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National Aerospace Leadership Initiative - Phase II

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Connecticut Center for Advanced Technology, Inc., Avetec, Inc and Concurrent Technologies Corporation

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NATIONAL AEROSPACE LEADERSHIP INITIATIVE

Final Progress Report for Period June 1, 2006 to December 31, 2009

THE NATIONAL AEROSPACE LEADERSHIP INITIATIVE-Phase II

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Executive Summary

The National Aerospace Leadership Initiative (NALI) was created to respond to the critical needs of the United States aerospace small-to-medium size manufacturers (SMM) and the manufacturing supply chain. Its initial focus has centered on needs of the United States Air Force (USAF) advanced propulsion and power systems and it has expanded to other critical components of our nation's weapons systems. The NALI goal is to assure the effectiveness of an innovative and highly-competitive domestic aerospace manufacturing supplier base to meet the current and future requirements of the Department of Defense and the U.S. national economy. This initiative supports maintaining U.S. leadership in aerospace applied research and development, fortifies the U.S.-based manufacturing supply chain, and helps to reinforce the U.S. aerospace original equipment manufacturers' technology and production market share as well as the underlying supply base. The three major objectives are to:

1. Strengthen the U.S. aerospace manufacturing supply chain
2. Accelerate technology transition from research to application– advanced laser processes, machining, and modeling and simulation
3. Assure an educated, capable aerospace manufacturing workforce

The NALI program is being executed in multiple, overlapping phases. Four NALI phases have been initiated to date and this document constitutes the Final Report for NALI Phase II. Timelines for the existing four phases are follows:

NALI I	May 15, 2005 – June 30, 2008 (completed)
NALI II	June 1, 2006 – December 31, 2009 (completed with this report)
NALI III	April 1, 2007 – March 31, 2012
NALI IV	June 6, 2008 – June 14, 2013

Implementation of the NALI program is performed by the NALI Consortium of three not-for-profit organizations in partnership with the U.S. Air Force. The three consortium members are:

Connecticut Center for Advanced Technology, Inc. (CCAT), headquartered in East Hartford, CT
Avetec, Inc. headquartered in Springfield, OH, and
Concurrent Technologies Corporation (CTC), headquartered in Johnstown, PA.

The NALI Phase II program is administered by the Air Force Office of Scientific Research.

To achieve its mission, the CCAT-led NALI Consortium works closely with the U.S. research and development community, OEM and prime contractors, and with small to medium size aerospace manufacturers to enhance and accelerate the transition of leading edge technologies. Additionally, the NALI Consortium collaborates with the Air Force Research Laboratory (AFRL), Air Force Materiel Command (AFMC), USAF Air Logistics Centers, Office of Installations, Environment, and Logistics (SAF/IEL), the Office of Science, Technology, and Engineering (SAF/AQR) at HQ USAF, and others.

Each of the current four NALI Phases incorporates four main tasks:

Task I -	National Center for Aerospace Leadership (Program Execution)
Task II -	Application of Modeling and Simulation to Accelerate Technology Transition and Assure the Effectiveness of an Integrated Supply Chain.
Task III -	Transition Next Generation Manufacturing Technologies
Task IV -	Address Total Supply Chain Enterprise Effectiveness

Task I – National Center for Aerospace Leadership (Program Execution)

Program and project planning, communication, and execution are coordinated under Task I. This CCAT-led task is executed in a neutral, trusted, objective manner that brokers knowledge, technology, and best practices among government, commercial manufacturers, and academia. Innovation and collaboration are fostered to rapidly meet the changing demands of the DoD and commercial aerospace for new systems and life cycle sustainment. Educational initiatives and workforce development activities are also coordinated under this task. Consortium partners promote the value and importance of manufacturing as a career choice and as an economic force to compete globally by strengthening the U.S. aerospace manufacturing supply chains, focusing on small and medium sized enterprises. As a focal point for a knowledge network that identifies, creates, and transitions strategic technologies, the development of a workforce capable of employing those technologies is nurtured. The goal is to elevate the visibility, capability and relevance of aerospace manufacturing locally, regionally, and nationally by providing solutions that are disseminated throughout the supply chain. Highlights for NALI Phase II include:

- CCAT established the leadership team that has facilitated both technical and management collaboration with the DoD/USAF, industry and academia. Clear communications with USAF Senior Managers and Technical Leaders have been strengthened to clearly define USAF high priority needs and select which NALI Consortium capabilities were to be implemented to provide solutions for those needs.
- Increased SMM and manufacturing supply chain companies' awareness of global progress being made in critical technologies, including modeling and simulation, supply chain effectiveness and laser based manufacturing processing. The Symposium for Aerospace Laser Applications (SALA) has become an annual event in East Hartford, CT that has been well attended by large OEMs and SMMs. The Consortium has been represented at key national conferences, including the Johnstown Showcase, Defense Manufacturing Conference, and the AIAA. In addition, the annual NALI Review and Technical Workshops continue to serve as an effective channel to communicate and demonstrate specific initiative achievements.
- CCAT, Avetec, and CTC executed educational programs to enhance student interest in the future of the aerospace industry and opportunities to work for the Air Force, including the LaunchQuest™ Program, STEM (Science, Technology, Engineering, and Math) Curricula, the *Wright Scholars Program* at the Wright-Patterson AFB Research Center, the STARBASE Program, and others.

- CTC conducted a Small Business Innovation Research (SBIR) event on May 31, 2007 and CCAT conducted, with support from NALI, the 2009 National SBIR Conference in Hartford, CT.

Task II - Application of Modeling and Simulation (M&S) to Accelerate Technology Transition and Assure the Effectiveness of an Integrated Supply Chain

This task builds and utilizes a distributed network of expertise and capabilities to solve critical problems and increase supply chain capabilities, which focuses on the application of Modeling and Simulation for advanced gas turbine engine performance as well as manufacturing, machining optimization, and sustainment processes. Activities specific to sustainment, legacy systems and reverse engineering are strengthened both in engine performance prediction and analysis as well as manufacturing process optimization. Highlights include:

- Demonstrated and validated M&S capabilities for manufacturing companies as follows:
    - Completed implementation of the Modeling and Simulation Laboratory at CCAT with more than fifty software tools for product and manufacturing process design and optimization as well as develop materials to distribute these tools for SMM and DoD use.

    - Developed a unique interface between Value Stream Mapping software (eVSM) and a Discrete Event Factory Modeling Environment to dramatically reduce the amount of time it takes to build a working factory model (from days to minutes) in order to support Lean Manufacturing "what if" analysis activity.

- Avetec developed and demonstrated significant advances in gas turbine engine performance modeling and simulation to solve the following problems related to aircraft propulsion systems:
    - Thermal Management – Avetec collaborated with a large aircraft manufacturer to understand the structure and underlying thermal physics of an existing MATLAB-based thermal management code in order to streamline this model to make it more generalized for users and to develop generic physics-based models for engine components and other necessary components.

    - Developed and applied Computational Fluid Dynamics (CFD) code for jet engine turbo machinery through a university, government and industry collaboration. CFD tools were applied in full annulus simulations of aircraft jet engines, and elements of the research were published at the International Gas Turbine Institute Turbo Expo (conference) in Montreal in May, 2007

    - Devised and validated CFD code for operation of a micro-channel heat exchanger.

    - Modeled gas turbine combustor flow field using Large Eddy Simulation (LES) techniques.

- Constructed detailed, non-proprietary turbine engine models that can be used by the Air Force, government contractors, educators, and researchers as a medium for the development of new turbine engine, control, and health management technologies

- Initiated time and cost saving activities with OC-ALC with the development of a virtual engine test cell

- Developed a laboratory and framework for virtual testing and prototyping turbine engine health management systems.

Task III - Transition Next Generation Manufacturing Technologies

In Phase II, knowledge and application of state of the art and next generation laser technologies was advanced. Targeted areas of concentration included laser drilling (of new and used components) for turbine airfoils and larger sized components (e.g., combustor, augmenter, and nozzle applications). Substrate material properties were taken into consideration, including ceramic-based thermal barrier coatings (TBC's) and "special" coatings, particularly in the areas of material property impact to sensing, measurement and breakthrough detection. Establishment of CCAT's Laser Applications Laboratory that includes next generation laser drilling workstations implemented as a flexible system to support new developing applications was a major objective of this task and was completed. Opportunities for qualification and implementation of precision laser machining and welding applications for Air Force needs were identified and tested under this task. Highlights include:

- Significant progress on the grand challenge of producing "designer" shaped cooling holes for military gas turbine engine airfoils directly from 3D files by solving software, machine tool motion and metallurgical issues to demonstrate next generation laser precision machining. A technique to detect hole breakthrough during laser drilling by acoustic monitoring and spectral analysis techniques have been advanced significantly.
- Developed laser part marking processes and optimization to maximize "readability" and durability while minimizing material damage, for application to meet the DoD's Unique Identifier (UID) initiative.
- Increased education in the area of laser technology through the support of university level courses, thesis research, senior capstone projects, and internships as well as hosting professional society meetings and workshops
- Demonstrated the use of a laser-generated, crack-like feature for more consistent, timely, and cost effective sample generation and materials property (and component) validation.

Task IV - Total Supply Chain Enterprise Effectiveness

The competitiveness and effectiveness of U.S. aerospace industry are closely linked to the extended enterprise of a network of small to medium manufacturers in a supply chain. This task focuses on overall supply chain enterprise effectiveness and brings into use advanced Information Technology (IT) and web-based capabilities that improve responsiveness to war fighter needs. Advances in supply chain planning, management, and execution were formulated. Highlights include:

- CTC completed the development of the framework for a V*isualization Support Tool*. This tool can provide total asset visibility of the supply chain from war fighter to manufacturer that can be synchronized with emerging Air Force systems.

- Continued development effort for a Web-Enabled framework for an *Advanced Decision Support Tool*. This tool will enable decision makers throughout the United States Air Force (USAF) and aerospace industry supply chain to initiate actions to improve the effectiveness and efficiency of the supply chain in meeting war fighter needs.

- CCAT develop a Supply Chain Service Center that, upon request, identifies companies that meet certain manufacturing requirements - including process and equipment capabilities, production capacity, quality certifications and delivery schedules. This project will develop the general structure of the service, evaluate and assess through interviews and surveys the need for the service and assuming the need is confirmed, conduct a pilot program to demonstrate that the process works.

- CCAT piloted a new SME benchmarking activity. The benchmarking pilot used the "PROBE for Manufacturing" tool to engage companies in workforce development, market expansion, and productivity improvement.

Bottom Line: In Phase II of the National Aerospace Leadership Initiative excellent progress has been made towards meeting its stated objectives. Building upon the first NALI phase that was focused upon organizing and creating the capabilities needed to achieve task objectives, many accomplishments have been made and a solid foundation of management and technical skills are in place. Through the efforts of the Connecticut Center for Advanced Technology, Avetec and Concurrent Technologies Corporation, the NALI Consortium has established a national capability to strengthen our U.S. aerospace manufacturing supply chain network to compete in the global market place and contribute to national security. The Consortium has made significant strides in NALI Phase II towards communicating with and collaborating with the USAF to apply those capabilities to high priority USAF technical challenges.

THE NATIONAL AEROSPACE LEADERSHIP INITIATIVE – PHASE II

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1. Introduction

Given the evolving global security and economic threats to our Nation, it is imperative that the United States maintain its world leadership in advanced propulsion and power systems, as well as preserve an innovative and highly competitive domestic aerospace manufacturing supplier base to meet the Department of Defense's and the nation's current and future industrial needs. The National Aerospace Leadership Initiative (NALI) responds to the critical needs of the United States aerospace manufacturing supply chain. It is focused on needs of the U.S. Department of Defense (DoD), particularly the needs of the U.S. Air Force, to assure the effectiveness of an innovative and highly-competitive domestic manufacturing supplier base to meet the current and future DoD requirements. The three major objectives are to:

1. Strengthen the U.S. aerospace manufacturing supply chain – advanced lasers processes, machining, and modeling and simulation
2. Accelerate technology transition from research to application
3. Assure a workforce capable of technology implementation

This initiative is used to support U.S. leadership in aerospace research and development, fortify the U.S.-based manufacturing supply chain, and advance our nation's manufacturing technology. NALI funded activities were carried out by three organizations referred to as the NALI Consortium (or Consortium):

- Connecticut Center for Advanced Technology, Inc. East Hartford, CT
- Avetec, Inc.; Springfield, OH
- Concurrent Technologies Corporation; Johnstown, PA

The NALI Program is comprised of four separate, overlapping phases that span the time period from May 2005 (start of NALI Phase I) through June 2013 (end of NALI Phase IV).

	Start Date	End Date
NALI I	May 2005	June 2008
NALI II	June 2006	December 2009
NALI III	April 2007	March 2012
NALI IV	June 2008	June 2013

The NALI funded activities are structured into four tasks:

Task I	National Center for Aerospace Leadership (Program Execution)
Task II	Enhance the Application of Modeling and Simulation (M&S) to Accelerate Technology Transition and Effectiveness of an Integrated Supply Chain.
Task III	Transition Next Generation Manufacturing Technologies
Task IV	Address Total Supply Chain Enterprise Effectiveness

This Final Performance Report summarizes accomplishments for the second phase of the NALI Program (i.e., NALI II). The NALI Phase II effort was started on June 1, 2006 and it extended through December 31, 2009.

Task I – National Center for Aerospace Leadership (Program Execution)

Program and project planning, communication, and execution are coordinated under Task I. This CCAT-led task is executed in a neutral, trusted, objective manner that brokers knowledge, technology, and best practices among government, commercial manufacturers, and academia. Innovation and collaboration are fostered to rapidly meet the changing demands of the DoD and commercial aerospace for new systems and life cycle sustainment. Educational initiatives and workforce development activities are also coordinated under this task. Consortium partners promote the value and importance of manufacturing as a career choice and as an economic force to compete globally by strengthening the U.S. aerospace manufacturing supply chains, focusing on small and medium sized enterprises. As a focal point for a knowledge network that identifies, creates, and transitions strategic technologies, the development of a workforce capable of employing those technologies is nurtured. The goal is to elevate the visibility, capability and relevance of aerospace manufacturing locally, regionally, and nationally by providing solutions that are disseminated throughout the supply chain.

Major objectives for this task are:

- Identify high priority USAF needs and utilize technical capabilities of the Consortium to solve those needs.
- Strengthen the effectiveness of OEM led manufacturing technology development teams to produce best in world advanced military power and propulsion systems
- Develop, support and maintain a domestic workforce that is world class in cost, capability and performance
- Assist government programs like the Small Business Innovation and Research (SBIR) program to encourage technology transition to Air Force benefit.

Task II - Application of Modeling and Simulation (M&S) to Accelerate Technology Transition and Assure the Effectiveness of an Integrated Supply Chain

The complexity of work interactions within manufacturers' firms, the components and systems design and the external network of firms involved, makes modeling and simulation an important set of tools to enhance the U.S. aerospace industry productivity. This task builds and utilizes a distributed network of expertise and capabilities to solve critical problems and increase supply chain capabilities that utilize Modeling and Simulation for advanced gas turbine engine performance as well as manufacturing, machining optimization, and sustainment processes. Activities specific to sustainment, legacy systems, and reverse engineering are strengthened both in engine performance prediction and analysis as well as manufacturing process optimization.

Major objectives for this task are:

- Create novel, innovative improvements to commercially available value stream mapping programs and factory models.

- Develop machining models and process models for the manufacture of advanced aerospace components.
- Collaborate with NASA and other national experts to simulate the integrated fan and engine inlet for aerothermal and mechanical response.
- Develop physics-based hot section models, combined with real-world aircraft performance data, to increase turbine durability
- Devise innovative high speed computing techniques

Task III - Transition Next Generation Manufacturing Technologies

This task advances the knowledge and application of state of the art and next generation laser technologies and other manufacturing technologies. Targeted areas of concentration include laser drilling (of new and used components) for turbine airfoils and larger sized components (e.g., combustor, augmenter, and nozzle applications), laser-based coatings removals, and advanced machining.

Major objectives for this task are:

- Develop novel laser-based manufacturing processes using state-of the art laser systems
- Develop advanced metrology and reverse engineering techniques for manufacturing aerospace components.
- Transition new manufacturing processes and technologies to the US aerospace supply chain.

Task IV - Total Supply Chain Enterprise Effectiveness

This task focuses on overall supply chain enterprise effectiveness and seeks to bring into use advanced IT and web-based capabilities that improve responsiveness to war fighter needs. Advances in supply chain planning, management and execution were identified and implemented within this task.

Major objectives for this task are:

- Expand the capabilities of a data visualization application and integrate into a prototype real-time information system to provide total asset visibility.
- Strengthen and improve resiliency of the domestic USAF supply base for critical components such as bearings.

The subsequent sections of this Final Report provide detailed summaries of the NALI Phase II accomplishments for each of the four major tasks.

2. Summary of Accomplishments

2.1. Task I - National Center for Aerospace Leadership (Program Execution)

2.1.1. Planning and Execution

Detailed planning and effective communication with USAF, SMMs, and other stakeholders helped ensure that Consortium efforts were executed properly with greatest positive impact. In NALI II, CCAT made significant progress on behalf of the Consortium in engaging with and communicating with the USAF and stakeholders. In-person planning meetings and teleconferences took place in 2009 with primary customers/stakeholders SAF/IEL, AFMC, AFRL, Tinker AFB, aerospace manufacturers, and others. As a result, technical plans and budgets were defined for those projects that were deemed as high priority by the USAF. Some of the USAF high priority projects identified were:

- Non-Destructive Inspection (NDI) for Corrosion
- Helium-Based Detection of Aircraft Fuel Leaks (new start in 2010)
- Laser Hole Drilling
- Supply Chain Risk Analyses
- eVSM Mapping and Factory Modeling
- Gas Turbine Engine Modeling
- Metrology (non contact inspection) and Reverse Engineering
- Air Logisitcs Center Bearings Supply
- STEM and /workforce development
- Assist government programs like the Small Business Innovation and Research (SBIR) program to encourage technology transition to Air Force benefit.

2.1.2. Education Activities

Education efforts have focused on engaging and inspiring K-12 students through project-based learning opportunities that develop the 21st century skills necessary for successful STEMM (science, technology, engineering, math, and manufacturing) careers. The Consortium's education mission develops and supports programs that advance scientific and technological literacy, stimulate innovation and enterprise, and promote training of the emergent workforce.

- LaunchQuest

  With the shrinking of NASA's budget and reduced resources for K-12 education, opportunities for student access to space have been limited. To address this gap, CCAT's Education team forged a partnership with commercial launch services provider UP Aerospace, Inc. to create LaunchQuest, a science education program that gives middle and high school students an opportunity to design research experiments that are sent into space. The parameters for every flight are unique, allowing each launch to be a testing environment for experimentation that cannot be conducted within the normal constraints of gravity and atmospheric pressure. Experiments have ranged from simple "fly and compare" (seeds, yeast, popcorn), to far more complex biological and materials science and technology and engineering investigations. By engaging students in authentic science and technology research projects, LaunchQuest develops interest in 21st century aerospace and engineering careers, while the partnership with UP Aerospace gives students a unique opportunity to experience how entrepreneurship and scientific progress go hand in hand. Through 2009, seven payloads have flown on three missions. LaunchQuest teams have come from NALI consortium partners and NASA Explorer Schools, representing over 50 schools from 17 states; more than 1000 students have collaborated on 108 experiments. An example of teacher evaluation of the LaunchQuest program includes the following comments: *"Encouraging students in their pursuit of learning with an emphasis in science is so important for our schools and for our country,"* and *"This has been a wonderful science and technology program for our students. They are proud of their work on this project and I believe this is just the beginning of the great things they will do in science and aerospace in the future."*

- CATALYST: Explorations in Alternative Energy and the Environment

  CATALYST is a weekly after-school enrichment program that engages students from diverse urban and suburban schools in the greater Hartford, CT area in hands-on, minds on inquiry-based science and engineering design activities, online resources and Web 2.0 collaboration tools, and field trips to industry sites to investigate sustainable energy and global climate change. The CATALYST curriculum is aligned with state frameworks and science content areas. For the capstone project, school teams create proposals for the elimination of the use of fossil fuels for electricity generation in three realistic communities. In its most recent iteration, teams prepared a mock presentation to obtain funds from the American Recovery and Reinvestment Act of 2009. Proposals received funding based on the degree to which they balanced environmental impact, social concerns, and financial costs for their particular community. Through participation in the CATALYST program, students are developing interdisciplinary skills in the areas of scientific inquiry and engineering design, information technology, and 21st century skills (especially collaboration, problem solving, and communication). CATALYST has created an opportunity for almost 200 students from dissimilar socio-economic backgrounds to collaborate using science investigation as an agent for social change and policy development. The program has also benefited participating teachers by providing opportunities to collaborate and share educational practices, as well as augmenting their content knowledge in a variety of science disciplines and workforce-related fields.

- Young Manufacturers Summer Academy (YMSA),

  The Young Manufacturers Summer Academy is a two week, manufacturing-themed, experiential, student summer program. The Academy provides an introduction to Connecticut's high-tech advanced manufacturing industries through hands-on activities and simulation-based learning, virtual machining environments, and travel to industry locations for on-site interaction with manufacturers. YMSA will educate up to 180 students in grades 7-9 about emerging opportunities in advanced manufacturing through shop-floor, CAD/CAM, and career development activities.

