TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

BRL-CAD Overview

June 2009

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Main Goals

BRL-CAD Tools & Techniques for Visualization

BRL-CAD Tools & Techniques for Geometry Analysis

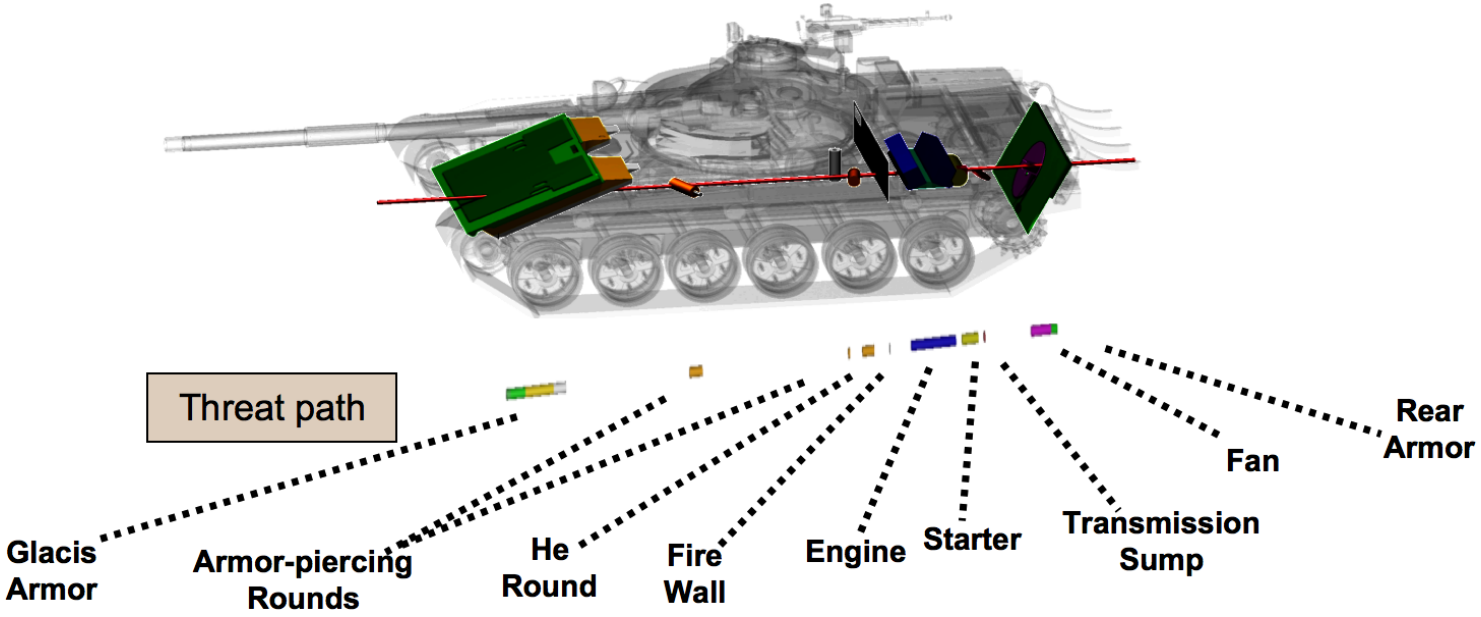
Boundary Representation & Conversion Support (BREP/NURBS & STEP)

BRL-CAD Geometry Service & Parts Library

Background

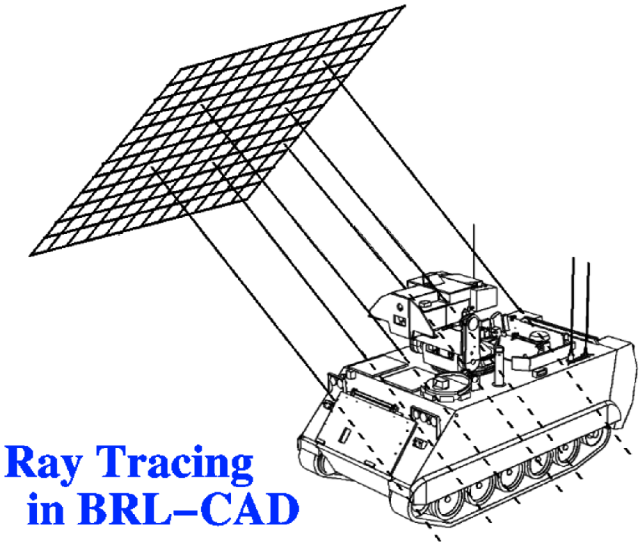
- BRL-CAD* is a powerful open source solid modeling system that includes interactive geometry editing, ray tracing for rendering & geometric analyses, a robust geometric representation, image & signal-processing tools, and more than 25 years of development history.

- Development of BRL-CAD directly supports ARL's strategic focus by providing tools, techniques, and methodology for performing vulnerability and lethality analyses. It is not only an asset within ARL, but to organizations and individuals around the world.



* BRL-CAD is correctly pronounced as "be are el cad"

Background (cont.)



Background (cont.)

- More than one million lines of code
- More than 400 binary applications
- More than a dozen libraries

1998 Technical Advisory Board, National Research Council

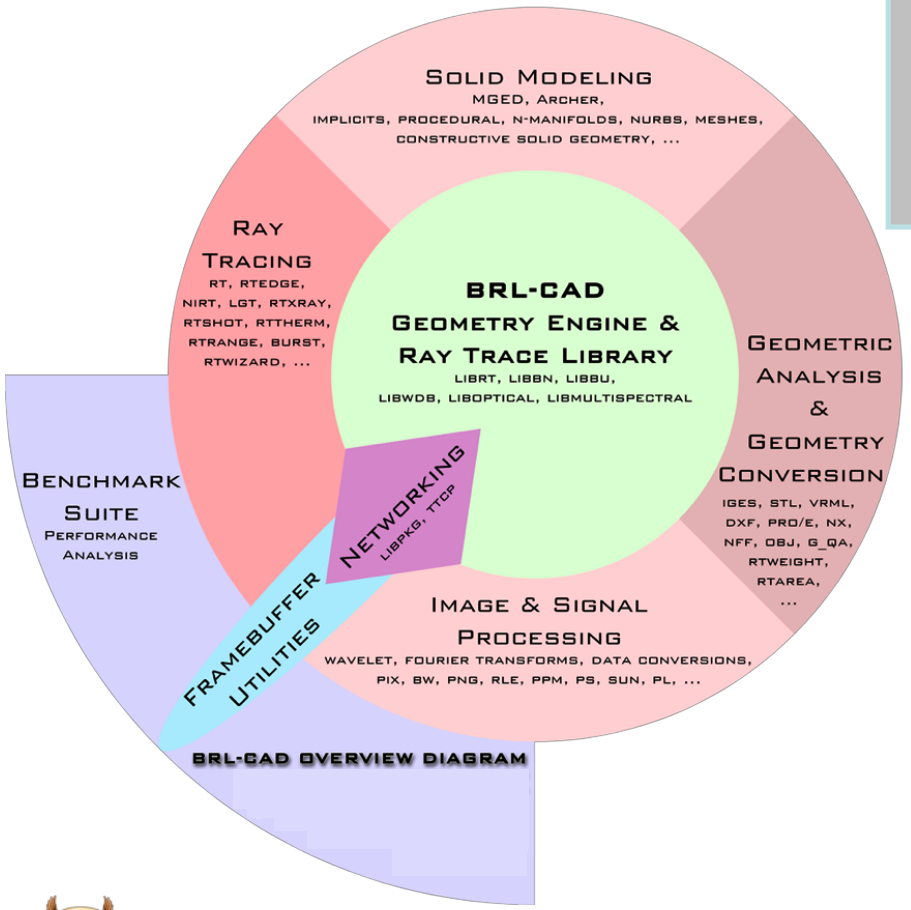
"an effective constructive solid modeling capability with highly efficient ray tracing"

…

"a computer-aided engineering (CAE) system uniquely suited to survivability and lethality applications"

…

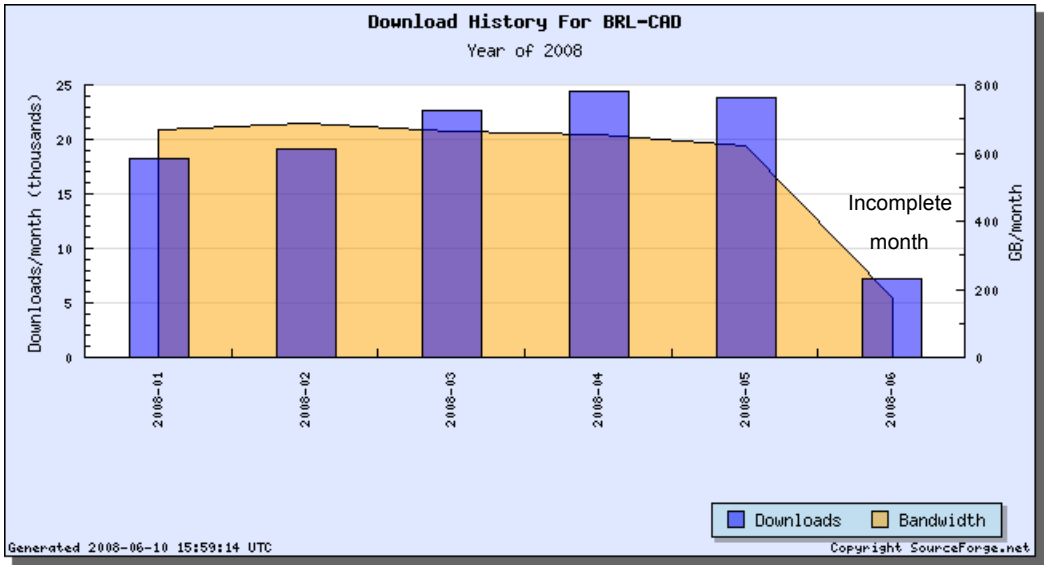
"a platform for a 'virtual test environment' that could provide a powerful, cost-effective capability for survivability and lethality evaluation"



- Extensively cross-platform Windows, Mac, Linux, UNIX, … *from desktops to supercomputers*
- Became Open Source software in 2004
  Open code, Open access, Open standards … It's free!
- BRL-CAD is the first & only Open Source solid modeling system in production use under OSI*-approved license terms

* Open Source Initiative http://opensource.org

BRL-CAD
Open Source Statistics



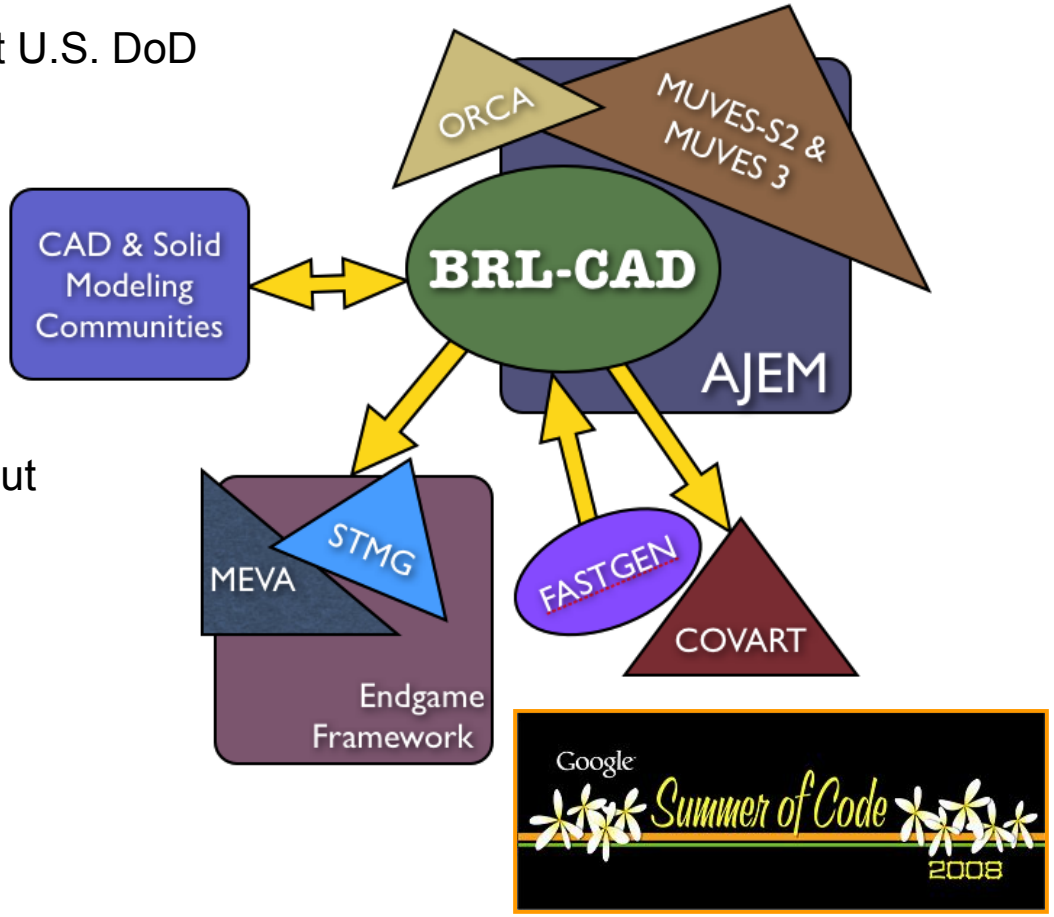
"***the world's oldest source code repository***"
– August 2007,
Robin Luckey, Ohloh Inc.

