USE OF EXISTING CAD MODELS FOR RADIATION SHIELDING ANALYSIS

K. T. Lee[1], J. E. Barzilla[2], P. Wilson[3], A. Davis[3], and J. Zachman[3]

[1]NASA Johnson Space Center, Houston, TX [2]Lockheed Martin, Houston, TX and [3]University of Wisconsin, Madison, WI

Background

The utility of a radiation exposure analysis depends not only on the accuracy of the underlying particle transport code, but also on the accuracy of the geometric representations of both the vehicle used as radiation shielding mass and the phantom representation of the human form. The current NASA/Space Radiation Analysis Group (SRAG) process to determine crew radiation exposure in a vehicle design incorporates both output from an analytic High Z and Energy Particle Transport (HZETRN) code and the properties (i.e., material thicknesses) of a previously processed drawing. This geometry pre-process can be time-consuming, and the results are less accurate than those determined using a Monte Carlo-based particle transport code. The current work aims to improve this process.

Although several Monte Carlo programs (FLUKA, Geant4) are readily available, most use an internal geometry engine. The lack of an interface with the standard CAD formats used by the vehicle designers limits the ability of the user to communicate complex geometries. Translation of native CAD drawings into a format readable by these transport programs is time consuming and prone to error. The Direct Accelerated Geometry – United (DAGU) project is intended to provide an interface between the native vehicle or phantom CAD geometry and multiple particle transport codes to minimize problem setup, computing time and analysis error.

Methods

This project focused on application of the DAGMC workflow to the Monte Carlo particle transport code FLUKA (FluDAG), building upon the DAG-MCNP5 product previously created at the University of Wisconsin. A Pro/Engineer (PTC, Needham, MA) drawing of the International Space Station (ISS) Robonaut was imported into SpaceClaim (ANSYS, Concord, MA) where the model was simplified and overlaps/gaps within the structure were eliminated. The model was then exported to an ACIS format with a simple thin aluminum shell added to represent a vehicle.

Robonaut geometry volumes were assigned the material properties of water, and all volumes (vehicle and Robonaut) were grouped by material composition using CUBIT (Sandia National Laboratories, Albuquerque, NM). The output geometry was then faceted (Figure 1) using MOAB (Argonne National Laboratory, Lemont, IL) and corrected to create a watertight volume to prevent particle loss during the simulation.

The resulting geometry and material data files were used as inputs to FLUKA to simulate propagation of a source distributed on a spherical surface surrounding the structure. For the simulation shown, a 1GeV proton source and 800 MeV/A oxygen source were modeled separately, and the energy deposition and dose within the Robonaut structure were assessed. The results of 100,000 particles per run for a total of 5 runs are presented here.

Results

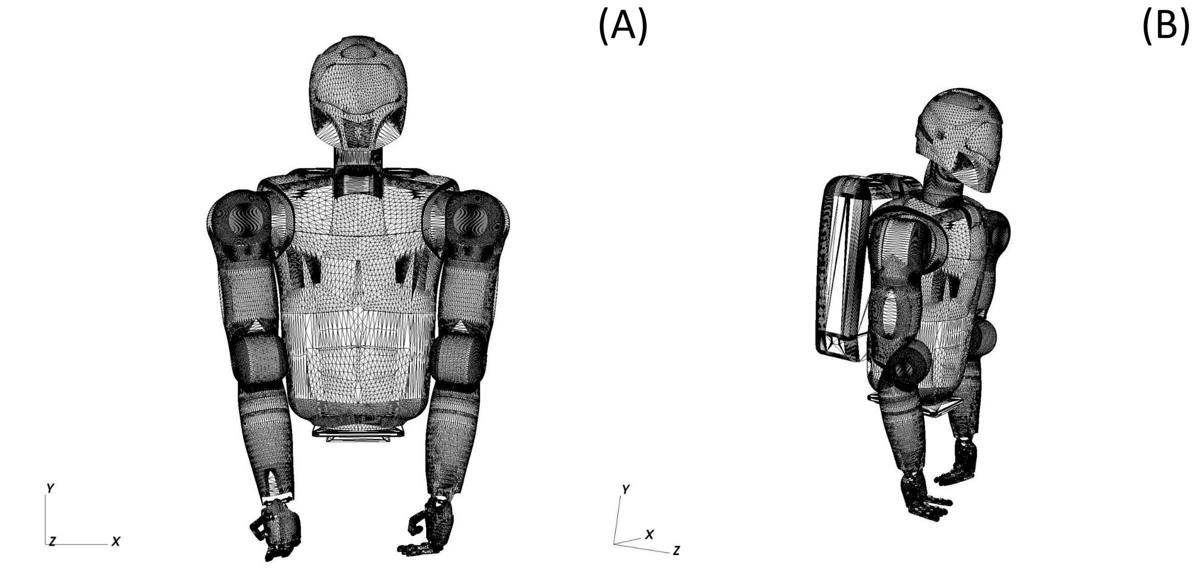

Figure 1. (A) Front and (B) rotated images of meshed Robonaut (vehicle not shown). Geometry was assigned material properties in Cubit, then processed using the DAGMC workflow.