- High-Tech Racing Challenge and Operation: Save the Astronauts!

  These hands-on workshop opportunities were developed for students participating in the DoD (Department of Defense) CT-STARBASE program. STARBASE is a national program, funded and supported by the Office of the Assistant Secretary of Defense for Reserve Affairs, which exposes students to activities in aviation and space exploration and gives them an opportunity to explore careers and make real-world connections. Students attending the first workshop see demonstrations of virtual reality simulations and engage in a problem-solving activity in 3-D modeling using SolidWorks© software. Students learn how these tools are used, as teams complete a challenge to design a futuristic vehicle that will compete in virtual "races" at the end of the workshop. The second workshop focuses on aerospace engineering through a brief history of space flight, a variety of hands-on activities woven together through a realistic and compelling problem-based scenario, a brief discussion of career opportunities in the field, and, time permitting, demonstrations of core force and motion concepts.

- The Future is Now and Eyes ⦿n the Future

  Working with Junior Achievement, CCAT's Education Initiative developed two new middle school curriculum modules focused on manufacturing and 21st century careers. "The Future is Now" presents a short biography of a manufacturing entrepreneur, an historical timeline, and an overview of next generation manufacturing. The student activity is an exercise in creating CNC machine code using simple graph paper, to see how this code can be used to make an actual manufactured "product." The second activity, "Eyes ⦿n the Future," introduces students to the high tech fields of nanotechnology, laser applications, aerospace engineering, and hydrogen fuel cell technology. Student teams work collaboratively to create a presentation that describes their field with the goal of recruiting their fellow students into careers in that area during a "21st Century Job Fair."

- The Quest to Fly

  The Quest to Fly is an after school enrichment program focused on increasing the number of students—especially girls and underrepresented minorities—engaged in STEM activities; enhancing student achievement in STEM content areas and motivating students to seek additional learning opportunities; and introducing STEM-related career opportunities. "Fly" engages students and industry mentors in hands-on, minds on inquiry-based science and engineering design activities; the curriculum explores the history of flight and the science, engineering, discovery, and innovation that has driven the fields of aviation and aerospace to greater heights. The program was recognized this year by the CT Governor's Prevention Partnership as one of the State's outstanding mentor supported activities.

- NASA-PLAN Teachers Academy

  One of the first and most fundamental steps in achieving the goal to improve STEM education and engage students in future career opportunities is to create a cadre of teachers trained in emerging fields and cognizant of the real-world application of new technologies to the needs of society. The NASA-PLAN Academy is an innovative professional development program that was designed to give middle and high school teachers the first opportunity to align high technology skill requirements with their own districts' curricula and with Connecticut's K-12 Science Framework. University professors and industry experts act as "master instructors," providing participating teachers with background information and hands-on experience on the nature and practical applications of **P**hotonics, **L**asers, **A**eronautics, and **N**anotechnology (**PLAN).** Morning sessions consist of traditional instruction where instructors introduce fundamental PLAN concepts. The afternoons are spent working with engineers and professors in research laboratories or touring local companies, providing educationally appropriate experiences to help classroom teachers make industry connections and infuse the selected technologies into their content areas. Teachers also work cooperatively in small groups to develop activities and curricula they use to introduce their students to PLAN technologies.

Thirty-two science, mathematics, and technology education teachers—from 15 school districts representing a cross-section of the state—have attended the NASA-PLAN Academy over the last two years. Many came from school districts with large, at-risk, underrepresented student populations targeted to address a cohort that traditionally does not pursue careers in STEMM. The impact of the instruction they received is exponential, as each was able to deploy strategies not only horizontally across their classes, but vertically to departmental colleagues. In addition to pre- and post-surveys and frequent conversations, teacher-response chat rooms help measure the success of the PLAN Academy. Feedback has been overwhelmingly positive in responses documented in surveys, which are available on the PLAN Academy website at http://education.ccat.us/plan.

- Interactive Online Learning Environment
  CCAT worked closely with Westfield Technical High school to provide access to the Immersive Learning Environment to get feedback on the usability of this technology to teach technical students the concepts of NC Programming. Central Connecticut State University also included access to this software as part of their curriculum and provided us with feedback on the capability. We are currently engaged in getting the software into a beta testing program with 4 technical high schools within Connecticut. We are also engaged with companies to show how they can customize this solution for teaching other subjects and for certifying the knowledge retained by the student in an online environment. The technology has been shown to the machining group at Warner Robins Air Force Base, and we anticipate showing it to the other ALC's in the near future.

Avetec's education team conducted a strategic planning process to develop its approach for addressing Science Technology Engineering and Math (STEM) challenges in the Springfield, Ohio region. The following table summarizes the conditions of that area and outlines Avetec's core plans to address those conditions. As seen in the table, within the area a transition is taking place in the economic conditions. A reduction in traditional manufacturing jobs and an increase in advanced manufacturing, research and related high technology jobs is anticipated. This creates a challenge for work force development. In order to address this challenge the Avetec educational outreach activity has focused on the actions shown. Desired outcomes and expected impact with their trends are shown in remaining columns of the table.

Table 1. Educational Challenges and Overall Goals

Conditions	Actions	Outcomes	Impact
Traditional Manufacturing	Create STEM Awareness • Community • Educators • Students	Number of students leaving high school and Entering STEM majors in college	Improved economic climate
Advanced Manufacturing, Research, Aerospace, Computer Modeling, High Technology	Create change in educational attainment levels	Number of college students graduating in STEM majors	Higher employment rates
Lack of skilled workers to fill new needs	Connect education with STEM career opportunities	Number of persons entering STEM careers in our region	Wages
			Higher college attendance rate
(Decreasing Trend)			(Increasing Trend)

Through NALI, Avetec's education team made a significant impact toward the above planned outcomes by focusing on the following strategies:

1. Increase the Quantity and Quality of Science, Technology, Engineering, and Math (STEM) graduates

2. Improve the Curriculum in Science, Technology, Engineering, and Math to match industry requirements

3. Increase Co-op, Internship and Employment Opportunities in Science, Technology, Engineering, and Math fields

4. Support Faculty Development in STEM fields

5. Increase the Community's Involvement and Understanding of Career Opportunities in STEM fields

Specifically the following outcomes were accomplished:

<u>52 students entered employment in STEM career fields.</u>

This included internships at Avetec and at Wright Patterson Air Force Base. Students were from area high schools, colleges and universities. This included a special partnership with Ohio's only public, historically black university, Central State University which provided funding to allow computer science students to work at Avetec during the summers of 2008 and 2009. Another example is the unique arrangement Avetec has with the Air Force Research Labs at WPAFB which resulted in 25 high school and college students working as Wright Scholar Research Assistants in the labs, many of whom have now been hired by the Air Force. A third prong of Avetec's internship approach is a relationship it has developed with the National Air and Space Intelligence Agency to create intelligence analysts for the future. Eight students worked on NASIC projects in 2009 producing three intelligence reports using open source data; the reports were accepted by NASIC, classified, and published in the intelligence community.

Figure 1. Wright Scholar Student Research in the AFRL Human Effectiveness Directorate

The above internships have resulted in at least 6 of the students obtaining on-going STEM career positions working with Avetec and the Air Force while the balance of students have returned to school, continuing their pursuit of higher degrees in STEM fields.

<u>630 students were introduced to engineering careers at the high school and middle school levels through implementation of PROJECT LEAD THE WAY (PLTW).</u>

Prior to Avetec's involvement no school in Springfield/Clark County was participating in the national high school pre-engineering program, PROJECT LEAD THE WAY (PLTW). Avetec's educational outreach team worked with community business and education leaders to assist three local school districts to implement PLTW, resulting in 630 high and middle school students to enroll and gain dual high school and college credit for the pre-engineering curriculum they entered. PLTW is now fully integrated into the curriculum in 4 area high schools and Gateway to Technology is operational in 3 middle schools with 3 additional middle schools considering implementation. In addition two elementary schools are currently working to implement the PLTW elementary curriculum. This has helped move educational thinking our area to a community-wide awareness of the need for engineers and other STEM professionals.

Figure 2. Clark County Students Investigate Solid Modeling.

3000 students, teachers and parents were involved in Avetec partnership programs including the national Department of Education Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP) and the Department of Defense STARBASE program at WPAFB.

Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP) is a national model program which assists under-performing school districts increase the number of students graduating and entering college. Clark County's college-going rate is among the lowest on Ohio and Ohio is 44th in the country. Avetec placed a staff person with the local GEAR UP project to assist Springfield students to enter college, specifically in STEM fields.

The Department of Defense funds STARBASE, a STEM learning program for 5th graders at WPAFB. Avetec has assisted to expand the program by providing transportation and teaching staff, allowing every fifth grader in Springfield to attend the STARBASE program at WPAFB. By broadly addressing all students Avetec has assured that an entire cohort of students in Springfield have access to early information about science and technology careers available at WPAFB and other STEM employers.

Figure 3. Clark County Student Participation in the STARBASE Program.

other community involvement to increase STEM awareness.

When Avetec began business in 2005, the phrase "STEM education" was literally an unknown term in our area. Through participation in Clark State Community College committees; Springfield Area Chamber of Commerce forums; Wittenberg, Wilberforce and Central State

Universities committees; the local Heritage Center and library task forces and numerous other community venues, Avetec has helped the Springfield/Clark County region mature an understanding of the need to focus on 21st century aerospace and STEM education in order to sustain our country's leadership in aerospace, engineering, advanced manufacturing and other technology fields.

2.1.4 Outreach

To execute an effective and credible initiative, activities under NALI must become an integral part of the local, regional and national aerospace environment. This means identifying and understanding key stakeholders, similar organizations, past efforts and where there may be points of collaboration or conflict.

Initial outreach activities revolved around the USAF, New England, Pennsylvania and Ohio aerospace manufacturers, Connecticut, Pennsylvania and Ohio schools and higher education institutions, and various state government agencies. Concurrent Technologies Corporation conducted a Small Business Innovation Research (SBIR) event on May 31, 2007. The purpose of this event was to assist and educate small businesses seeking funding from the over $2 Billion in SBIR/Small Business Technology Transfer Research (STTR) annual grants for developing technology or innovation. CCAT conducted, with support from NALI, the 2009 National SBIR Conference in Hartford, CT. Many of these outreach activities are described in following sections of this report.

A closer relationship with the Air Force Research Laboratories (AFRL) at Wright-Patterson AFB, OH was pursued and established. Likewise, relationships with Tinker AFB, USAF Global Logistics Support Center, and SAF/IEL, have been strengthened. Memberships have been taken in the National Defense Industries Association (NDIA), the Aerospace States Association (ASA), the National Council for Advanced Manufacturing (NACFAM), PDES, and the Supply Chain Council. Through these venues the Consortium stays current on relevant events, builds relationships with key people, and makes its presence known.

Important too is attending relevant DoD and commercial conferences and symposia. The Consortium attended high value defense conferences like the Defense Manufacturing Conference, the AFRL Wright Dialogues and the Turbine Engine Technology Symposium. Consortium members have spoken at conferences relating to various aspects of aerospace technology, manufacturing, workforce, as well as related business and logistics topics.

CCAT has created two annual outreach events: The Annual NALI Review and the Symposium for Applications of Lasers in Aerospace (SALA). The Annual NALI Reviews summarize the progress to date that the Consortium members have made towards accomplishing the task objectives of the NALI Grant. In conjunction with the review, workshops are held to provide a deeper understanding of the technologies that have been developed by the NALI Consortium. The SALA is a forum for describing and showcasing advances in the use of lasers in manufacturing. It combines the presentation of CCAT Laser Applications Laboratory advances with other papers and lectures on specific laser capabilities, and includes workshops. The most recent SALA event, held in April 2009, marked the fourth year that this outreach event was completed. Members of the CCAT staff and of our two Consortium members have also participated in a number of local events in CT, OH and PA which have helped raise awareness of the work being done.

2.2. Task II – Enhance the Application of Modeling and Simulation to Accelerate Technology Transition and Effectiveness of an Integrated Supply Chain

This task established the use of Modeling and Simulation (M&S) as the foundation for product development and total life cycle effectiveness to accelerate technology transition and to enhance productivity of an integrated supply chain. Aerospace systems and their design, building and in-service support are hugely complex. To effectively enhance designs, interactions, processes, and machines, modeling and simulation is needed. Through M&S, complexities of engineering systems, of machining and factory processes, and of the response of the network of activities can be better understood. The use of M&S provides the ability to reduce risk of changes while seeing potential results more clearly. Each of the NALI consortium members brought key strengths to the M&S activities to address several objectives in:

- Machining modeling and process/factory modeling and optimization (led by CCAT)
- Gas turbine engine performance modeling and high performance computing (led by Avetec)

Introduction and Scope of CCAT's M&S for Manufacturing Efforts

Under the NALI Phase II program, the CCAT Modeling and Simulation Team organized the efforts into distinct categories for applying manufacturing process modeling software tools, as shown in the list below. Included in this section of the Phase II final report are the activities that have been accomplished in these categories. The efforts of the team were focused on applying Commercial Off the Shelf (COTS) manufacturing process modeling tools that can provide the end user with methods to optimize the utilization of their manufacturing or maintenance assets.

2.2.1 Assembly Sequencing
2.2.2 Ergonomics and Virtual Reality
2.2.3 Robotic Workcell Design and Offline Programming
2.2.4 CAD/CAM Assessments
2.2.5 Machining Process Analysis/Optimization
2.2.6 Virtual Machining for NC Verification
2.2.7 Interactive Learning Environments
2.2.8 Integrated Manufacturing Models
2.2.9 Knowledge Based Manufacturing Technology
2.2.10 Composites Manufacturing
2.2.11 Value Stream Mapping and Factory Modeling
2.2.12 Electronic Work Instructions

The primary focus of the CCAT M&S team was to put together a collection of technology solutions and tools and to build a highly capable team of application engineers that know how to apply these tools. This is being accomplished through a series of technology demonstration projects at both Small Manufacturing Enterprises and with the USAF. With these projects the hope is to introduce our partners to the capabilities of these tools and to help them verify the capabilities for their own future adoption or to establish the CCAT M&S team as a long term partner for providing these capabilities out into the futures. A major list of accomplishments are highlighted below, with more details to follow on these subjects later in this report.

- Computer Aided Design (CAD)
  Continued to engage with small and medium sized enterprises (SMEs) to review their existing processes for integrating customer part requirements with the process design environment for making these parts. Provided SMEs with flow charts and information showing how their as is process exists, and recommend how they could use their existing software solutions more effectively.

- Computer Aided Manufacturing (CAM)
  Continued to engage with several SMEs to review their existing processes for integrating the CAD information with their CAM solutions in a more efficient manner, by showing how new options work, or how they can integrate the CAD data directly with the CAM solutions. Special macros within SolidWorks were devised to automatically develop casting raw geometry from the customers finished geometry to support the development of the machining process in the CAM solution.

- Assembly Sequence Simulation
  Continued to engage with several SMEs to demonstrate and educate how they can leverage their product design capabilities with 3D based assembly sequence environment (DELMIA DPM Assembly or 3DVIA) as the bases for showing their customers how to repair the product, and deliver electronic work instructions for the shop floor or maintenance field support. CCAT's M&S team developed a set of demonstration assembly sequences were created that can be used to show off the features of these types of software tools.

- Human Motion Analysis
  The Ergonomic Analysis project with the Western New England College (WNEC) was completed and a final report and two user tutorials were created. A human motion analysis tracking system was co-located in the WNEC Virtual Reality laboratory with DELMIA HUMAN V5 Human Analysis software. These tools were used in the design and development of systems that involve human interaction. Testing of the system usability seemed to indicate that this solution is not ready for real world applications as it presently exists. Another candidate solution, RTID Human from Haption, was also tested and this too seems to be limited for use within the DELMIA V5 Human solution at this time.

- Machining Game Changer
  The CCAT M&S Team continued to evaluate the Machining Game Changer solution to help the SMEs optimize their machining processes with an easy to use, minimal effort software tool integrated with their CAM NC programming tool. Collaboration continues with several SMEs as potential beta site candidates.

- Physics Based Modeling and Simulation for Grinding
  CCAT's M&S Team continued to evaluate Physics Based Modeling and Simulation for grinding. Engaged with several SMEs to evaluate grinding processes and to make recommendations on new operating parameters to reduce the overall processing time, and still maintain the surface quality of the parts.

- Physics Based Software Tools for Broaching
  Continued to evaluate the physics based software tools to optimize the broaching process and the design of the broaching tools to optimize the process performance. Two SMEs and two broaching tool suppliers were engaged initially in this effort. A project was initiated with Turbine Engine Components Technologies Corp. (TECT) to design/optimize the broaching tool designed in the BOSS software, fabricate it, and test it to demonstrate the value of this approach to make shorter tools that require less energy and reduced cycle time for the cutting process. The BOSS broaching tool assessment software has been utilized for evaluation in this effort.

- Advanced Machining
  Initiated activities in the development and support of advanced machining and machining process development. CCAT joined the Step NC development working group, as well as the MTConnect working group. CCAT staff participated in the weekly development of conference calls with Step NC group to track and guide the direction. CCAT successfully hosted an International Step NC demonstration workshop at the CCAT Innovation Center in October, 2008 that was attended by over 40 representatives of industry.

  Two machines are currently operational in CCAT's machining applications facility- a Haas 3-axis MiniMill and a DMG 5-Axis DMU EVO Linear Mill. These have been used to assist SMEs to develop new machining processes and to validate the various Machining Optimization software tools that are in place.

- Fuel Cell Modeling
  Completed the activity in Fuel Cell Performance Analysis with COMSOL FEA software in support of the development of an auxiliary power unit for USAF platform with GenCell Corporation, Danbury, CT.

- Virtual Model of Robotic Laser Cell
  Development of a Virtual Model of the Robotic Laser Cell for the Laser Applications Laboratory for use as the off-line programming tool has continued. The model has been calibrated to the real world, and robot programs have been successfully uploaded and downloaded between the two environments. A second workcell model, this for an SME arc welding robotic workcell, was created, calibrated, then demonstrated successfully on how to download and weld a new assembly.

- Composites Manufacturing
  Continued to develop and expand a program in Composites Manufacturing process assessment. Identifying state of the art techniques for simulating the composite manufacturing process, as well as technology that can support a lean manufacturing approach to process implementation. We have identified a number of software tools and acquired them for helping the design of the process for fabricating composite parts. A collaboration with Real Time Analyzers was conducted to determine if a sensor for in-process monitoring of the curing process could be developed to validate that a good part is being created, and are awaiting testing results for the completion of this effort.

- Integrated Manufacturing Models
  We have initiated a project to investigate and demonstrate how typical physics based process simulation tools might be integrated together to provide the end customer with a much better prediction of the quality and life expectancy of parts. Included in this effort will be assessments of the COTS solutions available for Casting, Forging, Heat Treatment, Machining, Grinding, Finishing, and Joining. As part of this effort, a project was initiated under the request of the USAF AFRL and AMPI program to assess the state of the art for Casting Process Simulation to determine how these tools could be improved and become more user friendly.

- Knowledge Based Manufacturing Systems
  We have initiated a project to investigate and demonstrate how knowledge of a process can be used to help in the design of aircraft engine blade forming tools. The intent of this system is to determine if this technology can minimize the typical iterative and labor intensive approach that is used today as identified by several SMEs. Beta software has been received from TechnoSoft by CCAT, and the testing will be completed during the next several months.

- Electronic Value Stream Mapping (eVSM)
  eVSM activities and capabilities have continued to expand, including the assessment of electronic Value Stream Mapping tools to support Lean Manufacturing activity, the development of interfaces between electronic Value Stream Mapping tools and the QUEST factory modeling software to support Lean Manufacturing, and the execution of two projects with the University of Connecticut to incorporate the subjects of Value Stream Mapping, Factory Modeling and Digital Manufacturing included within their Mechanical Engineering curriculum.

CCAT M&S Project Summaries

2.2.1. Assembly Sequencing

Team

- CCAT – Tom Scotton, Jon Fournier, Nasir Mannan, Cristina Cook
- Western New England College – Prof. Tom Keyser

Software Solutions

- DELMIA – V5 Assembly/Human
- SolidWorks – 3DVIA

Hardware Solution

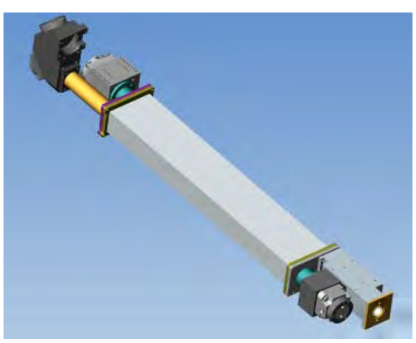
- Haption VR
- Motion Analysis

Goals/Objectives

3D CAD product definition data will be utilized to develop and validate the assembly sequence of multi-part assemblies. Tooling and fixturing will be included in the simulations as well. The simulations will become the basis for an interactive online set of electronic work instructions.