- More than **200,000** downloads and **2,000,000** website hits per year (as of 2008)
- Activity (both interest and development) is increasing year over year
- Presently receiving about **three-to-five staff-years** of contributed effort from the Open Source community including source code enhancements, bug fixes, documentation, website development, and more
- Received roughly an additional staff-year of effort in 2008 and 2009 by being accepted into the **Google Summer of Code**

BRL-CAD Community

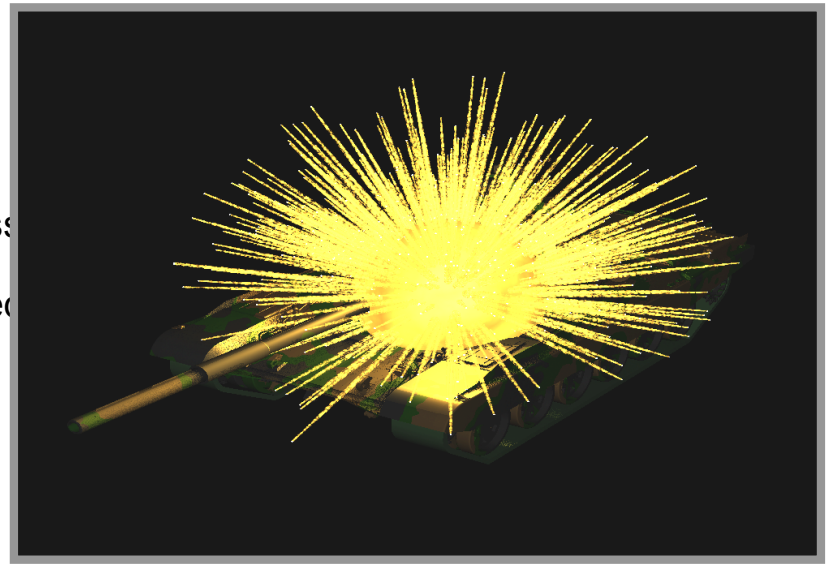
- SLAD V/L analysts and target describers
- MUVES and AJEM users throughout U.S. DoD
  - *Army, Air Force, Navy*
- International collaborations: Senior National Representative V/L Assessment Methodology (VLAM) working group
  - *United Kingdom, Germany, Netherlands, …*
- Extensive international ties throughout the Open Source communities, academia, and commercial industry
  - *University of Utah*
  - *University of North Carolina at Chapel Hill*
  - *Johns Hopkins University*
  - *Texas A&M University*

  … and much more …
- Google Summer of Code
  - *Exclusive Open Source opportunity*



Why develop BRL-CAD?

- BRL-CAD is custom-tailored to engineering analysis work providing high-performance geometric representation and geometry evaluation.
  - There is no conversion involved which is crucial for ensuring robust, consistent, and correct analytic results. *Data conversions introduce errors.*
- BRL-CAD is integral to V/L analyses where ray tracing is used to represent material interactions and determine paths of material propagation.
  - This is a **niche** requirement not strongly supported by other CAD systems.
- Ray tracing support in BRL-CAD is specifically tailored to MUVES and AJEM which typically require shooting millions of rays (with millimeter accuracy) at highly detailed target descriptions.
  - BRL-CAD's ray-tracing **outperforms** commercial ray tracers per internal development comparisons made against Unigraphics/NX, Pro/ENGINEER, and other CAD systems.
- Hundreds of existing BRL-CAD target descriptions represent a major investment that has been made over more than two decades.
  - **Extensive** model repositories exist at ARL and AFRL of foreign and U.S. assets.
- BRL-CAD's ray tracing provides scalability, robustness and verifiable accuracy that can perpetually and independently be customized and extended as needed
  - This allows the U.S. Government to not favor any particular CAD vendor, avoids expensive licensing, and protects ARL against corporate restructuring.
- **BRL-CAD is highly tuned to ARL's needs, more than any other CAD system.**



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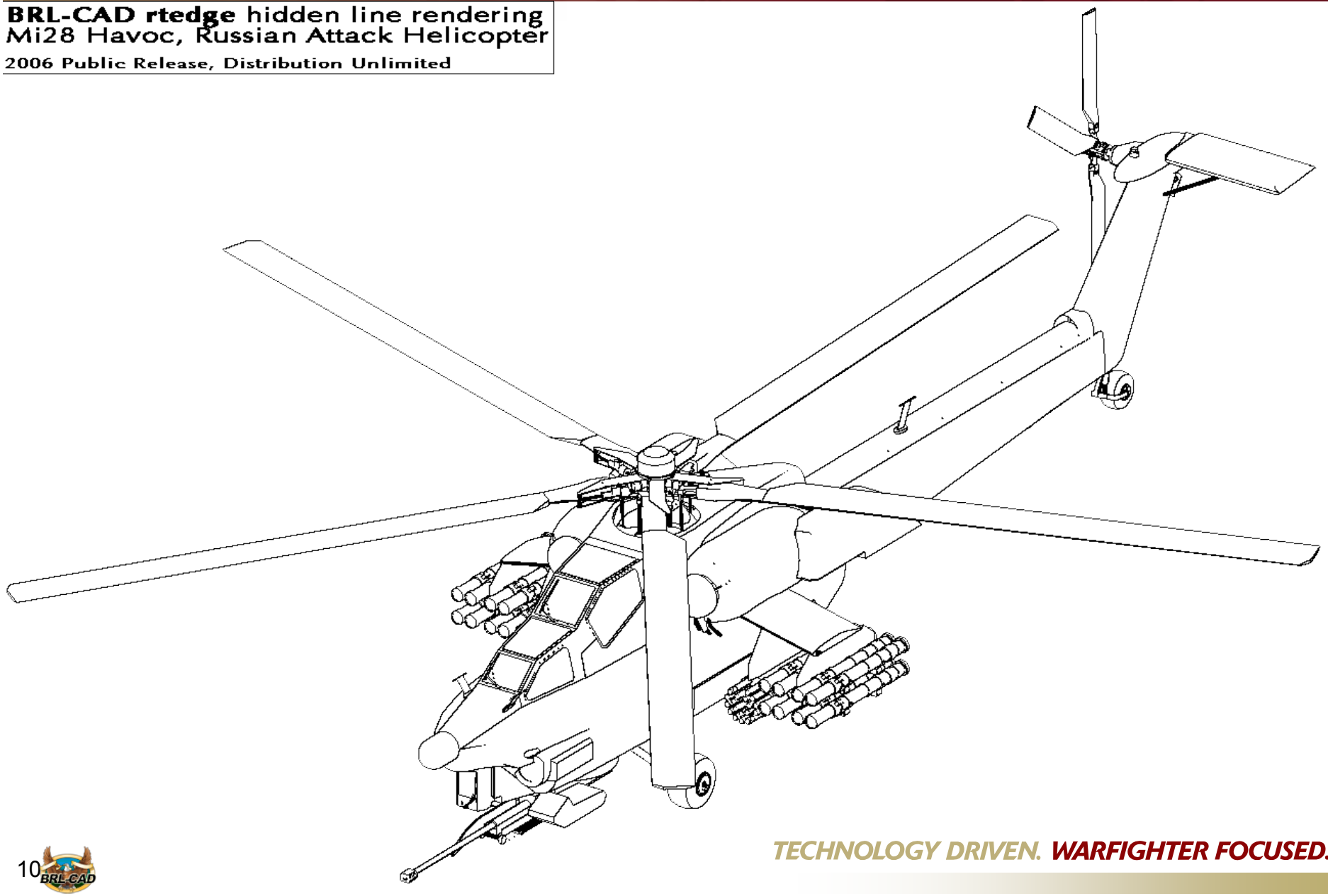
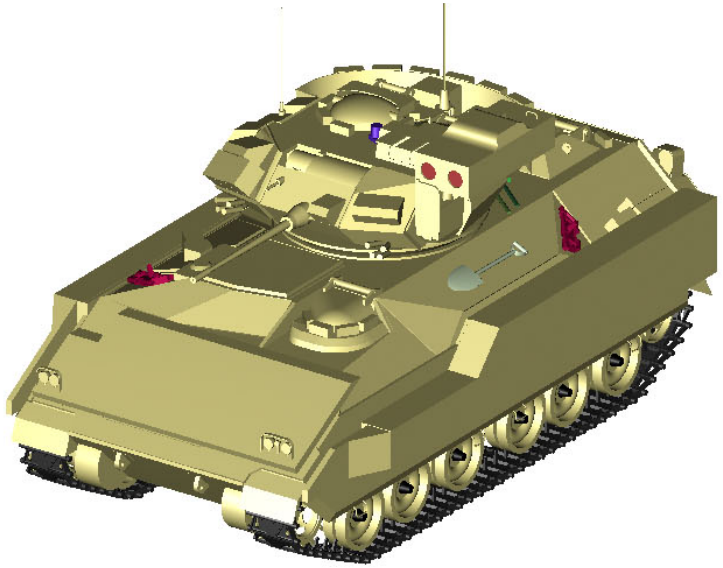
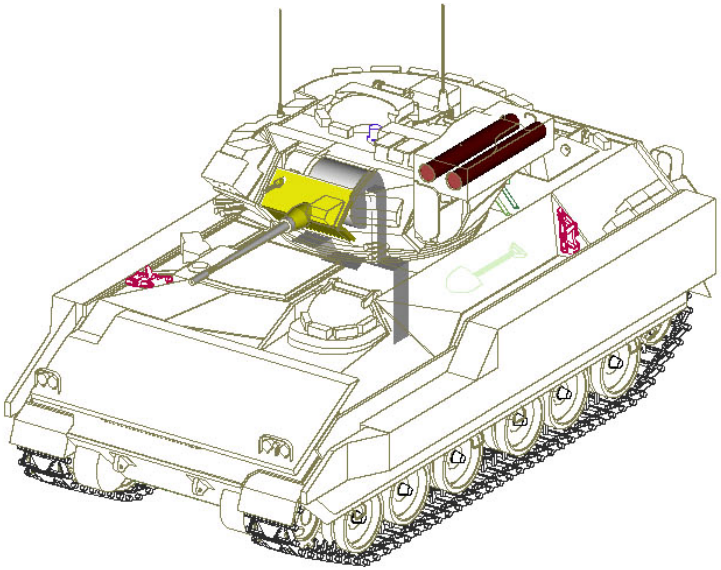
Hidden Line Diagrams

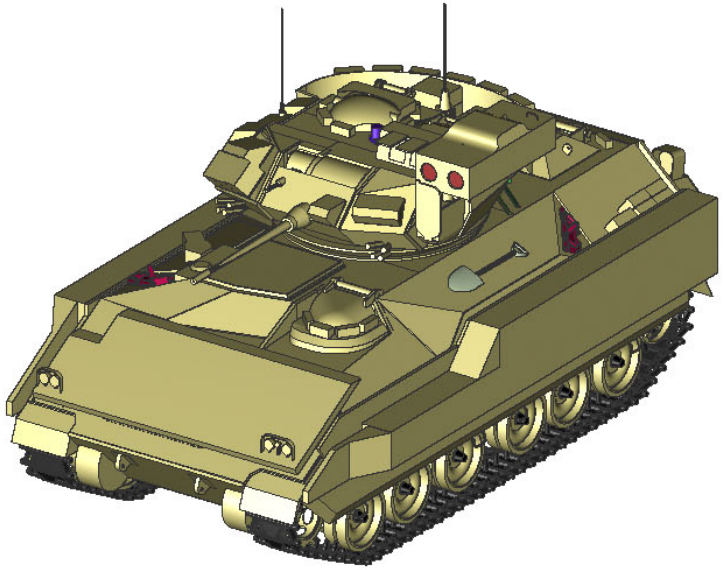
BRL-CAD rtedge hidden line rendering
Mi28 Havoc, Russian Attack Helicopter
2006 Public Release, Distribution Unlimited

