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TARGET IMPACT DETECTION ALGORITHM USING COMPUTER-AIDED DESIGN (CAD) MODEL GEOMETRY

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14. ABSTRACT

Probability of hit and probability of kill models evaluate fragment or bullet impacts against a target. The target can be simple or complex. This report documents a method and algorithm to export geometry from a three-dimensional, computer-aided design (CAD) model in a format that can be easily processed for fragment or bullet impacts. The target object can be a single object or multiple components like a vehicle or airplane. The level of target fidelity can be set by the export parameters in the CAD model. Using this method permits a rapid conversion from a target model into an analysis algorithm with high fidelity.

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INTRODUCTION

This report documents a method to use three-dimensional, commercial computer-aided design (CAD) software to export complex objects in a format that can be used in probability of hit and probability of kill models. Using the CAD software permits a rapid conversion of shapes into a useable format that reduces the time required to set up the probability of hit/kill models as well as permits the use of complex shapes with multiple parts.

COMPUTER-AIDED DESIGN GEOMETRY FORMAT

Commercial CAD software usually provides an option to export or save into standardized formats. One such format is commonly used in stereolithography (STL) applications (ref. 1). The STL format is advantageous because it provides a simple triangular surface representation of the object being portrayed. Basic geometric equations for lines intersecting surfaces (planes) can then be used to detect impacts, entrance and exit, thickness, impact location, and other attributes. The STL CAD file can be stored in either American Standard Code for Information Interchange (ASCII) or binary formats. The ASCII file format is used in this report; however, the binary format can also be used to reduce memory and file size.

The ASCII STL format starts with the solid name, and then for every triangular surface, it prints a facet paragraph that outlines the direction of the surface normal vector and the coordinates of the three vertices. The order of the vertices is such that the cross product provides the normal vector identified in the facet normal. In the example in figure 1, a cube of 1-in. square is exported in the STL format. The three-dimensional object is represented by 12 triangular surfaces. An excerpt from the STL file for surface one is depicted in figure 1.

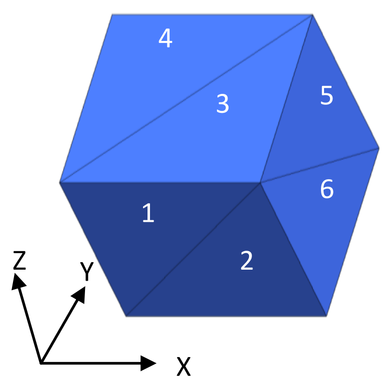
STL format	Cube example - surface 1	Cube example
solid *name* facet normal n_i n_j n_k outer loop vertex $v1_x$ $v1_y$ $v1_z$ vertex $v2_x$ $v2_y$ $v2_z$ vertex $v3_x$ $v3_y$ $v3_z$ endloop endfacet endsolid *name*	solid cube facet normal 0 -1 0 outer loop vertex 1 0 1 vertex 0 0 1 vertex 0 0 0 endloop endfacet	

Figure 1
STL format and example

The resolution of the object can be adjusted by setting the maximum segment length. This option is powerful for curved surfaces, where the segment length is critical in establishing how smooth the surface representation is. With this option, a complex CAD model can be simplified or imported with high resolution.

IMPORTING STEREOLITHOGRAPHY FILES

MATLAB® was used to read and parse the STL file format to extract all the surfaces into memory for manipulation. A basic format was established that would be useful in performing coordinate transformations, plotting, and visualization. A basic data structure hierarchy is shown in figure 2. The top level structure represents the object that can be made up of one or more solids. Each solid consists of multiple surfaces, which all contain three vertices with x, y, and z coordinates. The remaining fields relate to naming and plotting fields such as colors and transparency. A three-dimensional plot can be generated by plotting each surface using its vertices and applying the desired color and transparency. The transparency setting is useful for the visualization of components within a larger object.