Expected Benefits

- Leverages investment in 3D CAD product design
- Communication with visually enhanced work instructions



Status to Date

- Acquired DELMIA V5 DPM Assembly Software
- Trained CCAT AE's
- Obtained 3DVIA software
- Delivered 3DVIA Assembly Sequences to participants in free playback viewer formats (3DVIA viewer and PDF)
- Companies Engaged – Habco, GKN Aerostructures, Trumpf, Conn. Corsair, Peter Paul Mfg, Oxley, iRobot

The M&S team investigated a number of software tools to address the most economical and easy to implement for supporting the use of Electronic Work Instructions. The goal was to identify affordable and easy to use 3D environments that allow the user to create and validate how a complex assembly should be assembled. Under NALI Phase I, the M&S team tested and demonstrated the Dassault/DELMIA V5 based software tools. In Phase II, two new software tools were added to the CCAT tool kit: Dassault/3DVIA, and the Immersive Learning Environment. The most important focus in this effort was to identify software tools that were very affordable, flexible, easy to use, and have the ability to deliver information in a low-cost end user reviewable viewer as supplied by SolidWorks for 3DVIA or as embedded 3D sequences in a PDF document.

2.2.2. Ergonomics and Virtual Reality

Team

- CCAT – Tom Scotton, Jon Fournier, Nasir Mannan, Cristina Cook
- Western New England College – Prof. Tom Keyser

Software Solutions

- DELMIA – V5 Human
- Immersive Learning Environment

Goals/Objectives

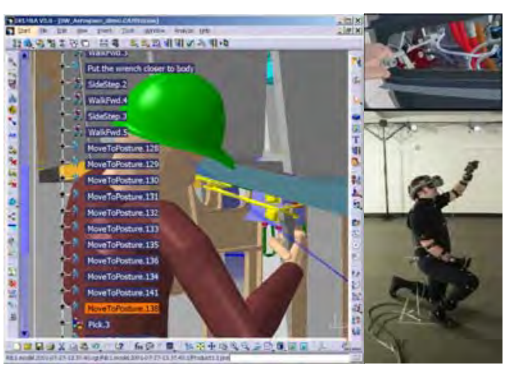
- Identify and evaluate Human modeling software solutions, and virtual reality interaction devices
- Partner with Technology Providers
- Implement a Virtual Environment laboratory for SMEs and the USAF to utilize

Expected Benefits

- Development of a workforce with skills in designing processes for ergonomically acceptable processes
- Provides ability to design ergonomically safe processes
- Virtual environments inspire learning of subject matter

Status to Date

Under this category the M&S team participated in a demonstration/evaluation of the DELMIA V5 Human solution linked directly to the Motion Analysis Tracking suit of sensors for Toyota of Australia. The Ergonomic Analysis project with the Western New England College (WNEC) was completed and a final report and two user tutorials were created. A human motion tracking system was borrowed from Motion Analysis and co-located in the CCAT Virtual Reality laboratory with DELMIA HUMAN V5 Human Analysis software. These tools were used in the design and development of systems that involve human interaction. Testing of the system usability seemed to indicate that this solution is not ready for real world applications as it presently exists. Another candidate solution, RTID Human was also provided from Haption that was tested and this too seems to be limited for use within the DELMIA V5 Human solution at this time. The CCAT M&S team participated in a demonstration/evaluation of the DELMIA V5 Human solution linked directly to the Motion Analysis Tracking suit of sensors for Toyota. The performance of the technology and the hardware software interface provided good data and there is opportunity to improve that system.



The M&S team also participated in project review meetings of the PDES, Inc., funded IDEV project which is looking at the development of applying VR Hardware and software tools for a more convenient method of collaboration of multiple companies during the design phase of a project. Under this project, the team members will be able to send their sections of a product from their own CAD environments into the collaborative learning environment to do real time design reviews. Multiple CAD formats will come into this environment loaded in the correct relationship and orientations as the partners sections of the product.

Western New England College (WNEC)

CCAT collaborated with WNEC to help WNEC establish a laboratory in Ergonomics Modeling and Virtual Machining. The Center for Human and Process Simulation at WNEC has enabled students and faculty to learn contemporary software tools applicable to the region's aerospace industry. Additionally, these tools have been applied and demonstrated at Hamilton Sundstrand in Windsor Locks, CT and at Pratt and Whitney in East Hartford, CT. The software suite/tools used was Delmia's PLM V5 and Delmia's QUEST. Each outcome is delineated below:

Outcome 1: Established a simulation laboratory equipped with Delmia's PLM software licenses for 10 workstations

Outcome 2: Trained students and faculty in Delmia's PLM environment

Outcome 3: Established a center staffed by faculty and students with expertise in human and process modeling. This expertise will be made available to regional aerospace manufacturers.

Outcome 4: Integrated Delmia's PLM software packages into the engineering curriculum at Western New England College. Currently HUMAN V5 is present in:

- IE 318 – IE Junior Lab I
- IE 428 – IE Senior Lab I
- IE 422 – Industrial Safety and Hygiene
- BME 350 – Biomechanics

QUEST D5 is present in:

- IE 334 – Discrete Event Simulation

Machining Solution V5 is present in:

- IE 428 – IE Senior Lab I

Outcome 5: Delmia's HUMAN is being used in IE 422 Safety Engineering

Outcome 6: Delmia's QUEST is being used in IE 334 Discrete Event Simulation.

Outcome 7: Developed a simulation model of a complex manufacturing facility using HUMAN models working within QUEST

Outcome 8: Developed three HUMAN models (one for IE 318, one for IE 328, and another for IE 422 as described above)

Outcome 9: Developed multiple QUEST based exercises and models (for IE 334 as described above)

Outcome 10: Developed two Virtual NC models (one for ENGR 103 and another for IE 424 as described above)

Many of the models and the activities associated with the deliverables can be found at the following website: http://www.wnecie.org/chaps/home.htm. Additional models and tutorials will be added in the future and the site will provide a mechanism for the local aerospace industry to have knowledge of our capabilities.

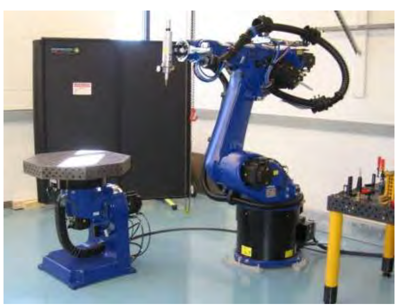
2.2.3. Robotic Workcell Design and Offline Programming

Team
- CCAT – Tom Scotton, Nasir Mannan
- U of Bridgeport – Tarek Sobh
- CCSU – Ravindra Thamma

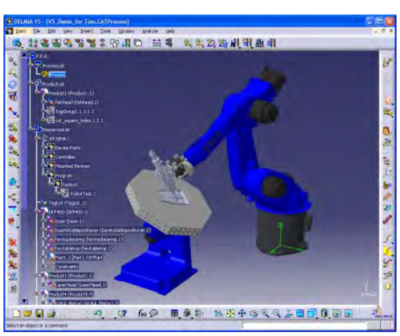
Software Solutions
- DELMIA V5 Robotics
- Fanuc Offline Programming
- Immersive Learning Environment
- MasterCAM Robotics Module

Goals/Objectives
- Implementation of Robotic Simulation Laboratory for educating industry and workforce in the principals of robotic applications and offline programming
- Faster and more accurate robot programming in LAL robot workcell

Expected Benefits
- Development of workforce capability in this field
- Creation of LAL Robotic Workcell Model and White Light Inspection Cell to support Bolton Works
- Off-Line programming Service training and services

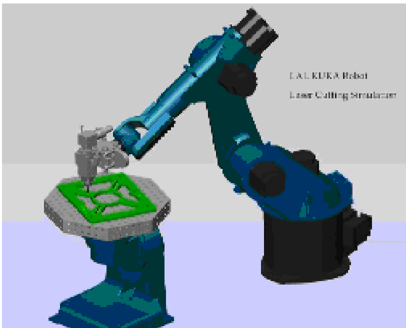


Status to Date
Under this technology category, the M&S team continued to complete a working model of the Robotic Laser Cell within both the DELMIA V5 Robotics solution as well as the MasterCAM robotics module in support of the Laser Applications Laboratory to be used for off-line programming or the system currently installed in the laboratory. With this workcell model, it is now possible to create complete robot motion based on 3D CAD file features being tracked by the robot end effector.



The CCAT M&S staff demonstrated how this technology can be implemented for robotic welding applications as well. In this technology demonstration project a workcell model was created, the virtual parts and fixtures were loaded into the software, and the program to weld the part was created. The program was then downloaded directly to the real robot cell and was able to weld the joints correctly on the first try.

CCAT also worked with Applied Controls Technology to create

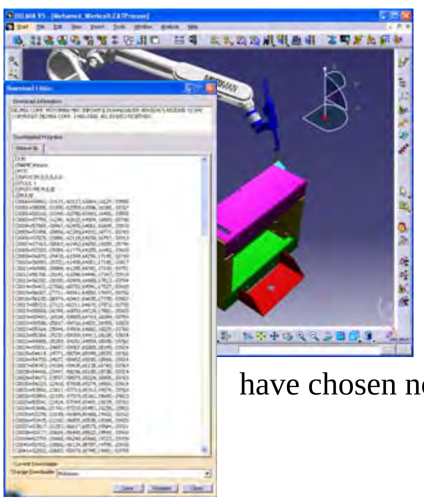


a workcell model of an aerospace buffing workcell that was fabricated for an aerospace engine manufacturer. In this technology demonstration project the CCAT team was provided access to the Fanuc workcell modeling software solution. The same workcell was also created in the DELMIA V5 Robotics solution to compare the capabilities of the two software tools.

RAM Welding, Naugatuck, CT

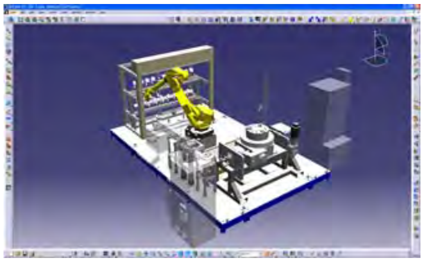
A technology demonstration/verification project was conducted to validate the capabilities of the use of the DS/DELMIA V5 Robotics software for offline programming of a welding workcell. In this project the CCAT applications engineer was able to quickly model the functionality of the robot cell, import the CAD geometry from SolidWorks, and then use the V5 solution to generate the robot motion for welding the imported assembly.

The workcell model was then brought onsite, and a program created in the model for the real robot. Once the motion was validated in the workcell model as the correct motion with the arc welding commands included, the path was translated into the Motoman robot language and downloaded to the real robot.



This program was then run and a quality welded part was created on the first try. The obvious benefit of this technology is that the end user is able to continue to use the robot processing parts while new processes are being designed offline. Due to economic issues the people at RAM Welding have chosen not to implement this capability at their facility to date.

ACT Robots, Inc., Southington, CT
ACT Robotics, Inc. is an automation system integrator that develops part finishing robot workcells to companies such as GE, PWA, and Rolls Royce. In this project we were able to learn how the Fanuc Robot Workcell modeling software functioned, by creating a working model of a system that ACT Robots had already designed in SolidWorks. The simulation workcell contained all tools, a two axis positioner (setup as extended axis 7 + 8 for robot), enclosures and vision systems. With the Fanuc software we were able to import the workcell design for a system that was being built for the deburring of aircraft engine combustion chamber parts. This workcell model was then used to develop functional robot programs and these were verified as executable by the workcell Fanuc controller.



As part of this effort, the same workcell was then also built within the DS/DELMIA V5 Robotics software solution to compare the capabilities of the two software packages. We were able to successfully demonstrate the differences in the technology for the people at ACT Robots, Inc. In this environment, it is possible that we can generate the robot motion based on the geometry of the parts being processed. This provides much better control of the robot motion for performing the various tasks to be done. It is also possible to automatically generate the robot motion from the part geometry if it is created with coordinates systems on the part surface within the CAD software tool.

2.2.4. CAD/CAM Assessments

Team
CCAT – Brian Kindilian, Chris Pfeifer

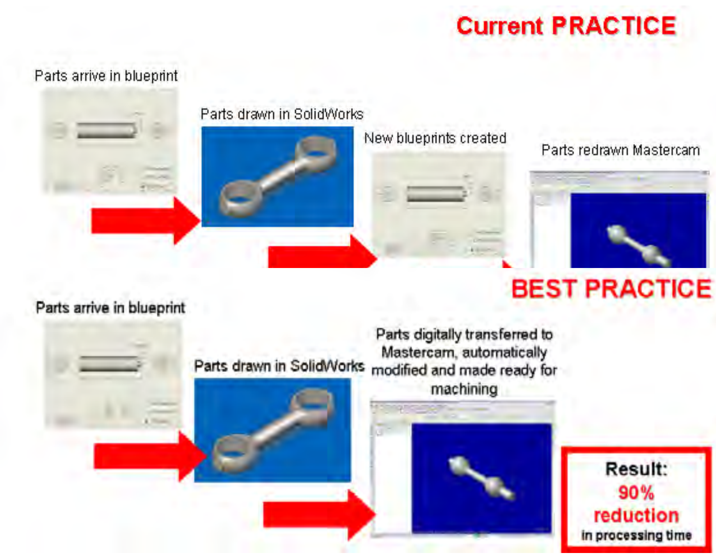
Software Solutions
- Autodesk AutoCAD, Inventor
- DS/SolidWorks
- DS/SolidWorks – Comsol
- CNC Software – MasterCAM
- Planit – EdgeCAM

Goals/Objectives
To better understand the needs of the Small Manufacturing Enterprises and how they interact with their customers for the manufacture of their parts, so that we can help them improve how they do business by providing them with better technology or how they apply the technology.

Expected Benefits
- Faster response to customer needs
- Lower operating costs

Status to Date

This technology category was addressed extensively within the NALI Phase I effort, which lead us to the selection of SolidWorks, EdgeCAM and MasterCAM as our software tools of choice for working with the SMEs. Under this technology category, we worked with two local SMEs (Horst Engineering, Aerogear) in helping them to evaluate the above software tools prior to their purchase of the best solutions for them.

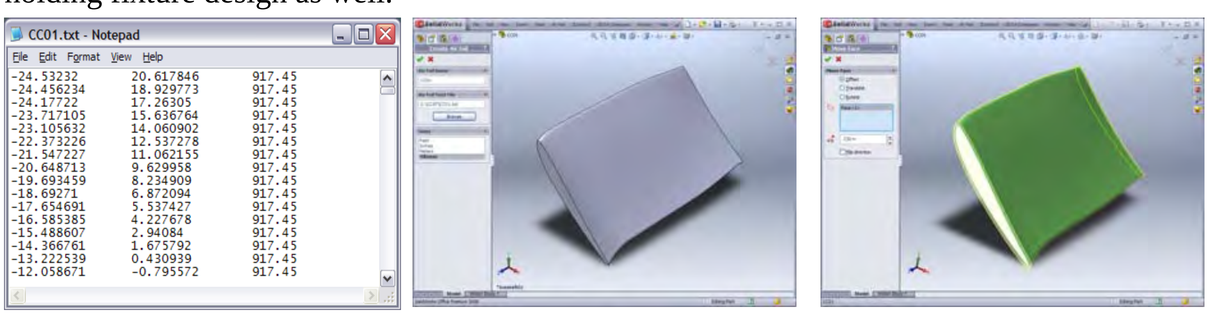


Horst Manufacturing

CCAT staff engaged with Horst Engineering, East Hartford, CT to help them evaluate their business practices for generating their NC programs within MasterCAM. By implementing our recommendations they would be able to reduce their CAD to CAM process time by as much as 90%.

BNB Manufacturing, New Hartford, CT

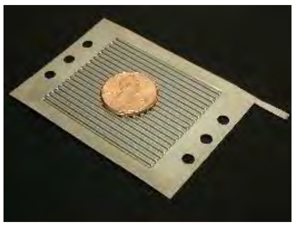
CCAT staff engaged with BNB Manufacturing to help them improve how they design and generate the process for cutting engine blades for their customers. A Visual Basic Add-In for SolidWorks was created that automatically converts point geometry of blade cross section as provided by customer into a solid model automatically for the blade surface and then provides the user with the ability to scale the surface up to account for the casting material that will need to be machined off. This eliminated the need for a lot of manual effort with SolidWorks. It was also of value as a tool for helping with the development of the part holding fixture design as well.

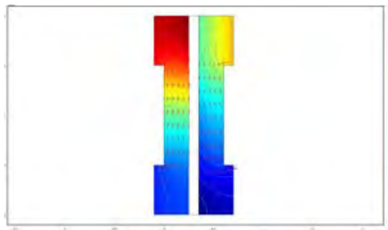


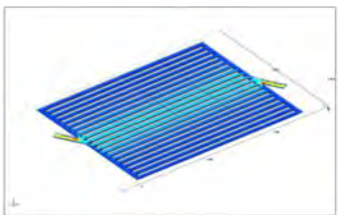
Text Input File, Generated Solid Geometry, Scaled Surface with Casting Outer Dimension

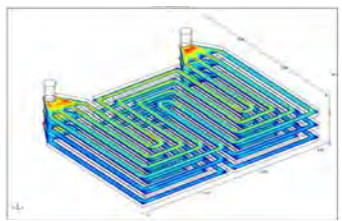
GenCell Corporation, Danbury, CT

CCAT staff engaged with Gencell Corporation to help them investigate how CAD tools can be applied to analyze and validate Fuel Cell Designs. This work was done by applying COMSOL Multiphysics® FEA Analysis of proposed designs for a Proton Exchange Membrane (PEM) Fuel Cell being proposed as an onboard energy source for DoD aircraft.





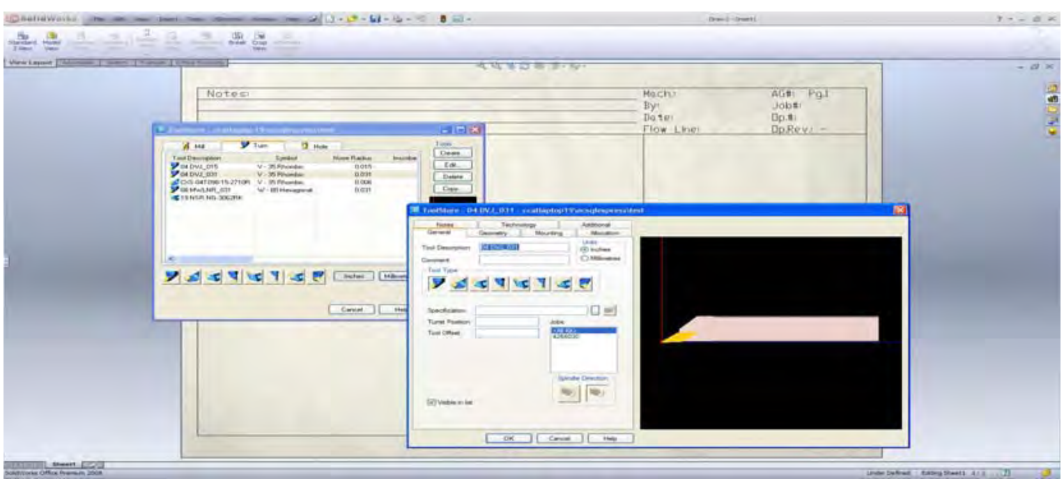




With Comsol the CCAT engineer was able to analyze the impact of the existing design for expected fluid flow, heat transport, diffusion through the membrane and the chemical reactions. As a result of this activity Gencell was able to better visualize and optimize internal flow through the channels, predict electrical and thermal output in order to optimize the stack design.

Aerogear, Windsor, CT

A Visual Basic Add-In macro was developed for use within SolidWorks to help the manufacturing engineers at Aerogear link their cutting tool definition database that was in EdgeCam directly with SolidWorks. This provided the ability to automatically bring the tooling information from EdgeCam directly into SolidWorks, and thereby eliminated a lot of hand entered data. The macro was also created to automatically generate the tool sheets that are delivered to the shop floor for machining jobs. This activity provided a reduction in the time required for process development as a replacement for the existing process of generating the tooling sheets in a third CAD environment, CADKey.



