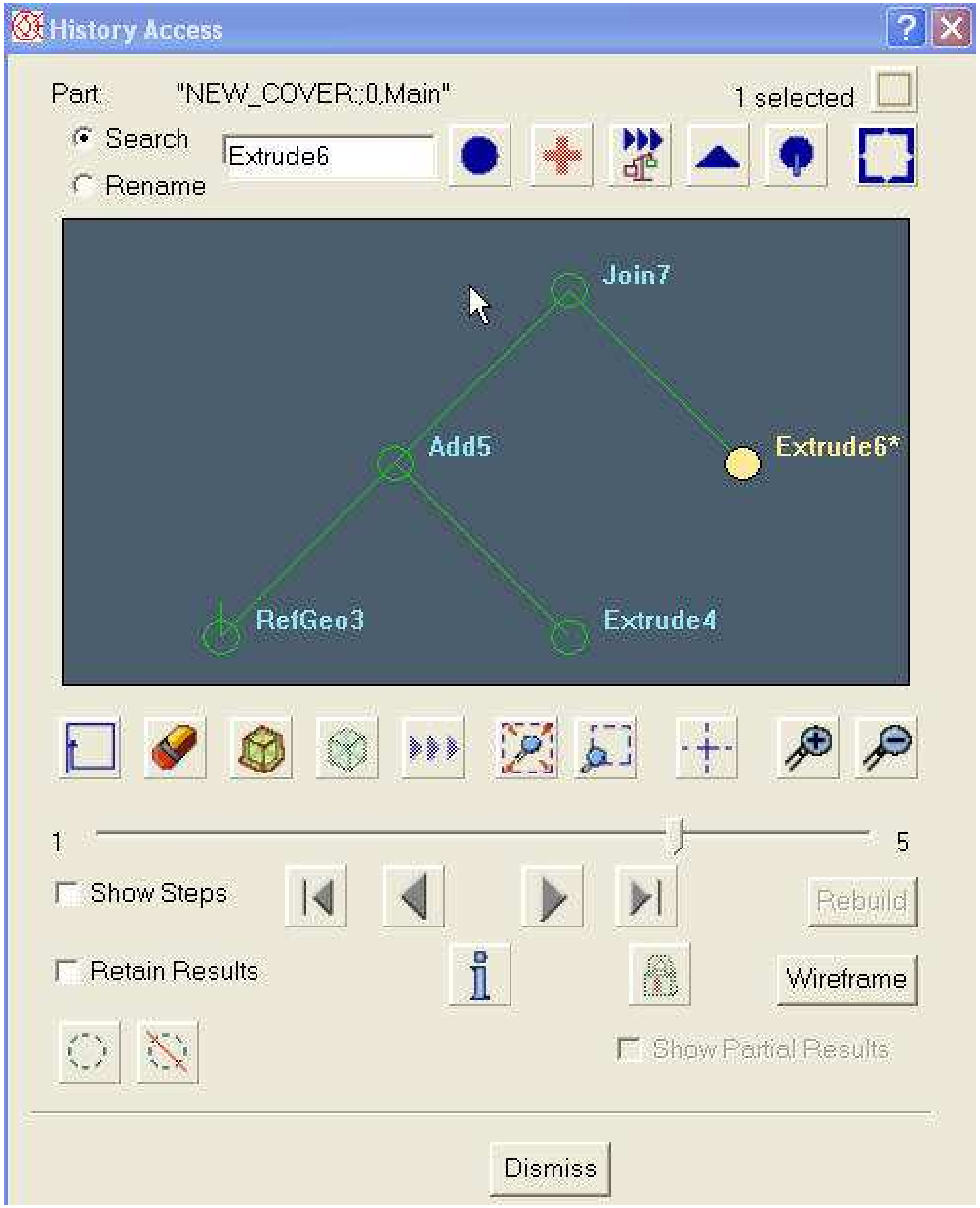
Idealized part

- 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:**
  - **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 $\partial(\rho h)/ \partial t + \partial(\rho U_j h)/ \partial x_j = \partial(\mu \{\partial U_i / \partial x_j + \partial U_j / \partial x_i \} - \underline{\rho u_j u_i})/ \partial x_j + S_{Uj}$**
  - **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