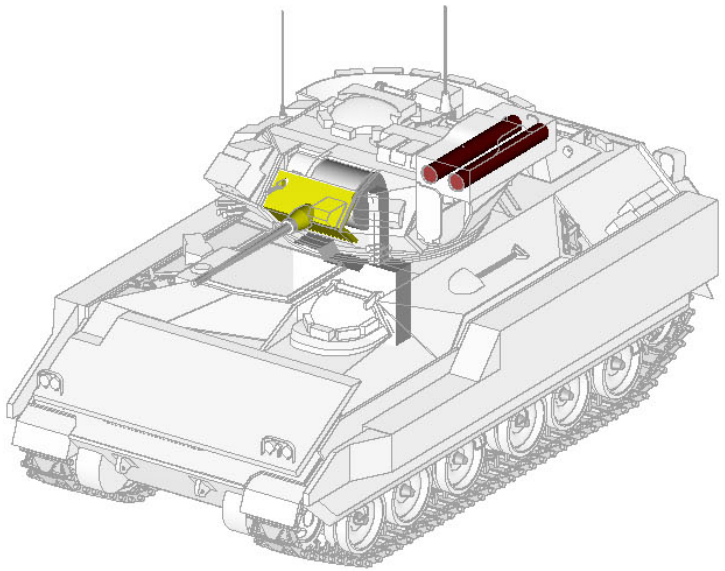


Hybrid Visualizations



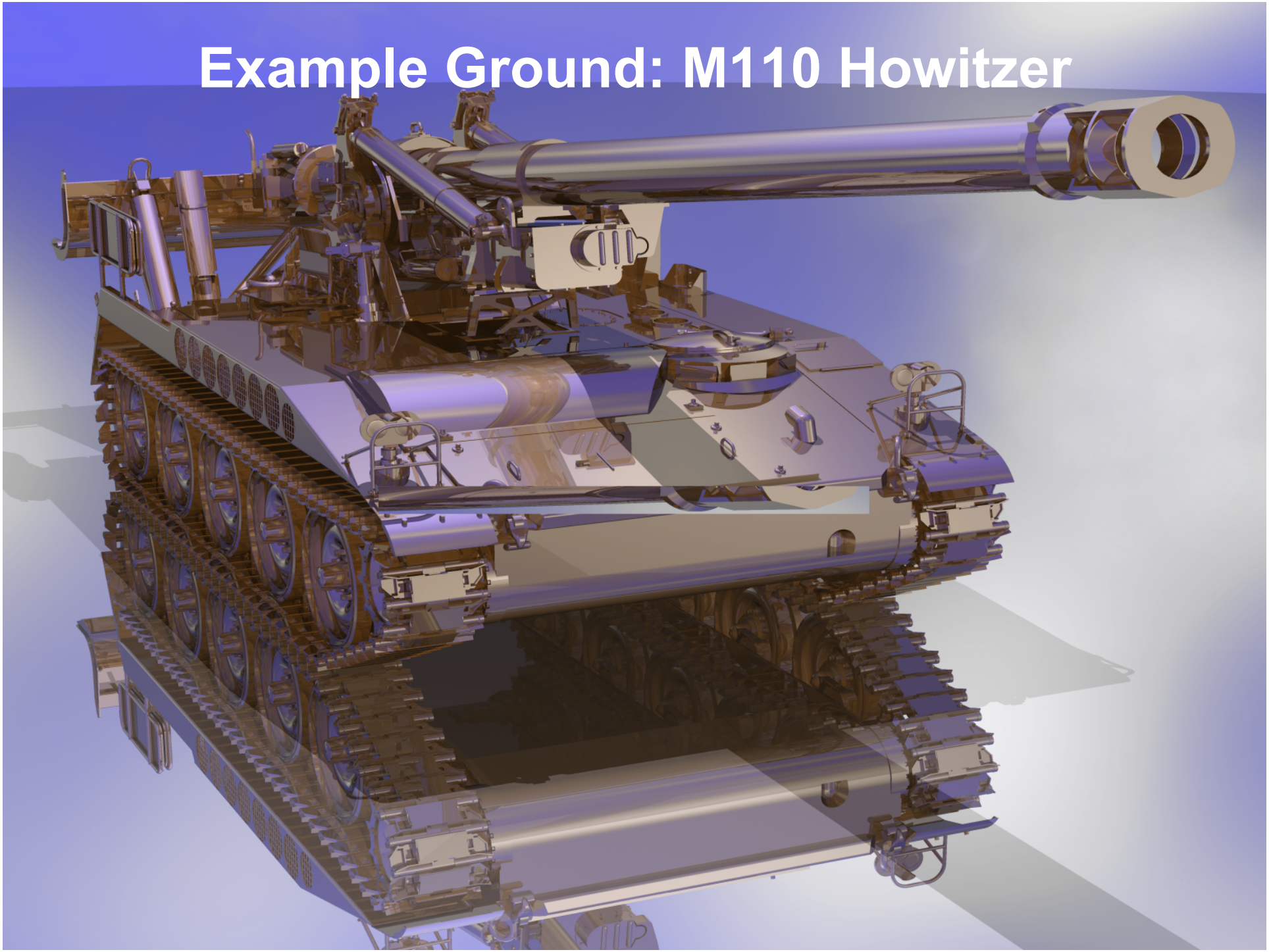




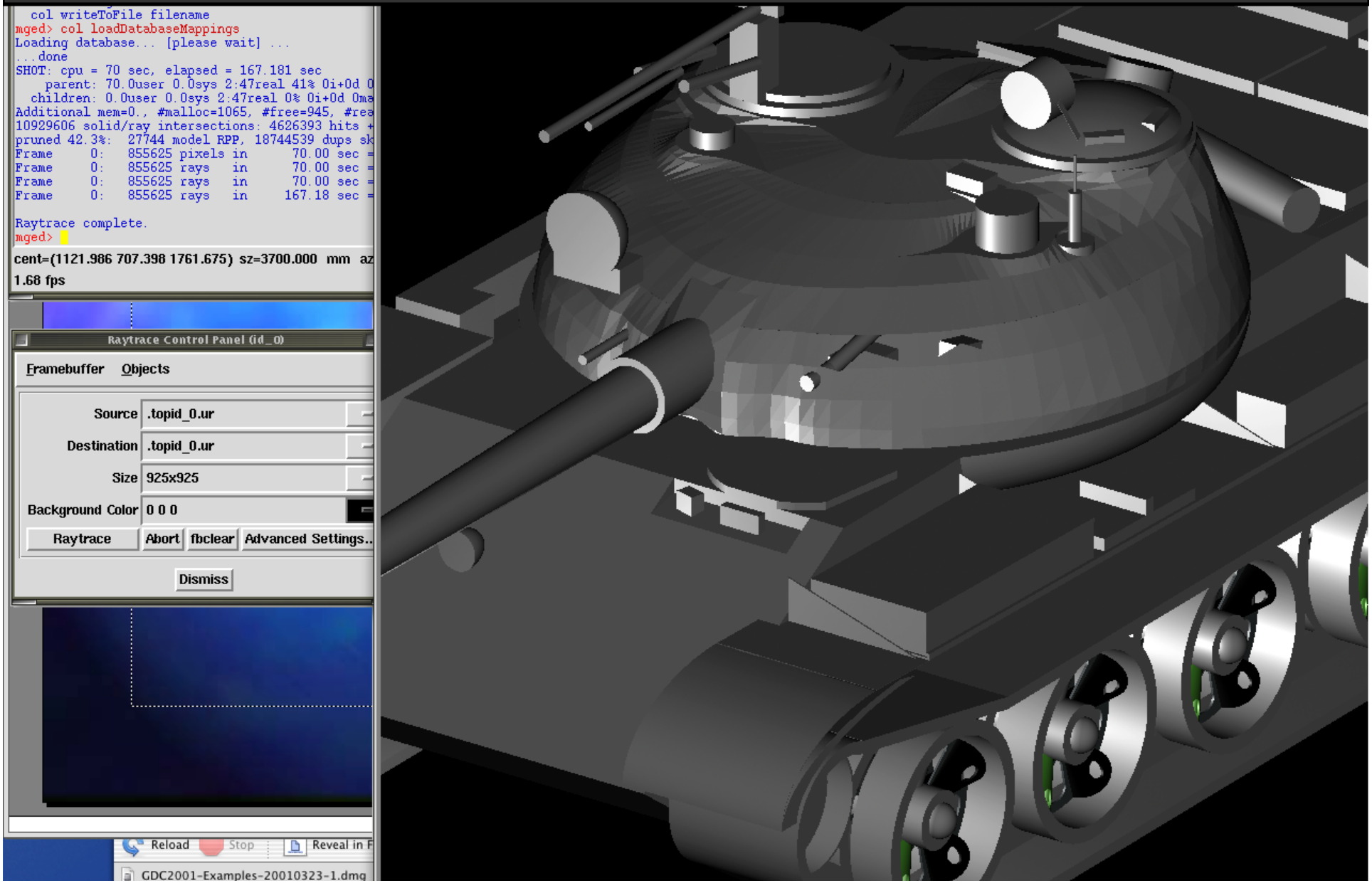


Example Aircraft: Fairchild A10

Example Ground: M110 Howitzer



Component Colorization



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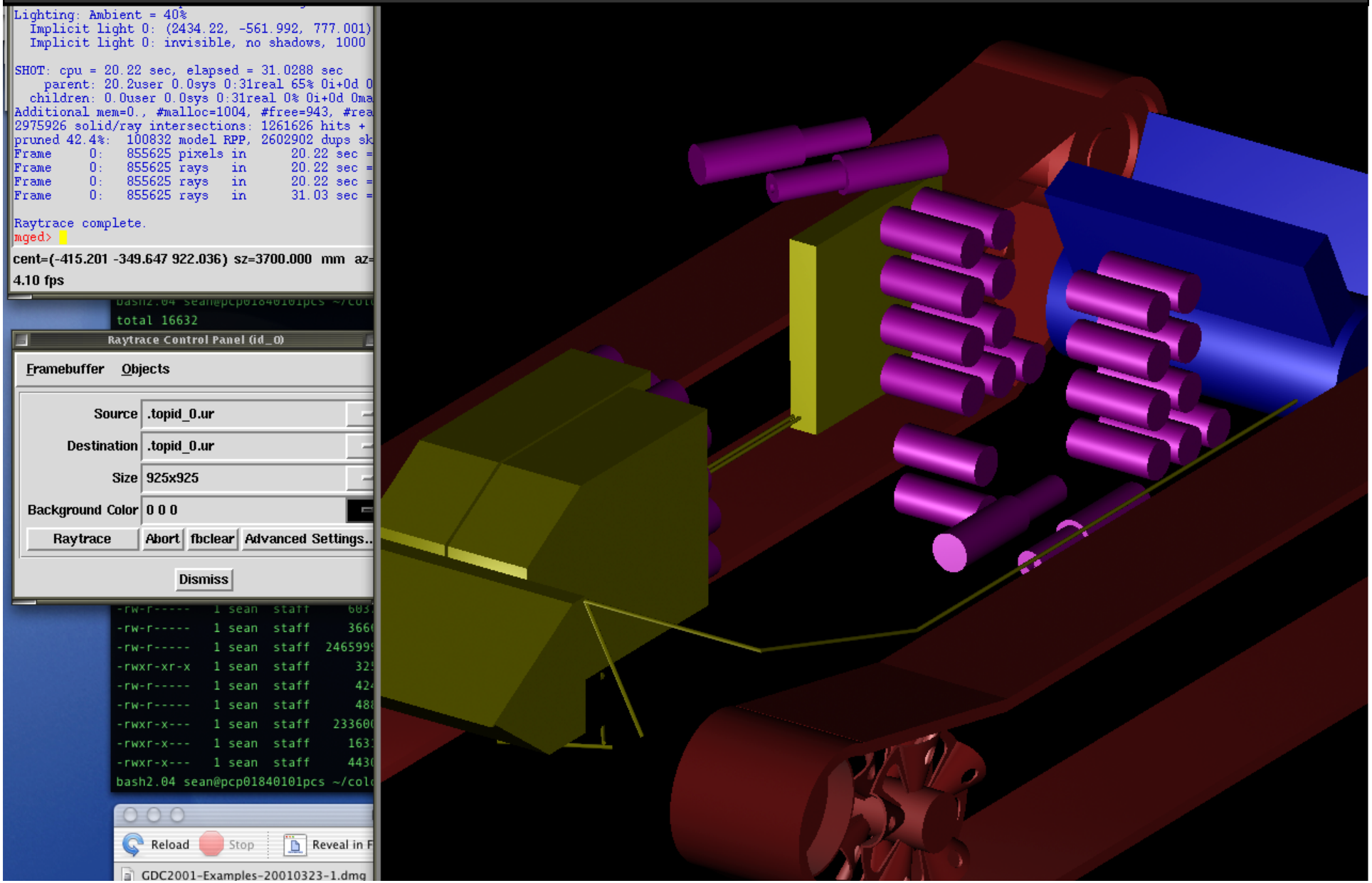

Example Full Light Simulation

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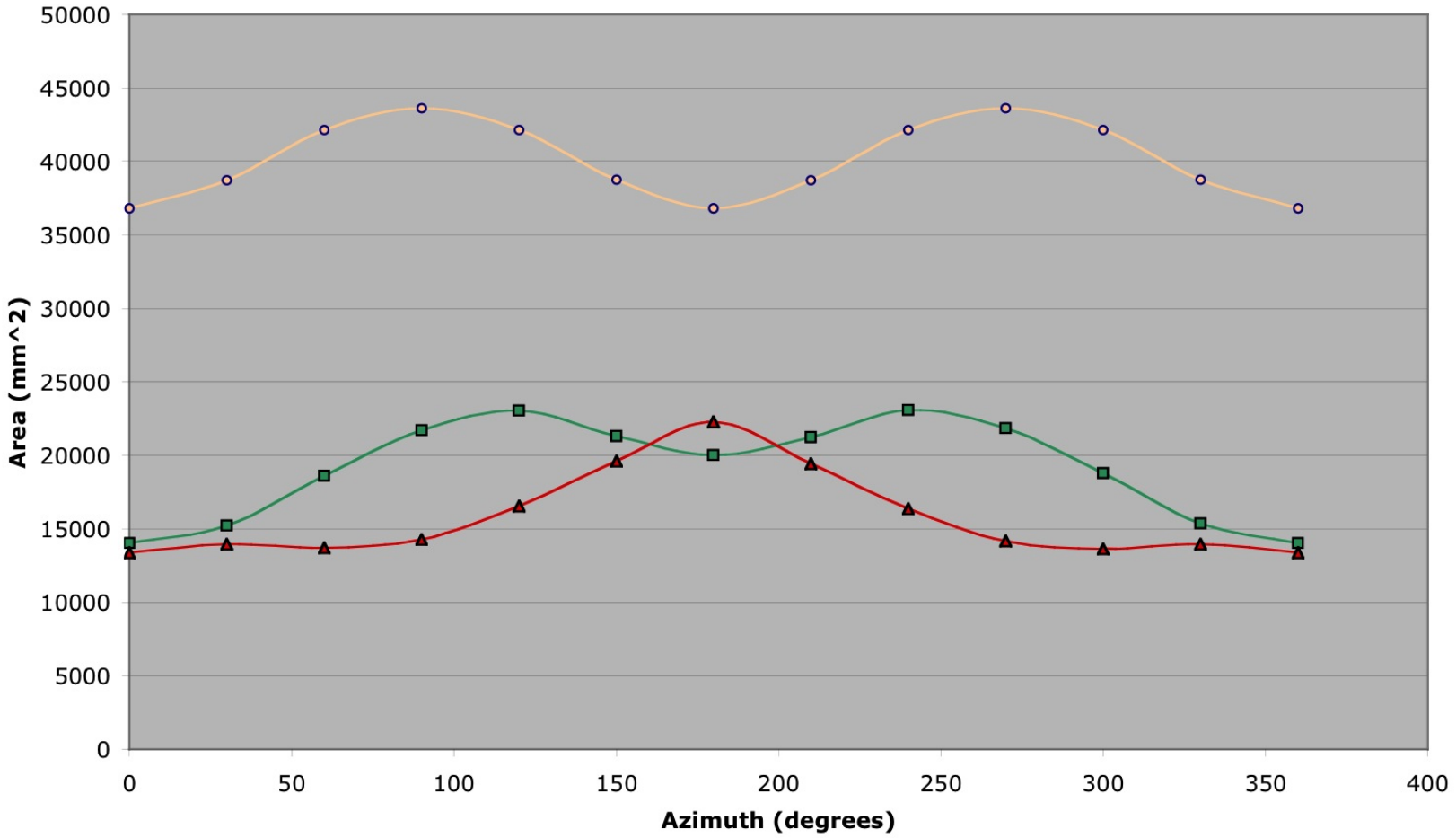
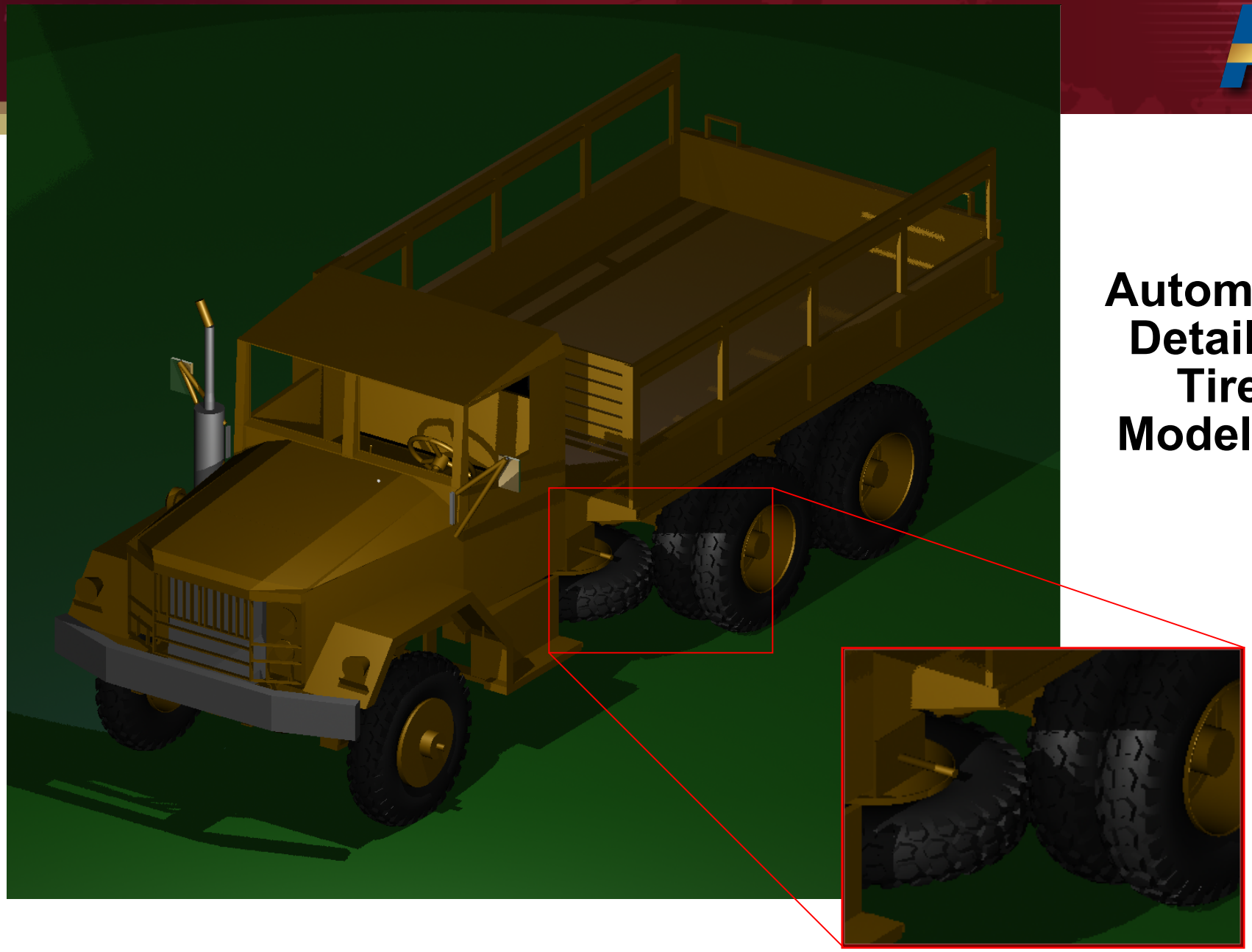
Comparisons of Area Exposure