2.2.5. Machining Process Analysis/Optimization

Team

- CCAT – Brian Kindilien, Matt Lloyd, Chris Pfeifer, Cristina Cook, Jonathon Ingram, Laura Weismantel
- UTRC – Dr. Tahany El-Wardany, Dr. Changsheng Gao
- RPI – Prof. Ernesto Gutierrez-Miravete
- UConn – Prof. Bi Zhang

Software Solutions

- MAL, Inc.'s CutPro / ShopPro
- TWS's Production Module 3D
- CG Tech's Vericut
- Broaching Optimization Simulation Software (BOSS)
- GrindSim, Continuous Dress Creep Feed Grinding (CDCFG)

Hardware Solutions

- MAL, Inc.'s CutPro / ShopPro
- Caron Engineering – Horsepower Profile Tracker

Goals/Objectives

- Introduce, demonstrate and validate the capabilities of physics-based process analysis software
- Engage software that generates machine tool chatter/vibration-free speeds and depth of cuts
- Identify limitations and restrictions for implementation of this technology for the supply chain level of machining job shops
- Engage in technology demonstration validation projects with industry
- Predict grinding power through software
- Calibrate power curve through on machine testing

Expected Benefits

- Reduce overall machining cycle times, leading to increased machining production capacity by over 20%
- Significantly increase material removal rates
- Improve machining quality
- Increase tool life
- Identify new operating characteristics that will provide high quality and shorter cycle times for existing processes
- Identify the balance between higher feeds and speeds without increasing the usage of grinding wheels
- Improved resource utilization

Status to Date

Under this phase of the NALI Program the CCAT M&S staff continued to ramp up our knowledge of machining, grinding and broaching process design, simulation and optimization tools by engaging with a number of aerospace part manufacturers. Included in the list of software tools available to us were:

Third Wave Systems AdvantEdge™ FEM: Computer Aided Engineering (CAE) software for optimization of metal cutting. AdvantEdge FEM is capable of predicting Stress and Temperature for Milling, Grooving, Boring, Sawing, Broaching, Drilling and Turning processes. Using results, process engineers are able to reduce the amount of trial and error, on-machine tests to determine optimal machining parameters.
http://www.thirdwavesys.com/products/advantedge_fem.htm

Multiple Responses Statistical Optimization: Utilizing Minitab®, process engineers are able to reduce number of on-machine tests and machining simulations during process development. Through statistical analysis, machining responses are defined as a function over a range of cutting parameters to identify an optimal combination.
http://www.minitab.com/en-US/products/minitab/

Third Wave Systems AdvantEdge™ Production Module: Machining process-analysis software capable of predicting Force, Power and Temperature. By calculating cutting conditions over an entire machining process and applying variable feed rates, cycle time can be reduced by optimizing machine utilization.
http://www.thirdwavesys.com/products/advantedge_production_module.htm

VERICUT Module: OptiPath®: Machining process-analysis software that calculates the amount of material removed in each segment of the cut. By increasing feeds to maintain constant volume removal rate, cycle time can be reduced by optimizing machine utilization.
http://www.cgtech.com/usa/optipath%C2%A9/

Mastercam® High Feed Machining: Toolpath optimization function that varies feed rate on 2-axis and 3-axis machining operations. By varying feeds based on volume of material being removed, cycle time can be reduced within the Mastercam CAM system.
http://www.mastercamforsolidworks.com/feedrate.html

NALI Developed Third Wave Systems Mastercam Interface: Machining operation export feature that seamlessly transfers all necessary information to and from AdvantEdge Production Module. The interface provides process-analysis ability to optimize machine utilization while maintaining file associations within the Mastercam CAM system.

MAL Inc. CUTPRO®: Machining process simulation, planning and trouble-shooting system that is capable of predicting Force, Power and Temperature for Milling, Turning, Boring and Drilling processes. Using results, process engineers are able to reduce the amount of trial and error, on-machine tests to determine optimal machining parameters. CUTPRO is also capable of Modal Analysis which determines the dynamic characteristics of a machine tool. This allows process engineers to avoid cutting conditions that lead to machining vibration.
http://malinc.com/products.html

MAL Inc. SHOP-PRO®: Practical machining toolkit for chatter avoidance. Through tap testing, the dynamic characteristics of a machine tool can be found, which provides the ability for process engineers to achieve high-performance machining with minimal effort.
http://malinc.com/Shop-pro.html

GrindSim®: Abrasive machining process simulation and optimization software that is capable of predicting Force, Power, Wheel Wear and Temperature in Inner Diameter, Outer Diameter, Surface and Continuous Dress Creep Feed Grinding processes. Through understanding and calculation of burn power, cycles can be optimized by changing feeds and speeds.

Broaching Operation Simulation Software (BOSS) Analyzer: Machining process simulation that is capable of predicting Forces and Power for Broaching processes. Using results, process engineers are able to reduce the amount of trial and error, on-machine tests to determine optimal machining parameters.
http://www.maxima.com.tr/boss.asp

DEFORM™ Machining Module: Computer Aided Engineering (CAE) software for optimization of manufacturing processes. DEFORM Machining is capable of predicting Stress, Strain, Temperature and Micro-Structure of Milling, Drilling and Tapping processes. Using results, process engineers are able to reduce the amount of trial and error, on-machine tests to determine optimal machining parameters.
http://www.deform.com/applications

Tool Monitoring Adaptive Control (TMAC®): Hardware solution that measures and records machine spindle horsepower of machining operations. By comparing power readings with previously run operations, it is possible to actively correct issues to prevent tool failure and increase machine utilization.

http://www.caron-eng.com/tmac/

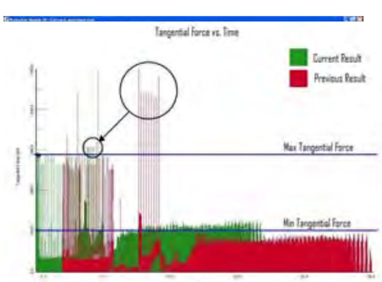
Celerative VoluMill™: Toolpath generation software that creates high-performance toolpath within Mastercam CAM software. By maintaining a constant material removal rate, the toolpath can be programmed with higher feed rates to optimize machine utilization.
http://www.celeritive.com/advantage.htm

In order to promote the application value of the software technologies described above it was necessary for us to implement a virtual Advanced Machining Center (Manufacturing Applications Lab), by sharing space with the Laser Applications Laboratory. We currently have two machines available on the floor for demonstrating and validating the above listed machining process optimization tools.

- Haas 3-axis MiniMill
- DMG 5-Axis DMU EVO Linear Mill

As part of our effort to understand and promote the latest technology to the SMEs the M&S team engaged and joined the Step NC development working group, as well as the MTConnect Technical Advisory Group. CCAT staff participated in the weekly development of conference calls with Step NC group to track and guide the direction. We successfully hosted an International Step NC demonstration workshop at the CCAT Innovation Center in October, 2008 that was attended by over 40 representatives of industry.

BNB Manufacturing



In this engagement the M&S Applications Engineers engaged in the assessment of the machining of Titanium Ti-6Al-4V turbine engine fan blade forgings. In this project we were able to collect the MasterCAM MCX files, tooling data, the work piece geometry and the NC program files for the existing process. After analyzing the process, the staff selected the roughing operations as the best opportunity for reducing the process cutting times. In this project the M&S Team was able to quickly use the machining game changer interface between Thirdwave Systems Production Module and MasterCAM. As a result of applying this optimization approach to these operations, we were able to reduce the cycle time by 10% per part, which led to 550 processing hours over the run of 3000 parts. Tony Nanni, VP of Eng. and Quality summed up the engagement, “What CCAT accomplished for us would not have been possible for us as we are a small manufacturing company with limited resources to complete projects such as these. It is great to have CCAT as a resource to help us remain competitive in a global marketplace.”

During this phase of the program we engaged with over 12 companies in other applications of the software tools described above, including Aero Gear, Apha Q, AO Sherman, B&E Tool, BNB Manufacturing, CBS Manufacturing, CNC Software, Delta Industries, SPX/Fenn, Sterling Engineering, TECT, Trumpf, Volvo Aerospace.

2.2.6. Virtual Machining for NC Verification

Team
- CCAT **–** Brian Kindilien, Matt Lloyd, Nasir Mannan

Software Solutions
- CG Tech’s VERICUT

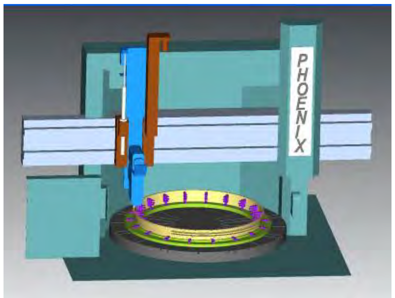
Goals/Objectives
- Identify limitations and restrictions for implementation of this technology for the supply chain level of machining job shops
- Create libraries of re-usable entities by industry for inclusion in machining simulations, available via the NALI website

Expected Benefits
- Detect errors, potential collisions, or areas of inefficiency before part is loaded on the machine
- Eliminate manual prove-outs
- Increase machining capacity
- Optimization of machining processes

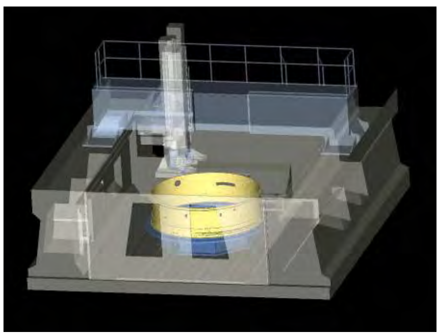
Status to Date
With this technology the M&S Application Engineers was able to help local companies get a better understanding of how their machines would execute the CNC programs prior to execution on the real machine. Under this phase of the NALI Program the team was able to engage with several companies to provide demonstrations of the technology and also provided technical support to them in terms of the best ways to model their machines. The list of companies included B&E Tool, Delta Industries, Pegasus Manufacturing, Sterling Engineering, Volvo Aerospace.

Volvo Aerospace

The CCAT-NCAL team worked closely with Volvo Aero to understand their machine tools to be modeled:



- Phoenix VTL mill/turn system with a 5-axis milling head retrofit. The CCAT-NCAL team extensive measurements and captured data from the multiple controls (one for milling and one for turning) to model the machine's milling operations.
- Zimmermann 5 axis mill also required extensive measurement taking and data analysis to build the models within the VERICUT machine/control environment.



CCAT visited Volvo on several occasions to obtain data and measure the machine. CCAT created machine models for the Zimmerman and assembled the models for use in VERICUT. CCAT also reviewed data collected to insure CG Tech would have everything require to complete the build and deliver a working VERICUT machine. CCAT delivered a complete kinematic machine model along with the required information for CG Tech to begin construction of the Phoenix's Fanuc control and perform final setup of the machine model. Installation of the Zimmerman is still underway. The CCAT-NCAL team completely assembled the kinematic model of the machines in the VERICUT software. These models were delivered to Volvo for utilization.

Volvo Aero is convinced that VERICUT is a powerful tool that can prevent significant problems in their machining processes. With assistance from CCAT, Volvo Aero now has two substantial models of mission-critical machines modeling within the VERICUT environment.

2.2.7. Interactive Learning Environments

Team

- CCAT – Chris Pfeifer, Mark Johansen, Jonathon Ingram
- CCSU – Prof. Dan Kirby, Prof. Ravindra Thamma
- Westfield Vocational High School – Clem Fucci

Software Solutions

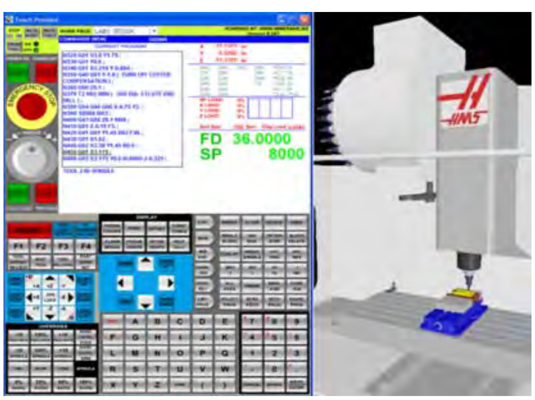
- Immersive Engineering

Goals/Objectives

- Implement a web based interactive learning environment with a fully interactive emulation of the machine

Expected Benefits

- Provide a virtual learning and training environment for future manufacturers and machine operators
- Guide Immersive into developing more aerospace specific machines and training aides
- Develop a capable manufacturing workforce
- Inspire Careers in manufacturing.



Status to Date

Under this NALI Phase II licenses of Immersive machine tool emulator and training technology were continued to be made accessible to Central Connecticut State University and Westfield Tech High School. Both educational groups were using this technology to teach students the concepts of NC programming. An additional module of curriculum was also added to the capability for the training of people in the application of MasterCAM. Many discussions are underway for rolling out this technology to more educational operations including the Connecticut Community Colleges and the State of Connecticut Technical High School System. Many presentations were also made to general industry representatives at conferences around the country promoting this technology as a vehicle for inspiring young people to consider careers in manufacturing. Discussions are currently under as well for providing this system for customized training of other subjects for companies, and for training at USAF bases as well.

2.2.8. Integrated Manufacturing Models

Team

- CCAT – Tom Scotton, Dr. Tony Dennis, Tom Meyer, Chris Pfeifer, Greg Hasko, Cristina Cook
- UTRC – Dr. Tahany El-Wardany

Software Solutions

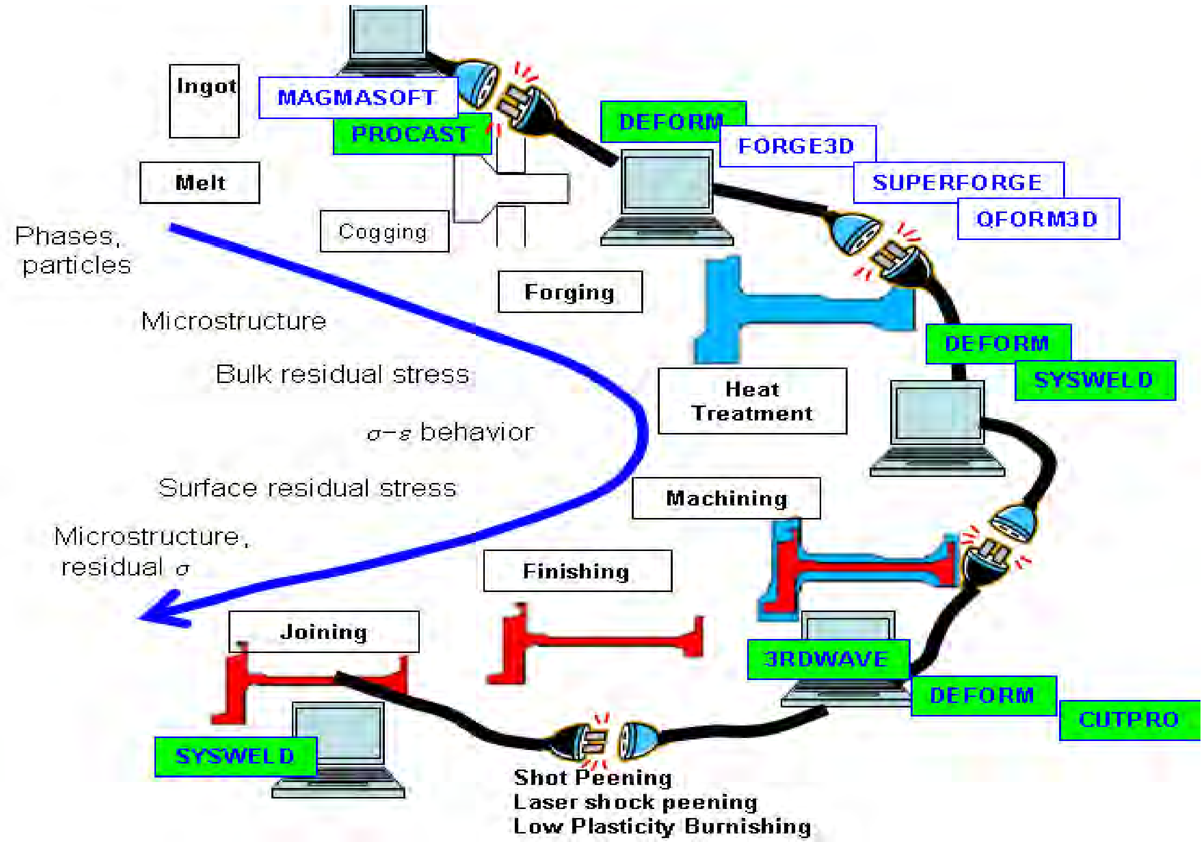
- ProCast
- Deform
- Sysweld
- ThirdWave Systems
- Cutpro

Goals/Objectives

- Investigate and validate the capabilities of COTS software tools that support the process design for the manufacturing of aerospace engine components
- Identify methods to integrate the existing point solutions into an integrated system of solutions that support upstream and downstream process data exchange

Expected Benefits

- Better knowledge and prediction of life expectancy for parts based on improved process design
- Enable more efficient manufacturing processes
- Enable new manufacturing processes while preserving key material characteristics for durability



Status to Date

As the M&S team began to learn and accumulate access to the latest software tools available for designing manufacturing processes and being able to predict how a process would execute, and the possible impact the process would have on the part being created or processed, it was recognized that the manufacturing of aerospace parts really takes place by the execution of many different operations and processes in sequence on the part to transform it from raw materials to a part that is usable on an aircraft. In the figure above we provide an outline of a typical sequence of processes that a part might go through, recognizing that often some of the sequence gets repeated several times, such as machining, heat treat, more machining, more heat treatment.

The figure shows in green the various software tools that CCAT has available to us to include in our investigation of how these various software tools from different software vendors might interact. Some of this has already been started, for example the output information from a ProCast analysis is possible to be imported into the Deform software for Heat Treatment. CCAT is currently applying each of these solutions as point solutions, and under this project heading we will determine how we might get more of these software tools to communicate their results between the tools.

Research Engineers from United Technologies Research Center were added to the team to help the CCAT staff to identify all of these software codes, and to assess them for how they might interface with other software codes. As they conducted their investigation it was discovered that there is no software tool available in industry that is able to predict how the process of shot peening will impact the quality and mechanical characteristics of the part. We anticipate under future phases we will attempt to identify approaches to do this. In addition, the team was tasked with identifying what materials are included in the various data bases within these software codes to identify if there are any missing that would be critical to the application for aerospace manufacturing processes.

This effort will continue on in future phases of the NALI program.

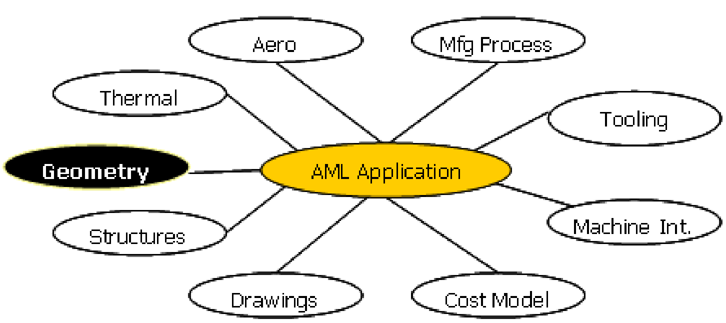
2.2.9. Knowledge Based Manufacturing Technology

Team
- CCAT – Tom Scotton, Bob Memmen
- TechnoSoft – Adel Chelamy, Steve Gerber, Jeff Fisher

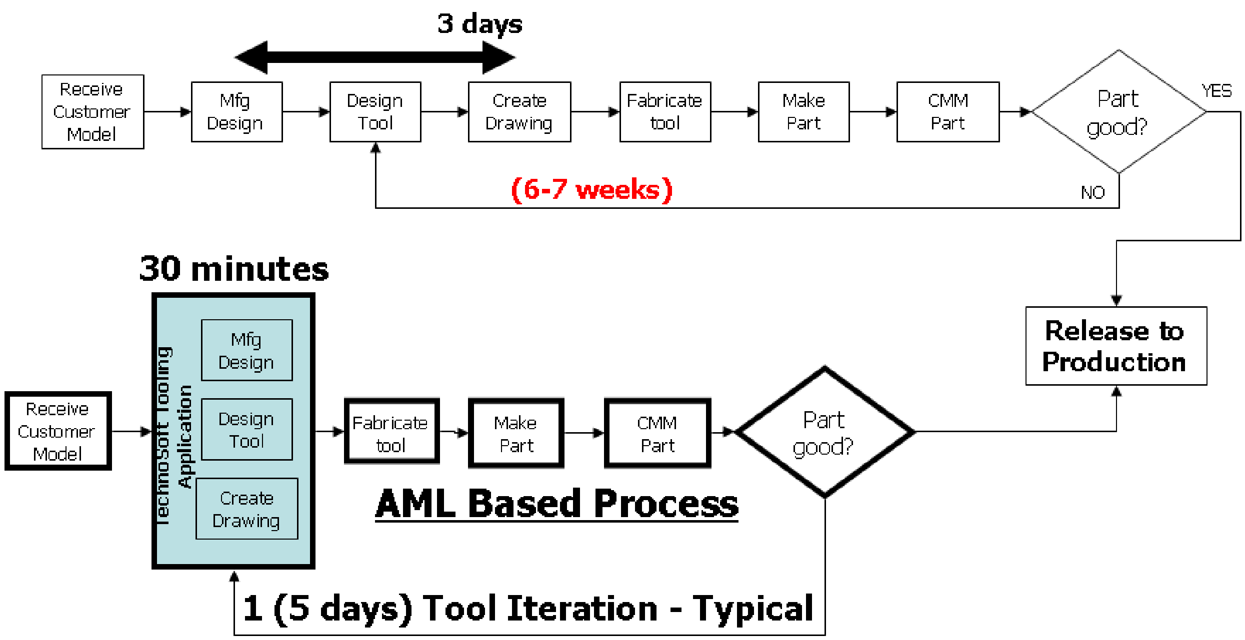
Software Solutions
- TechnoSoft - Advanced Modeling Language

Goals/Objectives
In this project we investigated the concept of applying knowledge based engineering technology on the development of the design of processes. As the first part of the project a survey was conducted to identify a manufacturing process that was difficult to implement at a number of regionally based SMEs. The process of blade forming was identified as of interest to 3 companies: AdChem, Birken Manufacturing, and AO Sherman. The goal was to develop a physics based software tool that could make the design of the form blocks become a less iterative trial and error process.

Expected Benefits
It was expected that by implementing this technology we could dramatically reduce the number of iterations for the design and validation of the form block tools and also the amount of time for each iteration of designing, fabricating, testing and modifying.



