SPECIAL STUDY

Real-World Examples of Supercomputers Used For Economic and Societal Benefits: A Prelude to What the Exascale Era Can Provide

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IDC OPINION

Since its introduction in the 1960s, high performance computing (also called supercomputing) has made enormous contribution to America's scientific, engineering and industrial competitiveness, as well as to homeland security and other government missions.

Supercomputers have played crucial roles in U.S. government agencies and departments. But that's just part of the story. Supercomputers have already made cars and planes much safer, more fuel efficient and environmentally friendly. They are crucial aids in discovering and extracting new sources of oil and gas, and for developing alternative energy sources. They have enabled the weather community to create more accurate predictions of severe storms that can devastate lives and property. They are heavily relied by industries ranging from financial services to medicine and health care, entertainment, consumer products, and more recently by Internet companies.

In short, high performance computing has become indispensable for maintaining America's national security and economic competitiveness. An IDC study showed that 97% of companies that had adopted supercomputing say that could no longer compete or survive without it.

That's why other nations and global regions including China, Europe, Japan and Russia, to name a few, are racing ahead and have created national programs that are investing large sums of money to develop exascale supercomputers for use later in this decade or early in the next decade.

The new return-on-investment (ROI) examples in this report underscore the benefits of providing American scientific and industrial researchers with access to the latest generations of powerful supercomputers housed at national centers and laboratories.

IDC believes that the United States needs to maintain and advance its global standing in high performance computing, by providing adequate funding and commitment to achieve exascale capability. Without these investments the competitiveness of key U.S. industries will be substantially reduced, and it will compromise America's national security capabilities.

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REAL-WORLD EXAMPLES OF SUPERCOMPUTERS USED FOR ECONOMIC AND SOCIETAL BENEFITS

EXECUTIVE SUMMARY

This report provides examples of how U.S. private- and public-sector organizations have been using supercomputers to achieve breakthroughs of major scientific or economic importance. These achievements, many of which were accomplished through access to very powerful supercomputers and HPC experts at U.S. national laboratories, already have saved American companies, many millions of dollars and have the potential to save many billions of dollars.

This report provides examples of how U.S. organizations have been using supercomputers to achieve breakthroughs of major scientific or economic importance.

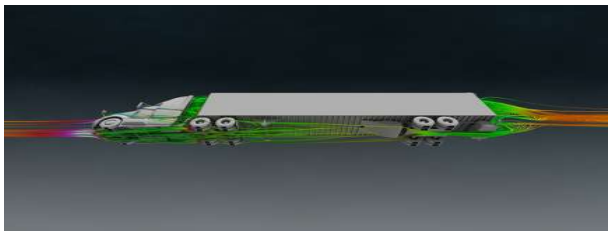
Over the last two decades, DOE has paved the way with breakthrough HPC architectures and software programming models. Other nation states are now trying to take the lead in advanced HPC technologies. If that happens, the next wave of scientific breakthroughs and industrial innovations in many industries could come from outside the US and US will miss out on the next wave of economic expansion.

Without these achievements and the supercomputer access they depend on, these American companies and research organizations would be dramatically less competitive than they are today. They would almost surely be able to provide fewer jobs and make smaller contributions to the nation's economy, now and in the future. Examples of the impact of supercomputers in US industry include:

- GE used a supercomputer to reveal a new aspect of turbine behavior that is already providing GE with a competitive advantage in fuel efficiency. Every 1% reduction in fuel consumption saves users of these products $2 billion/year.
- BMI utilized supercomputers and computational models to design components that could save 1.5 billion gallons of fuel and $5 billion in fuel costs per year.
- Supercomputers were used to generate more oil and gas from US reserves. This promises billions of dollars per year in savings and reduction of US dependence on foreign energy.
- Automotive and engine manufacturers are using high performance computing to develop next-generation engines that use less fuel. These fuel savings are estimated at more than $1 billion per year.

These fuel savings are estimated at more than $1 billion per year.

An Example of Reducing Fuel Consumption of Our Trucking Fleet

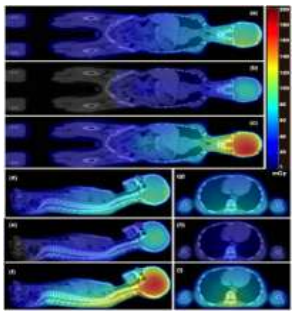


Source: BMI, Oak Ridge National Laboratory, 2014

Supercomputers have played crucial roles in U.S. government agencies and departments. In addition to their use in classified government, including a recognized role in helping to end the Cold War, supercomputers enable NOAA's national weather and severe storm predictions that have help save lives and billions of dollars in property. Supercomputer make possible the development of advanced military aircraft and spacecraft, and are essential for planning, executing and improving NASA missions. Supercomputers were used to identify the causes of the NASA "Challenger" tragedy and the collapse of the World Trade Center towers on 9/11. Supercomputers are being evaluated today to transform the ability of CMS and other agencies to catch fraud. USPS is now using supercomputers to alleviate costly errors and fraud. Examples include:

- Seismic simulations are used to generate advanced hazard maps and this research team developed software that significantly advances this map-making ability. The potential saving is in billions of dollars in preventing property loss/damage, along with protecting lives.
- Researchers from the Centers for Disease Control (CDC) created a far more detailed model of the hepatitis C virus, a major cause of liver disease. Annual health care costs associated with this virus are $9 billion in the U.S. alone.
- For the first time researchers developed a computer model that comprehensively simulates the human heart down to the cell level. This innovation has significant potential for saving health care costs by reducing heart disease and improving heart health. This research has strong potential for helping to reduce coronary heart disease, which costs the United States over $100 billion each year.

Using HPC to Improve Cancer Treatments



Source: Mary Bird Perkins Cancer Research Center , Louisiana State University, 2014

But that's just part of the story. Without supercomputers, detecting today's sophisticated cyber security breaches, insider threats and electronic fraud would be impractical. In short, high performance computing has become indispensable for both maintaining America's national security and economic competitiveness.

That's why other nations and global regions including China, Europe, Japan and Russia, are racing ahead and have created national programs that are investing large sums of money to develop exascale supercomputers. What this global race is really about is supremacy in supercomputing and in all the disciplines and markets that depend heavily on this game-changing technology.

HPC CASE STUDY SUMMARIES

These shining examples illustrate the importance of continuing to provide this diverse community of HPC users with access to first class supercomputers whose capabilities are on a par with those of other leading nations and global regions, including exascale supercomputers as soon as those begin to appear around the world. Anyone who doubts the importance of supercomputers for scientific and economic competitiveness should consider the examples in this report:

- The Centers for Disease Control (CDC) used a supercomputer to advance understanding of the hepatitis C virus, a major cause of liver disease. This paves the way for researchers to discover new therapies for combating the virus. Annual health care costs associated with this virus are estimated to be $9 billion in the U.S. alone.
- The Mary Bird Perkins Cancer Center (Baton Rouge, LA) made important advances that could lower the incidence of second cancers caused by radiation in children receiving radiation therapy. The collaborators saved more than $12 million by using high performance computing. The researchers estimate this achievement has accelerated radiation toxicity research by more than a decade.
- Researchers at the Salk Institute (San Diego) are using supercomputers at the nearby NSF-funded San Diego Supercomputer Center to investigate how the synapses of the brain work. Their research has the potential to help people suffering from mental disorders such as Alzheimer's, schizophrenia and manic depressive disorders.
- About 600,000 people die of heart disease in the United States every year-that's 1 in every 4 deaths. Scientists from DOE's Lawrence Livermore National Laboratory (LLNL) modeled the human heart in much greater detail than before, using one of the world's most powerful supercomputers. This advance lays the foundation for progress in preventing and treating heart disease.
- Turbines are literally responsible for keeping the lights on, since most of the world's electricity is generated by turbines. And jets couldn't stay aloft without them. Recently, GE used a supercomputer to reveal a new aspect of turbine behavior that is already providing GE with a competitive advantage.
- Thanks to new research on a supercomputer Ramgen will begin testing a 13,000-horsepower CO_2 compressor this year. This compressor is projected to reduce the capital costs of CO_2 compression by 50 percent and produce a minimum of 25 percent savings in operating costs. Applying these cost savings to a new 400-megawatt clean coal plant would result in capital cost savings of approximately $22 million and an annual operating cost savings of approximately $5 million.
- A BMI Corp. SmartTruck technology developed on a supercomputer could save 1.5 billion gallons of diesel fuel and $5 billion in fuel costs per year. This technology is now in use.
- Boeing Corporation saved many millions of dollars by using supercomputers. Boeing physically tested 77 prototype wing designs for the 767 aircraft, but for the new Boeing 787 Dreamliner only 11 wing designs had to be physically tested (a 7 fold reduction in the needed amount of prototyping), mainly because over 800,000 hours of computer simulations on supercomputers had drastically reduced the amount of needed physical prototyping.