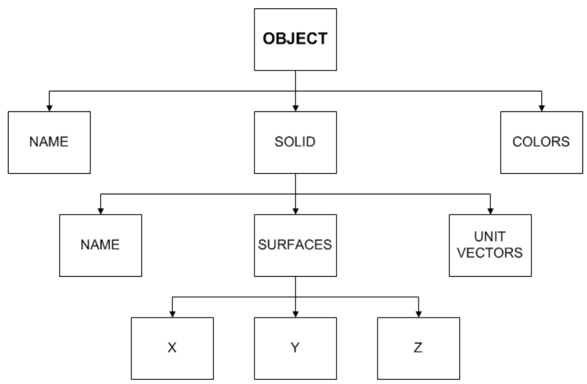


Figure 2
Data structure

COORDINATE TRANSFORMATIONS

The part or assembly is imported into the previously described data structure using a body aligned axis or local coordinates. Placement of the object into another coordinate frame is done using coordinate transformations. Each surface point can be manipulated with six degrees of freedom to achieve realignment of the object to a new coordinate frame. Using this method, a simple manipulation such as the cube being shifted in one direction to a complex manipulation (an airplane being flown along a trajectory with roll, pitch, and yaw) can be performed. Equation 1 represents the Euler angles associated with the coordinate transformation using the roll-pitch-yaw angles that are used in the aeronautical field for aircraft.

$$R(\phi) = R_z(\varphi)R_y(\vartheta)R_z(\psi) = \begin{bmatrix} c_\varphi c_\vartheta & c_\varphi s_\vartheta s_\psi - s_\varphi c_\psi & c_\varphi s_\vartheta c_\psi + s_\varphi s_\psi \\ s_\varphi c_\vartheta & s_\varphi s_\vartheta s_\psi + c_\varphi c_\psi & s_\varphi s_\vartheta c_\psi - c_\varphi s_\psi \\ -s_\vartheta & c_\vartheta s_\psi & c_\vartheta c_\psi \end{bmatrix} \tag{1}$$

Rotation matrix (ref. 2)

Euler angles are used to rotate each surface vertex as a vector with the origin located at the coordinate frame origin. A simple loop can be implemented to perform this task on the whole data structure point by point. The translations can then be applied to each respective axis after the rotations have been performed. This low level function can be implemented and called thousands of times to manipulate complex objects easily.

DETERMINATION OF OBJECT INTERSECTION

Once the object is oriented and placed in the desired location, a trajectory or projection of a fragment or projectile can be checked for intersection with the object. A common coordinate frame should be used for both the trajectory and interceptor. The core equations associated with determining if the trajectory line intersects an object surface or multiple object surfaces are shown in equations 2 through 4.

A line is described by

$$I_a + (I_b - I_a)t \quad where \quad I_a = (x_a, y_a, z_a) \; and \; I_b = (x_b, y_b, z_b) \quad and \quad t \in \mathbb{R} \tag{2}$$

Line description

The surface is described by its vertices

$$p_0 + (p_1 - p_0)u + (p_2 - p_0)v \qquad where \qquad u, v \in \mathbb{R} \tag{3}$$

Surface description

If an intersection occurs, there will be a point on the line that equals a point on the surface. The solution can be found by manipulating the equations from each axis into matrix form and solving simultaneously.

$$\begin{bmatrix} x_a & -x_0 \\ y_a & -y_0 \\ z_a & -z_0 \end{bmatrix} = \begin{bmatrix} x_a - x_b & x_1 - x_0 & x_2 - x_0 \\ y_a - y_b & y_1 - y_0 & y_2 - y_0 \\ z_a - z_b & z_1 - z_0 & z_2 - z_0 \end{bmatrix} \begin{bmatrix} t \\ u \\ v \end{bmatrix} \tag{4}$$

Intersection matrix

If the solution satisfies the two conditions in equations 5 and 6, then the intersection point lies on the surface and within the vertices that describe the surface. Figure 3 depicts an example of a line intersecting the surface where the solution was between zero and one, and the summation was less than one.