The tooling design process for press forming is iterative and time consuming. In general the process is initiated by the import of the airfoil design model and the use of a common CAD system to manually design the tooling geometry. The tooling geometry is exported to an application software (many are available) to generate the NC part file. The NC part file is used to produce the tooling. The resulting tool is used in producing a set of airfoils. The produced airfoils are scanned and the resulting models are compared to the initial airfoil design. The deviation between the design shape and the resulting produced airfoil models are used to modify and update the tooling. This process is repeated numerous times (up to seven times based on our visits to manufacturing sites) before converging to a production ready final tooling design. Each tooling design iteration requires the manufacturing or rework of the tool, the forming of a number of airfoils, the inspection of the airfoils through CMM, the calculation of the nominal geometry resulting from the inspected airfoils, the calculation of the deviation between the airfoil design geometry and the resulting nominal geometry, and the updating of the tooling design. This process time consuming and expensive since the tooling manufacturing and inspection process can be quite costly. The down time of the production press equipment during the tooling design process adds to the overall cost.



As initially investigated by TechnoSoft through the visits to each of the manufacturing organizations, the Phase II development effort was to focus on the general underlying common methods and functionality. Through the collaboration with participating manufacturing organizations the system will be then customized during Phase III to meet the unique forming process characteristics and tooling design requirements of specific manufacturers.

CCAT funded TechnoSoft to create the generic, Phase II engineering software application built upon TechnoSoft's AML engineering software framework. The application research and development effort focused on a process design that is based on importing the airfoil design geometry and proceeding in the reverse steps for building the production shape and the related tooling. Based on an imported part model of the final design, key system functionality developed included the following geometric modeling methods and operations:

- Import airfoil cross section points data in Uascii text file format
- Construct airfoil section using the imported points data, creating mid (camber) curve, And thickness line
- Create airfoil mid (camber) surface
- Create airfoil surface
- Extend airfoil mid (camber) surface and airfoil surface
- Modify airfoil cross section: rotate (twist) cross section or re-camber (flatten) cross section

- Create tooling die cross section: define flash gate, encroachment and transition area
- Create tooling die surface
- Import airfoil cross section re-cut points data
- Modify airfoil section using the re-cut points data, recreate die surface

As of the completion of this phase of work, and the development of this software, a full set of part geometric data had not been gathered that would allow us to validate the capabilities of this solution. However, the M&S team continues to try and identify an opportunity for application of this tool.

2.2.10. Composites Manufacturing

Team
- CCAT – Tom Scotton, Greg Hasko

Software Solutions
- PAM/RTM – RTM Process Modeling, ESI
- Abaqus – Finite Element Analysis, Dassault Systemes
- Compro – Cure Springback, Peak Composites
- Laminate Tools – Ply Draping, Anaglyph
- Interactive Drape – Ply Draping, Interactive Prototype's
- CAD – TBD (Siemens NX, Dassault, Vistagy)

Goals/Objectives
The goals/objectives of this effort in the subject of composites manufacturing were to:
- Assess and Document Industry/USAF Needs
- Assess COTS Product/Process Improvement Technology
- Investigate In-Process Control and NDI Techniques
- Expand the use of VSM and Factory Modeling in support of composite manufacturing

Expected Benefits
- Faster turnaround of art to part for composite manufacturers
- Improved part quality
- Higher process yields

Status to Date
Under the Phase II NALI Program an effort was undertaken to ramp up a capability in this area of identifying issues that limit the ability to effectively and efficiently manufacture aerospace components out of composite materials. This was initially started in Phase I by our engagement in the application of our Factory modeling technologies for the layout of the GKN Structures manufacturing facility in Cromwell, CT where they were ramping up the production of the Joint Strike Fighters composite inlet component. It was this work that helped us to identify some of the issues that composite manufacturers and the USAF encounters during fabrication and the

repair of composite structural components. Our efforts to date have been focused on carbon fiber based parts.

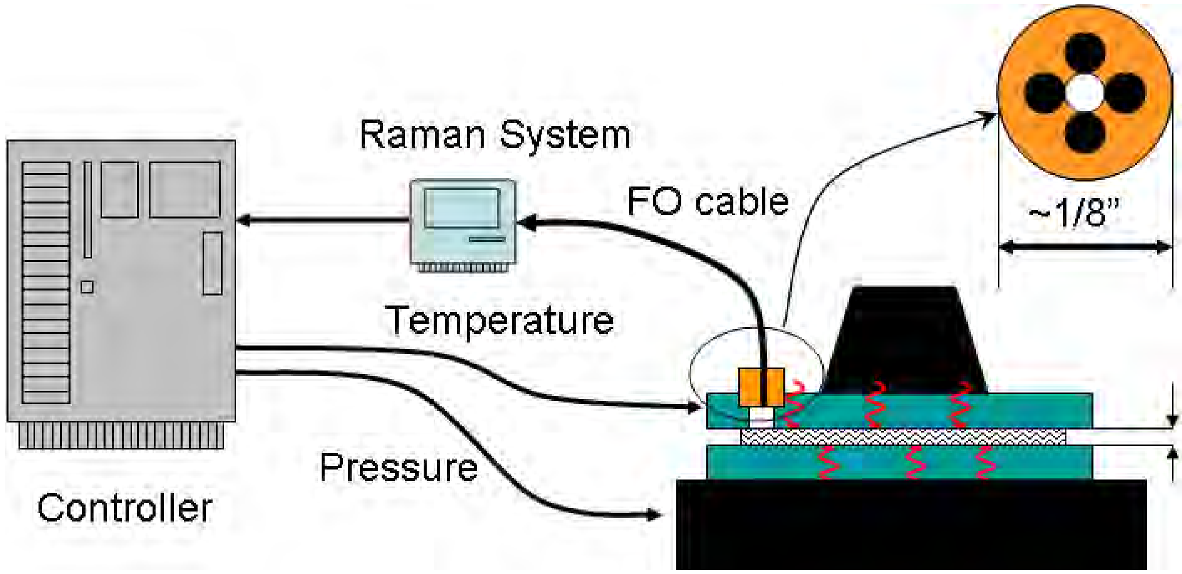
A major part of the effort under this phase of the NALI program was to identify COTS modeling and simulation software tools for evaluation and testing for their capabilities. We try to conduct the testing based on real world part process design scenarios that we get from industry or the USAF. The software tools that we have acquired and attempted to evaluate are shown in the list below:

- ESI: **PAM-RTM** FEA for ply draping, mold flow and resin cure
  http://www.esi-group.com/products/composites-plastics/pam-rtm
- Convergent: **RAVEN** for resin cure
  http://www.convergent.ca/products/raven/index.html
- Dassault: **Abaqus** for thermal & structural FEA
  http://www.simulia.com/products/abaqus_fea.html
- Convergent: **COMPRO** plug-in to Abaqus for springback analysis
  http://www.convergent.ca/products/compro%203d/overview.html
- Anaglyph: **Laminate Tools** for ply draping, laminate properties
  http://www.anaglyph.co.uk/LT.htm
- Interactive Prototype: **Interactive Drape** for ply draping
  http://www.interprot.com/interactivedrape.php

AeroComposites Industries (ACI), Windsor, CT
CCAT staff engaged with ACI to investigate the possibility of the development of a variable pitch fan blade concept made possible by a unique design of a flexible composite strap concept for controlling the pitch of the blade. This provides a much lower weight rotational approach than the previously tested metal based mechanical designs. Under this task a contract was funded with Trebor Systems (South Windsor, CT) to do a high level analysis of the concept and its impact on the performance of such an approach for implementing the concept of a rotating inlet fan blade. The results of this study showed that it is expected that this concept could indeed improve the performance of commercial and transport military engines by as much as 15 – 20%. More in depth analysis will be investigated in the next phases of this program.

Consortium for Improving Advanced Composites Processes Consortium (CIACP)
CCAT has become an active member of the CIACP in order to understand the state of the art capabilities currently being investigated for the fabrication of graphite based composite structural members. As part of this presentation, CCAT has hosted a regional meeting at our East Hartford facility, and also participated in two other sessions at other locations. CCAT staff was provided the opportunity to talk about the modeling and simulation capabilities that we are developing for the support of industry and the USAF.

Real Time Analyzers (RTA), Rocky Hill, CT
A contract was funded with RTA to investigate the potential application of their Raman Spectroscopy sensor technology to determine if this approach could be used to provide the



composite manufacturer with a method for monitoring the compression molding process in real time to improve the process yield of good, quality parts. These sensors would be used to track the viscosity of the resins during the mold heating and filling process so that the application of the pressure can be applied at the correct minimal viscosity moment for the particular batch of material being used in the part. The results of this project showed that for the particular material selected, it does indeed seem to be able to track the viscosity in a test case, simple geometric shape scenario.

2.2.11. Value Stream Mapping and Factory Modeling

Team
- CCAT – Tom Scotton, Jon Fournier, Susan Coffey
- UConn – Prof. Zbig Bzymek, Prof. Manuel Nunez

Software Solutions
- Gumshoe KI – eVSM
- Wisconsin MEP – MCpT
- DS – QUEST
- Gumshoe, KI – eVSM
- FlexSim, ProModel, Arena

Goals/Objectives
- Educate industry on how VSM helps to identify waste and support their the documentation of their lean journey

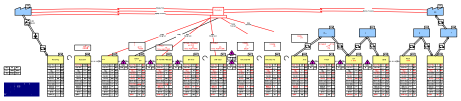
- Identify value stream mapping environment and create a semi-automatic method for quickly inputting this data into a QUEST Factory model for showing and validating production capacity in a manufacturing production line.
- Work with supply chain level companies to model the existing manufacturing production system to serve as the baseline for quantifying improvements for the implementation of Lean Manufacturing concepts. Virtual Kaizens will be supported with this factory modeling technology

Expected Benefits
- Electronic documentation of lean exercise progress
- Faster, easier method to build factory model
- Applicable with off the shelf software tools
- Easier to use methods for creating factory models to support assessment of implementing lean manufacturing concepts

Status to Date
- Supported ConnStep 3 Accelerate Lean activities with eVSM
- Engaged in VSM of 8 LO Coating panel repair processes
- Developed interfaces with eVSM and NIST CMSD
- Companies Engaged: ConnStep (regional MEP), GKN Structures, GKN Aerospace, AeroGear, Kaman Fuzing, Trumpf, AdChem, Sterling Engineering, Birken Manufacturing, Beacon Industries, Fuel Cell Energy, USAF AFRL, USAF ACC Langley
- Completed bearing assembly cell model for Kamatics, validated model with real production data
- Supported the implementation of Factory Modeling labs at U of New Haven, UConn, Central Connecticut State University
- Completed GKN for JSF inlet case facility, delivered recommended capital investment ramp up schedule
- Completed lean machining cell for Senior Aerospace to help them determine level of staffing required
- Companies Engaged: ConnStep (regional MEP), GKN Structures, GKN Aerospace, AeroGear, Kaman Fuzing, Trumpf, AdChem, Sterling Engineering, Birken Manufacturing, Beacon Industries, Fuel Cell Energy

Aerogear, Windsor, CT

In this project, the M&S application engineer engaged with the industrial engineering staff to model the expected material flow approach in the QUEST software. Aerogear staff provided CCAT with the process information via an Excel spreadsheet. CCAT imported this information into the QUEST software to build the model on top of a layout drawing file. The factory model was then used to help the customer develop the best lot sizing policy to minimize the impact of changeover times and maximize the utilization of the manufacturing equipment.



Development of eVSM and Factory Modeling Macros

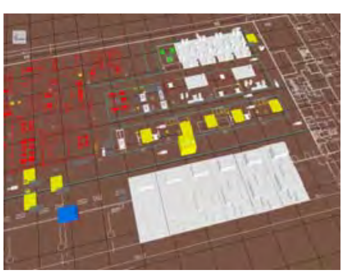
Under this project the M&S staff developed a set of macros that run inside of the eVSM software that provides the CCAT team with the ability to create Value Stream Maps of a manufacturers operations faster then through the standard off the shelf interface provided with eVSM. Included in the macro capability is the ability to:

- Quickly add/modify data to eVSM processes
- Automated connection and tagging of processes
- Streamlined creation of Spaghetti Diagrams
- Automatic connection and tagging of processes
- Add/remove castle wall, inventory data to whole VSM
- Build eVSM with Excel Import
- Line Balancing
- AutoBuild Export to QUEST Factory Modeling Software

The capability has been presented at many meetings/workshops/conferences over the past two years. The CCAT M&S team is investigating how this technology can best be provided to industry in order to help to promote the implementation of Lean Manufacturing principles. The M&S team will continue to improve the development of these tools in the follow-on phases of the NALI program.

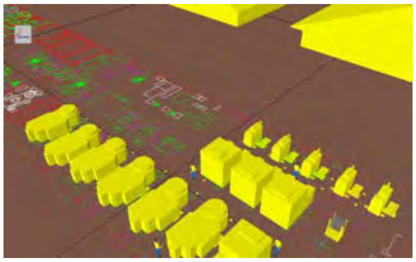
Macros to link eVSM and MCpT

In this effort the M&S team engaged with CONNSTEP to help them learn and begin to use the eVSM software for Value Stream Mapping exercises at suppliers of PWA located in Connecticut through the UTC "Accelerate" program. CCAT staff conducted training lessons for CONNSTEP to ramp them up on the application of eVSM, and also engaged with them by supporting the use of the eVSM software during three actual Lean Manufacturing Exercises at the suppliers facilities. As part of the Accelerate program, CONNSTEP was also required to apply the Manufacturing Critical path Time (MCT) as provided by the Wisconsin MEP, that takes processing times and applies them to actual calendar times for part delivery schedule by accounting for the number of shifts and hours run per day in the manufacturer's facility. Initially the CONNSTEP team was required to create the VSM within the eVSM software as their method of collecting the process information, then taking the output of the VSM and retyping the data into the MCT software. CCAT application engineers developed a macro within eVSM that could export the appropriate date fields and generate the MCT formatted project files to eliminate all this manual retyping and save the lean applications sense's hours of conversion time. The application engineers at CONNSTEP are using this macro on a regular basis in other follow-on engagements. The CCAT team also was able to use the eVSM macros to then build QUEST factory models for the companies that were participating in these events very quickly.



Fuel Cell Energy, Danbury, CT

In this project the CCAT M&S team was able to again engage in an opportunity to evaluate the capabilities developed under the NALI program via the use of eVSM and the QUEST factory modeling tool. Fuel Cell Energy was looking into the possibility of investing in a new facility in Wallingford, CT. The CCAT team built the Value Stream Map of the process, imported the conceptual layout and then automatically generated the QUEST factory model to help the Fuel Cell Energy team to assess the plan to implement such a facility. In this project the CCAT team was able to identify material flow and handling issues up front, and also predict the utilization of resources, and how the company could ramp up to full rate production. In the end the decision was made not to move forward with this investment.

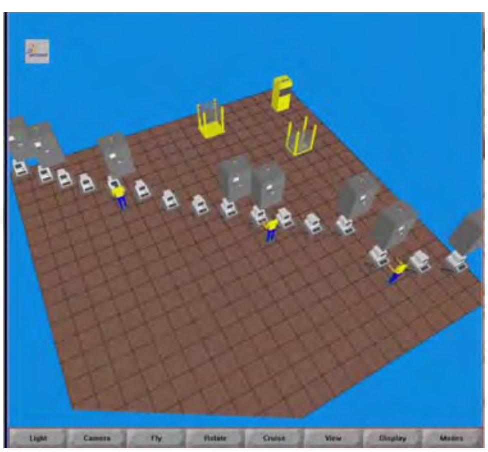


GKN Aerospace, Manchester, CT

The CCAT M&S team engaged with GKN Aerospace to help them understand the value of the VSM and Factory Modeling technology to support their lean manufacturing implementation concepts prior to implementation. In this plant, GKN machines large aerofoil vane castings and machines them to their finished shapes. In this project the CCAT team again engaged by capturing the material flow and transformation process sequence via the eVSM software and then created the factory model in QUEST "automagically". The QUEST model was then used to try out different scenarios to improve the flow of the parts through the facility. Brian J. Wilczynski, Continuous Improvement Manager for GKN concluded: "CCAT has provided access to tools that have helped us better understand how to make our value stream lean. Using their value stream mapping and factory modeling software, we were able to run "what if" scenarios on our future state. Our team was able to see the impact of batch sizes, buffer stock and asset utilization in a virtual environment before implementation. This has given us the validation we needed to move forward on our shared resource value stream. I highly recommend any manufacturing company to tap into the CCAT's state of the art offerings."

University of Connecticut (UConn) - *Development of Laboratory for Research and Teaching of Industrial Modeling*

CCAT teamed with UConn to implement a laboratory that will allow the Management and Engineering for Manufacturing Program within the School of Business and Mechanical Engineering Department to teach the concepts of lean manufacturing utilizing factory modeling technology. The Laboratory's main objective was to provide students with an environment to learn and practice the concepts and techniques of simulation modeling in the context of manufacturing. Also, the Laboratory would complement the Senior Design Capstone Project experience of students enrolled in the Management and Engineering for Manufacturing (MEM) program. The Laboratory was envisioned to provide knowledge to MEM students who would be well-versed in simulation modeling and capable of serving as resources to aerospace industry manufacturers in Connecticut. Four courses were supported by this laboratory during the course of this project Mechanical Engineering #3221 in the fall semester of 2008 and 2009, as well as the MEM4915 course in the spring semester of 2008 and 2009.



2.2.12. Electronic Work Instructions

Team

- CCAT – Chris Pfeifer, Nasir Mannan, Jon Fournier, Mark Johansen

Software Solutions

- Dassault – DPM Assembly
- Dassault – SolidWorks 3DVIA
- Anark
- Immersive Learning Environment

Goals/Objectives

To identify affordable methods for the creation of Electronic Work Instructions that could be used by the SMEs to provide internal training materials, real time work instructions for manufacturing processes, electronic delivery of product user manuals for customers, and electronic manuals for product field service.

Expected Benefits

These software tools provide a capability which can leverage the 3D CAD product files created in the product design process. They allow the user to validate and document how products will be assembled or used by customers and product maintenance service providers. Because they are interactive and visual in nature the documents can help to overcome language barriers.

Status to Date

Under this category the M&S team identified software solutions that supported the concepts, and then did a series of technology demonstrations with SMEs locally. The intent of this effort was to get a better understanding of what the various software packages could do, and how the simulation sequences could be used by customers on the shop floor, for training of staff, and for product training and servicing in the field. Authoring capabilities and delivery capabilities were both considered as we continued to gain a better understanding of the most capable and affordable solutions for implementation of this technology.

The initial effort focused on the application of the DELMIA V5 DPM Assembly software, which provides a great amount of capability for authoring complicated assembly paths and sequences and was easy to learn and use. However the delivery mechanism of the sequences as instructions was only possible via a V5 viewer that would have to be purchased by the people wishing to review these files.

The SolidWorks 3DVIA solution was then evaluated and found to have very similar capabilities and was able to deliver the sequences via a free downloadable viewer. For this reason, most of our engagements with SMEs have been using the 3DVIA solution.

Connecticut Corsair

One such engagement was with the Connecticut Corsair Group. In this engagement, CCAT staff created an assembly sequence of the major components and some details for the aircraft that was provided to us as a SolidWorks assembly. This is now viewable through the free downloadable viewer off of the SolidWorks Website.

As part of this effort we were also able to demonstrate that this free viewer can be linked directly into MSWord, and MS Powerpoint documents, as well as PDF files. This helps address the issue of affordability and transportability, making this a very powerful solution for authoring work instructions and delivering true 3D based work instructions.

In the next phase of the NALI program we will continue to engage companies with these tools as a technology for easy deliver of information to support:

- Manufacturing Process Instructions/Information
- Assembly Sequencing
- Stand alone files/Web based
- Field Maintenance Instructions
- Educating workforce

The third tool we acquired was the Anark software that we will be evaluating in the future NALI phases. This software provides us with the ability to translate various CAD assemblies into their solution and others, as well as to re-tesselate the polygonal surface definition of the geometry to minimize the size and weight of the 3D files, helping the end user to make smaller and lighter files which will be easier to deliver to the final user of the instructions.

Introduction and Scope of Avetec's Modeling and Simulation Efforts

Avetec has established a National Center for Advanced Modeling and Simulation to use advances in modeling, simulation, and advanced computing to address the research and national competitiveness needs of the aerospace industry supply chain. Working in collaboration with the NALI Consortium members, Avetec addressed critical needs of the Air Force including:

- Use of modeling and simulation to support next generation propulsion and weapon system platform acquisition programs,
- Issues related to aircraft sustainment,
- High performance computing and information system infrastructure, and 4) educational outreach to prepare the next generation work force.

The remainder of this section summarizes Avetec's role in the National Aerospace Leadership Initiative. Further details of the work scope are contained in the following section. Avetec completed the objectives of the Phase II work scope through the execution of a series of collaborative projects during the period of the grant. Summaries of the projects, their results, and impacts are given in subsequent sections.

Avetec's role within the NALI task structure was concentrated on the application of modeling and simulation (M&S) to accelerate technology transition and effectiveness of an integrated supply chain. This work is based on the belief that M&S is critical to the future success of the supply chain at all levels of endeavor. Avetec's participation in NALI Phase II activity continued to be focused on applied M&S for accelerating the transition of new technologies. The objectives of phase II work were as follows:

- **Establish the National Center for Advanced Applied Modeling and Simulation**

  Establish a world-class modeling and simulation research center requires a facility that will house a new class of computational and data management assets, along with the development of new engineering tools, software integration models, and design display and visualization tools.