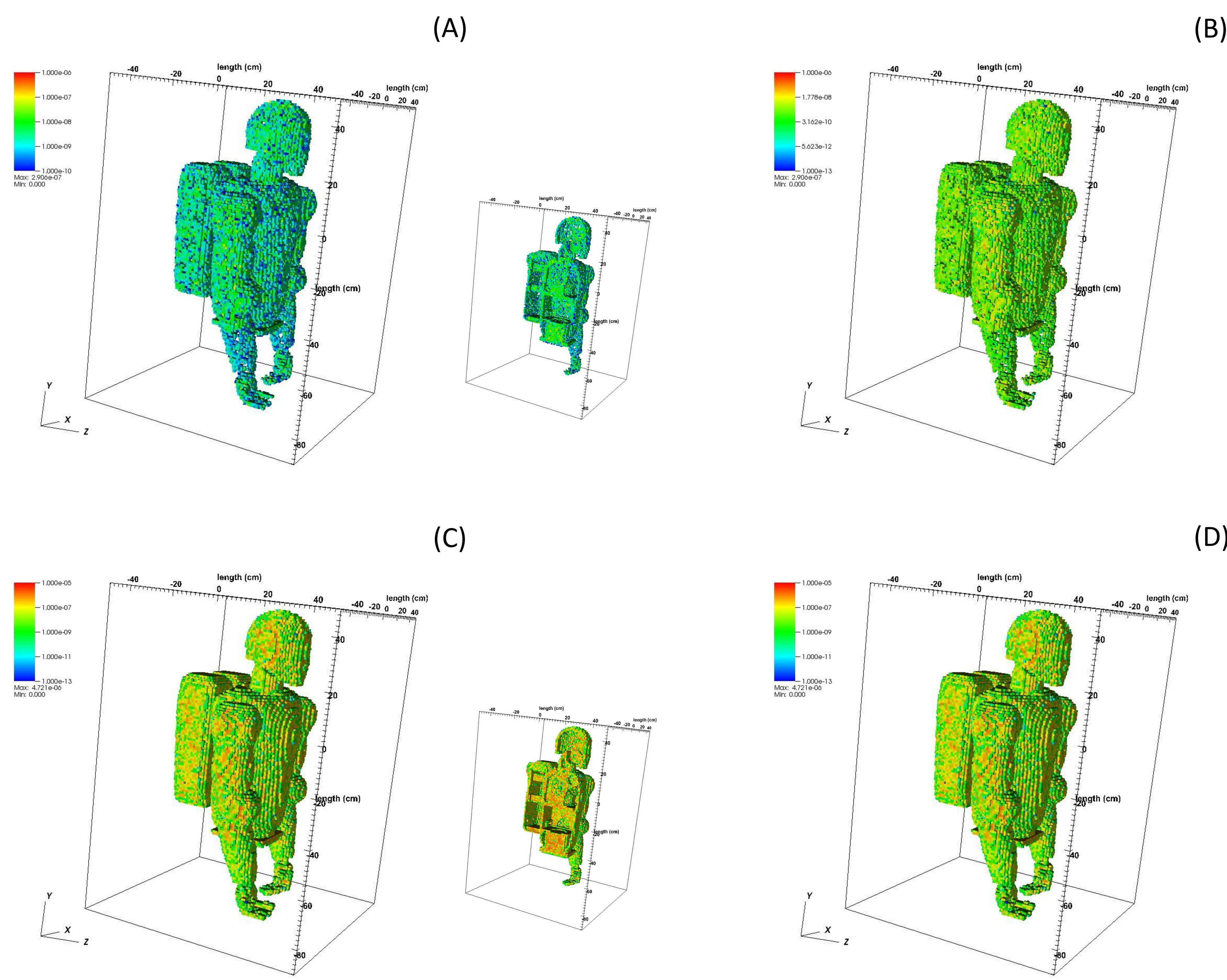

Figure 2. (A) Energy deposition (in GeV/cm3-primary) and (B) resultant dose (in GeV/g = 1.602×10^{-7} Gy) of 1GeV proton isotrophic source. (C) Energy deposition and (D) dose of 800MeV/A oxygen isotropic source. (A) and (C) insets, cut at x=0, show that results were propagated through the external and internal Robonaut volumes. Aluminum vehicle shell not shown.

Discussion

Previous comparisons between the FLUKA (using native geometry) and FluDAG (using external geometry) workflows indicated that the two approaches produce nearly identical results in simple geometries (results not shown). Figure 2 displays the results of the simulation of the 1 GeV proton and 800 MeV/A oxygen sources through the complex Robonaut geometry. Although not shown here for simplicity, energy was deposited throughout the aluminum vehicle structure as well as the Robonaut body.

As expected, the results show that energy from the two particle sources was deposited throughout the Robonaut geometry. During simulation run time, there were no errors due to multiple material definitions of a volume on a particle trajectory, neither did they experience significant particle loss that would have caused the entire run to fail. Since the detailed geometry from the original CAD drawing was successfully used as the final input to the FLUKA transport program, these results show that the user is able to model the impact of radiation exposure on almost any CAD geometry (vehicle or human phantom) of interest.

The FluDAG workflow begins with a CAD file that was not intentionally created for use in radiation transport and results in a robust geometry file that can be used by the FLUKA code. These results show that the structural details of the complex ISS Robonaut geometry were successfully communicated to the particle transport program, indicating that modeling a desired source through a complex structure is possible.

Conclusions

The results show that the FluDAG workflow integrates Monte Carlo particle transport programs with the complex geometries used within NASA. It is therefore possible to determine deposited energy and dose to the extent allowed by the chosen particle transport code. This workflow has been extended to the use of the Geant4 transport code, and incorporation of the current NASA standard (HZETRN) is in progress. When completed, the DAG suite of programs can be applied to the radiation shielding analysis of more complex vehicle geometries, such as the next-generation Multi-Purpose Crew Vehicle (MPCV). The inclusion of a defined human phantom is also in work, which will result in a complete end-to-end assessment of projected crew radiation exposure for future space missions.

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