- Seismic simulations were used to generate a hazard map, with the potential saving of many lives and properties. Upon completion of California state-wide seismic hazard map savings will be many billions dollars. These National Seismic Hazard Maps will help set building codes and insurance rates, as well as provide short-term forecast of the frequency of damaging earthquakes in California over a specified time span.
- Supercomputing has led to significant improvements in the Navy's effort to improve tropical cyclone intensity prediction.
- Manufacturers will have valuable new information that will ultimately help them design better engines more quickly and at a lower cost. These new models will allow researchers to stretch uses of the models beyond what can currently be done experimentally, testing out theoretical innovations such as low temperature combustion
- RENCI used supercomputing to compute new data in order to update coastal floodplain maps for North Carolina. These maps are required by FEMA for local communities and municipalities to be eligible for flood insurance coverage under the National Flood Insurance Program (NFIP). The modeling program was so successful in North Carolina that it was used by FEMA and the US Army Corps of Engineers to provide data to update coastal floodplain maps from the Virginia-North Carolina state line to the Delaware Bay.
- The low-cost, post-processing system powered by supercomputing, reduces the need for observation wells and has demonstrated commercial success in oil and gas recovery, carbon capture and sequestration and geothermal energy. The system is already in use to track injected carbon dioxide in several energy exploration projects
- Researchers are using simulations to decrease the materials scrapped during the continuous casting process. Decreasing the material scrapped due to defects such as cracks, even by a small percentage, results in a large net savings to steel manufacturers and customers. Based on the roughly 100 million tons of steel produced each year in the U.S. and approximately $400 per ton net cost of scrapping, a one percent reduction in yield loss would save about $400 million per year.

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SUPERCOMPUTING SUCCESS STORIES

A) IMPROVING HEALTH AND QUALITY OF LIFE

Finding Cures for Hepatitis C (Cornell University and CDC)

What Was Accomplished

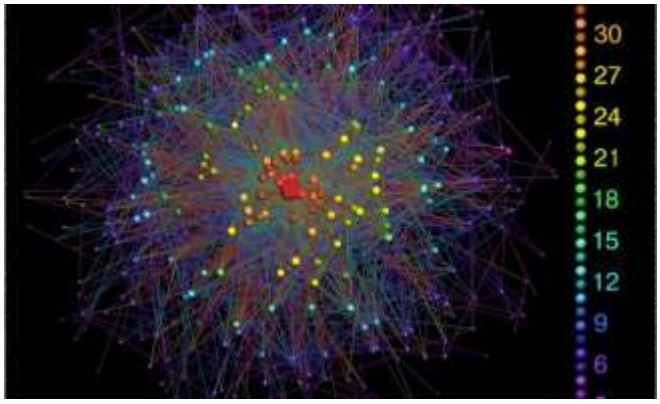
Researchers from the Centers for Disease Control (CDC) created a far more detailed model of the hepatitis C virus, a major cause of liver disease. Annual health care costs associated with this virus are estimated to be $9 billion in the U.S. alone. By scaling the virus model from a desktop computer in Atlanta to an HPC cluster at Cornell, researchers improved our understanding of the virus's networks of amino acids, paving the way for new therapies for combating this devastating virus.

Savings/Potential Savings: $9 billion per year; $360 billion over 40-year patient lifetimes.

Potential Savings: **$9 billion per year; $360 billion over 40-year patient lifetimes.**

FIGURE 1

Visualization of a Hepatitis C Virus Network (Campo et al).



Source: Cornell University, 2014/CDC Campo et al.

Organization

The Centers for Disease Control and the Cornell University Center for Advanced Computing.

Supporting Organizations

The HPC cluster was funded by the National Science Foundation and was executed through industrial partnerships with MathWorks (Natick, MA) and Dell (Round Rock, TX).

Industry

Education, Scientific Research, Engineering

ROI or Innovation Description

With the cost per liver transplant in the range of $280,000 for the first year alone, liver transplantations due to hepatitis C cost nearly $300 million per year in the U.S. The average lifetime cost for hepatitis C without a liver transplant has been estimated at $100,000 per person. Assuming that 80% of the 4.5 million Americans believed to be infected by this virus develop chronic liver disease, the annual health care costs for the U.S. population affected with chronic hepatitis C total about $9 billion and the lifetime costs for this group of 3.6 million persons, assuming average survival of 40 years, amount to a staggering $360 billion in today's dollars

Type of Innovation

This basic Innovation was rated among the top 50 innovations in the last decade.

Nature of Research

Through faster computations (more than 175 times speed-up), a better understanding of networks of coordinated amino-acid variation has opened the door for the discovery of new therapeutic targets for the hepatitis C virus (HCV). Over 500,000 jobs ran on the Cornell system over two years, generating new scientific insights and publications in condensed matter physics, gravitational wave detection, biomedical imaging, orthopedics, neuroscience, and optics.

Broader Impact

According to the world health organization (WHO), about 150 million people are chronically infected by HCV, with 3 to 4 million new infections every year. 75% to 85% of newly infected individuals develop chronic disease with long-term complications, including liver cirrhosis and liver cancer. Since to date no vaccine is available and more than 350,000 patients die yearly from hepatitis C-related diseases, the virus poses a major health concern. Supercomputer simulations can significantly accelerate research on viruses like hepatitis C and help develop effective cures.

Lowering the Cost of Advanced Cancer Care (Mary Bird Perkins Cancer Center and Louisiana State University)

What Was Accomplished

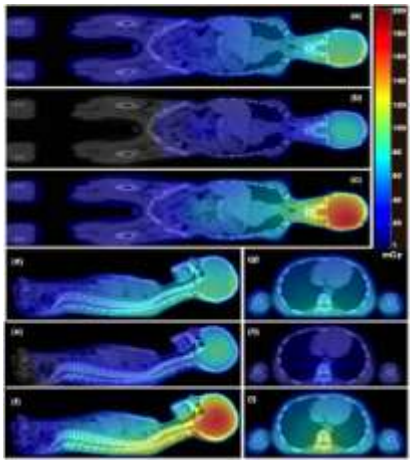
In this research, HPC-driven cancer research enabled better outcomes for long-term survivors of cancer. Advances in cancer detection and treatment have led to large improvements in survival rates. But with increased survival comes an increased need to minimize long-term treatment-related negative effects. In particular, children receiving radiation therapy are more susceptible to radiation-caused secondary cancers (carcinogenesis) later on. Researchers have conducted clinical trials with the help of supercomputer simulations, and these trials are helping to improve success rates for long-term, advanced cancer care. The simulation driven research has generated valuable data that is being used to inform clinical and health policy decisions

Savings/Potential Savings: $12 million in research costs and 6 months in constructing a new $125 million therapy center.

Potential Savings: **$12 million in research costs**

FIGURE 2

Doses For CSI And Boost Treatment Superimposed On A Patient's CT Image



Source: Mary Bird Perkins Cancer Research Center, Louisiana State University, 2014

Organization

The Mary Bird Perkins Cancer Research Center and Louisiana State University. The Mary Bird Perkins Cancer Center, founded in 1971, is the region's largest provider of radiotherapy, community-owned (not-for profit) organization based in Baton Rouge, LA.

Supporting Organizations

The National Institutes of Health (NIH) and the Department of Defense.

Industry

Healthcare, Education, Scientific Research,

ROI or Innovation Description

More than $12 million was saved in research costs by using HPC simulation. Even more important, this simulation-driven research has accelerated progress in the field of advanced cancer care. In addition, the ability to simulate therapy equipment saved more than 6 months on the construction of a new $125 million proton therapy facility and has accelerated radiation toxicity research by more than a decade.