- **First Phase Research Program**

  Develop a detailed Work Breakdown Structure to guide the researchers in the first phase of operations. Initial research will focus on a front-end integrated propulsion system model. Researchers have partnered with General Electric Aircraft Engines and AFRL/ML to develop a plan to conduct turbine lifeing studies as well as actual engine performance modeling studies. By applying this research agenda, Avetec addressed the accurate and high fidelity modeling tools and simulations needed for virtually testing integrated turbine engines, as well as the need to visualize simulation data for significant design insight. Additionally, the development of product design tools and techniques addressing areas such as visualization and simulation not only furthered the research mission of the Center but also promoted rapid commercialization of modeling and simulation tools.

- **Network Expansion and Connectivity**

  Develop new software architectures, engineering tool technologies and data visualization techniques. Construct a High Performance Computing facility to provide the computing platforms necessary for success. Linked into Ohio's high-bandwidth Third Frontier network, AVETeC will create a virtual testing environment across the state.

- **Computational Asset Acquisition and Maintenance**

  Obtain and maintain high performance computing assets to support research program elements through a relationship with Computer Sciences Corporation.

The efforts completed as a result of NALI phase II funding have been instrumental in later phases of the program. As a result of these efforts Avetec has demonstrated the art of the possible for transitioning new M&S technology into the United States aerospace supply chain. Avetec also used Phase II funding to continue successful educational outreach efforts that are critically important to the development of the next generation of the American workforce.

Avetec Modeling and Simulation Project Summaries

Avetec accomplished the objectives for NALI phase II funding through the execution of a series of projects with extensive government/industry/academic collaborative partnerships. In addition to partnerships with external organizations, Avetec also established internal research and development staff, employed staff to complete the planning stages of the National Center for Advanced Modeling and Simulation and begin construction of the new facility. Project summaries below highlight accomplishments in three areas: 1) External research programs through collaborative efforts, 2) Internal research program initiation and educational outreach, and 3) Infrastructure planning and development.

2.2.13. Turbomachinery CFD Development (with GE Aviation)

The objective of this research effort was to improve industrial CFD tools and demonstrate there use on problems with very large grid sizes. The focus was on three areas: 1) Grid Generation, 2) CFD Solvers, 3) Post processing of simulation data. The research team was composed of Dr. Brian Mitchell, Dr. Ivan Malcevic, Dr. Alexander Stein, and Dr. Jixian Yao of GE Global Research in New York and John Aicholtz of GE Aviation in Evandale Ohio. Work scope was divided into seven distinct tasks:

- Task 1: Grid Genration Tool Development,
- Task 2: TACOMA CFD Solver development,
- Task 3: Parallel Grid Partitioning,
- Task 4: Post Processing Tool Development,
- Task 5: CFD Analysis and Tool Performance Evaluation,
- Task 6: Management oversight
- Task 7: Inlet Distortion Studies

The following technical accomplishments were noted in the final report:

1) A parallel grid smoothing capability was added to grid generation tool development. In the grid generation process a parallel smoothing algorithm designed for quad-core processing nodes was developed and validated. A one dimensional constrained smoothing algorithm was added to the grid generation process.

2) The TACOMA Solver was extended to a 64 bit architecture and as a result CFD simulation throughput was improved by a factor of 2. Processing capability for the solver was extended to accommodate from 100-200 million grid cells per blade row in a turbomachinery CFD simulation.

3) A Parallel Grid Partitioning Tool was developed based on the Par-METIS grid portioning code. The tool was tested on a 1 billion element test case using 250 processors.

4) In post processing tool development efforts the NPLOT3D code was improved to handle node counts larger than 100 million nodes. The tool was demonstrated using a full wheel grid in a mid range computing architecture that featured 16Gb of random access memory. The development team evaluated commercial tools for post processing and recommended Ensight for use in future work.

5) As a part of the CFD Analysis and Tool Evaluation Support task, both geometry for a three stage, full annulus compressor rig and a turbine rig were provided to research teams at the University of Cincinnati and The Ohio State University. The GE research team provided technical support to the university teams.

6) The Par-METIS grid partitioning algorithm was exercised in an inlet distortion study. The research team and Air Force Research Laboratory evaluators noted “significant advances in the understanding of flow physics in terms of distortion transfer and fan response.”

Parts of this work have been published in conference proceedings.

2.2.14. GE90 Full Engine Simulation (with NASA Glenn Research Center)

The goal of the GE90 full engine simulation study was to use the GE90 engine as a baseline engine and assess the predictive accuracy of a full engine, high fidelity simulation based model. The study included extensions of the Numerical Propulsion System Simulation (NPSS) code developed under industry consortium governance by researchers at the NASA Glenn Research Center. The NASA Research Team included Dr. Russ Claus, Dr. Scott Townsend, Tom Lavelle, and Dr. Mark Turner at the University of Cincinnati. The research team also received some support from Dr. Jen Ping Chen at the Ohio State University and Dr. John Reed at the University of Toledo.

The objectives of the study were focused on answers to three research questions identified by the team:

1) How will analysis code errors roll up in an engine system level performance analysis?

2) Can coupled multi-level simulations fully converge?

3) Is accuracy dependent on operating point?

The research team concluded that:

1) The physics modeled in the simulation appear to be somewhat self-correcting. So that although system simulation complexity is increased in a multi-fidelity simulation, accumulated errors are not detrimental to the overall accuracy of the simulation.

2) A multi-level simulation that converges can be constructed. However, there are additional technical challenges that must be overcome to put this level of simulation capability to work in an industrial setting.

3) Validation of simulation results show that component changes can be assessed with simulation results to levels of accuracy less than 5 percent.

During the course of the research investigation, the research team developed and documented procedures for conducting high fidelity full system simulations of a gas turbine engine. The gas turbine engine represents a complex engineered system that must be simulated on many levels using simulation codes across multiple disciplines. Figure 4 captures three dimensions of the modeling and simulation problem including dimensions for system components, engineering disciplines and levels of model fidelity. Levels of model fidelity shown range from a one dimensional steady state model that determines steady state values of thermodynamic quantities along the centerline (for example) of an engine to full three dimensional, unsteady transient models. Engineering disciplines involved range from acoustics through manufacturing and include disciplines in thermal sciences, materials, structures and economics. The third dimension shown in the figure represents an understanding of system level behavior at the component level.

A comprehensive modeling and simulation environment must consider zooming along the fidelity axis to incorporate multiple levels of fidelity using the lowest fidelity required to capture the desired affects in the simulation. Coupling affects between disciplines and integration of component level models are necessary along the other two axis. Incremental volumes within the cube represent appropriate modeling and simulation tools required to attack modeling and simulation objectives at indicated coordinates within the space.

The development and application of the Numerical Propulsion System Simulation (NPSS) modeling and simulation tool was a focus of research team efforts. NPSS addresses each dimension of the complex system simulation space described above. NPSS features the ability to perform component level system simulation at the zero dimensional (parametric) and one dimensional mean-line level. A zooming capability was added that allowed the incorporation of computational fluid dynamic simulations for components where additional model fidelity was desired. The object oriented structure of NPSS also permits the addition of simulation components spanning the disciplines required of a full system simulation.

To demonstrate the utility of tool developments, the research team conducted a series of simulation experiments involving lower fidelity simulations on platforms available at the NASA Glenn Research Center in Cleveland Ohio along with coordinated, high fidelity, computational fluid dynamic simulations conducted on the Columbia supercomputing platform available at the NASA Ames Research Center. A diagram of the multi-fidelity simulation model is shown in Figure 5.

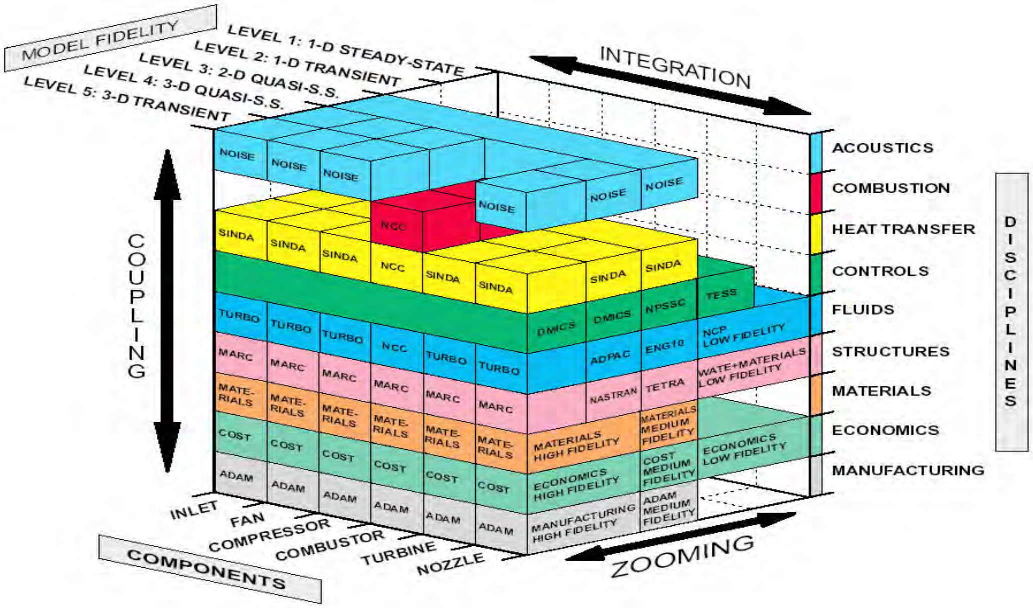


Figure 4. Three Dimensions of Complex System Simulation.

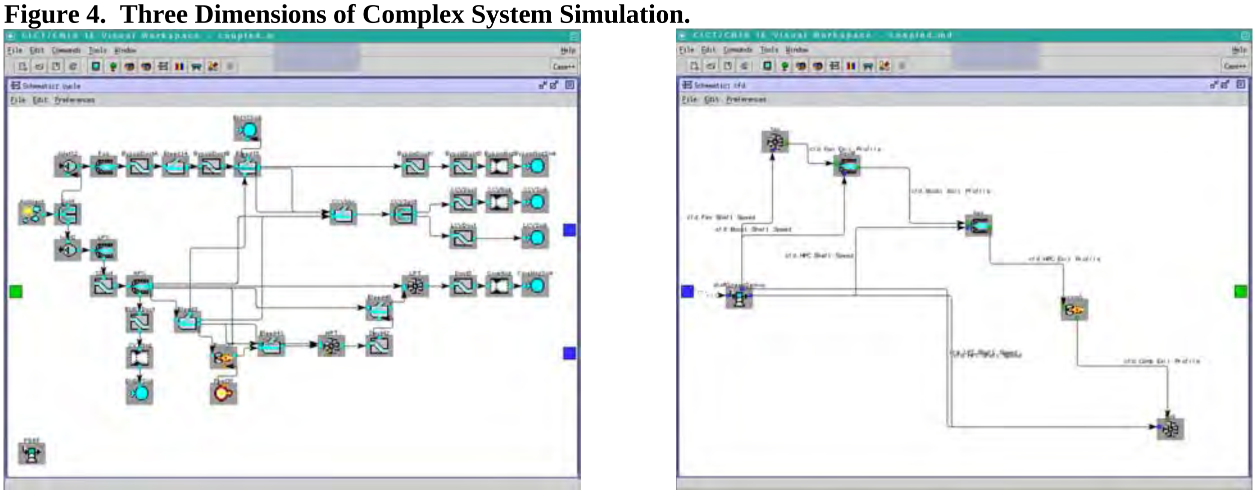


Figure 5. NPSS Multi-Fidelity Simulation Capability.

The zooming concept is illustrated more completely in Figure 6 which shows an NPSS parametric steady state cycle model of a gas turbine engine with additional detail required from the high pressure compressor. The cycle model establishes boundary conditions which are added to known geometry of the high pressure compressor to formulate a CFD problem. Results of a CFD analysis are then averaged to obtain mean-line values that feed a one dimensional component model that can be used to derive a compressor map that is fed back into the 0-dimensional cycle model. Further results of the research have been documented in publications produce by the research team. Proprietary model and simulation lessons learned were supply to the Avetec research team. Additional results and lessons learned have been documented in a series of papers authored by the research team **Error! Reference source not found.**], **Error! Reference source not found.**], **Error! Reference source not found.**], **Error! Reference source not found.**].

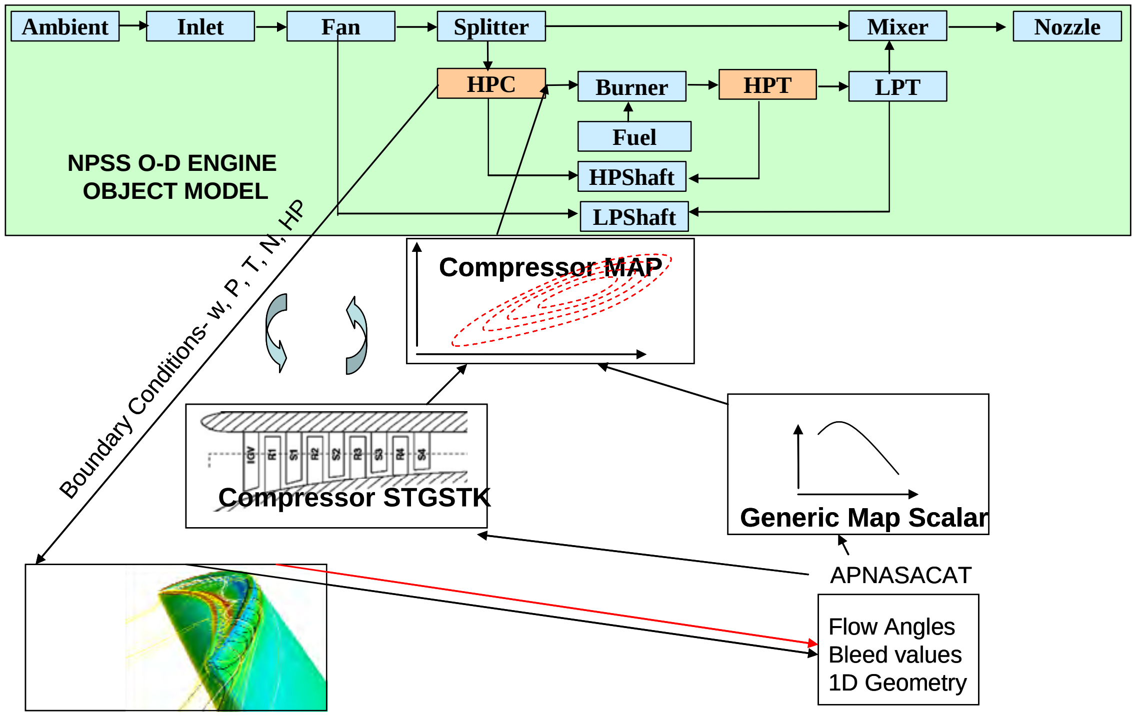


Figure 6. NPSS Zooming Methodology.

2.2.15. CFD Tool Development (with The Ohio State University)

NALI Phase II Funding was used to continue to support research in Computational Fluid Dynamics tool development by Dr. Jen-Ping Chen at the Ohio State University. Under program funding, Dr. Chen continued to develop the TURBO CFD code for turbomachinery computational fluid dynamics simulations. Dr. Chen and his students also provided expertise and support to other Avetec research teams that include researchers at 1) NASA Glenn Research Center, 2) The Army Research Laboratory, 3) The Air Force Research Laboratory, 4) GE Aviation and GE Global Research Center, 5) Honeywell Engines and Systems, and 6) Avetec.

The TURBO CFD code is a multi-stage, full-wheel compressor or turbine unsteady aerodynamic analysis. It has been used in flow simulation studies involving 1) Flutter simulation, 2) cooling flow simulation through purge-flow and real-gas modeling, 3) Full annulus simulation with phase lag approximation. The TURBO code solves unsteady Reynolds Averaged Navier-Stokes equations using an implicit finite volume solver. During the course of NALI funded research efforts it has been used at the Aeronautical Systems Command DSRC at Wright-Patterson Air Force Base on the SGI Origin 3900 with up to 2048 processors and on the SGI Altix 3700 with 2048 processors. The code has also been run on the NAVO DSRC IBM P4 on over 3000 processors. It features a parallel efficiency of 93% - 95%.

Validation studies conducted during the course of Avetec's NALI funded research have shown that the TURBO CFD code is mature and can be used for design purposes. It offers a complementary tool to physical experiments for understanding the physics of complex flows. It is a necessary tool for engine development for engines with high stage loading. Simulation experiments have provided researchers with flow field details that have not previously been available. It has demonstrated improved design and performance prediction in industrial design settings and provides development teams a means for reducing empiricism that often prevails in the preliminary design of new engine concepts.

The Ohio State University research team has used results of tool developments to study flow physics related to the inception of rotating stall. An understanding of unsteady flow interactions that lead to rotating stall represent a key research area for the further development and improvement of gas turbine engine technologies. The simplified diagram of a turbomachinery blade row shown in Figure 7 illustrates flow conditions at the entry of the blade row that lead to flow separation within the blade row. This is an unsteady flow interaction that is not properly captured when flow simulations are developed based on averaging. Full annulus, unsteady, time accurate simulations using complete geometries as shown in Figure 8 are required to capture the affects that lead to rotating stall. This level of simulation capability is currently on the boundaries of the state-of-the-art. Currently existing commercial modeling and simulation tools and the computing platforms that they run on are not yet capable of the level of simulation required to capture these effects. Figure 9 illustrates the difference between an average passage code that is used to reduce computational complexity and a full annulus code. As seen in the figure, details that are important to the study of rotating stall are not properly captured in the average passage method. As a result of tool development under NALI funding, the research team has documented studies that are providing mitigation strategies for rotating stall through tip injection as shown in Figure 10.

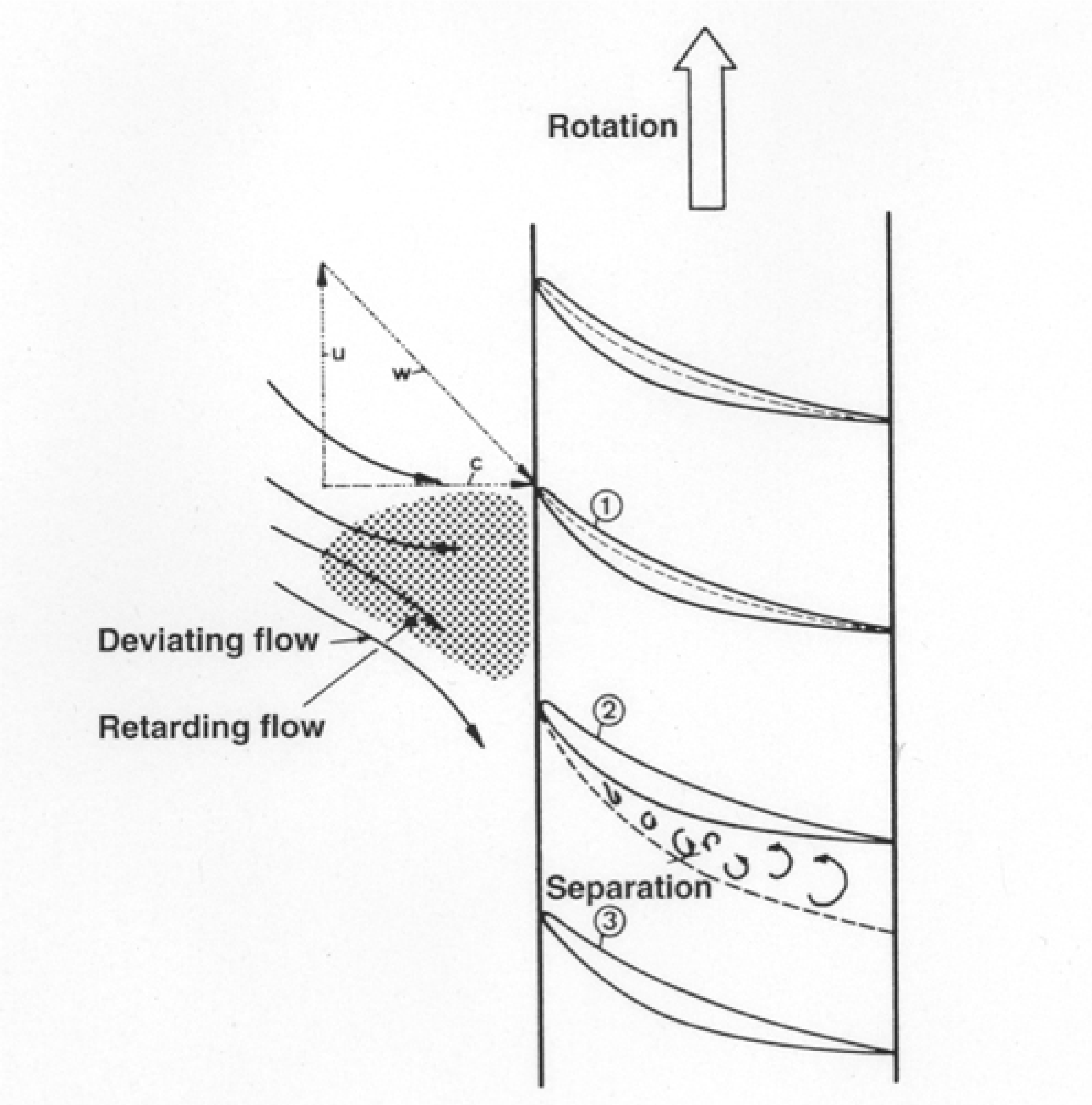


Figure 7. Separation of Flow at the Onset of Rotating Stall.

