SAND2018-1859R

SAND Number: SAND2018-xxxx x
UNLIMITED RELEASE

Return on Investment (ROI) Framework Case Study: CTH

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

CTH

Background

CTH is a Eulerian code developed at Sandia National Laboratories capable of modeling the hydrodynamic response of explosives, liquids, gases, and solids. The code solves complex multi-dimensional problems characterized by large deformations and strong shocks that are composed of various material configurations. CTH includes models for material strength, fracture, porosity, and high explosive detonation and initiation. The code is an acronym for a complex series of names relating to its origin. A full explanation can be seen in Appendix A.

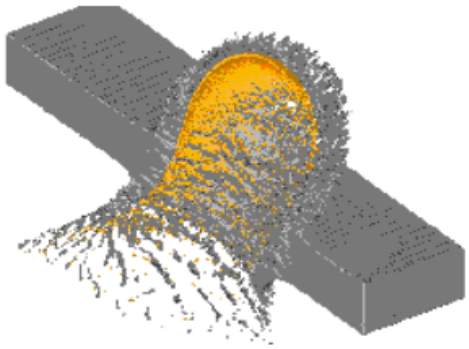

Figure 1: CTH calculation of a copper ball penetrating a steel plate.

The software breaks penetration simulations into millions of grid-like "cells". As a modeled projectile impacts and penetrates a target, progressively smaller blocks of cells are placed around the projectile, which show in detail deformations and breakups.[1] Additionally, the code is uniquely suited to modeling blunt impact and blast loading leading to human body injury.

CTH is influenced greatly by its predecessor codes, CHARTD and CSQ. Sandia developed the precursor to CTH in the 1970s for one-dimensional problems, expanding it to simulate problems in two and three dimensions in the 1980s. The software was created to expand Sandia's production shock physics code suite to 3D. The labs began licensing the shockwave physics code in the early 1990s to DOE, DoD, contractors, and some private US companies with interests in shock physics.[2]

CTH was modified to run on massively parallel computers in 1992-1993 and was enhanced with parallel adaptive mesh refinement in 1998-2000.[3] An updated version of the software, which is export controlled, is distributed to customers about every 18 months. The latest, Version 12.0, was released in August of 2017.

The classes of problems that can be analyzed with CTH include high-speed impact, penetration, perforation, explosive detonation, and blast loading of structures; analyses involve a variety of materials including the human body itself. Applications of CTH code are numerous and include some of the following:

- ***Astrophysics:*** Asteroid Chelyabinsk and Comet Shoemaker
- ***Safety Assessments:*** explosives detonation

[1] http://www.sandia.gov/CTH/Capabilities-leftnav-level1_js.html
[2]https://books.google.com/books?id=ksDsDAAAQBAJ&pg=PA18&lpg=PA18&dq=What+does+CTH+software+do?&source=bl&ots=TEGKoBzRfo&sig=3hCFYKmXIuuylPs9YiXEnis4RgE&hl=en&sa=X&ved=0ahUKEwib1czthpnXAhUBWWMKHQaMCME4ChDoAQgwMAM#v=onepage&q=What%20does%20CTH%20software%20do%3F&f=false
[3] http://www.sandia.gov/CTH/Release-leftnav-level1_js.html

- ***Accident Investigations:*** USS Iowa and Columbia Space Shuttle
- ***Blast Design:*** nuclear weapon effects, anti-armor, and missile defense
- ***Threat Assessments:*** urban nuclear detonation and aircraft
- ***Fracking:*** penetration predictions
- ***Medical:*** brain injuries from explosive blast and wound injury mechanics

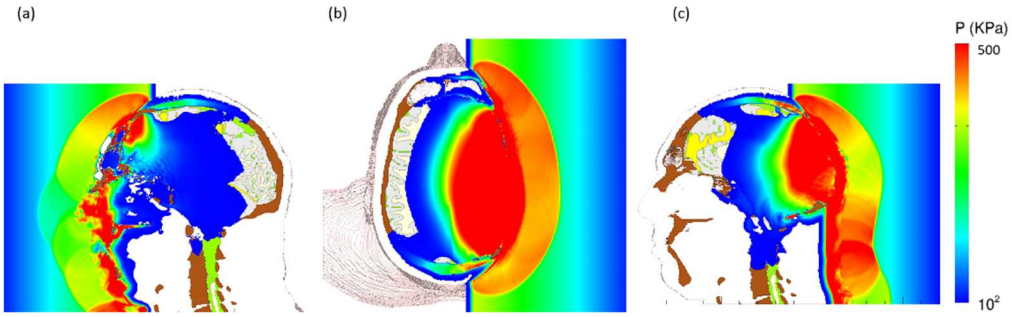

Figure 2: CTH Human Modeling Image

Return on Investment

The return on investment for CTH is evident in the programs and partnerships generated, recognition and credibility for the laboratory, and public good.

Program Development

CTH is one of the most highly used computational structural mechanics codes on DoD high-performance computing platforms as well as the number one code at Sandia in terms of computing hours.[4] At Sandia, the code is used in national missile defense, hazardous material dispersal by explosive detonation, weapon components design, wound injury mechanics, personal body armor assessment, and reactive materials research.[5] CTH has made a direct impact on the national security mission of the laboratory. Additionally, it has been used for planetary sciences and in the oil and gas industry.

The program for wound injury mechanics and traumatic brain injuries is currently growing. The program requires significant computing power to run (head and neck models alone have six to seven million individually modeled elements). The program currently has produced a model including the head, neck, and torso of a male. Future plans for the team include creating working models of the entire human body for both a male and a female. [6] The research being done by this department supports traumatic injury studies; impact- or blast-generated shock waves can elevate shock levels that induce stress or trauma upon the brain or body which causes shear stress and localized tissue damage. CTH is used to predict these stress levels, and the results of simulations are used to investigate the effects of blunt impact or blast exposure – especially useful in assessing body armor and helmet designs to better protect the human body.