Presented Area, Weight/Mass, Volume, Line-of-sight Equivalence, Shape Factors, …

Comparisons of Area Exposure

Helmet presented area coverage comparisons



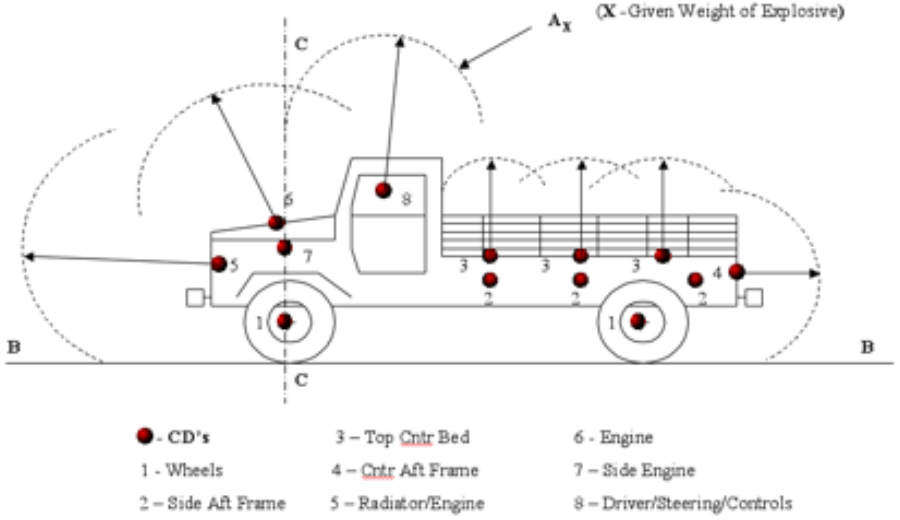


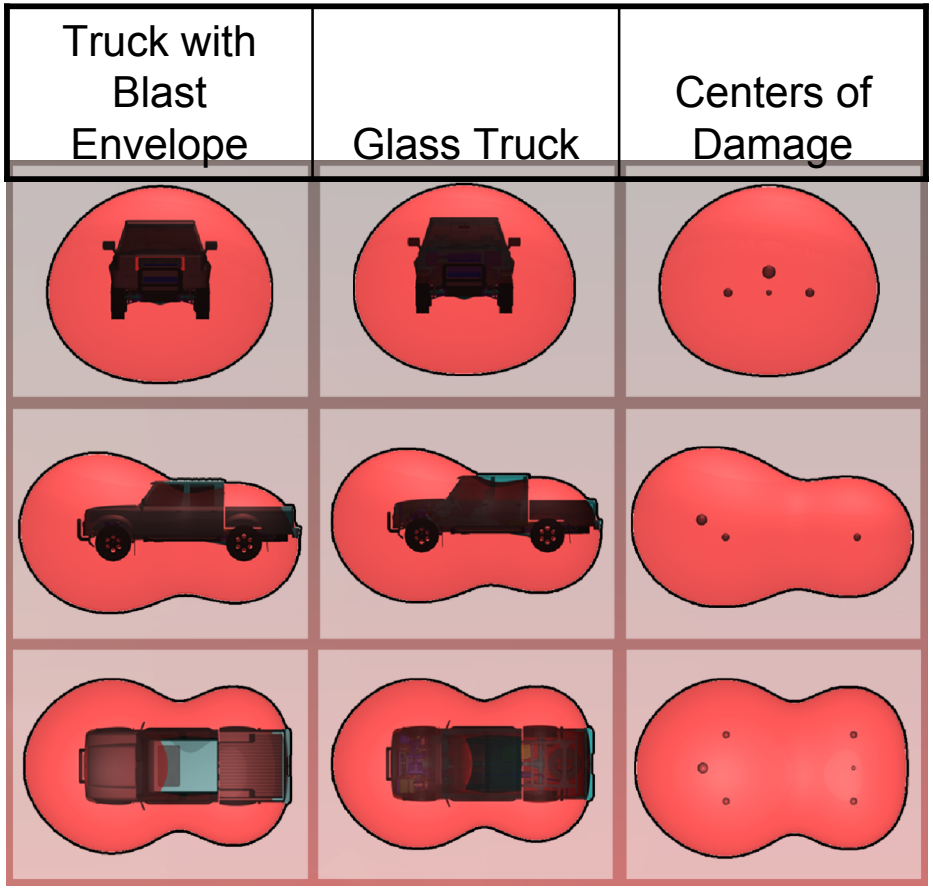
Automatic Detailed Tire Modeling

Metaballs for Blast Volumes

- The engineer traditionally:
  - Specifies a center of damage and lethal miss distance
  - Manually interpolates a curve in 2D
  - That 2D curves is then extrapolated into a 3D surface

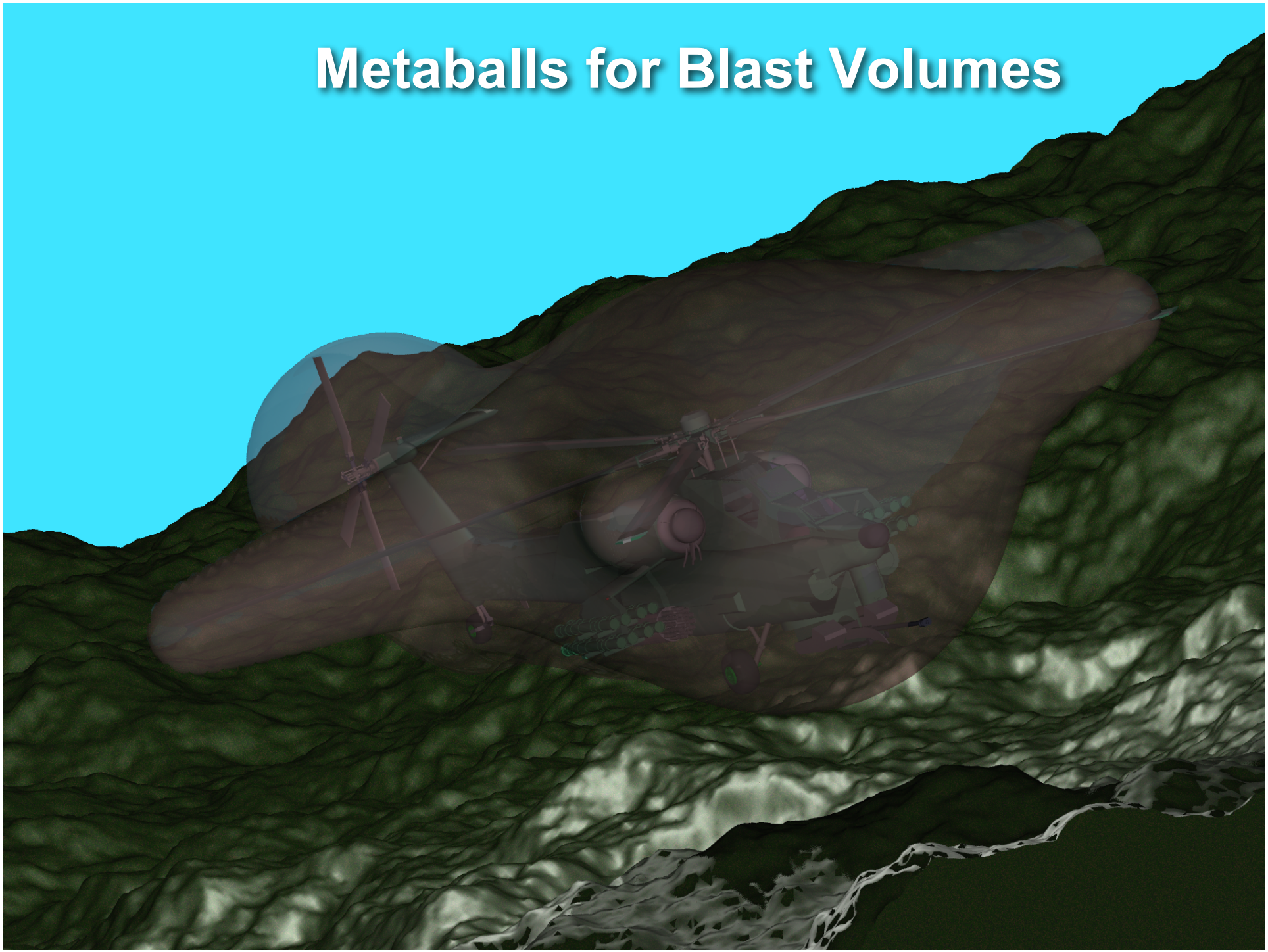
- With metaballs, the 3D surface is automatically generated based on centers and lethal miss distances



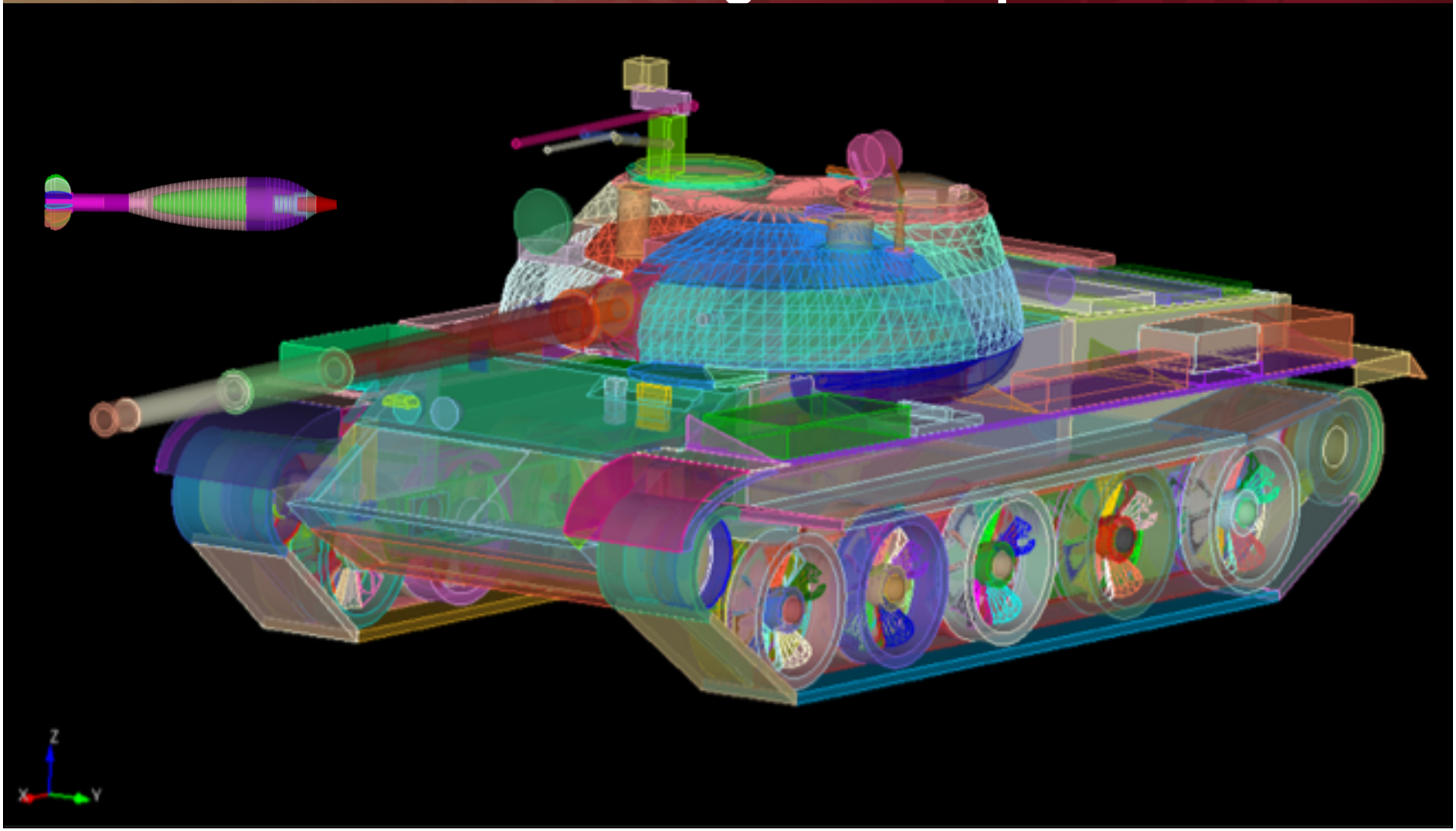


- This methodology is integrated into MUVES-S2 for blast vulnerability predictions