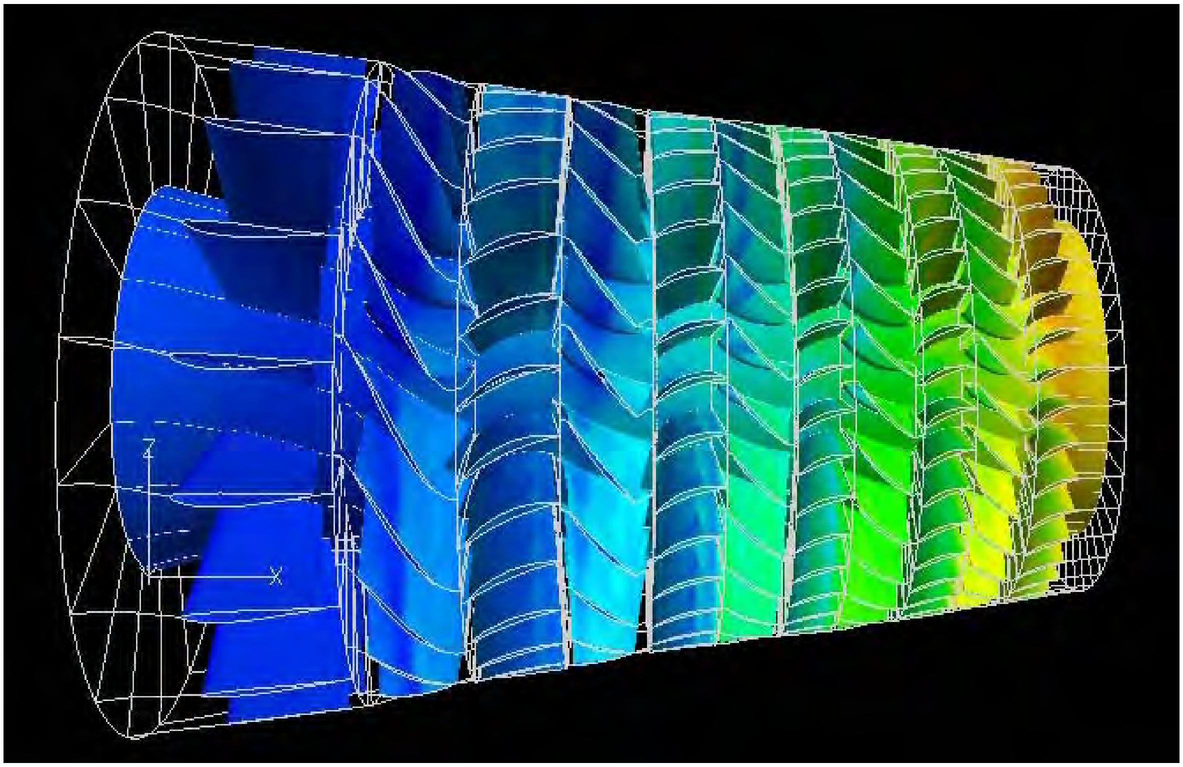
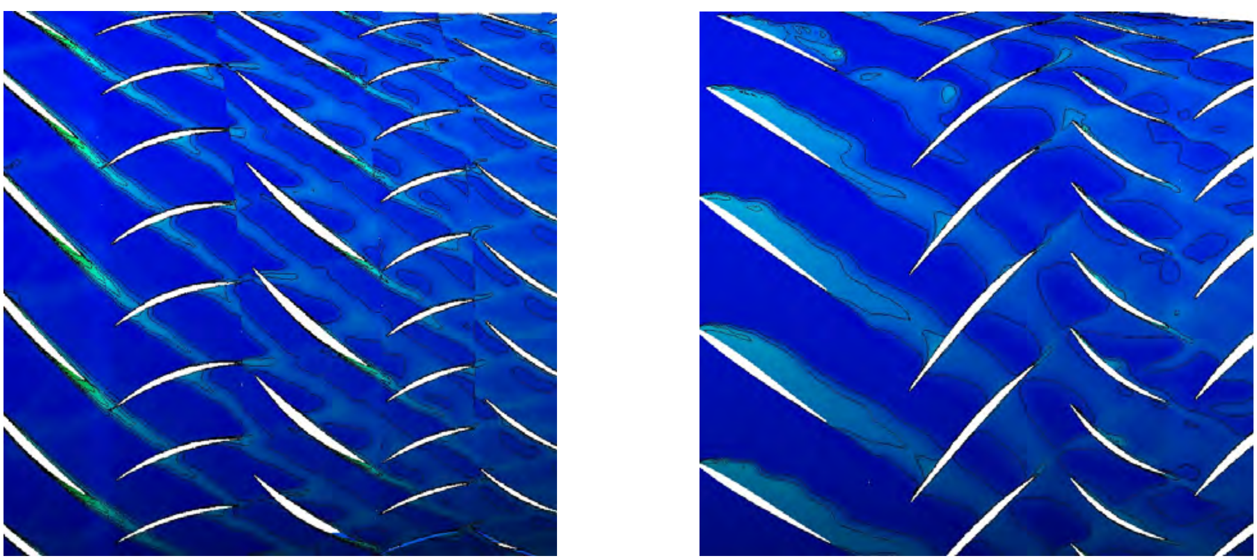


Figure 8. Full Annulus Turbomachinery Solid Model



(a) (b)

Figure 9. (a) Average Passage vs (b) Full Annulus Flow Simulation

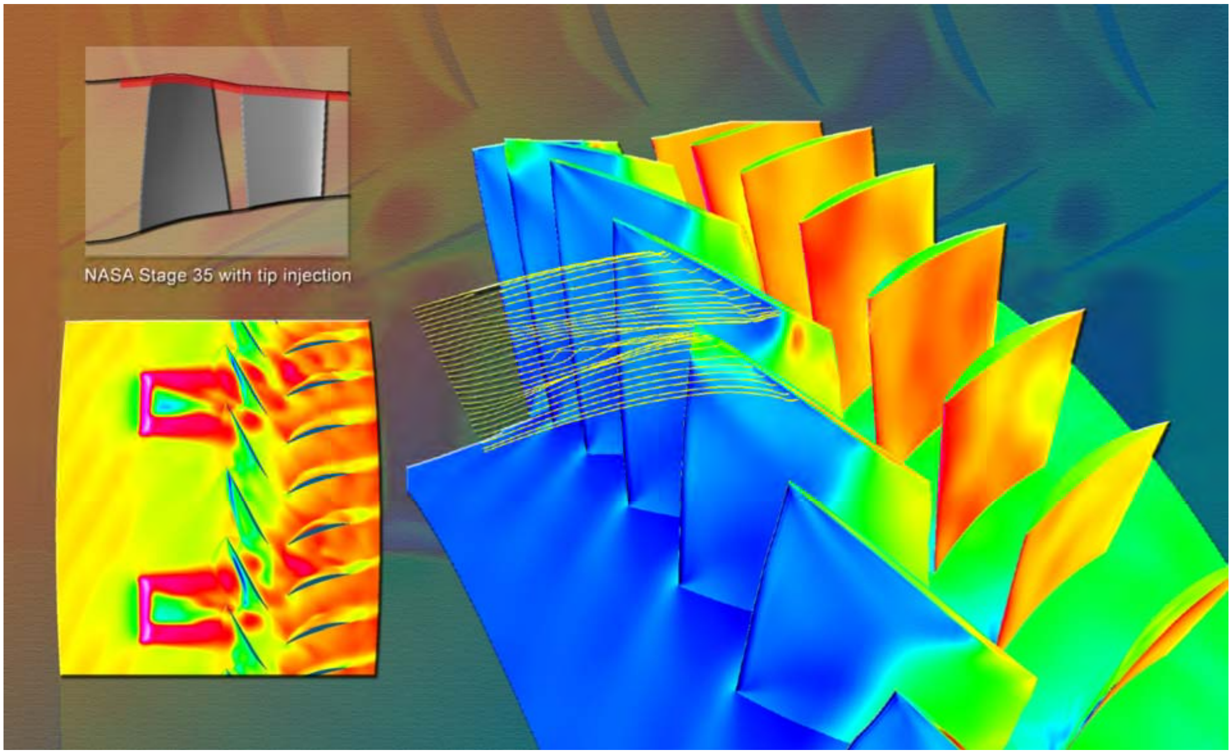


Figure 10. Compressor Stall Control with Tip Injection.

2.2.16. Microchannel Heat Exchanger Modeling (with UDRI)

A NALI sponsored research project at the University of Dayton Research Institute (UDRI) addressed critical needs of the Air Force for understanding heat exchange technology that could be used to address thermal management issues in onboard electronics for air vehicles. Dr. Alex Heltzel conducted the research as a post-doctoral researcher at UDRI. The remainder of this section summarizes Dr. Heltzel's work.

Advanced aircraft have formidable design challenges. Energy management requires viewing an aircraft as an integrated system, simultaneously considering mechanical, thermal, and electrical aspects. In order to perform trade studies of several potential system-configurations, system-level models are needed to permit the rapid simulation of integrated systems. From the perspective of an individual component, detailed computational fluid dynamics (CFD) simulations assist the fundamental understanding and development of cutting-edge technologies, such as micro-heat exchangers. The development of performance laws for micro-heat exchangers is a difficult undertaking. An accurate representation of the thermal performance of micro-channel flow requires CFD in concert with experimental validation. Existing performance and scaling laws are relied upon commonly for conventional/compact heat exchanger designs; however they are inadequate for micro-heat exchangers needed to disseminate ultra-high fluxes. Moreover, modeling approaches which have different levels of detail must be linked. Input data derived from first-principle simulations of single components should be incorporated within less-detailed system-level models. With this philosophy, we have simulated micro-heat exchangers and have begun to incorporate the results within performance maps. The performance maps were created by carrying out parametric studies to fit solution data over a range of thermal conditions. Although not a part of the work described in this report, these performance maps may eventually be incorporated into a MATLAB/Simulink system-level tool as part of a thermal management model.

In the current work, micro-scale pin-fin and cross-flow heat exchangers with hydraulic diameters on the order of 100 µm were simulated using CFD. Three-dimensional solutions of the Navier-Stokes and energy equations in both the solid and liquid domains were obtained. Predicted temperature gradients and pressure drops compared reasonably well with published experimental measurements. Performance curves were obtained for single-phase and coolant/air micro-heat exchangers for the engineering design of cooling components.

Three-dimensional CFD models of two micro-scale heat exchanger designs were created, utilizing a segmentation technique that allowed for full-device simulation. The simulations included the laminar flow approximation in both micro pin-fin and micro cross-flow heat exchanger, and were shown to predict heat transfer and pressure drops with reasonable accuracy. A range of flow conditions was modeled with the intention of generating performance curves under a variety of operating conditions. The predicted values of heat transfer coefficient indicate a high degree of volumetric efficiency, a critical factor when considering implementation in advanced aircraft. Heat loads up to 2 kW/cm^2 have been shown feasible for electronic cooling using micro-fabricated, liquid-cooled heat sinks.

Corresponding pressure drop dependencies on liquid flow rate have been described. It was shown that the heat exchanger material is of little importance when the wall thickness is on the order of 50 µm, allowing the designer to focus on lightweight materials without a significant thermal sacrifice. In micro- cross-flow heat exchangers using a gas as one working fluid and a liquid as the other, the gas phase had the limiting thermal resistance. This result implies that the use of filters or other design modifications that could allow reduction in gas slot dimensions could prove valuable for overall heat exchanger performance. It was also shown that water outperforms Jet-A fuel as a coolant, however both fluids are effective in micro heat exchangers where thin hydrodynamic and thermal boundary layers combined with large surface area to volume ratios dominate heat transfer performance.

A schematic of the micro-pin heat exchanger considered in this study is shown in Figure 11. The results of a computational fluid dynamic simulation showing temperature profile across the volume of the heat exchanger are shown in Figure 12 and validation results that compare simulation data to published experimental data are shown in Figure 13. The work was presented at a SAE conference and was selected for journal publication..

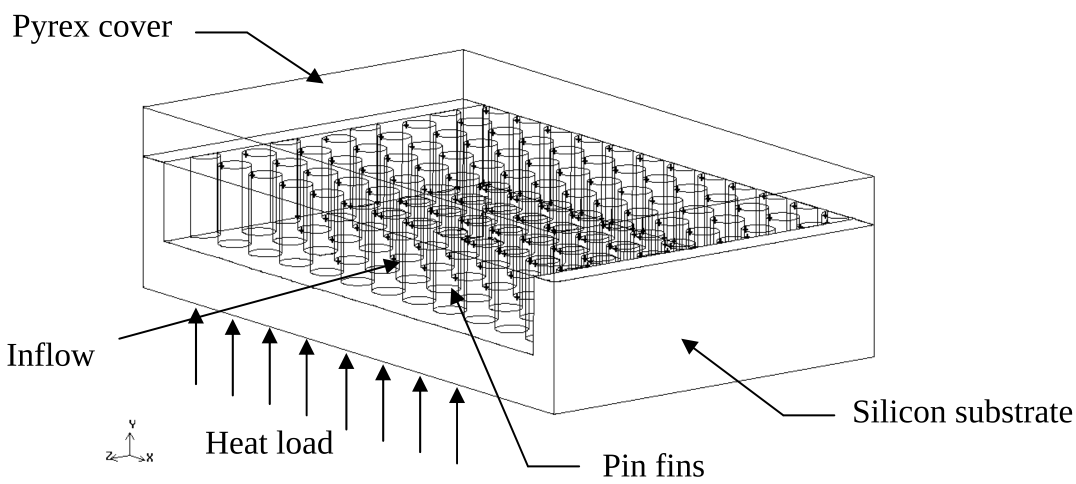


Figure 11. Schematic of a Micro-Pin Fin Heat Exchanger.

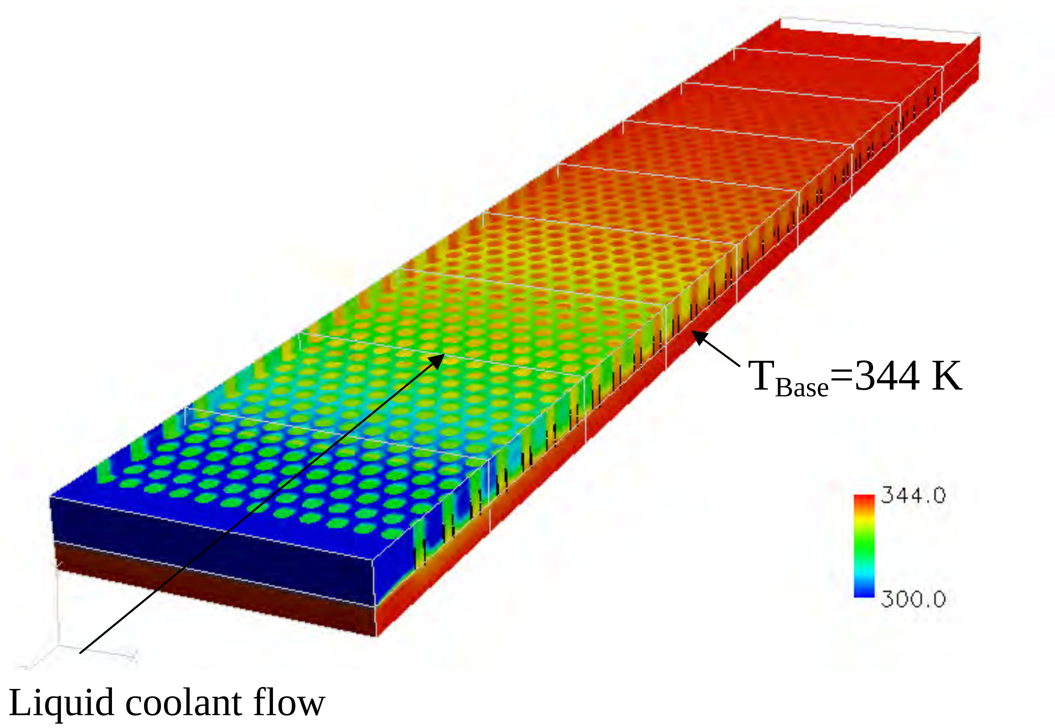


Figure 12. CFD Resolved Temperature Distribution in Micro-Pin Fin Heat Sink.

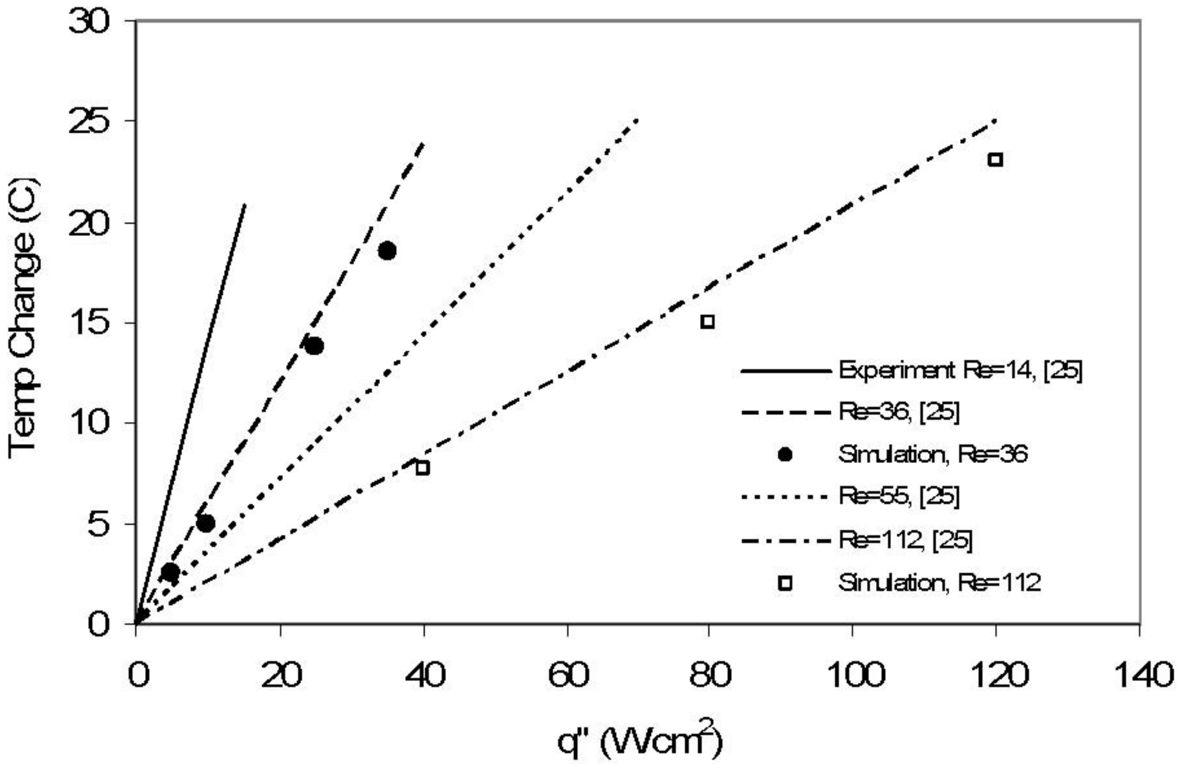


Figure 13. Average Temperature Change Through Micro-Pin Fin Heat Exchanger.

2.2.17. Combustion Modeling and Simulation (with UDRI)

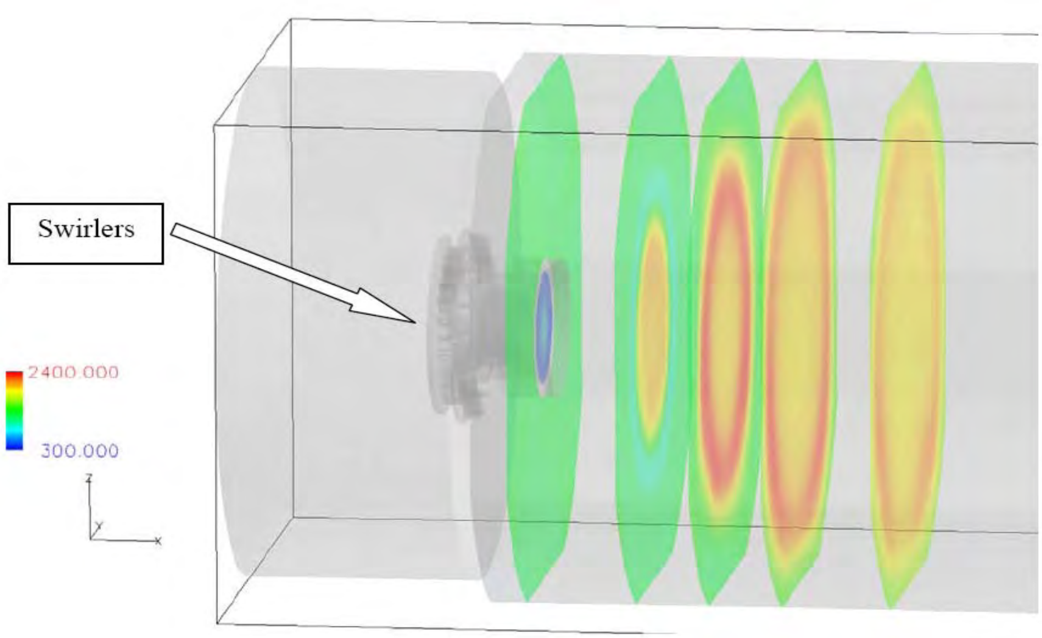


Figure 14. Temperature Variation Along the Axial Direction of Combustor Flow

2.2.18. Data Intensive Computing Environment Development

NALI phase I research funding was used to establish a Data Intensive Computing Environment (DICE) research program at Avetec. Funding for DICE continued through NALI phase II funding. The goals of the DICE program have been 1) to serve the Department of Defense (DoD) in translating high performance computing (HPC) requirements of the DoD into goals and objectives for further development among HPC vendors, 2) to serve the DoD as an independent evaluator of new technology to verify that vendor products meet requirements, and 3) To develop infrastructure required to support test and evaluation of new products and provide impetus to industry for the use of high performance computing in order to enhance national competitiveness. As a side benefit of the DICE research program technologies were developed to support Avetec's core research objectives.