Type of ROI

A conservative estimate of future monetary gains as a result of removing obstacles to founding new proton theory centers is on the order of $300 million. The research has also enabled estimated cost savings of $15 million.

Nature of Research

Predictions of exposure to charged particle radiation are commonly performed for patients receiving radiotherapy. Researchers studied the physical interactions and bioeffect-modeling approaches to predict radiation-produced toxicity in patients. Computer modeling approaches were used in several aspects of the research, to predict radiation dosages and radiation-caused risk for developing second cancers. These approaches applied Monte Carlo methods and supercomputing techniques.

The researchers simulated a pediatric brain tumor treatment to calculate stray radiation. The largest proportions of this risk were assumed by the skin and then the thyroid. The research revealed that using proton beams reduced the total lifetime risk of second cancer from over 30% after photon therapy to about 5% for proton therapy.

The researchers estimated the excess lifetime risk of second-cancer fatality from stray radiation for pediatric male patients who receive this treatment at 4% to 5%, depending on the nature of proton treatment. They note that while this risk is small compared with the benefits of the radiotherapy, it is not negligible. As such, it is important to continue attempts to reduce stray radiation exposure as much as possible. Ultimately, the team aims to generate a high-quality evidence to support clinical decision making as to whether a patient receives proton or photon therapy

Broader Impact

This research was fundamental in demonstrating that computer-based clinical trials can be a cheaper, faster way to generate scientific breakthroughs. In this research, simulation-driven cancer research enabled better outcomes for long-term survivors of cancer. Additionally this research enabled the participation of students and post docs in mentored research training.

Finding Cures for Alzheimer's, Schizophrenia and Manic Depressive Disorders (Salk)

What Was Accomplished

This research has the potential to greatly help people suffering from mental disorders such as Alzheimer's, schizophrenia and manic depressive disorders.

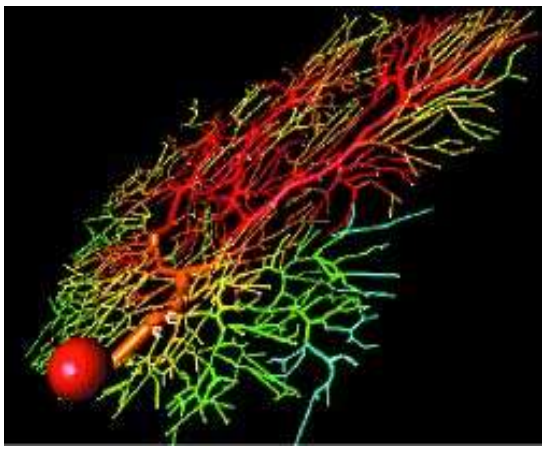
Researchers at the Salk Institute (San Diego, CA) are using supercomputers at the nearby NSF-funded San Diego Supercomputer Center to investigate how the synapses of the brain work. In addition, the use of supercomputers is helping to change the very nature of biology – from a science that has relied primarily on observation to a science that relies on high performance computing to achieve previously impossible in-depth quantitative results.

This research could ultimately help reduce the overwhelming cost for treatment and long-term care of brain related disorders.

Savings/Potential Savings: This research could ultimately help reduce the overwhelming cost for treatment and long-term care of brain related disorders.

FIGURE 3

GENISIS of a Purkinje Cell



Source: Salk Institute, 2013

Organization

The Salk Institute

Industry

Healthcare, Scientific Research,

ROI or Innovation Description

Significant progress in the modeling of chemical transmission across nerve synapses, which involves an array of complex electrochemical processes

Nature of Research

The research focuses on the events that occur when a neuron, or nerve cell, sends its chemical message across a synapse to influence another neuron. This is a key way in which messages are communicated along neural pathways. This involves modeling the release of neurotransmitter, its diffusion across the synapse, and its binding to receptors to generate currents in the receiving neuron.

The improvements resulted in a 150-fold speedup of simulations, and the speedups enabled an increase in simulation complexity. Researchers can develop 3D representations of cellular structures, with resolution down to the electron microscope level.

Broader Impact

The supercomputing-simulation driven approach is one of the key ways in which Salk Institute is building computational bridges between brain levels from the biophysical properties of synapses and function of neural systems. This research could ultimately help reduce the overwhelming cost for treatment and long-term care of brain related disorders. Modeling driven precision in circuit information will help researchers understand the scale and scope of problems while enabling them to test and develop targeted therapies that are ultimately more effective.

Developing Lower Cost Heart Disease Treatments (LLNL)

What Was Accomplished

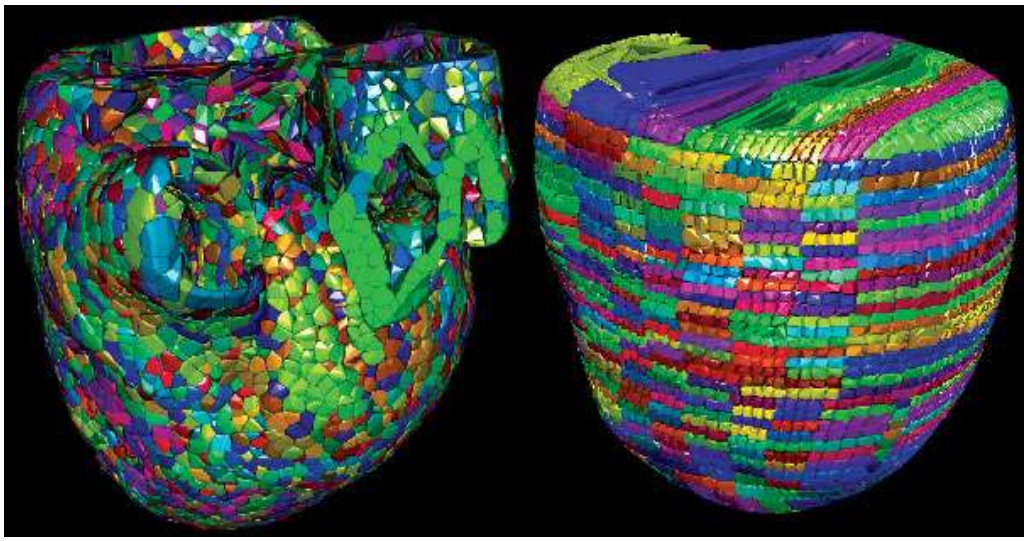
For the first time researchers developed a computer model that comprehensively simulates the human heart down to the cell level. This innovation has significant potential for saving health care costs by digitally screening drugs and drug candidates for cardiotoxicity, reducing mortality from heart disease and improving the effectiveness of heart therapies. The researchers were able to simulate a heartbeat per second, compared with prior modeling that took at much as 45 minutes to simulate a single heartbeat.

This research has strong potential for helping to reduce coronary heart disease, which costs the United States over $100 billion each year.

Savings/Potential Savings: This research has strong potential for improving the lives of patients with coronary heart disease, which costs the United States over $100 billion each year.

FIGURE 4

Computer Visualization Of the CARDOID Heart Model



Source: LLNL, 2014

Organizations

Lawrence Livermore National Laboratory (LLNL) and IBM Research

Industry

National security and information technology

ROI or Innovation Description

The research partners discovered new information about the functioning of the human heart that has significant potential for alleviating the health and monetary costs of heart disease.

Type of ROI

Technical innovations with strong potential for health and monetary savings in human societies.

Nature of Research

Computational models of cardiac cells have been in developed since the 1960s. However developing a comprehensive model of the human heart is complex, because the heart is composed of cells that are discrete and individual in the sense that each is an excitable system. Because each cell in the heart muscle needs to be simulated at the same time, modeling all this activity in detail would take too long even on the largest supercomputers. LLNL and IBM researchers have for the first time developed a multi scale model that comprehensively simulates the human heart down to the cell level.

