A Practical Method to Model Complex Three-Dimensional Geometries with Non-Uniform Material Properties Using Image-based Design and COMSOL Multiphysics®

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Abstract

Introduction:

Multiphysics modeling of complex three-dimensional (3D) geometries remain a challenge. The challenge is greater when such geometries involve assembling of parts with different material properties (e.g., chicken carcass with bone, skin, and meat sections). A common approach is to simplify the geometry using basic shapes and/or to consider the multi-part geometry as a unit having uniform material properties to minimize model complexity. However, there are situations where such simplifications are not possible as accuracy of the simulation can be highly compromised. Image-based computer aided design (CAD) is a practical alternative to reconstruct complex geometries from cross-sectional images. Nevertheless, incompatibilities between different CAD file formats and simulation software can occur, especially when dealing with multipart geometries that require assembling. Our objective was to develop a practical method to use complex geometries with non-uniform material properties in COMSOL Multiphysics® without the challenge of assembling multiple parts.

Use of COMSOL Multiphysics:

The proposed method involves five steps: (i) 3D imaging (e.g., Computer Tomography (CT) scanning) of the geometry; (ii) surface reconstruction and volume meshing of the entire geometry as a unit, and of each of its sections (Figure 1); (iii) export meshes as text files (COMSOL .mphtxt); (iv) use a custom-made algorithm to label geometry nodes with corresponding materials; and (v) use interpolation functions to define material properties as a function of mesh coordinates in COMSOL. The method was used in a model to simulate coupled heat and mass transfer during industrial air-cooling of chicken carcasses. The Heat Transfer in Solids and Transport of Diluted Species physics interfaces were used in addition to LiveLink™ for MATLAB® to carry out the simulations.

Results:

A 3D geometry of a chicken carcass was built using the proposed methodology. Material properties corresponding to the meat, skin and bone sections of the carcass were easily defined using a single mesh, and without the need of assembling parts or defining multiple sections (Figure 2). The coupled heat and mass transfer model for air-cooling of chicken carcasses was successfully validated in a local poultry processing facility (Figure 3). The developed model can be used to support food safety management decisions, quality assurance, and process optimization in the poultry industry.

Conclusion:

The proposed method allows incorporating complex geometries with non-uniform material properties in COMSOL without the difficulties that arise in assembling complex multipart geometries. More importantly, this method is a practical alternative to avoid the need of critical geometry simplifications that may compromise model accuracy for certain applications (e.g., industrial food processing applications). The basics of this method can be potentially implemented as features in future versions of COMSOL to increase geometry definition and meshing flexibility.

Figures used in the abstract

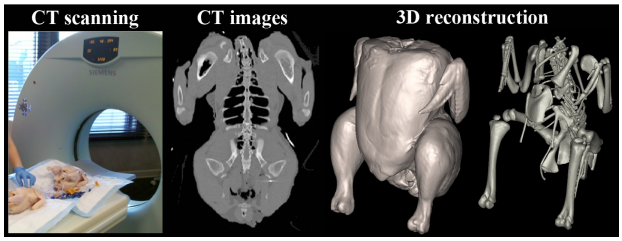

Figure 1: Image-based CAD of a complex geometry with non-uniform material properties (i.e., chicken carcass).

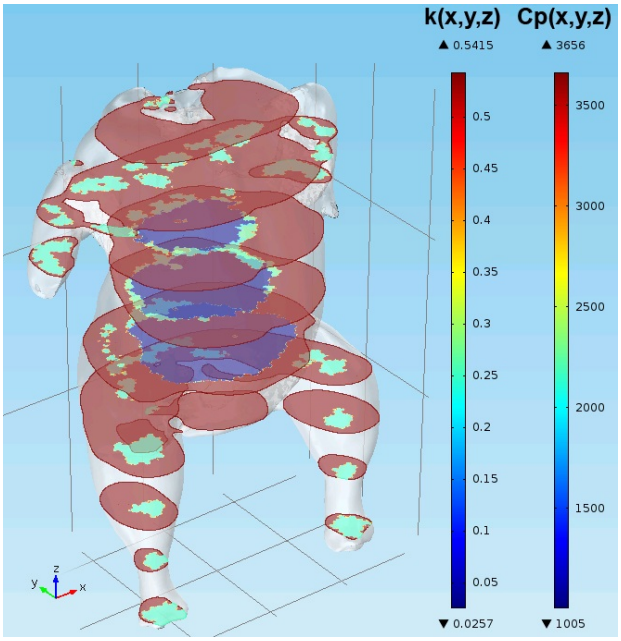

Figure 2: Slice plot of a chicken carcass geometry illustrating non-uniform thermal conductivity (W/mK) and specific heat (J/kgK) defined using the proposed method.

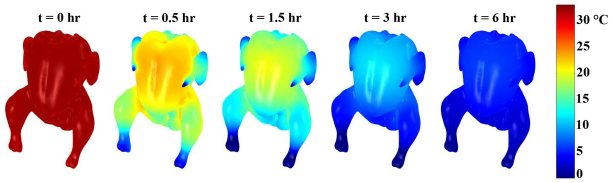

Figure 3: Simulation of industrial air-cooling of a poultry carcass using COMSOL Multiphysics.