- Sij includes the buoyancy terms, Coriolis forces, and centripetal forces
- Buoyancy: $-g\beta(T-Tr)g$
- Coriolis: $-\rho(2\omega X V + \omega X \omega X R)$
  - V is the velocity vector and ω is the angular velocity vector

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 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**

Boundary Conditions

- **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**

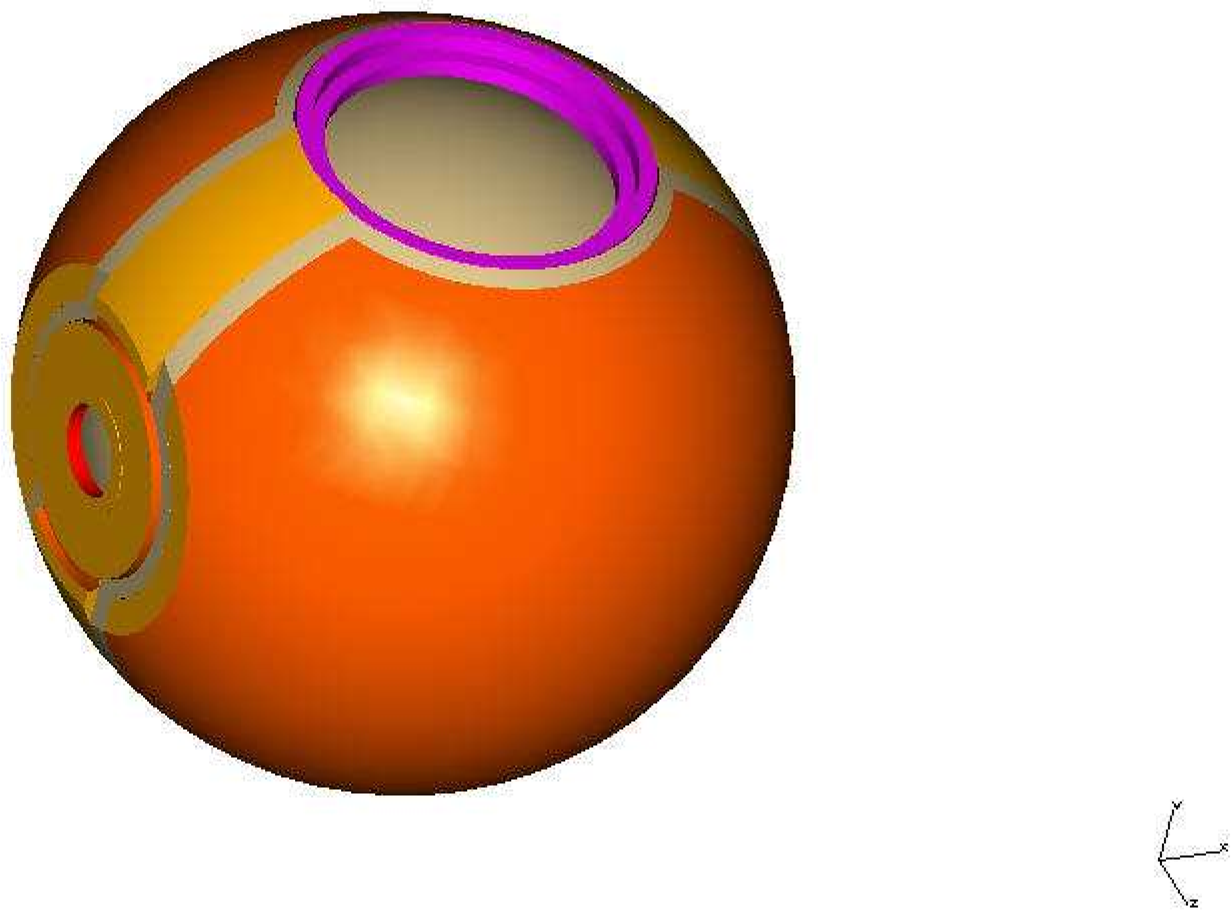
Example

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

Background

- The system consists of parts inside a sphere called instrument mount which rotates about another sphere called inner sphere
- This rotates about another sphere called outer sphere which in turn rotates about another sphere called case. The case does not rotate but fixed.
- The innermost sphere is kept fixed in an inertial frame of reference
- The parts dissipate heat and cooled by water on the case
- It is desired to keep the part temperature at a desired level