---

[4] Interview with source.

[5]https://books.google.com/books?id=ksDsDAAAQBAJ&pg=PA18&lpg=PA18&dq=What+does+CTH+software+do?&source=bl&ots=TEGKoBzRfo&sig=3hCFYKmXIuuylPs9YiXEnis4RgE&hl=en&sa=X&ved=0ahUKEwib1czthpnXAhUBWWMKHQaMCME4ChDoAQgwMAM#v=onepage&q=What%20does%20CTH%20software%20do%3F&f=false

[6] Interview with source.

Although the exact number is unknown, there have been several publications written on the subject at Sandia over the years, including over half a dozen concentrated on wound injury mechanics and traumatic brain injuries.[7] CTH's sphere of influence is extensive; classes are offered biannually at Sandia, and the code has over a thousand users.

IP, Licensing and Partnerships

There are no cooperative research and development agreements (CRADA) associated with CTH; although, there are over 100 active licenses and approximately 1,000 users for the software.

Intellectual Property and Licenses

Although CTH is export controlled, it has been copyrighted for both government and commercial use. The current version, 12.0, came out in August of 2017. CTH has over 100 active licenses, the majority of which are either to the government or government contractors. Commercially, there are a handful of companies utilizing CTH to model and simulate rock perforations for penetration predictions, such as fracking.

Due to this vast number of software users, the code is continually being refined and updated. The various users, use the code in a variety of ways which provide applicable updates across the user field and a consistent ease of use.

Partnerships

Interest in the software is particularly high among customers like the DOE and the DoD, which uses the software for studying weapon effects, armor/anti-armor interactions, warhead design, high-explosive initiation physics, and weapon safety issues. In blast injury mechanics, Sandia partners to create improved models for armor and helmets.

LDRDs

In the last 20 years, Laboratory Directed Research and Development (LDRD) related to the development of CTH equals a total value of just over $9 million. There have been two LDRDs specifically focused on wound injury mechanics and traumatic brain injuries.

Public Good

CTH has contributed to public good through a wide variety of national security and defense, health, and space applications. Its largest contribution is its wide-ranging implications for national security and ultimately the protection of US citizens.

National Security and Defense

CTH's use for high velocity and high temperature applications, such as nuclear weapons effects, anti-armor, and missile defense, ultimately provides protection to US citizens throughout the country.

Accident Investigations and Safety Analysis

Sandia has contributed to the national space program; the Laboratory played a key role in helping NASA determine the cause of the space shuttle Columbia disaster in 2003 through using computational fluid

[7] Interview with source.

dynamics and CTH for impact analysis studies. The codes led to added understanding to determine impacts that shuttles can withstand and to design mitigation methods to prevent impacts that could cause damage. “Sandia’s expertise in the areas of impact testing and modeling, material testing, non-continuum aerodynamics, and thermal analysis has been invaluable to our investigation teams,” writes William Readdy, NASA associate administrator for space flight, in a letter to Sandia. “The cooperative effort and sharing of ideas, test methods, and analytical tools have been beneficial to both our organizations.”[8]

The Navy had a training accident on the USS Iowa in 1989 in which 47 sailors were killed. The Navy concluded that the accident was due to one of the sailors killing himself, but when Sandia conducted an independent investigation analysis led to the conclusion that the resulting explosion was an accident. Sandia’s computational and experimental results caused initial naval results to be reconsidered. CTH was used in the investigation.[9]

Health

CTH provides the backbone at Sandia for modeling to improve helmet and body armor design. The results of simulations used for blunt or blast impacts, such as a head hitting a windshield in a car accident or in athletics, are used to improve designs to better protect the human body. The technology provides the warfighter, athletes, civilian protective forces, or anyone needing to wear a helmet with added protection against traumatic injuries to both brain and body.

The code has contributed to the creation of microscale models of concise sections of the human brain, which are being used to observe traumatic brain injuries. The research has resulted in discovering a cavitation phenomenon which creates bubbles in the brain after an impact. When the bubbles eventually collapse, tissues are damaged within the directly surrounding areas. These microscale calculations assist in learning new facets to traumatic injuries that were previously unprecedented.

Astrophysics

CTH has had an effect on astrophysics. It was used to model the asteroid Chelyabinsk – an asteroid that landed in Russia in 2013 and killed over 1,500 people. CTH was used to mimic the entry process of the asteroid, and has led to research in asteroid science showing that smaller asteroids could potentially do much more damage than previously thought possible.[10] Additionally, CTH was used to simulate the penetration, breakup, and fireball of a comet hitting Jupiter. The impact of Comet Shoemaker-Levy 9 on Jupiter in 1994 was the largest, most energetic impact event on a planet ever witnessed. The comet and resulting simulations were the first of its kind.[11]

[8] http://www.sandia.gov/LabNews/LN09-05-03/labnews09-05-03.pdf
[9] http://jacobsschool.ucsd.edu/ceerkickoff/docs/CEER-Johannes.pdf
[10] http://www.nature.com/nature/journal/v503/n7475/full/nature12741.html
[11] https://www.osti.gov/scitech/servlets/purl/1140737

Appendix A: CTH Origin

- ***CHART D (created in 1969 by Sam Thompson)***
  Radiation-Diffusion Hydrodynamic Code (1-D)
- ***CSQ (created in 1975 by Sam Thompson)***
  $(CHART\ D)^2$ (2-D)
- ***CTH (created in 1987)***
  $CSQ^{3/2}$ (3-D) – 1987

Appendix B: Timeline