Metaballs for Blast Volumes



Finite Element Analysis of BRL-CAD Target Descriptions



Converted from BRL-CAD CSG format to a finite element mesh via g-sat and CUBIT

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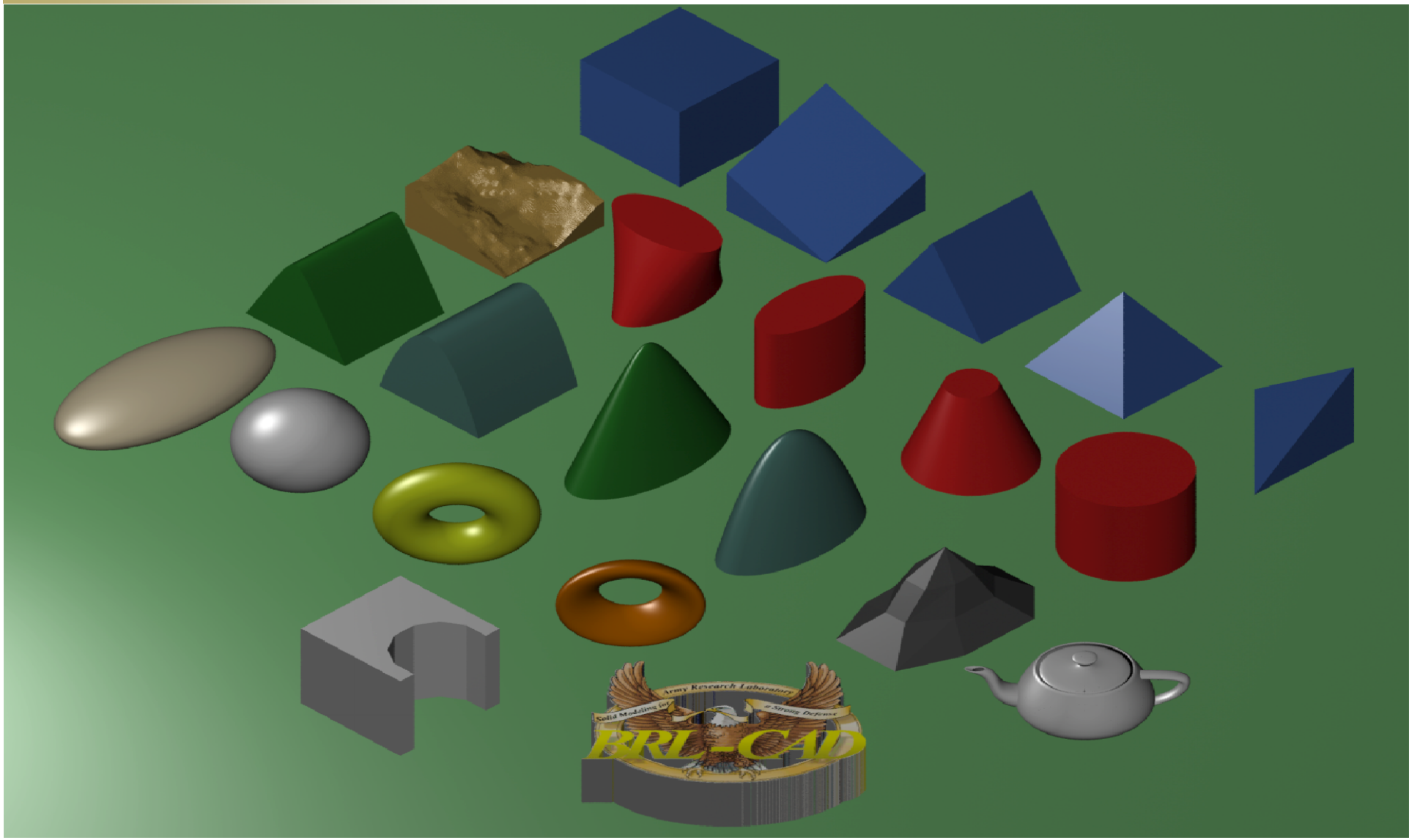
Some of BRL-CAD's Primitives

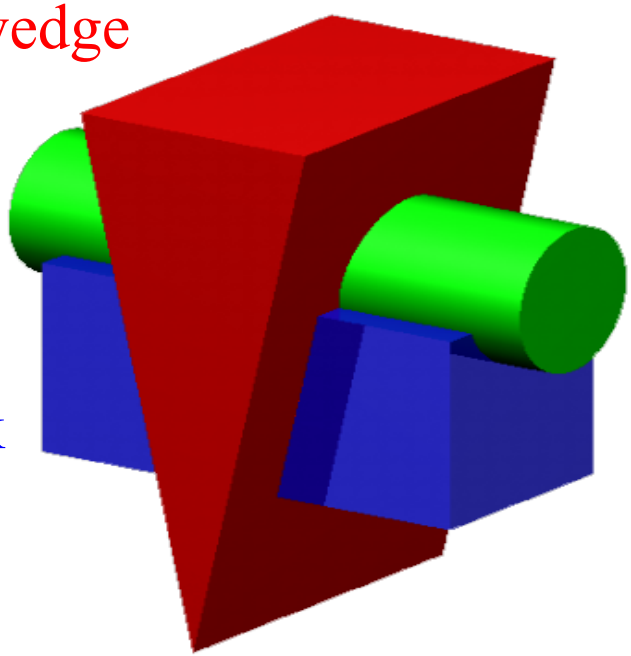


Constructive Solid Geometry

wedge

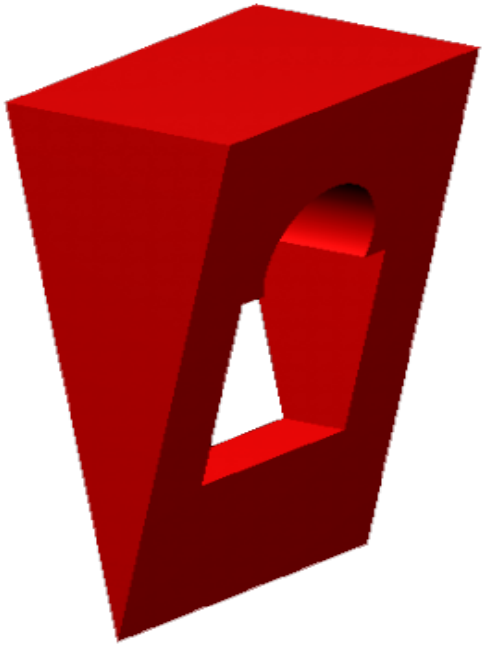
cylinder

block

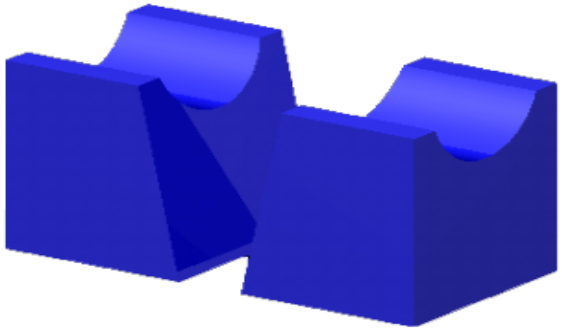


(wedge ∩ block) – cylinder

wedge – block – cylinder

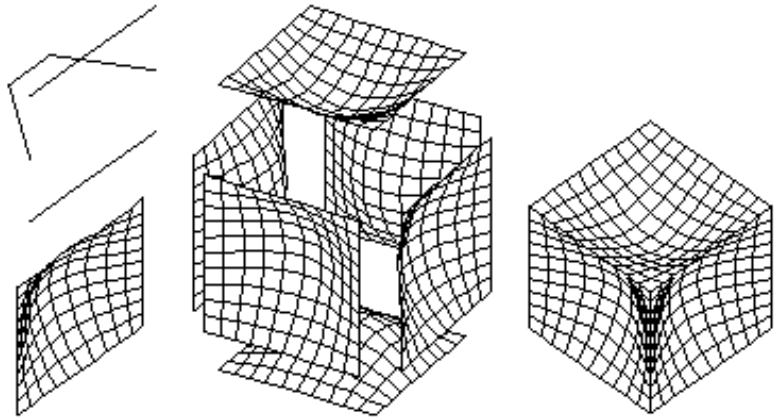


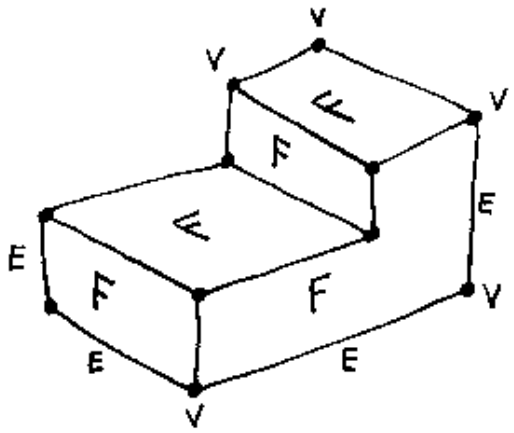
block – (wedge ∪ cylinder)



BREP Structure

- Boundary representations are constructed from vertices, edges, and faces
  - NURBS surfaces also include trimming curves
- *Vertices* are joined to form *edges*
- *Edges* are joined to form *faces*
- Faces are connected to other faces on their edges in order to enclose space and represent a solid object (i.e., a “shell”)



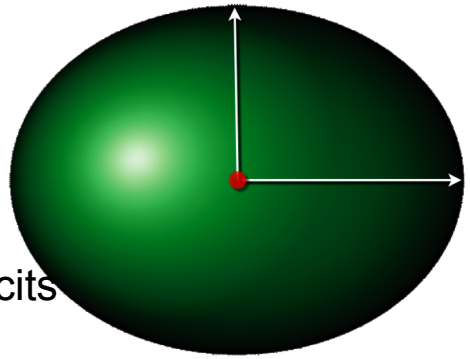


» Where two faces are joined and share an edge, there is potential for **gaps** due to floating point precision

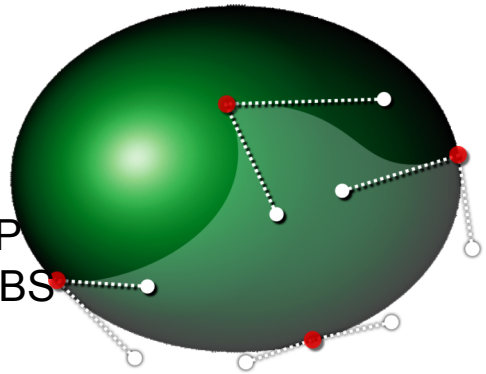
» Extra care must be taken to ensure that a solidity constraint is preserved in order to obtain consistent and accurate results