To use the laboratory's powerful supercomputer more efficiently, the researchers created new ways to divide the heart tissue into small pieces of equal work units that could be evenly distributed across the supercomputer's 1,572,864 computing elements. The researchers were able to model the human heart in unprecedented detail and at unprecedented speed by developing novel software and methods for exploiting one of the world's most powerful supercomputers located the Lawrence Livermore National Laboratory

Broader Impact

This innovation has significant potential for saving health care costs by reducing heart disease and improving heart health. According to the Centers for Disease Control and Prevention:

- About 600,000 people die of heart disease in the United States every year–that's 1 in every 4 deaths.
- Heart disease is the leading cause of death for both men and women. More than half of the deaths due to heart disease in 2009 were in men.
- Coronary heart disease is the most common type of heart disease, killing more than 385,000 people annually.
- Every year about 715,000 Americans have a heart attack. Of these, 525,000 are a first heart attack and 190,000 happen in people who have already had a heart attack.
- Coronary heart disease costs the United States $108.9 billion each year. This total includes the cost of health care services, medications, and lost productivity.

B) REDUCING FUEL COST AND CO EMISSIONS

Improving Fuel Savings in Jet Engines (General Electric)

What Was Accomplished

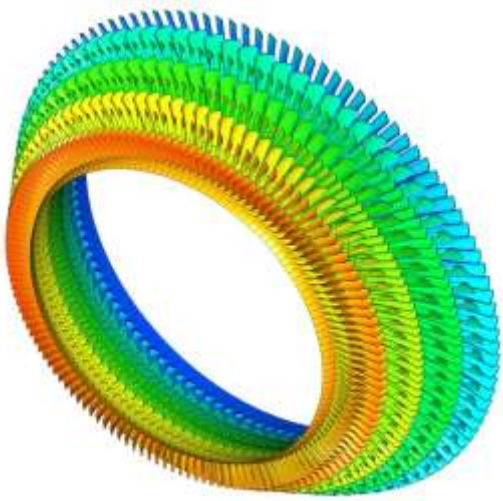
Each year, about $200 billion worth of fuel is consumed globally on GE's gas turbine products, both aircraft engines and land-based gas turbines used for the production of electricity. Every 1% reduction in fuel consumption therefore saves the users of these products $2 billion/year.

Savings/Potential Savings: Multiple billions of dollars per year.

Savings/Potential Savings: Multiple billions of dollars per year.

FIGURE 5

A Visualization of A 4 Stage Low-Pressure Turbine



Source: GE Global Research, 2013

Organization

Scientists and Researchers at the GE Global Research Center collaborated with experts at Oak Ridge National Lab to conducted the jet engine simulations

Supporting Organizations

Supercomputers hosted at the Department of Energy's Oak Ridge National Laboratory were used in this research.

Industry

Manufacturing, Aerospace, Automotive, Consumer Products

ROI or Innovation Description

Scientific advance useful for practical engineering of aircraft

Type of ROI

The models employed would not have been practical or in many cases even possible without the supercomputer.

Type of Innovation

GE observed a phenomenon spanning multiple blade rows of the engine that was not observable before. This was rated as one of the top 10 innovations in the last decade.

Nature of Research

For more than a century General Electric (GE) has been building turbomachines and is currently a major producer of turbines for the electric power generation and aircraft engine industries. More recently GE has begun to utilize supercomputers and computational models to accelerate its R&D in turbomachinery.

GE researchers use supercomputers to model unsteady flows from industrial turbines that are deployed in jet engines, power stations and beyond. Computational models enable designers to make advanced and fine-grained adjustments to the turbomachinery while generating greater operating and fuel efficiencies. GE researchers were able to investigate unsteady flows and design solutions that met several key design criteria. The researchers were also able to simulate the turbomachinery in 3D and 4D (3D + a time dimension) and were able to study turbomachinery design impacts over time.

Developing turbomachinery is an extremely complex and globally competitive business with multiple top-tier corporations competing with GE to sell jet engines and gas turbines in different application domains. Consequently any company that can achieve even 1% improvement in efficiency can potentially cause market disruption, as the resultant efficiencies would overtime add up to enormous cost savings to customers, thus providing market advantage.

Broader Impact

The studies performed by GE are targeted towards improving the aerodynamic efficiency of jet engines. Improvements to jet engines can be leveraged to improve the efficiency of land based gas turbines which GE also manufactures. Each year, about $200 billion worth of fuel is consumed globally on GE's gas turbine products, both aircraft engines and land-based gas turbines used for the production of electricity. Every 1% reduction in fuel consumption therefore saves the users of these products $2 billion/year.

Saving Fuel Cost on Long Haul Trucks (BMI SmartTruck)

What Was Accomplished

BMI utilized supercomputers and computational models to design components that could save 1.5 billion gallons of diesel fuel and $5 billion in fuel costs per year.

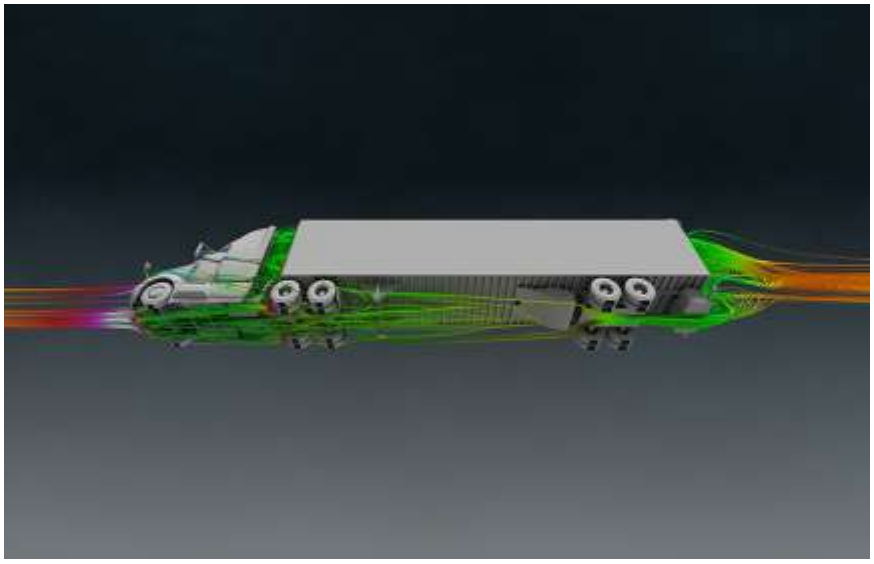
The big rigs barreling down America's highways day and night are essential to the country's economy – they carry 75% of all U.S. freight and supply 80% of its communities with 100% of their consumables. Thus far, long haul trucks have often averaged 6 MPG or less resulting in very high fuel costs and considerable impact to the environment with emissions of more than 423 million lbs of CO_2. The BMI engineers combined their aerospace and race care design expertise with the power of supercomputers to create a new, long haul "SmartTruck" to increase fuel efficiency and reduce carbon emissions

Savings/Potential Savings: **1.5 billion gallons of diesel fuel and $5 billion in fuel costs per year.**

Savings/Potential Savings: 1.5 billion gallons of diesel fuel and $5 billion in fuel costs per year.

FIGURE 6

Supercomputing Simulations Of The SmartTruck UnderTray System



Source: BMI, Oak Ridge National Laboratory, 2013

Organization

BMI (Greensville, SC)

Industry

Manufacturing, Aerospace, Automotive, Consumer Products

ROI or Innovation Description

Since 2011 SmartTruck Systems of Greenville, S.C., has sold more than 25,000 UnderTray Systems to trucking fleets in North America. The award-winning, EPA-certified UnderTray Systems are trailer add-on components that improve highway fuel efficiency by more than 10 percent and save an estimated $5,000 annually in fuel costs per truck. If all of the 1.3 million Class 8 trucks in the country were configured with just the minimum package of new components, the U.S. could annually save almost 1.5 billion gallons of diesel fuel, reduce CO_2 by 16.5M tons and save more than $6B in fuel costs.

Nature of Research

Using BMI's SmartTruck UnderTray System to improve the aerodynamics of 18-wheeler (Class 8) long-haul trucks, the typical big rig can achieve fuel savings of between 7 and 12 %. Using supercomputers BMI simulated UnderTray System, including components such as aerodynamic wheel fairings and special airflow directing mechanisms. Computational models run on supercomputers were also used to design and develop the rear diffuser, the biggest component of the UnderTray System.