Sphere



The 3-Axis System

- The air gap between the sphere conducts heat
- The case is cooled by water
- A control system maintains the temperature of the casing to a desired set point

Thermal Model

- The goal of the thermal model is to be able to predict the thermal profile of the system which will help in studying the effect of various parameters on the performance
- Finite element thermal model and validated

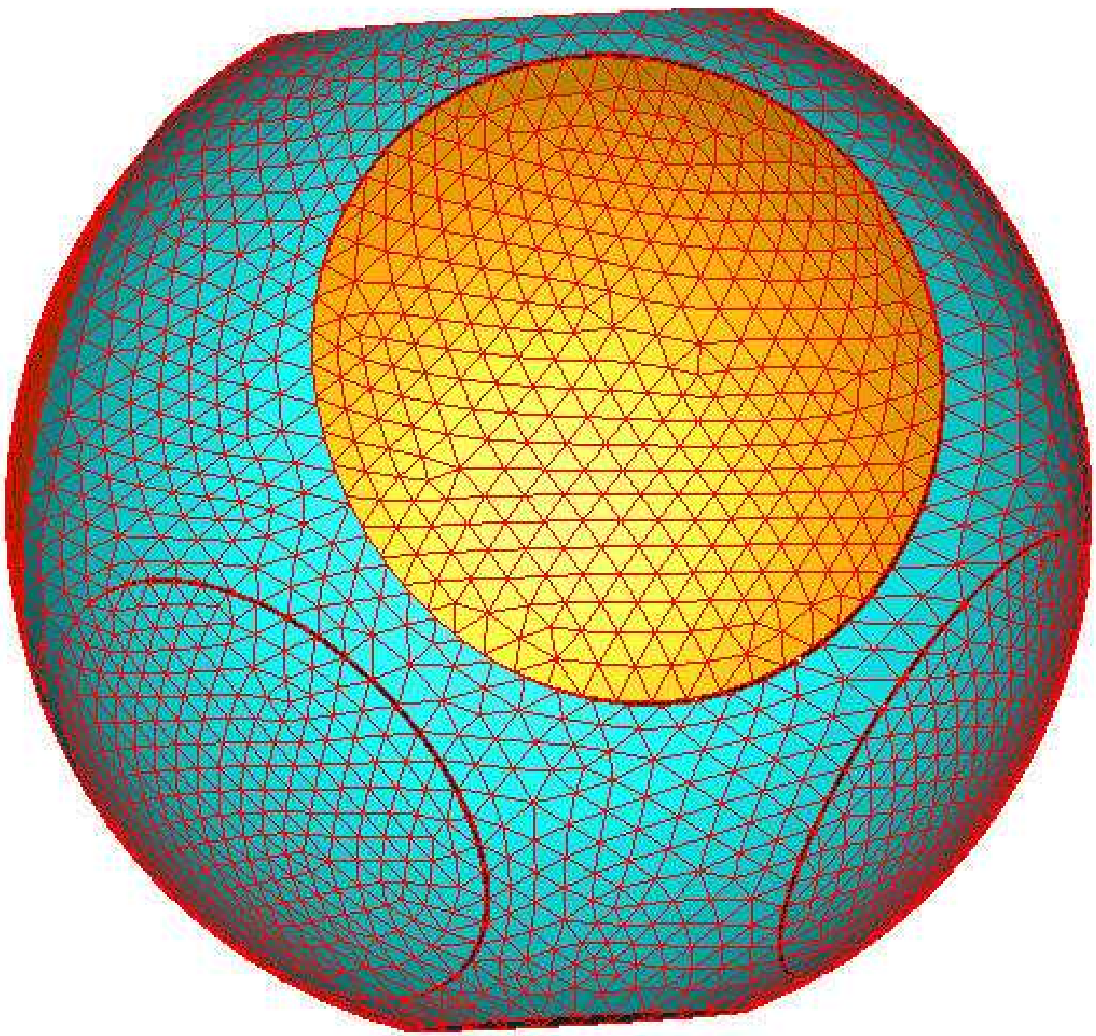