Geometric Representations

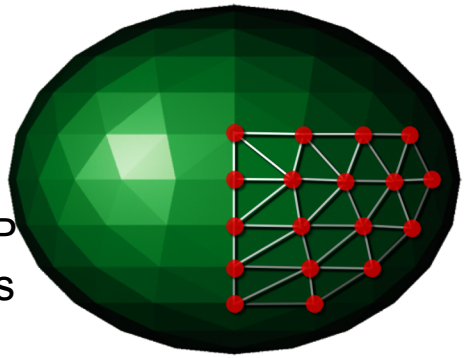
CSG implicits



BREP NURBS



BREP facets



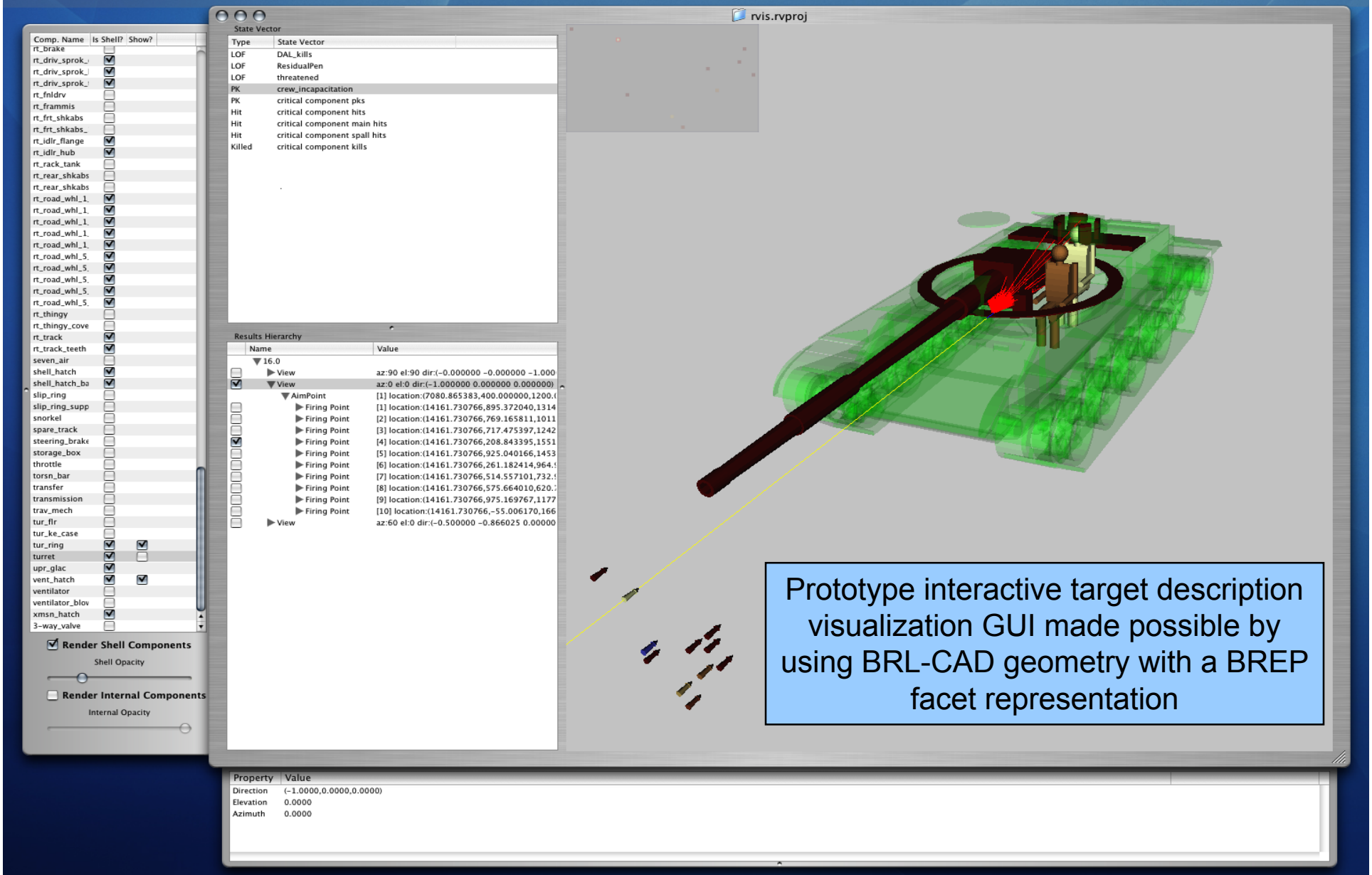
Geometric Definition	Applications of Use
4 values •Radius •Position	• Implicit primitives with constructive solid geometry (CSG) provide a representation format that is very compact and numerically robust (no cracks) — Solidity constraint is guaranteed making it well-suited for solid modeling and engineering analysis purposes
200 values •Surface •Patches •Knot •Values •Weights	• Spline surface boundary representations are prevalent in commercial CAD systems for their modeling flexibility — More recently they are also the subject of real-time ray tracing computer graphics research
1000 values or more (configurable) •Individual •Polygons •Vertices •Normal values	• Polygonal boundary models are commonly used by display systems (e.g., OpenGL and DirectX) for interactive rendering and real-time visualization — Many advancements have been made over the years on high-performance ray tracing of triangle models

Representation Data Implications

Exponential Geometric Growth

CSG implicts	2 MB
BREP NURBS	20 MB
BREP facets	200 MB

Example BREP Visualization



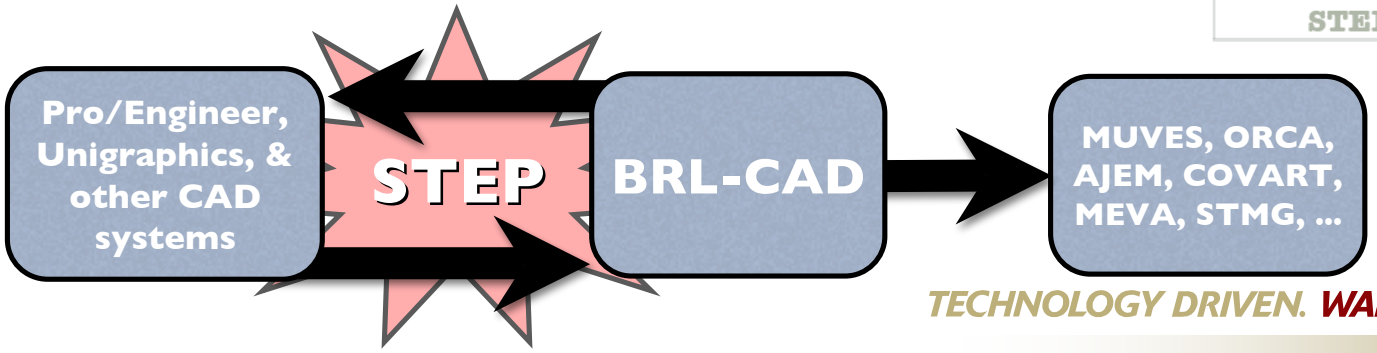
Prototype interactive target description visualization GUI made possible by using BRL-CAD geometry with a BREP facet representation

STEP Converter

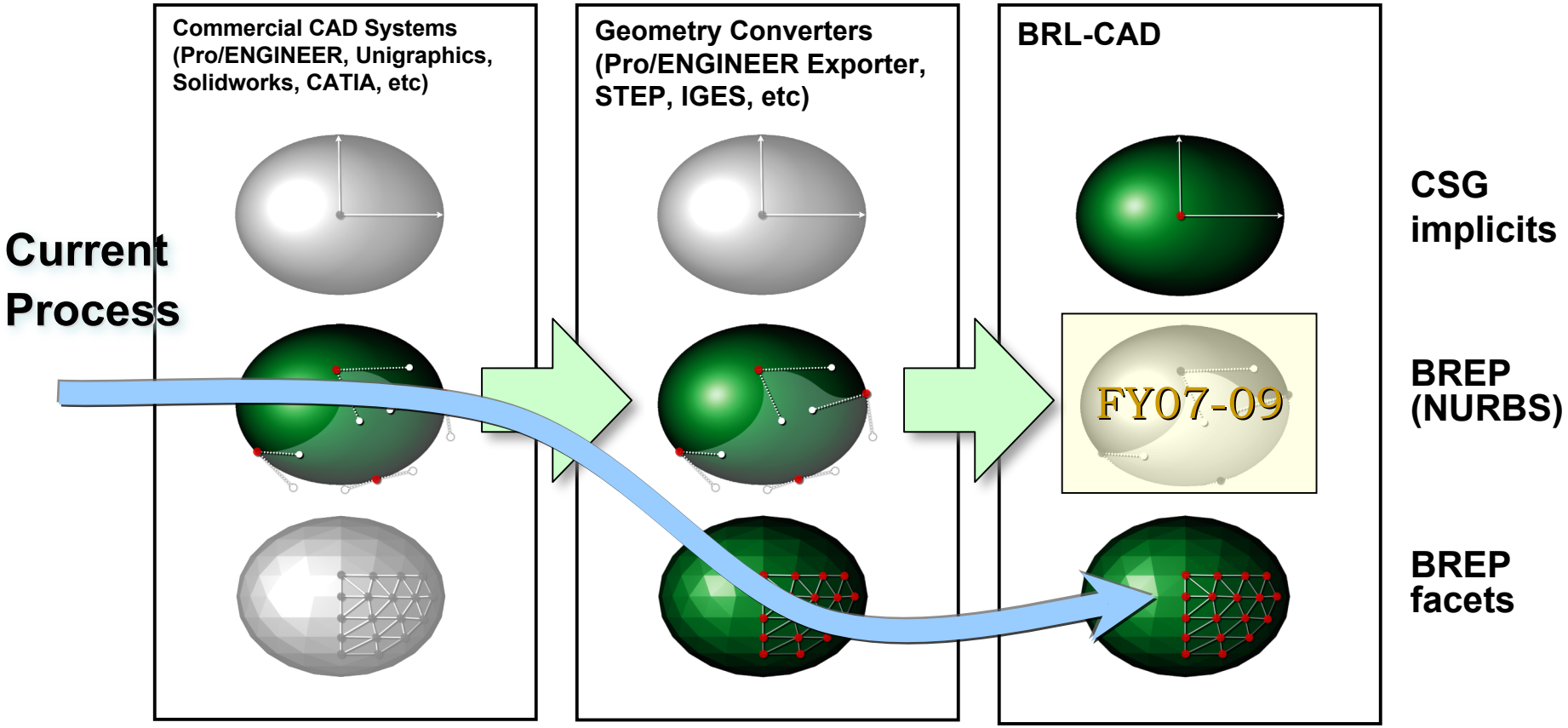
- Standard for the Exchange of Product Model Data (STEP) is an International Standards Organization (ISO) standard that
  1. describes a vendor-neutral non-proprietary format for the exchange of geometry models
  2. is supported by all major commercial CAD vendors
  3. replaces the previous International Geometry Exchange Standard (IGES)

- Importing BREP geometry through a STEP converter
  - avoids changing the fundamental underlying geometric representation format
  - reduces introduction of new modeling errors
  - preserves existing geometric representation fidelity

Importers	Exporters
BRL-CAD ASCII	BRL-CAD ASCII
Comgeom	ADRT
CY	Lockheed ACAD
DXF	**DXF**
ENF	NFF
ASCII Euclid	ASCII Euclid
Fastgen	Wavefront OBJ
IGES	**IGES**
Jack	Jack
OFF	OFF
Nastran	VRML
Patch	X3D
PLY	
Pro/ENGINEER	
Rhino 3DM	
STL	**STL**
Tankill	Tankill
Unigraphics/NX	
Viewpoint	
STEP	**STEP**



BREP / NURBS



- Geometry from most commercial CAD systems is imported by transforming the model from a spline surface-based BREP/NURBS representation to a BREP facet-based polygonal representation
- BREP/NURBS support in BRL-CAD allows geometry import without changing the underlying representation
  - Preserving the representation is crucial for ensuring robust, consistent, and correct analytic results
  - **Data representation changes introduce errors and greatly increase conversion time**

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BRL-CAD Tools & Techniques for Geometry Analysis

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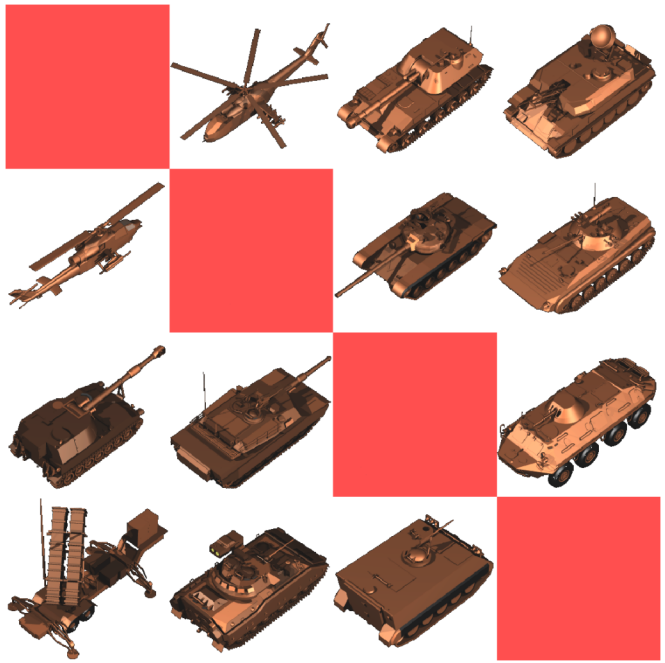
BRL-CAD Geometry Service & Parts Library

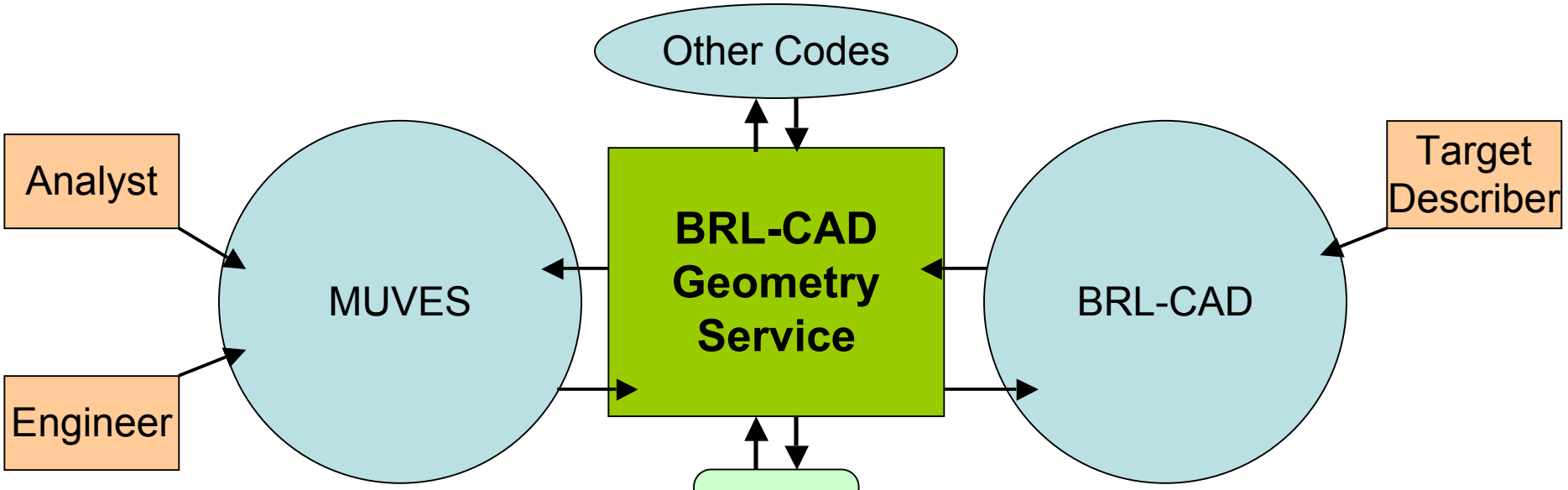
BRL-CAD Geometry Service

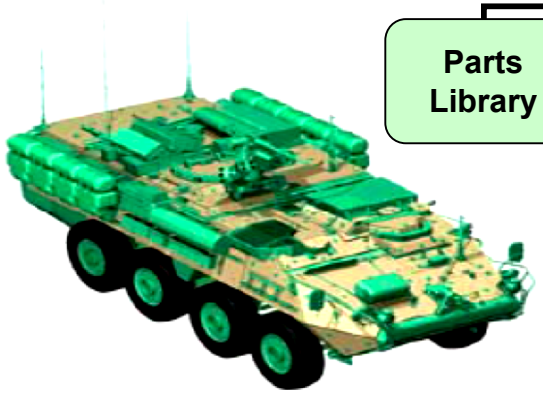
The *BRL-CAD Geometry Service* is a networked service interface for software application codes (*e.g., MUVES, ORCA, and BRL-CAD)* to access revision-controlled target description data and their geometric properties in a unified geometry parts library



The BRL-CAD Geometry Service provides cross-application notification of changes to geometry and allows concurrent collaboration