Running design simulation models on the supercomputers allowed BMI to jump from concept to a design that could be turned over to a manufacturer in 18 months instead of the more usual 3½ years. BMI's goal was to design add-on parts for existing trucks and trailers to make them more aerodynamic. By reducing drag BMI boosted fuel efficiency and cut the amount of carbon that's being dumped into the environment.

Extensive testing was used to validate BMI's CFD simulations, demonstrating gains of 6.8%. BMI is working with NASA to improve additional techniques and newly developed optimization techniques,

BMI also earned one of the key industry awards and citation as top 20 products of the year for products made possible simulation work performed on supercomputers.

Broader Impact

BMI currently employs more than 25 workers throughout the U.S. and works with materials suppliers nationwide. UnderTray Systems have a quick payback period and a favorable return on investment, so fleets have strong incentive to upgrade trailers with the components, which are manufactured entirely in the USA and are 100 percent recyclable.

BMI also plan to utilize similar modeling and supercomputer driven design methodology to further improve the aerodynamics of both existing tractors and trailers.

Making America Energy Independent By Improving Oil and Gas Exploration (LLNL, Industry Partners)

What Was Accomplished

Supercomputers were used to develop an advanced reservoir-monitoring technology in order to generate more oil and gas from US reserves. This will help reduce the US dependence on foreign sources of energy.

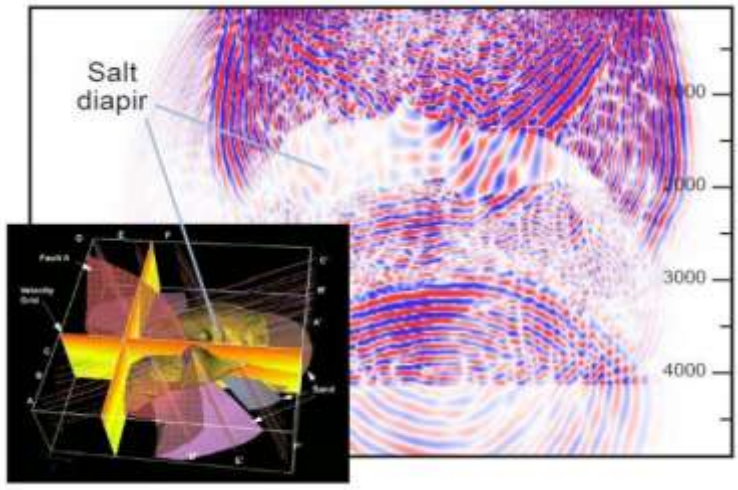
Billions of dollars per year in savings and reduction of US dependence on foreign energy.

Using the supercomputing power of its HPC machines, researchers and engineers in collaboration with LLNL developed a technique that integrates separate measurement data to predict subsurface fluid distribution, temperature and pressure. The system obviates the need for numerous observation wells, and the low-cost system works well for oil and gas recovery; carbon capture and sequestration; and geothermal energy.

Savings/Potential Savings: Billions of dollars per year in savings and reduction of US dependence on foreign energy.

FIGURE 7

Extracting More Oil from Reserves in the Gulf of Mexico



Source: LLNL, 2014

Organization

LLNL and various US industrial partners.

Industry

Oil and Gas industry

ROI or Innovation Description

The system developed by LLNL and its partners is already in use to track injected carbon dioxide in projects in multiple locations. Through modeling and simulation, private sector participants have improved well recovery and reduced failure risk.

Type of ROI

Process improvement resulting in multi fold speed up and increased safety

Nature of Research

Oil and gas companies traditionally have been some of the most aggressive and advanced users of Supercomputing. Most of the O&G companies use supercomputing for geophysical processing of 3D and 4D seismic imaging volumes for exploration and production. O&G companies also harness supercomputing for reservoir management, development of new compounds and chemicals, and planning drilling efforts.

The lab has partnered with oil and gas companies to develop tools to improve recovery with low cost and low environmental impact. Central to these efforts is a tool that directly assesses the probability of key reservoir characterization and sub-surface plumes and fluid distributions. The low-cost, post-processing system powered by supercomputing, reduces the need for observation wells and has demonstrated commercial success in oil and gas recovery, carbon capture and sequestration and geothermal energy. The system is already in use to track injected carbon dioxide in multiple projects.

Broader Impact

The need for greater energy independence, a sustainable environment, and reduced conventional production has driven innovation and enterprise in the global oil and gas industry. Through advanced modeling and simulation, private sector participants have improved well recovery, reduced operating costs, and reduced failure risk. These early results suggest higher promise for HPC in improving domestic energy production with reduced environmental consequence.

Developing Innovation Performance Engines for Alternative Fuels (ANL)

What Was Accomplished

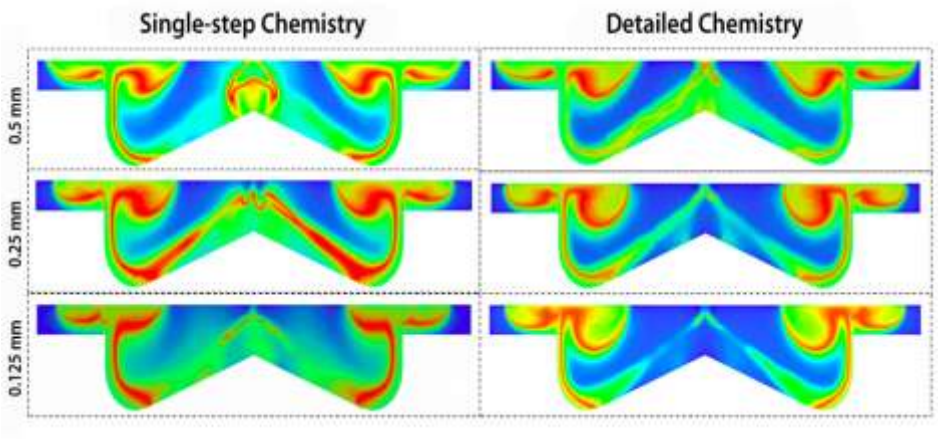
Automotive and engine manufacturers are using high performance computing to develop of next-generation engines that use less fuel. A key competitive differentiator in designing engines is development of fuel injector technology that can utilize a new generation of bio fuels. Through the use of large scale supercomputers and computational models engineers are developing more robust fuel spray and combustion models for predictive engine simulations.

Savings/Potential Savings: Estimated at more than $1 billion per year.

Savings/Potential Savings: **Estimated at more than $1 billion per year.**

FIGURE 8

State of the Art Fuel Spray Modeling



Source: ANL, 2014

Organization

Argonne National Laboratory

Industry

Automotive Engineering, Manufacturing

ROI or Innovation Description

Using larger and detailed simulations at a faster rate, manufacturers will have valuable new information that will ultimately help them design better engines more quickly and at a lower cost. These new models will allow researchers to stretch uses of the models beyond what can currently be done experimentally, testing out theoretical innovations such as low temperature combustion

Type of ROI

Innovative Modeling Process

Nature of Research

High-fidelity engine simulations allow researchers to develop detailed and intricate models of a virtual combustion chamber to better understand how injected fuel, air and combustion products intermingle inside an engine. The fuel injector, for instance, atomizes liquid fuel into fuel vapor, changes that require complicated fuel spray, two-phase flow, and heat transfer modeling. Turbulence produced by the chaotic motion inside engine cylinders due to the fuel spray necessitates the inclusion of these high-fidelity computational fluid dynamics approaches to describe the spray of the fuel into the combustion chamber. This complicated process involving fluid dynamics, chemistry and combustion determines engine performance and emissions characteristics, but it would be impossible to observe and understand without the aid of computer models.

Advanced large scale supercomputing resources allows researchers and engineers to simulate the activity inside an engine at a much finer scale. The space simulated in a computational fluid dynamics models is divided into cells and the smaller the cell, the more accurate the model. Industrial models typically use millimeter resolution, but the scaled-up high resolution models created at Argonne can simulate at a micrometer scale -- a thousand times more precise.