Thermal Model

- **Both solid and surface elements were modeled.**
- **Heat conduction and radiation across gaps were modeled with articulation.**
- **Cooling thermal control system was modeled by user subroutines**
- **Rotation was also included in the model**

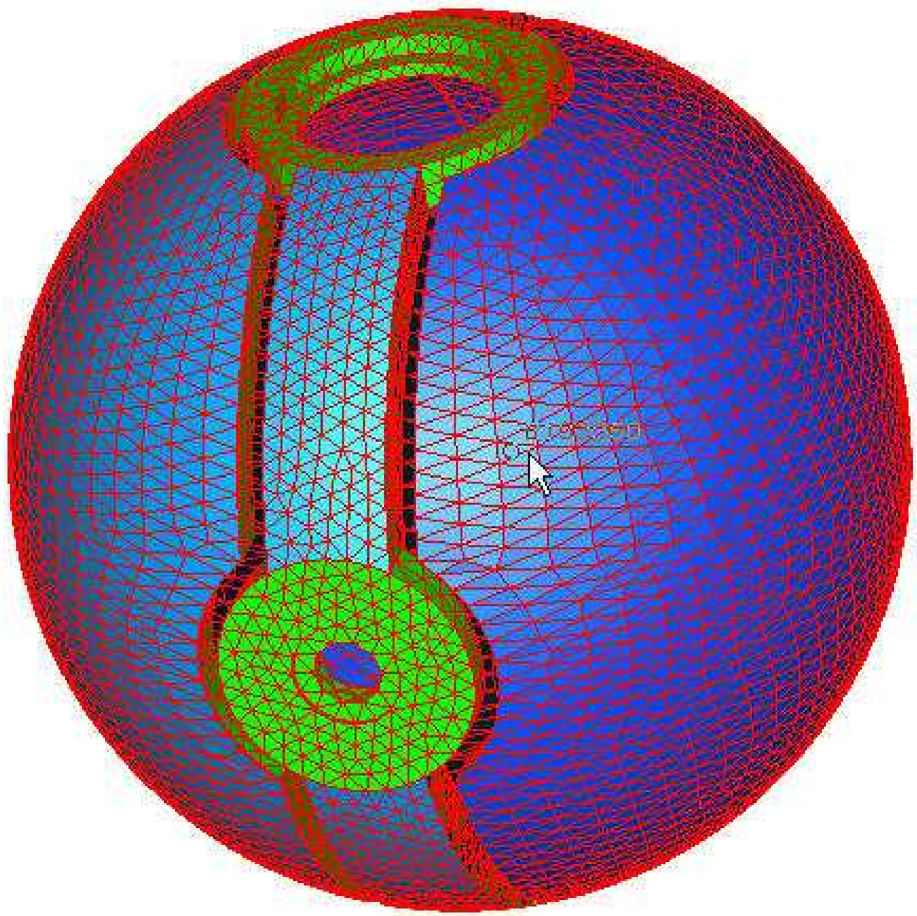
Thermal Model

- **Natural convection in the central air pocket was modeled in a rotating frame of reference using the CFD equations in ESC**