BRL-CAD Geometry Service

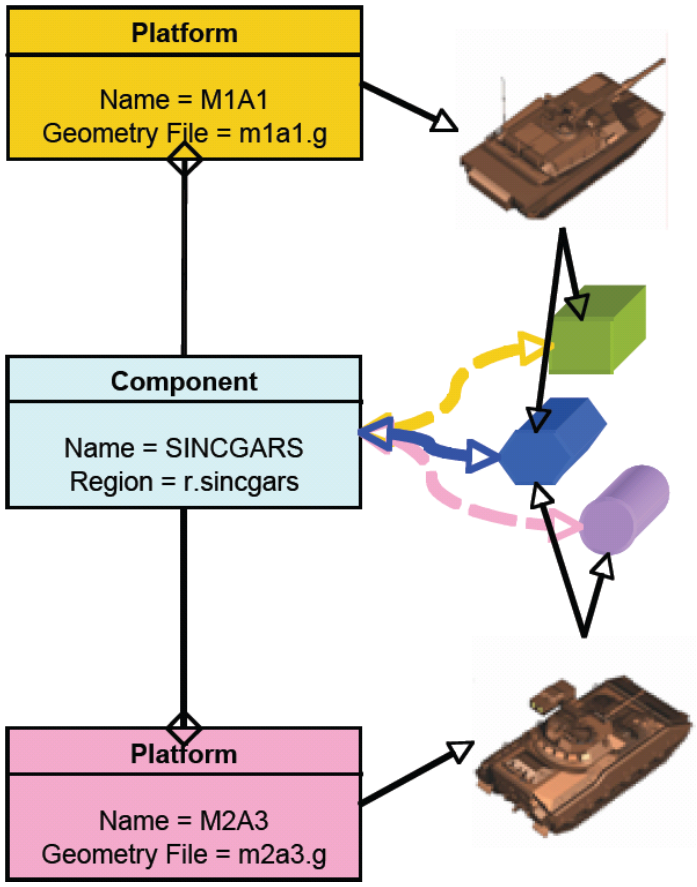




TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Geometry Service Benefits

- Can be readily integrated with ARL software codes including BRL-CAD, MUVES, ORCA, S4, and other software codes as a network geometry service
- Leverages existing infrastructure in BRL-CAD in a backwards-compatible manner
- BRL-CAD Geometry Service provides:
  - **Geometry versioning** (multiple threats/targets)
  - **Direct association** of targets/threats with analysis data
  - **Dynamic geometry** (for calculating multiple-hits and articulation support)
  - Vehicle **articulation** and editing constraints
  - **Unified repository** of targets in one storage location (automatic target description library)
  - **Reuse** of identical target geometry parts (single instancing)
  - Improved/advanced analyst and modeler **collaboration** (users can work in parallel)



Questions? Comments?
Thank you!

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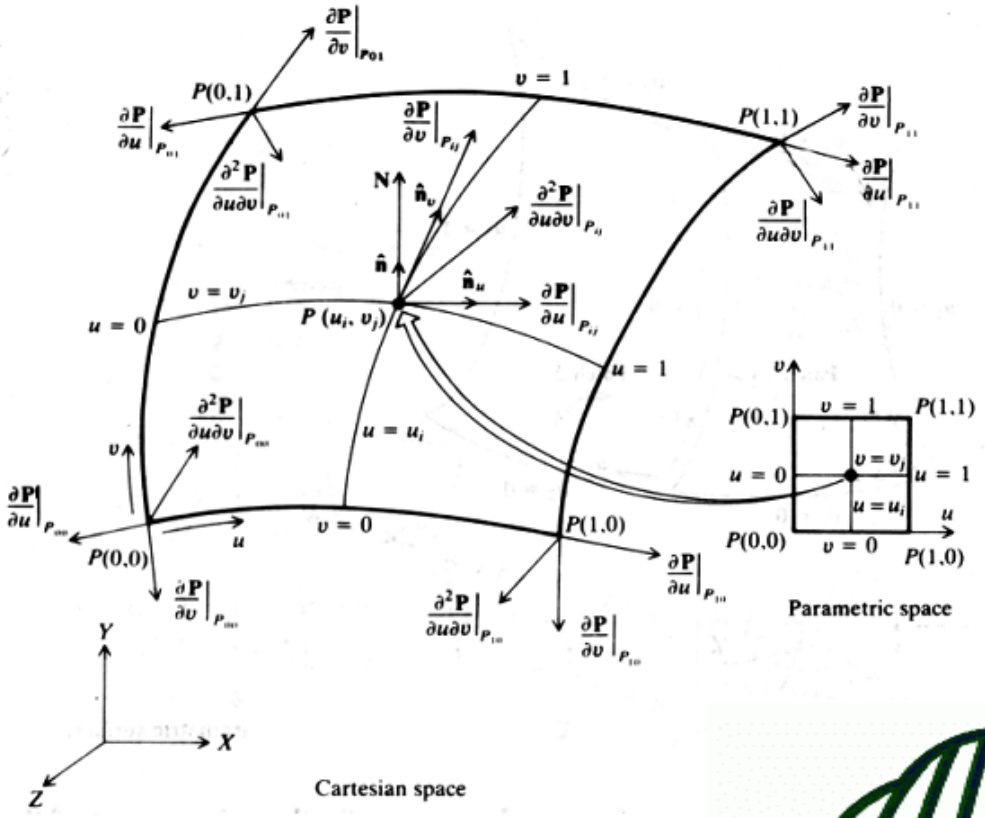
Several of the images and videos contained within this presentation were created with the support and efforts of many individuals. The following deserve special recognition and thanks:

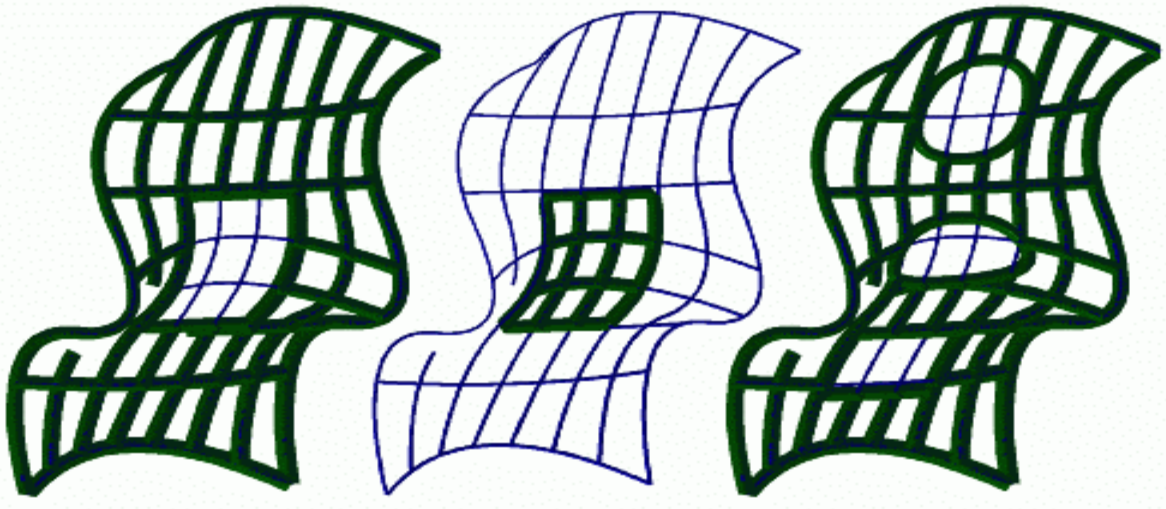
Mike Muuss
Lee Butler
Erik Greenwald
Ron Bowers
Jason Owens
Edwin Davisson
Mike Gillich
Cliff Yapp
Justin Shumaker
Geometric Solutions, Inc.

Additional Information about BRL-CAD

NURBS Trimming Curves

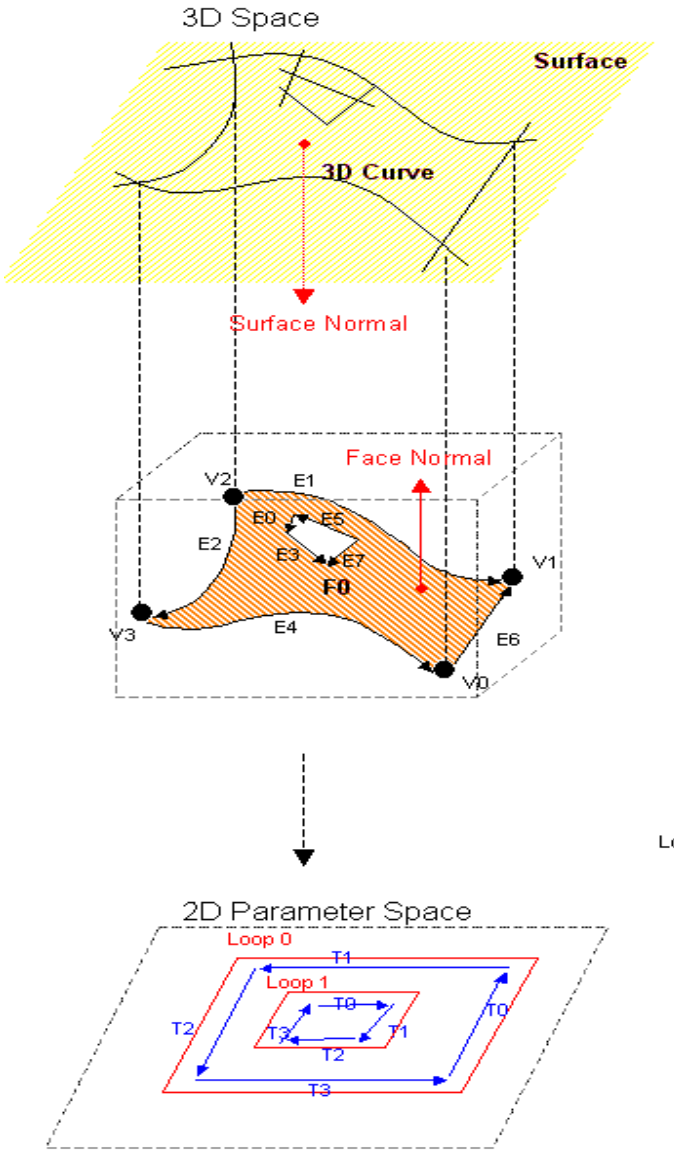


Shown on the left is a single spline surface showing how a point may be mapped from the surface's uv parametric space to a 3D Cartesian coordinate space.



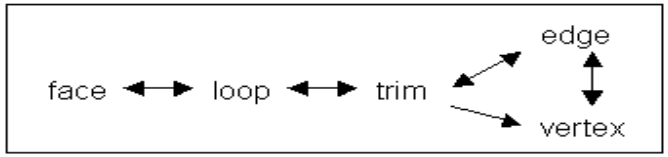
Shown on the right are three identical surfaces, each with a different set of trimming curves

Boundary Representation (B-rep) in the context of OpenNURBS



Boundary representation (B-rep) is used to unambiguouly represent objects in terms of their boundary surfaces

```
ON_Brep
//geometry
 ON_CurveArray  m_C2;
          // Pointers to parameter space trimming curves
          // (used by trims).
 ON_CurveArray  m_C3;
          // Pointers to 3d curves (used by edges).
 ON_SurfaceArray m_S;
          // Pointers to parametric surfaces
          // (used by faces)
 // topology
 ON_BrepVertexArray m_V;  // vertices
 ON_BrepEdgeArray   m_E;  // edges
 ON_BrepTrimArray   m_T;  // trims
 ON_BrepLoopArray   m_L;  // loops
 ON_BrepFaceArray   m_F;  // faces
```



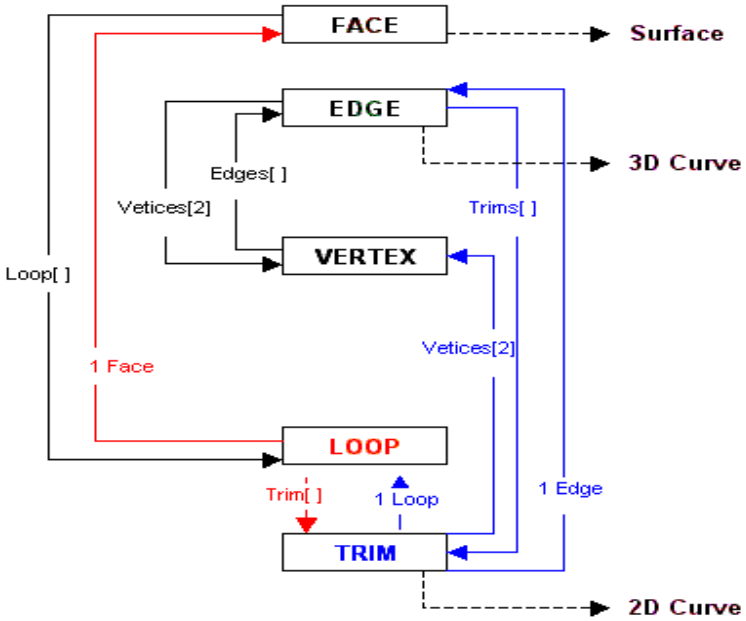
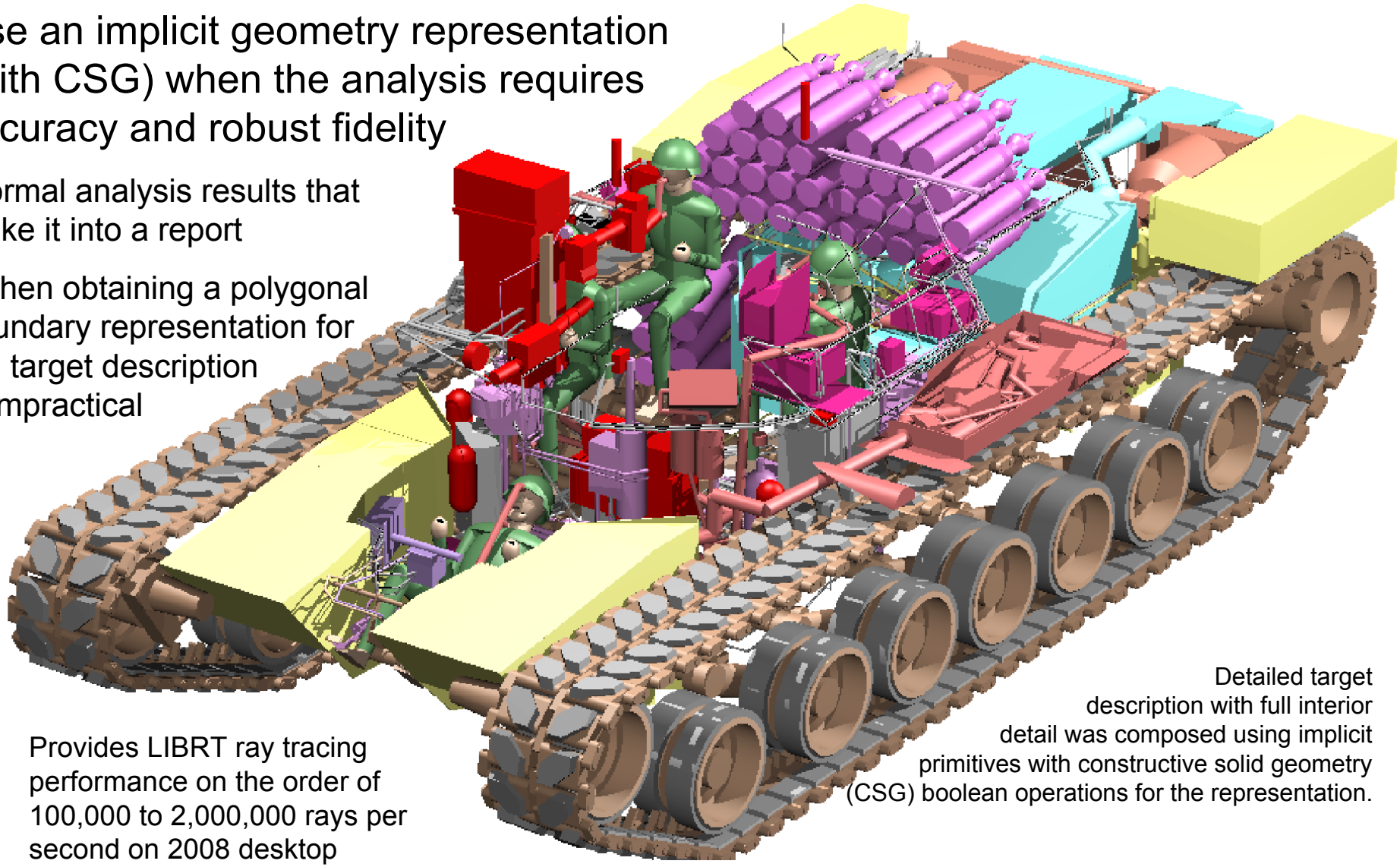