Broader Impact

In addition to improving the scale at which physics and chemistry can be simulated and observed, the high resolution engine models will also be valuable testing ground for the future of alternative fuel. With different types of fuel options including biofuels based on corn, soy, and other new sources, their performance and emissions in different engine designs can be simulated virtually before they are tested in the laboratory. Moreover, with the ability to execute fine grained engine simulations at a faster rate, manufacturers will be able design better engines more quickly and at a lower cost

C) IMPROVING MANUFACTURING AND GLOBAL COMPETITIVENESS

Saving Energy While Increasing Profits for Casting Steel (UIUC, NCSA)

What Was Accomplished

Casting steel with fewer defects has the great benefits of making safer steel products and reducing the cost of steel.

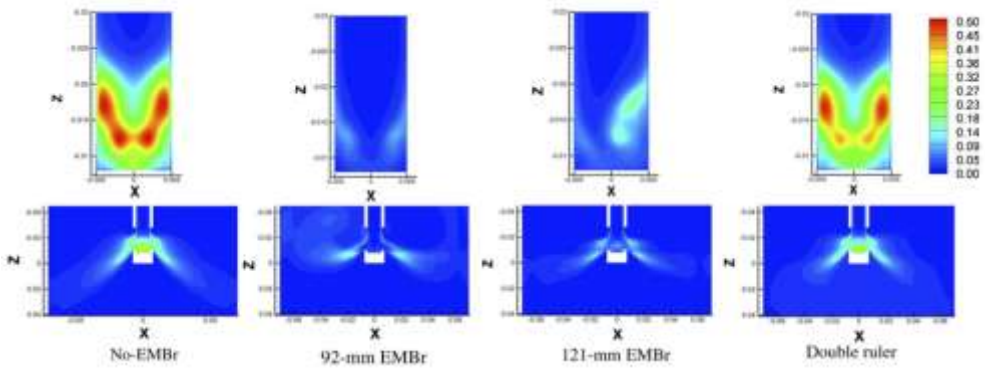
The process of continuous casting steel -- the process that turns molten steel into sheets and that is used to produce 92 percent of the world's steel. With annual global steel production at almost 1.5 billion tons (100 million tons in the United States, 96 percent of that through continuous casting), steel production accounts for an important fraction of the total energy consumed and greenhouse gases produced in the world. Even small improvements to this process, can have a profound benefit to society.

Savings/Potential Savings: More than $400 million per year, and keeping many jobs in the US.

Savings/Potential Savings: More than $400 million per year, and keeping many jobs in the US.

FIGURE 9

Modeling Of Metallurgical and Mechanical Processes In Continuous Casting



Source: CCC, The University of Illinois, 2014

Organization

This project is supported by the Continuous Casting Consortium at the University of Illinois and the National Center for Supercomputing Applications (NCSA)

Industry

Manufacturing, Scientific Research, Industrial Products

ROI or Innovation Description

Decreasing the material scrapped due to defects such as cracks, even by a small percentage, results in a large net savings to steel manufacturers and customers. Based on the roughly 100 million tons of steel produced each year in the U.S. and at approximately $400 per ton net cost of scrapping, a one percent reduction in yield loss would save about $400 million per year

Type of ROI

Engineering and manufacturing advances and potentially million of dollars in cost savings

Nature of Research

Continuous casting is an important commercial process to solidify molten metal into semi-finished billets, blooms, or slabs for subsequent rolling. It produces over 95% of steel in the world today, so small improvements have a huge impact. Many defects in final steel products originate in this process. Many defects arise due to problems with the flow pattern, such as level fluctuations that lead to inclusion entrapment. For example, argon gas is often injected into the nozzle to prevent clogging and to help carry away inclusions, in order to improve the steel quality, and also to control the flow. But, this gas also changes the flow pattern, which could be detrimental if not properly taken into account by changing other process variables.

The molten steel flow is also controlled by the nozzle geometry and by Electromagnetic Braking. A magnetic field is generated by applying a direct current to coils, and since molten steel is a conductor, a current field is generated in the fluid, which causes a force that affects flow in the mold cavity. The solidifying shell is very brittle, and if subjected to excessive mechanical or thermal distortion, can form internal cracks, called hot tears. These cracks can lead to defects in the final product, or to expensive and dangerous breakouts, where the solidifying shell tears open and spills molten metal over the casting machine and plant floor. CCC uses supercomputers to improve understanding of this complex process using comprehensive computational models, and to apply those models to find operating conditions to improve the process.

Broader Impact

During the casting process itself, large cracks may cause “breakouts” (where molten steel pours through the crack in the partly-solidified casting, covering the region with superheated molten steel) which are very dangerous (and costly) for the steel plant workers. Undetected defects worsen the mechanical properties of steel products. Increasing casting speed and decreasing spray cooling to conserve just 10% more of the internal energy of the strand would produce energy savings during reheating of $350 million per year, (based on $0.06 per kWH, 100 million tons/year in US) and associated decrease in emissions

Lowering the Fuel Burn and Emissions of Airline Travel (Boeing)

What Was Accomplished

With advanced supercomputers, the Boeing team is able to refine its simulations further and bring safer, more efficient aircraft to market sooner and cheaper.

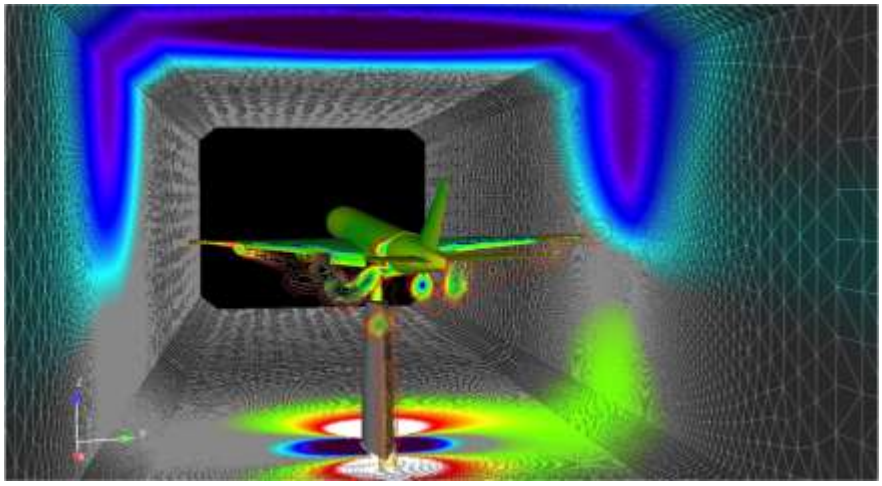
Boeing researchers used the supercomputers to validate aerodynamics codes for airplane design, saving substantial R&D time that otherwise would be spent calculating solutions. The team validated and improved several aerodynamics codes, saving the company time and money and likely influencing the process by which next-generation Boeing aircraft are designed and manufactured.

HPC use has already saved the aerospace industry multiple tens of billions of dollars

Savings/Potential Savings: HPC use has already saved the aerospace industry multiple tens of billions of dollars over time, and has kept the industry and many jobs in the US. This newest achievement could save additional billions.

FIGURE 10

Aircraft Simulation By Boeing



Source: Boeing, 2013

Organization

Boeing

Industry

Aircraft. Aerospace

ROI or Innovation Description

The team validated and improved several aerodynamics codes, saving the company time and money and likely influencing the process by which next-generation Boeing aircraft are designed and manufactured

Type of ROI

Scientific

Type of Innovation

Engineering research innovation

Nature of Research

Researchers at Boeing, utilize simulations to assist in efficient computational modeling and design of passenger and military aircraft. Using HPC resources, enables Boeing to reduce design cost, accelerate R&D while using the best tools and capabilities towards improving the safety and efficiency of modern aircrafts. HPC simulation allows Boeing researchers to improve diverse design characteristics of aircraft components for example wing design and wind tunnel testing.

Computational modeling of different aircraft components in combination with supercomputers have enabled a 50% reduction in wind tunnel testing for lines development. The computers simulations on the supercomputers very closely matched the wind tunnel results of the tests that Boeing performed in several of its facilities around the world

Supercomputing is now used to design a significant chunk of an aircraft from cab design, cabin noise, interior air quality, high speed wing design, wing tip design, exhaust system design, engine bay thermal analysis, vertical tail and aft body design and much more.