$$u, v \in [0,1] \tag{5}$$

$$(u + v) \leq 1 \tag{6}$$

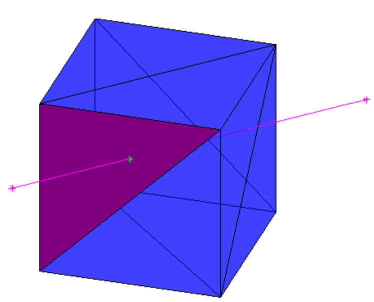


Figure 3
Graphic representation of a line intersecting surface 1 of the cube example

EXTRACTION OF TARGET IMPACT INFORMATION

Given the basic equations to determine intersections, additional information can be extracted from an impact event such as the impact of internal components, entrance and exit obliquities, and the thickness of the perforation at the given obliquity. To facilitate describing the calculation of this data, a generic model airplane is shown in figure 4. Note that the internal components are made visible by setting the fuselage transparency to 50%. This example demonstrates a complex geometry with multiple components. Components were grouped by category (such as the electronics in green) when they were exported into the STL format. Multiple components were added as “solids” to create the airplane “object” as depicted in the data structure in figure 2. The object is composed of 14 solids as depicted by the legend. The colors are assigned to group-like categories. The number preceding the name of the components in the legend represents how many triangular surfaces are used to describe it. Finally, another example is shown in figure 5. The projectile model can be imported in the same manner as the model airplane for use as a target in air defense studies.

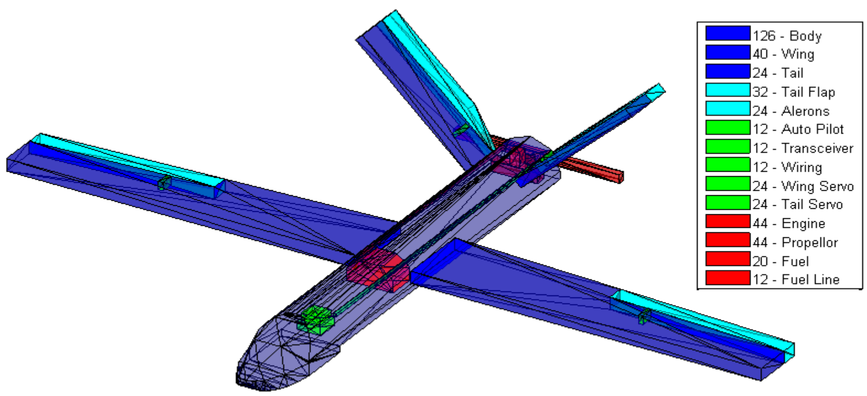


Figure 4
Sample model airplane representation imported from a CAD model

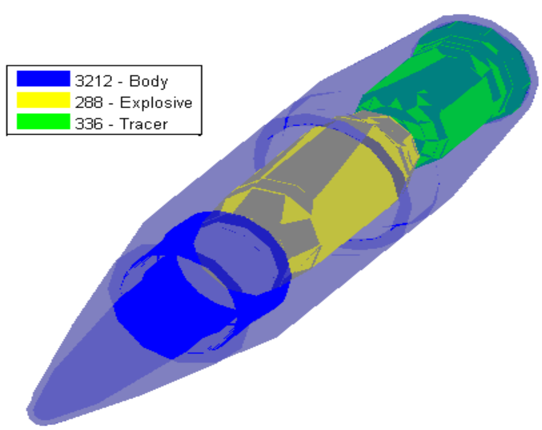


Figure 5
Sample projectile imported from a CAD model

CONCLUSIONS

A method was presented in this report to rapidly convert computer-aided design geometry into a useable format compatible with assessing impact geometry of a fragment or bullet hitting the target object. Using the stereolithography format enables the use of basic line and surface equations to detect an intersection with the object, the coordinates of the intersection, and the orientation of the intersection. Implementing this method in an algorithm permits the capability of evaluating simple or complex target objects in a probability of hit or kill assessment. The target resolution can be set based on the analysis to be conducted and the computing resources available.

REFERENCES

1. Sciavicco, L. and Siciliano, B., “Modeling and Control of Robotic Manipulators,” Springer Publishing, London, UK, ISBN 1-85233-221-2, October 1999.

2. http://en.wikipedia.org/wiki/STL_(file_format)

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