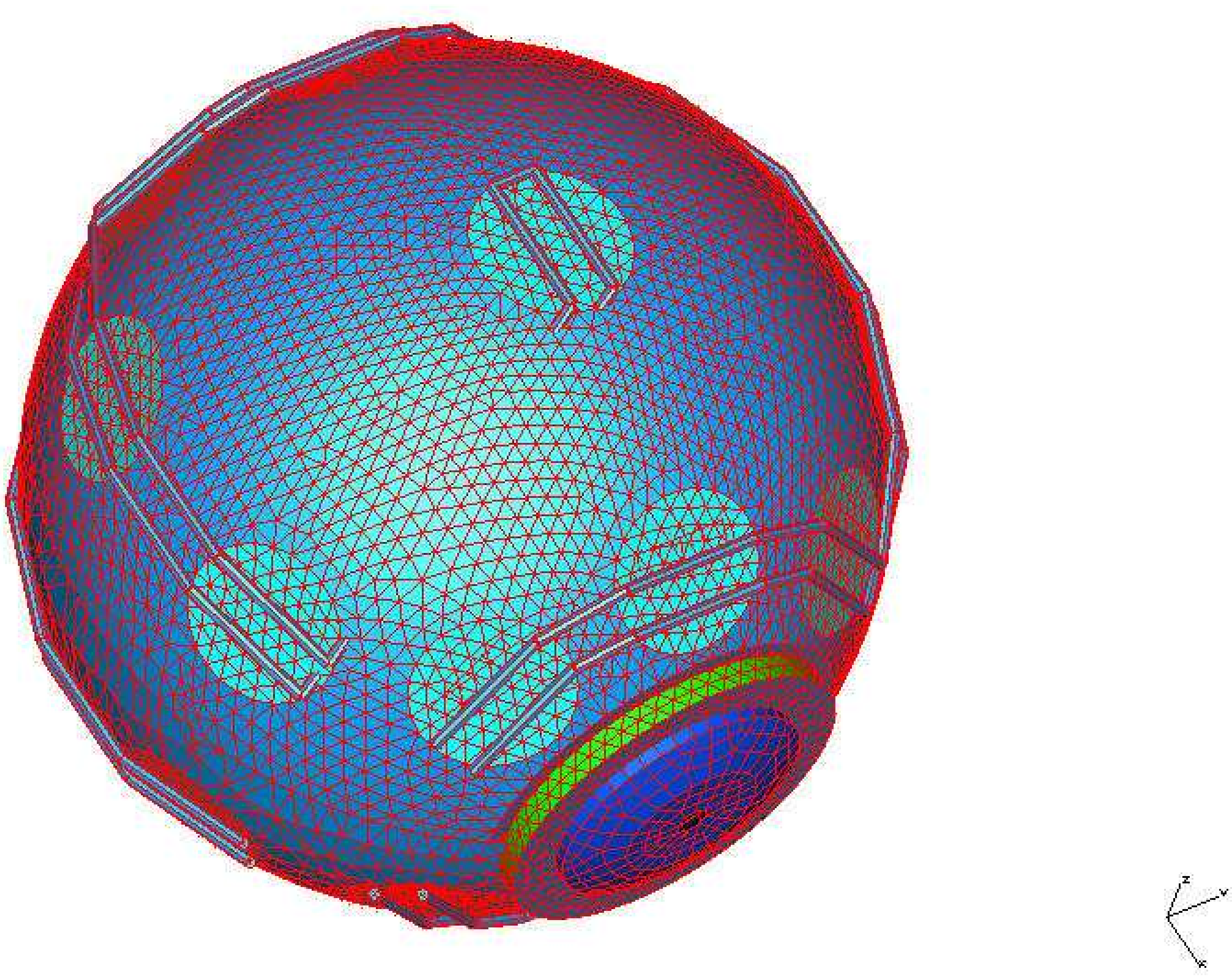
FE Model of the Assembly



FE Model of Sphere



FE Model of the Tubes



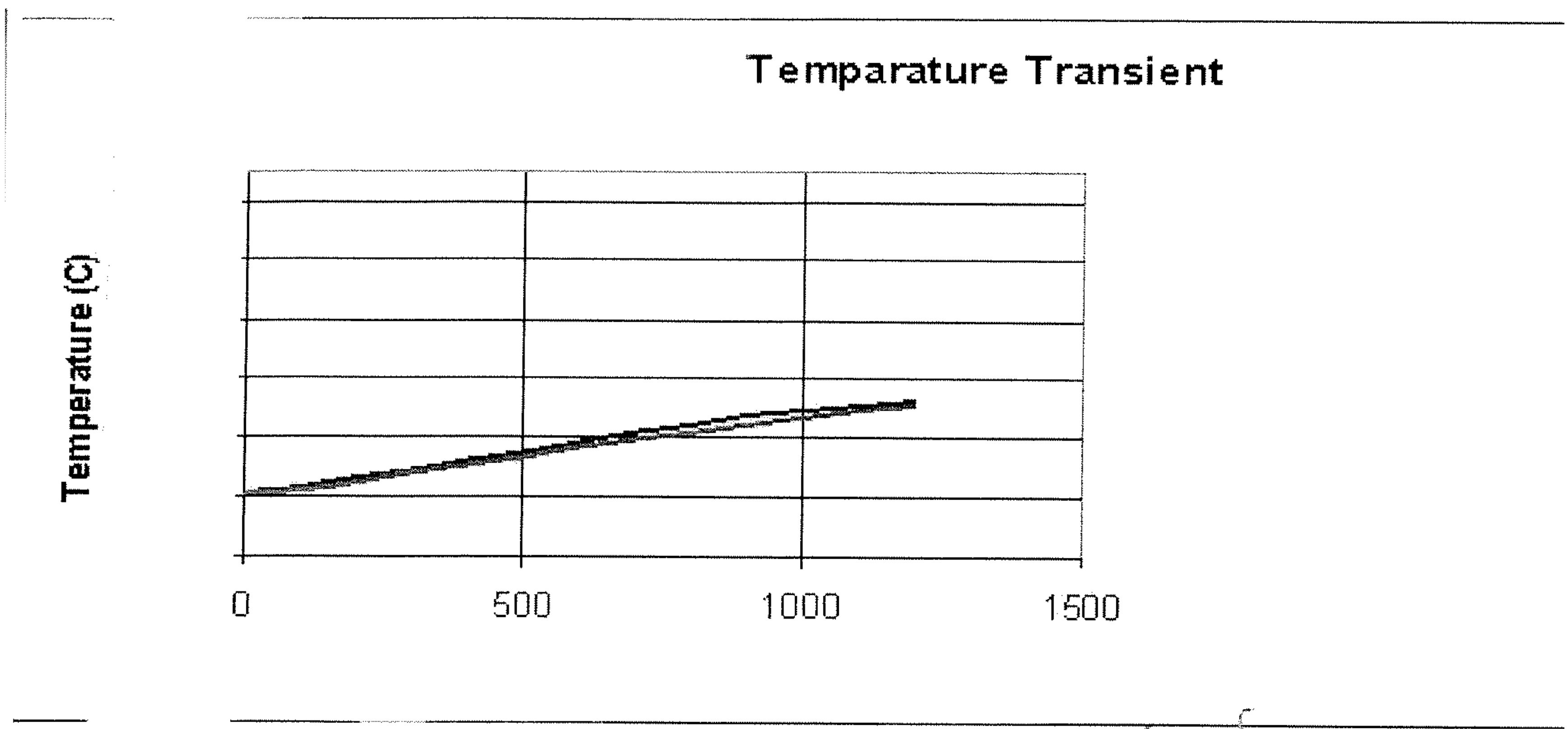
Thermal Model

- Contact resistances at various bolted joints were modeled
- Conduction through bearings in torquers and encoders were modeled from the MIT report "Analytical and Experimental Investigation on the thermal Resistance of Angular Contact Bearings" by MM Yovanovich, 1967
- Conduction across air gaps (rotating) was modeled as articulation