Computational modeling techniques have contributed greatly to the development of new products. Boeing anticipates that the twin factors of need to reduce development cost and cycle time will drive greater dependence on computer simulations. Computational models of different components enabled researchers to accelerate innovation and design cycle times while enabling them to explore more variables, thus enabling development of better products.

Broader Impact

The Boeing team can refine its simulations further and bring safer, more efficient aircraft to market sooner and cheaper, all the while keeping America competitive in a global economy. Boeing Corporation physically tested 77 wing designs for the 767 aircraft, but for the new Boeing 787 Dreamliner only 11 wing designs had to be physically tested mainly because over 800,000 hours of computer simulations on supercomputers had drastically reduced the amount of needed physical prototyping. For the latest 747-8 aircraft only 6 wing designs had to be physically tested.

Developing Future Supersonic Turbomachinery (RamGen)

What Was Accomplished

Computer simulations have helped Ramgen design highly efficient CO_2 compressors that can potentially reduce the capital costs of CO_2 compression by 50 percent and produce a minimum of 25 percent savings in operating costs.

Savings/Potential Savings: **capital cost savings of approximately $22 million**

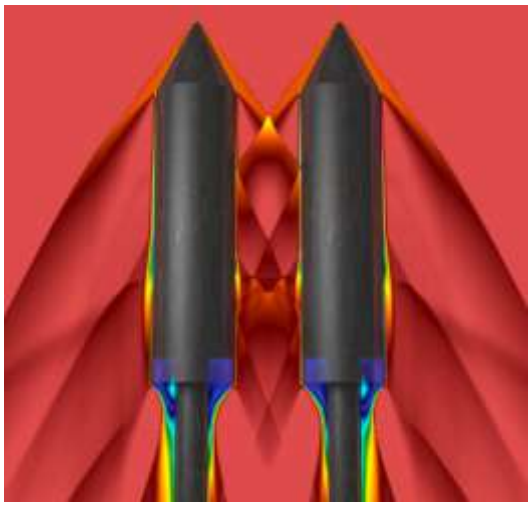
Ramgen Power Systems, a small, Seattle-based energy research and development (R&D) firm, is developing a novel gas compressor system based on shock-wave technology used in supersonic flight applications. These emerging technologies will have significant impact on the broader turbomachinery industry.

Savings/Potential Savings: For each traditional 400 MW clean coal plant, capital cost savings of approximately $22 million and an annual operating cost savings of approximately $5 million..

(INSERT PICTURE)

FIGURE 11

High Resolution Simulation Showing Complex Structures.



Source: Ramgen, ORNL, 2013

Organization

Collaboration between scientists and engineers from Ramgen under funding from Department of Energy and partner Dresser-Rand

Industry

Energy, Aerospace, Manufacturing

ROI or Innovation Description

Engineering advance

Type of ROI

$4 million savings in gas compressor system development.

Nature of Research

Ramgen demonstrated an approach combining high performance computing based computational models to optimize turbomachinery and extensive testing based validation. Simulation models enabled Ramgen to accelerate R&D resulting in significant reduction in time required to optimize technology performance for commercial applications. Realization of these complex and advanced technologies requires groundbreaking advances in fluid dynamics simulations at extremely high speeds.

Ramgen is utilizing shockwave compression, similar to phenomena encountered in supersonic ramjet inlets, to achieve very high levels of turbomachinery performance. Ramgen executed thousands of design combination simulations, with up to 50 parameters each, to find the optimal designs. Using supercomputers to execute their design simulations, Ramgen cut the projected time from concept to commercialization by at least 2 years and reduced the cost by over $2M.

Additionally the simulation driven optimization process has been perfected to require just 8 hours, down from previous requirements of months. Combined effect of these advances is enabling Ramgen to advance the design of turbomachinery to a timeframe that simply would not have been possible without supercomputers and simulation models. The supercomputing driven accelerated R&D will enable Ramgen to test a 13K horsepower CO_2 compressor. By applying HPC to design optimization, Ramgen's work has the potential to reduce decades of traditional development process for aerodynamic refinement of shockwave compression based turbomachinery.

Broader Impact

Ramgen's HPC based designs of shockwave compression technology at the scale, represent a paradigm shift in how new turbomachinery is developed. This process can be scaled to different types of gases as well. These technologies can now enter the marketplace sooner. This compressor technology is projected to reduce the capital costs of CO_2 compression by 50 percent and produce a minimum of 25 percent savings in operating costs. Applying these cost savings to a traditional 400 MW clean coal plant would result in capital cost savings of approximately $22 million and an annual operating cost savings of approximately $5 million, per plant.

D) INNOVATIVE DISASTER MITIGATION AND RECOVERY

Saving Lives and Reducing Cost from Tropical Cyclones (DOD MOD)

What Was Accomplished

Without supercomputer resources or computational models, it would be impossible to reasonably predict potentially life-threatening hurricanes and cyclones.

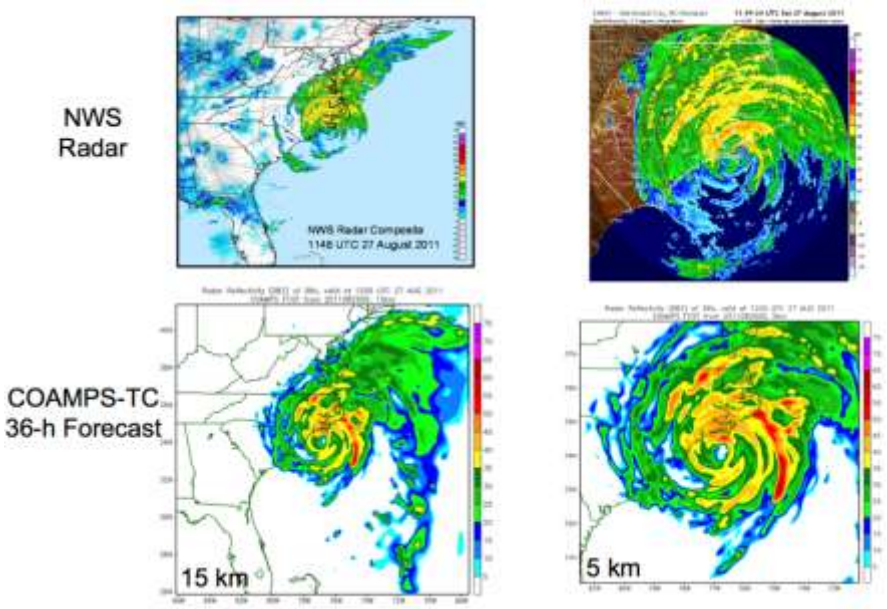
A new version of the software enabled researchers to more accurately predict the track, intensity and size of tropical cyclones with nearly a 120 hour lead time. This new 5-day lead time allows more time to activate emergency evacuations and develop contingency plans.

Savings/Potential Savings: Avoiding hundreds of millions of dollars annually in evacuation costs, as well as the loss of human lives from less-accurate forecasts.

Savings/Potential Savings: **Avoiding hundreds of millions of dollars annually in evacuation costs, as well as the loss of human lives.**

FIGURE 12

Predictions Of Hurricane Irene (Computer Visualizations)



Source: Naval Research Laboratory, 2014

Organization

The Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC™) has been developed by the Naval Research Laboratory (NRL) Marine Meteorology Division in Monterey, California

Supporting Organizations

DOD HPC Modernization program

Industry

Meteorology, weather forecasting, military

ROI or Innovation Description

Significantly improved numerical model for tropical cyclone forecasting. Documented savings of $6 million in one event alone, with far greater potential savings

Type of ROI

Scientific Research and Savings

Nature of Research

The software developed by the Naval Research Laboratory, is designed specifically for forecasting tropical cyclones. The COAMPS-TC model contains a representation of dissipative heating near the ocean surface, which has been found to be important for tropical cyclone intensity forecasts. The system also contains a flexible nesting design that has proven useful when more than one storm is present in a basin at a given time as well as special options for moving nested grid families that independently follow individual tropical cyclone centers of interest.

The system has options to predict the ocean circulation, temperature, and salinity, and ocean surface waves as well as the interactions between the atmosphere, ocean circulation, and waves (Multiple Paragraphs Detailed Description of what was done… Technology detail oriented)

Broader Impact

This has led to significant improvements in the Navy's effort to improve tropical cyclone intensity prediction (COAMPS-TC was the best numerical model for intensity in the Atlantic during the recent 2010-2012 seasons).

