A parallel scalable software framework built to conduct fluid-thermal radiation analysis.

Governing Equations

\[
DU + \nabla \cdot (\kappa \nabla T) - \nabla \cdot (\Gamma \nabla T) + \nabla \cdot (\sigma(T^4 - T_i^4) + f(t)) = \nabla \cdot \kappa \nabla T
\]

Physical considerations

Conduction: Conducted on 3D sheet bodies in 3D space. Dictated by thermal diffusivity (k) of the conducting material.

Convection: Coefficient (h) governed by Grashoff Number (Gr) for natural convection and the Prandtl Number (Pr) for forced convection. Streamline convection is dictated by the surface velocity generated.

Solar Flux: The solar flux takes into account the effects of short-wave thermal, Planckian and specular-diffuse radiation. Values are correlated to lookup tables generated from experimental data.

Radiosity: Radiosity is governed by the surface temperature, surface to surface view factors and the emissivity (\varepsilon) of the surface.

Radiosity Formulation

The Finite Element Method is extended to the formulation of the radiosity solution. The radiosity is the total radiation intensity leaving a surface and is dependent on all other surfaces in the system.

\[ R_i = \varepsilon_i \sigma T_i + \rho_i \sum_{k=1}^{N-1} \frac{VF_{ik}}{k} R_k \]

The Galerkin weak statement is used to transform the radiosity energy balance into an integral form.

\[ \langle GWS, N \rangle = \int_{\Omega} \left[ -\varepsilon_i \sigma T_i^4 + \rho_i \sum_{k=1}^{N-1} VF_{ik} T_k^4 \right] dA = \{0\} \]

Transformation of the GWS to the element matrix form gives the following algebraic expression.

\[ \frac{1}{\varepsilon_i} \frac{\partial}{\partial t} \left[ \kappa \nabla \cdot \nabla (T_i) \right] + \rho_i \sum_{k=1}^{N-1} VF_{ik} \frac{\partial}{\partial t} (T_k) \right] = \frac{1}{\varepsilon_i} \frac{\partial}{\partial t} \left[ \kappa \nabla \cdot \nabla (T_i) \right] \]

Assembly of the radiosity formulation into a hyper-matrix allows for solution of a dense matrix using cuBLAS libraries.

Abstract

Conservation of Energy within a control volume and across the boundaries.

The Galerkin weak statement is used to transform the radiosity energy balance into an integral form.

The finite element method is extended to the formulation of the radiosity solution. The radiosity is the total radiation intensity leaving a surface and is dependent on all other surfaces in the system.

Simulations are done on multi-core + GPU’s supercomputers, Kraken and Keeneland.

Sun Visibility

Sun Visibility test on multiple objects with obstruction (red denotes visibility).

Software Framework

Multi module support for additional flexibility in physics

Test Cases

- Single Cubi - Focus on diffusion, simple radiation and solar flux
- Multi Cubi - Introduces obstruction to radiosity and solar flux
- SUV - Complex geometry, substantial mesh size and multiple material properties

Benchmark Validation

- 24 hour experiment provides data correlation for solar flux on surface of flat plate
- Data from single plate used in computing solar flux on surface of flat plate
- 24 hour experiment provides data correlation for solar flux on surface of flat plate
- Data from single plate used in computing solar flux on surface of flat plate
- Numerical solution of parallel plates closely matches experimental results giving validation to solar flux inclusion