Diagram courtesy McNeel & Associates

Example CSG implicits model

Use an implicit geometry representation (with CSG) when the analysis requires accuracy and robust fidelity

- formal analysis results that make it into a report
- when obtaining a polygonal boundary representation for the target description is impractical



Detailed target description with full interior detail was composed using implicit primitives with constructive solid geometry (CSG) boolean operations for the representation.

Provides LIBRT ray tracing performance on the order of 100,000 to 2,000,000 rays per second on 2008 desktop hardware

Example BREP facets model

Use a polygonal boundary representation (e.g., triangles) for visualization purposes

- detailed global illumination rendering
- high-performance interactive ray tracing

Provides ADRT ray tracing performance on the order of 250,000 to 10,000,000 rays per second on 2008 desktop hardware

Stryker ICV model was obtained directly from the manufacturer.

Model was converted to a polygonal representation for visualization purposes.

Provides:

–Fast and interactive shotline queries

–Input assistance when preparing for detailed MUVES analyses

–Foundations for advanced modeling and graphical user interface design

Stryker ICV w/ Slat Armor — 14,542,092 Triangles — Rendered with ADRT/RISE — 8 Trillion Rays

BRL-CAD Collaborations

Recent conferences, publications, and presentations

BRL-CAD has been actively developed and engaged in various communities for more than 20 years. Included below are some of the more recent interactions*:

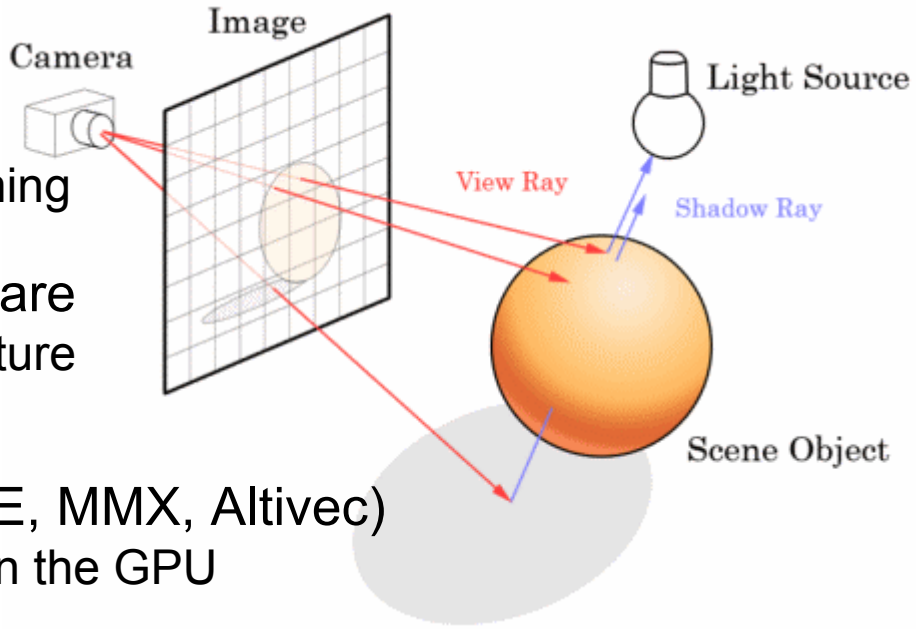
- Actively engaged in the computer graphics, visualization, high-performance computing, and solid modeling communities
  - IEEE Symposium on Shape Modeling (2006, 2008)
  - ACM Solid and Physical Modeling (2002, 2006, 2008)
  - ACM SIGGRAPH (every year, 1984-2007)
    - **BRL-CAD Birds of a Feather user group sessions (2005, 2006, 2008)**
    - **Published paper presentation (Butler 1997)**
  - IEEE Visualization (2002, 2006)
  - IEEE Symposium on Interactive Ray Tracing (2006, 2007)
    - **Published paper presentation (Butler 2007)**
  - IEEE/ACM International Conference for High Performance Computing, Networking, Storage, and Analysis (i.e. "IEEE/ACM Supercomputing" – 2002, 2004)
  - USENIX Tcl/Tk Conference (2001)

  … and more …
- Various technical presentations
  - ***Open Source project management***, **Google Mentor Summit, Mountain View, CA (2007)**
  - ***Introduction to BRL-CAD***, **Various Audiences & Locations (Morrison, 2006-2008)**

** Presentations and publications given to public international audiences are in **bold***

- **Open Source**
  - Active international user and developer community
  - Instrumental in working with VLAM counterparts
  - Made international slashdot.org announcement when released
  - More than three hundred mailing list subscriptions
  - Thousands of downloads per month, millions of on-line website visitors per year
  - Is recruitment avenue for new employees (one full-time, one part-time)
- Extensive user documentation published to ARL and on-line audiences
  - ***Vehicle Tire and Wheel Creation in BRL-CAD*** **(Yapp, 2008)**
  - ***Interactive Raytracing – the nirt Command*** **(Yapp, 2008)**
  - ***BRL-CAD Industry Diagram*** **(Morrison, 2006)**
  - ***MGED Quick Reference*** **(Morrison, 2006)**
  - ***BRL-CAD Overview Diagram*** **(Morrison, 2006)**
- **BRL-CAD Users Group Symposium (2002)**
  - International symposium hosted by the BRL-CAD Advanced Computer Systems Team

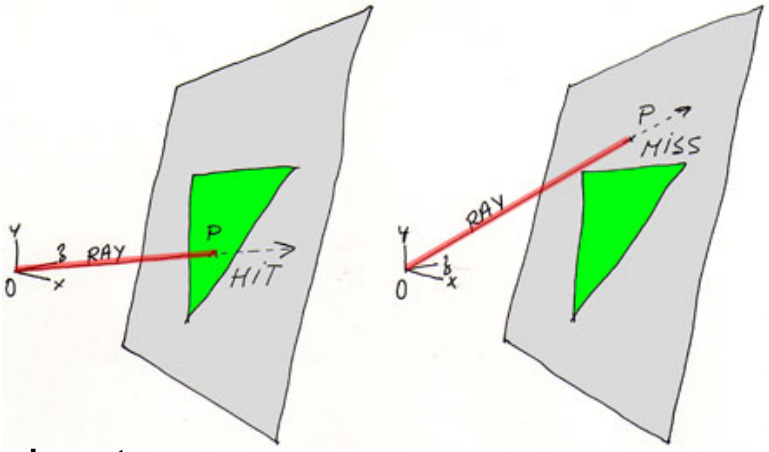
Real-time Ray Tracing



- Preserve cache coherency
  - Shoot rays in bundles
  - Use optimized space partitioning
- Run in parallel on SMP hardware
  - Utilize a distributed infrastructure for complex jobs
- Utilize SIMD vectorization(SSE, MMX, Altivec)
  - Perform stream processing on the GPU
- BRL-CAD includes the Advanced Distributed Ray Tracer (ADRT) developed by Justin Shumaker for high-performance ray tracing of polygonal models
  - Includes the Interactive Shotline Selection Tool (ISST) for real-time visualization of target descriptions and predictive shotline selection
- The very first implementation of a “real-time” ray-tracer was credited at the 2005 SIGGRAPH computer graphics conference as BRL-CAD’s REMRT/RT tools developed by Mike Muuss in 1987

BREP Evaluation Issues

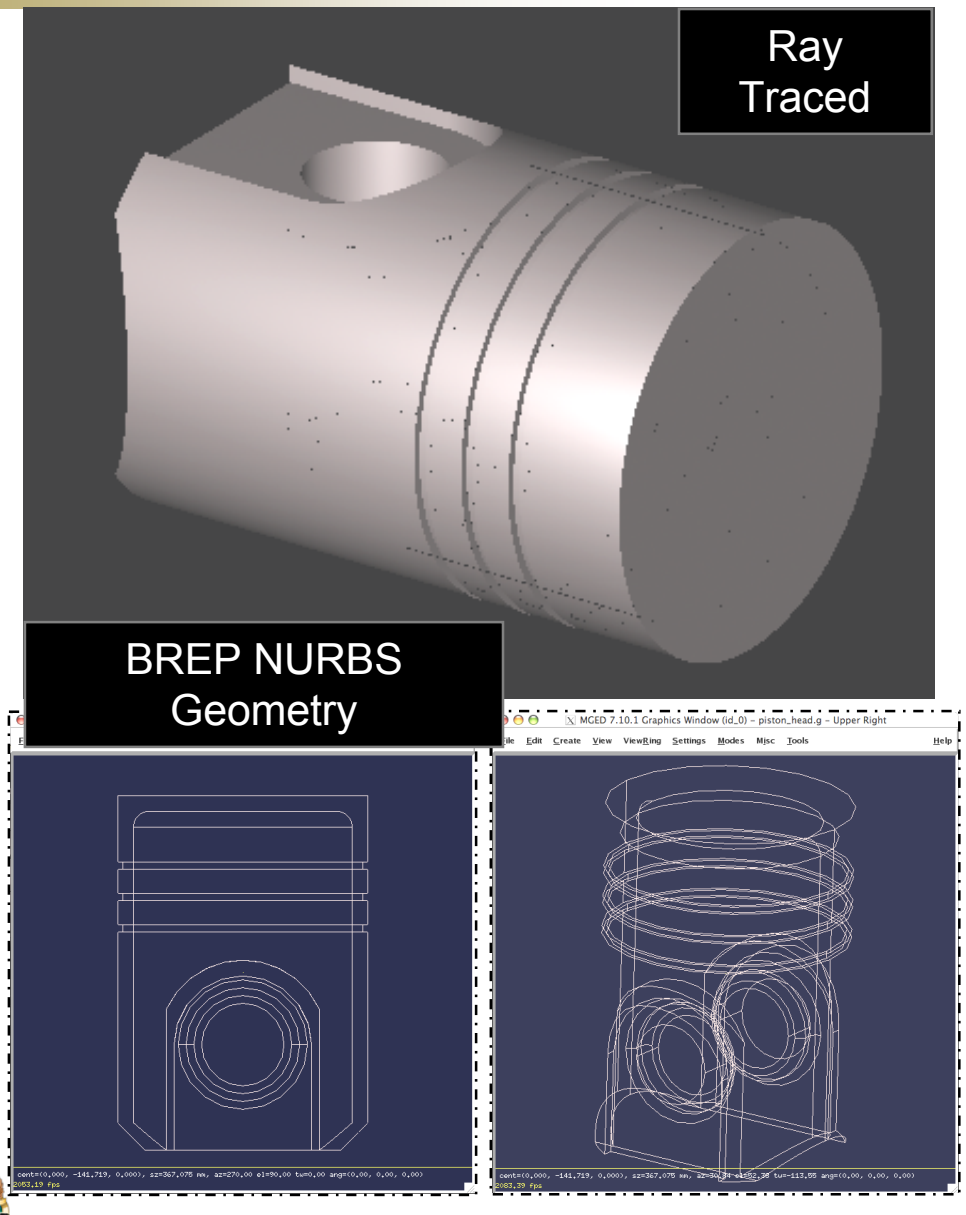
- Boundary representation (BREP) geometry involves stitching together 3D surfaces to hopefully form closed topological structures
- During ray-tracing, a ray can "slip through a crack" if the implementation is not sufficiently robust



Example Triangular trimming curve on a rectangular surface patch

- Floating point arithmetic increases the numerical instabilities substantially
- Fixed precision arithmetic provides much better stability but is several orders of magnitude slower to evaluate
- We are using the open source OpenNURBS library for BREP storage, but still have to implement routines for ray tracing and surface evaluation

BREP Progress



Great progress made so far on BREP/NURBS support in BRL-CAD especially with OpenNURBS integration. However, we need to:

- ❑ Resolve tolerance and “acne” problems during ray tracing
- ❑ Optimize performance
- ❑ Develop a STEP geometry converter
- ❑ Implement surface-surface intersection routines