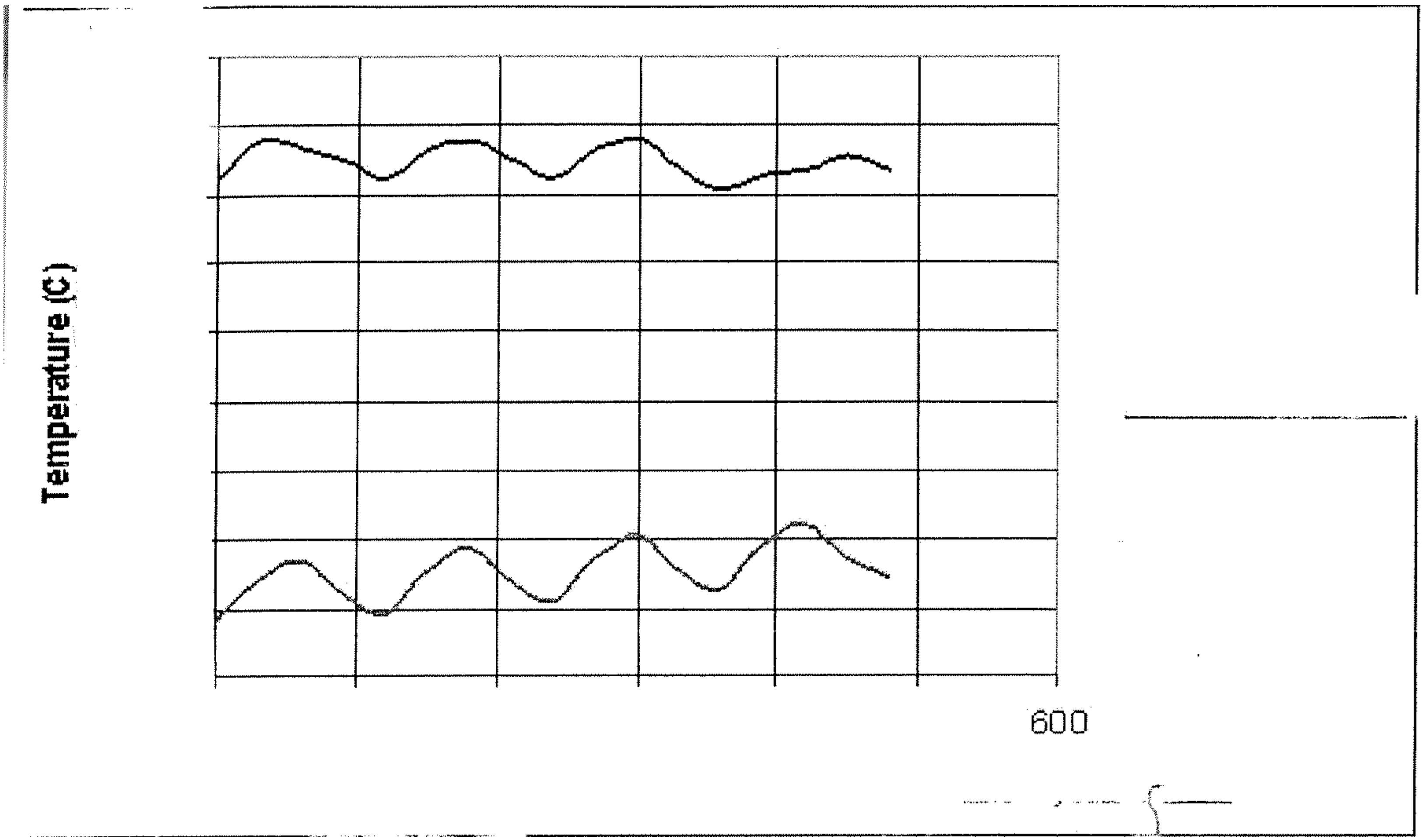
Feed-Back Control System

- Tcerr = (Tcase – Tcset)
- Case Current: Icase = Kpc Tcerr
- Toserr = (Tos – Tosset).
- Outer Sphere Current: Ios = Ios + Kiog Toserrdt.

Results



Results



Conclusions

- **Concurrent engineering concepts enabled design analysis of the system**