In addition, this research will lead to new capabilities in the form of ensemble forecasts, providing the Navy with probabilistic forecasts of tropical cyclone intensity and structure for the first time. It is also expected this research will help motivate new field campaigns that focus on the key measurements needed to further advance our understanding of the convective structure and dynamics of these systems as well as provide validation.

Providing Advanced Warning of Storm Surge and Waves (RENCI)

What Was Accomplished

Supercomputers are used to provide more detailed predictions of coastal storm impacts for vulnerable coastal areas. The University of North Carolina (UNC) and collaborators at Seahorse Coastal Consulting have developed the ADCIRC Surge Guidance System (ASGS) to enable federal and academic research groups to provide high-resolution predictions of storm surge and waves for vulnerable parts of the US Atlantic and Gulf of Mexico coasts. ASGS automates the running of the ADCIRC tide and storm surge model, providing a robust framework for real-time computations in HPC environments. The predictions of storm surge inundation and wind-wave characteristics are made available to forecasting experts and emergency management groups for impacts assessments, evacuation planning, pre-positioning of supplies and response personnel, for search and rescue, and for other event-based decision support as needed. The products provide an additional source of critical information to decision makers, augmenting official guidance from the National Weather Service

Savings/Potential Savings: The costs of the computational resources needed for detailed, high-resolution coastal storm impact predictions inhibits operational centers from directly running the finite element ADCIRC model. Because of RENCI and UNC's work. operational centers have access to additional, much higher resolution geospatial information, potentially affecting large parts of the coastal population and infrastructure. The advancements have led to discussions with the National Hurricane Center to make this type of information easily accessible to storm surge forecasters.

FIGURE 13

Coastal Emergency Risks Assessment Site: Forecast of Hurricane Irene, Advisory 35

Source: Renaissance Computing Institute, 2014

Organization

The research was conducted at Renaissance Computing Institute and UNC

Industry

Weather Forecasting, Oceanography, Coastal Storms Impacts and Risk Assessment

ROI or Innovation Description

This accomplishment has proven to be an innovation in real-time modeling of natural systems and has great potential to generate financial ROI by substantially improving our ability to rapidly and accurately predict the impacts of severe storms in coastal areas. It has enabled more effective awareness and dissemination of destructive impacts of storm surge and waves during events. Together, these greatly improve the ability of coastal communities to respond and be more resilient to catastrophic tropical cyclones and extratropical storm systems

Type of ROI

Innovation and Scientific Research in coastal hazards prediction

Nature of Research

RENCI's high-performance computing resources have enabled the development of a robust forecast system with dedicated supercomputer cycles, which for the last four years has been an important tool during East Coast tropical and extratropical storms. Typical operational resolutions of other products, such as the National Weather Service's surge model, show coastal detail at 2-5 kilometers. The ASGS system is a major leap forward in the evolution of tools and software used to model natural systems. The research involves not only how to rapidly compute predictions, but also how to most effectively communicate the results to decision makers. During Hurricane Sandy (2012), the U.S. Coast Guard (USCG) extensively used the ASGS output graphics, and as Vice Admiral R. C. Parker said, "significantly closed the gap that exists within our current suite of weather prediction tools." During Hurricane Irene in 2011, the USCG used information obtained through this modeling effort in deciding to move its fleet Command and Control from Portsmouth, VA, to St. Louis, MO. The model allowed the USCG to understand that even though Hurricane Irene was a relatively weak storm, coastal flooding and inundation was likely to be widespread. Events unfolded such that the Portsmouth USCG base was flooded and lost power shortly after staff evacuated. The modeling work related to Hurricane Irene was recognized with the U.S. DHS's Science and Technology Impact Award in 2012

Broader Impact

The software advances in ASGS and the use of high-performance computing assets for coastal storm predictions and risk awareness can be applied to understanding the full spectrum of coastal risks and to research into the sustainability of coastal infrastructure. The ASGS system provides the computational framework for extending the research into determining optimal, risk-based evacuation routes and shelter locations during hurricanes, as well as to civil infrastructure planning assessments for the New York Harbor area in the aftermath of Hurricane Sandy

Better Understanding and Forecasting of Earthquakes (San Diego)

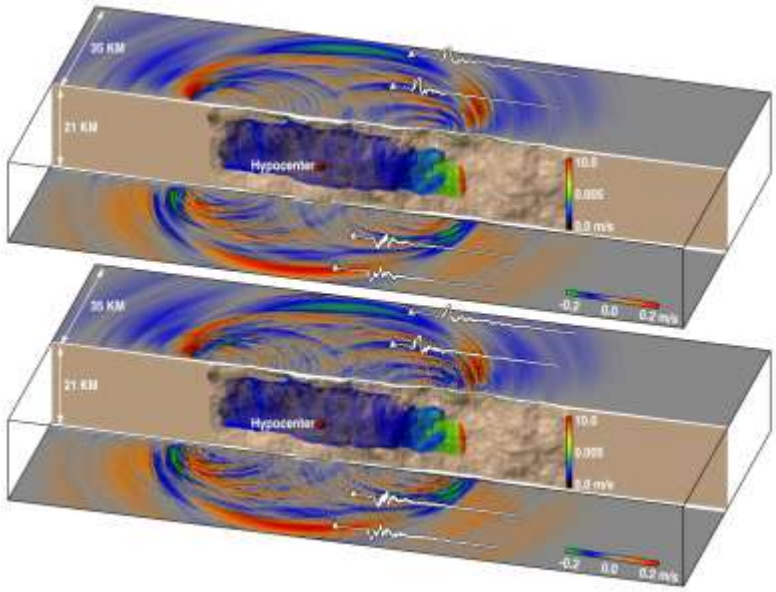
What Was Accomplished

A research team led by SDSC Computational Scientist Yifeng Cui has accelerated seismic simulations to generate advanced hazard maps and this research team developed software that significantly advances this map-making ability.

Savings/Potential Savings: Billions of dollars in preventing property loss/damage, along with protecting lives

FIGURE 14

Simulating Earthquake ground motions relevant to building engineering design



Source: Cui et al. 2013

Organization

This research was carried out by researchers in University of San Diego, San Diego State University, and the broader Southern California Earthquake Center consortium.

Supporting Organizations

Southern California Earthquake Center, Oak Ridge National Laboratory and National Center for Supercomputing Application.

Industry

Scientific Research, Seismic Simulations

ROI or Innovation Description

Researchers simulated realistic 0-10 hertz ground motions on a mesh comprising 443 billion elements in a calculation that includes both small-scale fault geometry and media complexity at a model size far beyond what has been done previously

Type of ROI

Innovative Earthquake Simulation Optional

Nature of Research

In Southern California, it's only a matter of time before a massive earthquake along the San Andreas fault strikes. To help predict the potential destructive power of this quake, supercomputers are being called on to model how waves are generated by and travel outward from the fault, and then interact with complex 3D geological structures, such as sedimentary basins in the Los Angeles region.

Realistic 0-10 Hz earthquake ground motions were simulated, the largest-ever earthquake simulation performed. The code sustained 2.33Petaflop/s on the supercomputer, resulting in a speedup in key strain tensor calculations critical to probabilistic seismic hazard analysis by a factor of 110.

This achievement makes a California state-wide hazard model a goal reachable with existing supercomputers

Broader Impact

Seismic simulations were accelerated to generate a more advanced hazard map, with the potential saving of thousands of lives and properties upon completion of California state-wide seismic hazard map. Savings could be many billions dollars. Incorporating the simulation results into the U.S. Geological Survey's National Seismic Hazard Maps will set building codes and insurance rates, as well as provide short-term forecast of the frequency of damaging earthquakes in California over a specified time span.

Producing realistic seismograms at high frequencies relevant to building engineering design, up to 10 hertz, will require a major increase in supercomputing power with exascale hardware capabilities. Moreover, to realistically calculate seismic hazards across huge expanses of California and other tectonically active regions requires rapid recompilation of the hazard map to reflect short-term probability variations provided by operational earthquake forecasting.

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