Roger Panton served Avetec as the director of the DICE program and during NALI phase II funding worked closely with Avetec leadership to define the DICE program, build a core team of support staff, and collaborate with industry to achieve program infrastructure development goals. A governance board and a technical review board were established for the program and policies and procedures developed for the management of computing and network infrastructure and for the execution of projects for vendor product evaluation established. Al Stutz was hired as the Avetec Chief Information Officer and worked with Avetec staff to initiate planning for a research network to support the DICE program, Avetec research needs and needs of the Air Force Research Laboratories and the Aeronautical System Command at Wright-Patterson AFB. Computer Sciences Corporation (CSC) was contracted to support program development.

Targeted research areas established for the program included issues involving:

- Data Locality
- Data Movement
- Data Manipulation
- Data Integrity

Data Locality involves the access and use of data from different locations even though it may be stored at a single location and the optimal placement of multiple sources of data. Data movement research is needed to understand issues involved in moving data efficiently and reliably between geographically dispersed systems. Data manipulation is concerned with post processing and exploitation of data sets after they have been collected and finally data integrity is essential for the use of mission critical data.

Each of the areas described above are key concerns for the development and use of next generation design tools that will be deployed across the defense supply chain for weapon system development. These are critical needs to support the Avetec vision for the use of advanced modeling and simulation in virtual test environments to augment physical testing and reduce acquisition and lifecycle costs. To illustrate the difficulties that must be addressed, consider the preliminary design and analysis of a turbomachinery component for a gas turbine engine. A single computational fluid dynamic simulation can produce over 12 terabytes of data. In some programs, engine component simulations from multiple prime contractors must be coupled for system level understanding of performance at the design stages of an air vehicle platform. Intellectual property must be protected, decisions must be made about where data should be located, how it should be shared, how post processing should be done, and what infrastructure is required to move it. The DICE program was established to attack these issues.

During the course of NALI phase II funding, DICE program leadership established a research environment with three interconnected, geographically dispersed high performance computing system sites to support vendor product testing. Although there were some variations in the equipment installed at each site, a standardized site architecture was established as shown in Figure 15. DICE node sites feature hardware and software from over 25 vendors as shown in Table 2. Figure 16 shows the concept for site interconnection. At the conclusion of the NALI phase II funding support, sites were established at 1) Avetec in Springfield Ohio, 2) the Aeronautical Systems Command's (ASC) Major Shared Resource Center (MSRC) at Wright-Patterson Air Force Base and 3) the NASA Goddard Space Flight Center. Two calls for projects were issued and projects were reviewed and selected for evaluation within the environment. Results of the tests were documented in a series of reports that are now available to the research community on a program website. Seventeen HPC vendors had an interest in test and evaluation projects that were conducted in the DICE test bed as shown in Table 3.

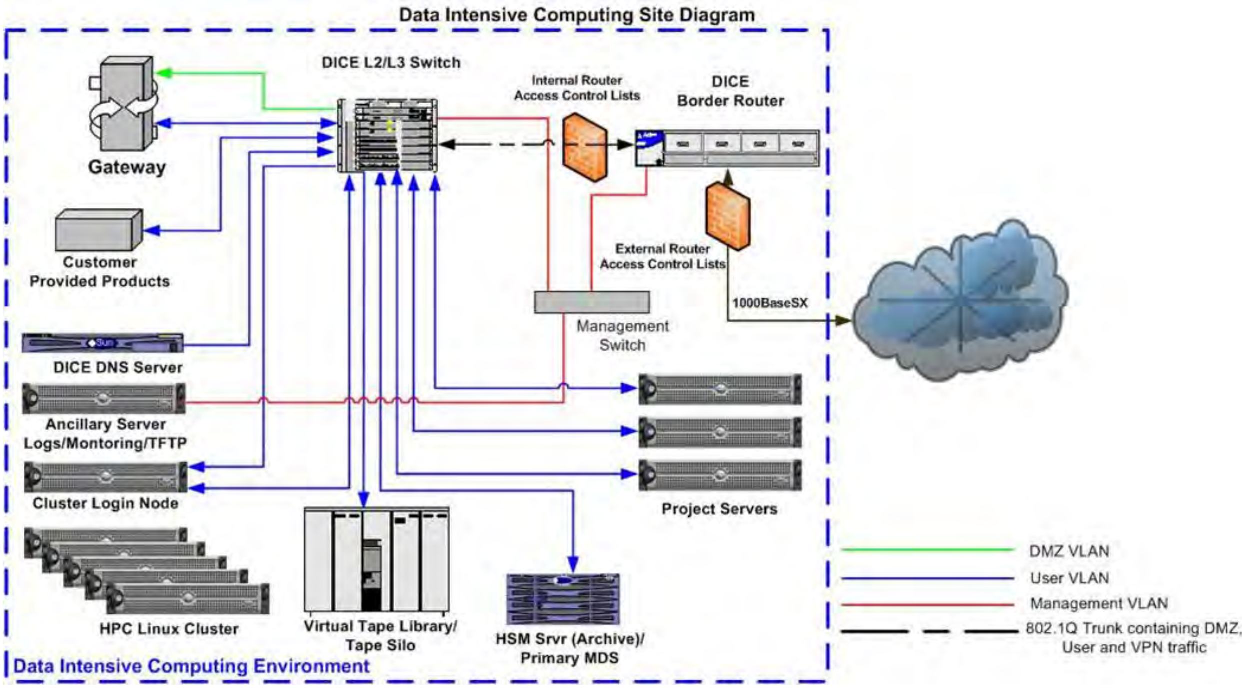


Figure 15. DICE Node Architecture

Table 2. DICE Environment Software or Equipment Partners

Cisco Systems Inc.	DataDirect Networks, Inc.	Dell Computer Corp
Ektopath	EMC2	Etnus LLC
FalconStor	Force 10 Networks, Inc.	Foundry Networks
Intel	Juniper Networks	Kitware, Inc.
Linux Networx	McData	Mercury
Novell	PANTA Systems, Inc.	Pillar Data Systems
Platform Computing, Inc	QLogic Corp	Red Hat
Sun Microsystems/Storage Tek	Sybase	ViON Corp
Wolfram Research	Yotta Yotta, Inc.	

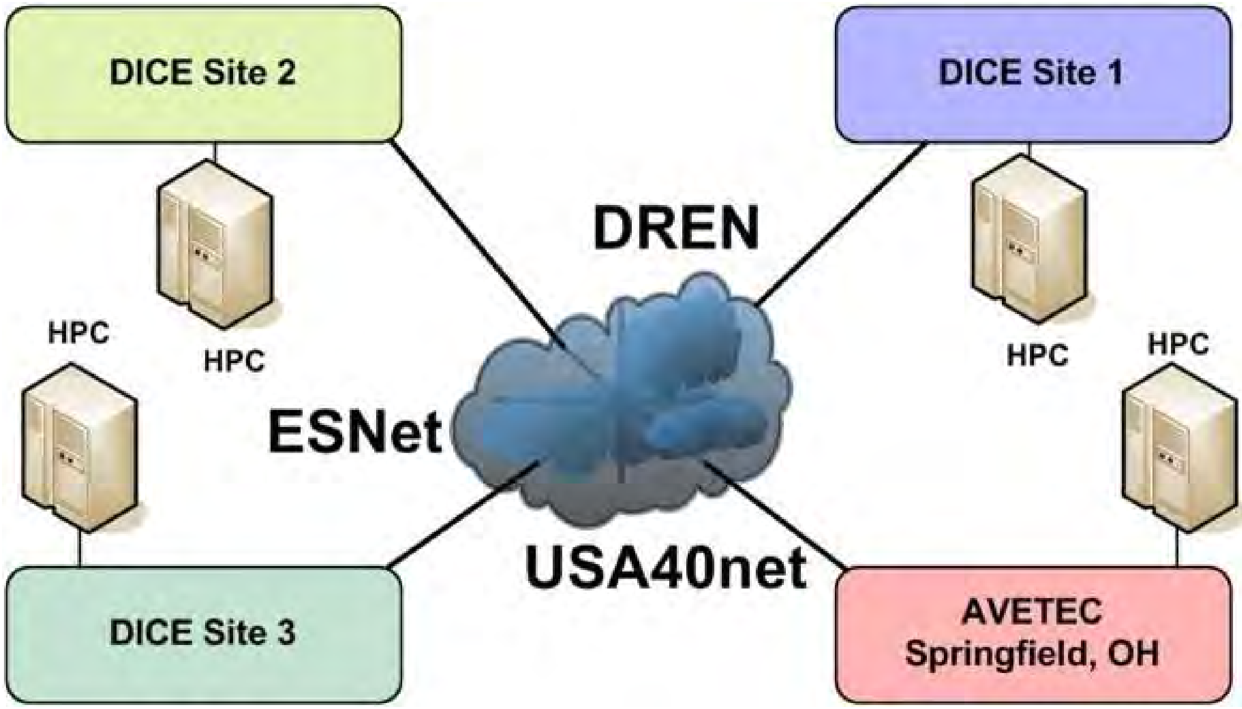


Figure 16. DICE Site Interconnection Diagram

Table 3. DICE Collaborators Selected for Project Evaluation.

NASA	Ohio State University	Ohio Supercomputing Center
Platform Computing, Inc.	Sun Microsystems	ViON Corporation
University of Maryland	Yotta Yotta, Inc.	Intivity
Isilon Systems	NetApp Storage	Panasas
Microsoft	General Atomics	Teradata
Apple Cloverleaf	Obsidian Research	

Computer Sciences Corporation (CSC) was contracted to support the DICE research program staff and was a key contributor for DICE program development during the early stages of the program. The following subsections outline accomplishments reported by the CSC team.

2.2.18.1. CSC Accomplishments, July 2006 to September 2006

CSC Continued to support equipment installation in support of the Avetec Data Intensive Computing Environment (DICE) research program. Computing and networking equipment installation took place at the Aeronautical Systems Command (ASC), Major Shared Resource Center (MSRC) at Wright-Patterson AFB. The ASC/MSRC serves as the center for Air Force high performance computing under the direction of the Department of Defense Modernization Office. The following was accomplished at the ASC/MSRC during the current reporting period:

- All equipment including cables are in place
- Additional 10/100/1000 BaseTX switch was added to the ASC Dell cluster for better performance
- Equipment is ready and awaiting final accreditation approval
- Accreditation for ASC is almost complete. The final review is in mid-October and will include updates to the CONOPs and Security Policy, as well as a full set of network security scans.
- Access Guidelines documentation which defines services at DoD sites and on DoD networks is still in process and related questions are being answered by vendors to append to this document.

Avetec also supported equipment installation at NASA Goddard Space Flight Center to support a DICE node at NASA Goddard support equipment for a PANTA cluster was connected on the NASA network. The cluster itself was ready to be placed on the network and is awaiting paper work from SUSE (Linux) to clarify false positives detected in network scans. Communication lines were established over Internet2 to the Ohio Super Computing (OSC) facility.

All network support equipment was installed and attached to the OSC network. A Linux Networx Cluster was prepared for installation of the GPFS parallel file system. Network communication to NASA was established over the Ohio Third Frontier Network.

In addition to equipment installations described above, CSC supported the development of a change management process for the DICE program and created a process flow for user account management.

Of eleven selected research projects, five were initiated during the reporting period. These are shown below in Table 4. An additional project from the VION Corporation to evaluate their HyperStor solid state disk with file system performance was added to the list of accepted projects for DICE and a kick-off meeting was scheduled for mid-October, 2006.

Table 4. DICE Project Initiations, 3rd Quarter 2006.

Project Title	Organization	DICE Challenge Area
Center for Performance Evaluation of Cluster Networking and I/O	The Ohio State University	Network Protocols and Applications

Technologies (PECNIT).		
3D Visualization and CELL BE processor	Mercury Computer Systems	Remote Visualization
Global Data Sharing and Enabling of Site Agnostic Resource Management and Job Scheduling Across Geographically Distributed Environments.	Yotta Yotta	Global Data Sharing
Explore Technology for Dynamically Establishing SN Extensions, on an As-needed basis, to Collocated Storage Resources	NASA/University of Maryland	Distributed and Parallel File Systems
GrADS	NASA	Remote Visualization

CSC worked with Avetec to setup a DICE computing node at the SuperComputing 2006 Conference to be held in Tampa Florida in November 2006. The OSC node will be moved to Tampa for the duration of this conference to support this effort and provide demonstrations. CSC continued to work with Avetec to identify and plan for the growth of the DICE environment. Planning for a new site at Pacific Northwest National Lab (PNNL) in Richland, WA was initiated.

2.2.18.2. CSC Accomplishments, October 2006 – December 2006

During the 4th quarter, 2006 reporting period CSC completed the accreditation of computer and network equipment at the ASC/MSRC and initiated preparation of required documentation for security related to traffic flows. This was required to satisfy security constraints in connecting to the Defense Research and Engineering Network (DREN). DICE Kerberos Domain Controllers (KDCs) were established on the MSRC network to address authentication needs for other DICE sites. CSC initiated the documentation of Access Guidelines for DICE equipment in a standard format that defines services at DoD sites and on DoD networks.

NASA received required security documentation to address concerns for the operating system on the PANTA cluster and communication was established between the NASA site and the OSC network. During the current reporting quarter, the DICE equipment located at the OSC site was shipped to Tampa Florida to support an Avetec DICE booth at the conference exhibition. When it was returned, it was shipped back to a new Avetec facility established in the Edison Center in Springfield Ohio. This facility was established in close proximity to the Avetec temporary office location in the Kissel Center in Springfield. Network connectivity to the Edison Center was established in December.

At the Super Computing 2006 conference in Tampa Florida, the DICE program had equipment in an Avetec hosted booth and also in booths hosted by Juniper and Yotta Yotta. Avetec supported a 10 Giggabit Ethernet connection to the SCinet backbone network. The DICE node at the conference exhibition supported demonstrations for Yotta Yotta, VION, and Mercury.

Briefings were given in both ASC and NASA booths. Additional presentations were supported from VION and Yotta Yotta with DICE assistance in the conference Exhibitor Forums. A Data Intensive Computing Pannel Discussion was sponsored by the DICE program.

Status of projects that were active on the DICE test environment during the fourth quarter of 2006 are shown in Table 5 below.

Table 5. DICE Project Status, 4th Quarter 2006.

Project Title	Organization	DICE Challenge Area	Status
Center for Performance Evaluation of Cluster Networking and I/O Technologies (PECNIT).	The Ohio State University	Network Protocols and Applications	Team has developed benchmarks to run on DICE systems. DICE has received Mellanox IB switch and will receive Cisco IB switch in January. Awaiting user accounts once ASC KDC is removed from ASC network.
3D Visualization and CELL BE processor	Mercury Computer Systems	Remote Visualization	Received the Cell BE simulator system that is under test at NASA. The final system has been delayed to Cell BE processor delays.
Global Data Sharing and Enabling of Site Agnostic Resource Management and Job Scheduling Across Geographically Distributed Environments.	Yotta Yotta	Global Data Sharing	Successfully tested a replication of a Sun SAM-QFS file system between OSC and NASA. Recreated the setup at SC06 and are working with Yotta Yotta to include the ASC site.
Explore Technology for Dynamically Establishing SN Extensions, on an As-needed basis, to Collocated Storage Resources	NASA/University of Maryland	Distributed and Parallel File Systems	Installed GPFS file system for use in this project. Have been able to set
GrADS	NASA	Remote Visualization	Installed client for GRADS using Red Hat Linux Operating

			System. Testing comparisons of Data Direct RAID disk with files compared to a VION Solid State Disk.
VION	NASA	Distributed and Parallel File Systems	Evaluating the VION SSD with different file systems. Comparisons are being made with Fibre channel and IB attachments to the device. Also, early tests have looked good for use as a local memory extender to older legacy systems. Released initial report on this project at SC06.

2.2.18.3. CSC Accomplishments, January – March 2007

During the first quarter of 2007 the DICE project stabilized its three sites at Avetec Springfield Edison Center, the ASC/MSRC, and NASA Goddard Space Flight Center. Virtual Private Network tunnels were established for communicating traffic between ASC and the other sites. The KDCs at ASC were activated and allowed all regular users access to systems at all three DICE sites. The Avetec site was operated at a reduced network bandwidth of 6 Mbps a Force10 switch was placed into operation at the Avetec site.

CSC assisted in the establishment of a review process for project final reports so that all required reviews are received prior to public release of the reports. CSC also initiated the development of a DICE User Guidelines documentation package that regular users can reference as they access DICE equipment, applications, and perform project work.

Several DICE projects were active on the test bed and testing neared completion for these projects. Status at the end of the quarter is shown in Table 6 below. A new project for Network Attached Storage evaluation was approved by the DICE Technical Review Board. Projects from General Atomics and Crosswalk entered the review process during this reporting period. Planning for an additional DICE site at Sandia National Laboratory in Albuquerque NM was initiated.

CSC also supported the planning process for a DICE sponsored mini-conference named the DICE Alliance. DICE Alliance Conference is a two day event scheduled for May 8-9, 2007. The conference was intended to bring together stake holders in the DICE program to showcase project results and identify issues facing the high performance computing industry. A panel discussion was planned. Guidelines for a second call for projects were assembled.

Table 6. DICE Project Status for First Quarter 2007.

Project Title	Organization	DICE Challenge Area	Status
Center for Performance Evaluation of Cluster Networking and I/O Technologies (PECNIT).	The Ohio State University	Network Protocols and Applications	Dr. Panda's team has received all user accounts and is actively working on the ASC cluster. The team plans to test Double Data Rate Infiniband and Low Latency 10 GbE on the AVETeC cluster in the coming quarter.
Data Location Awareness in the Grid Scheduling Process.	Platform	Intelligent Job Schedulers	Platform has completed the first phase of their project. There installed their data aware version of LSF and was able to schedule the use of Mathematica at two sites using the multi-cluster setup for LSF. The two sites active for this test was ASC and AVETeC. They will return in May for a three site test and advanced features.
3D Visualization and CELL BE processor	Mercury Computer Systems	Remote Visualization	Mercury has withdrawn their project, but DICE is still planning to implement their system to be used at NASA. NASA personnel will perform several code ports and visualization tests with this new gear
Global Data Sharing	Yotta Yotta	Global Data	Yotta Yotta was

and Enabling of Site Agnostic Resource Management and Job Scheduling Across Geographically Distributed Environments.		Sharing	delayed until the VPNs were created between the sites and until the Platform project first phase was complete. Re-start date of this project will be in early April.
Explore Technology for Dynamically Establishing SN Extensions, on an As-needed basis, to Collocated Storage Resources	NASA/University of Maryland	Distributed and Parallel File Systems	Installing a Network simulator and an additional NIC into the test system to evaluate delays and performance for the file system
GrADS	NASA	Remote Visualization	Installed the GrADS client on the ASC cluster. The GrADS project team has tested various TCP window sizes for best network performance and will be implementing a network delay simulator to validate performance with
OpenSMS for HSM using the XFS file system	Sun/GrovesTech	Data Staging	The equipment for this project has arrived at the AVETeC site. The collaboration agreement has been signed and project is set to begin in early April. An additional server will be sent to NASA for the two site phase of this project
VION	NASA	Distributed and Parallel File Systems	This project is nearing completion. Benchmarks with the VION Hyperstor SSD were completed from the DICE Ancillary system and more tests with a SuperMicro Segment Server will

			be conducted using Fibre Channel and Infiniband Connections

2.2.18.4. CSC Accomplishments, April – June 2007

During the 2nd quarter of 2007 the DICE team worked with network specialists from NASA, DREN and MAXGigapop to understand network performance issues that were observed on the route from the ASC/MSRC DICE node and the node at NASA. The PANTA cluster at NASA was stabilized. The team identified a need to establish a management server at the NASA site that could be used for change management. NASA established reciprocity for information assurance (IA) training so that IA training from Department of Defense sites could be used in place of NASA's own IA training. Sun Microsystems made the decision to donate an L180 tape library to the DICE environment following the completion of the Sun/Grovtech project. The Springfield DICE site continued to operate at the reduced bandwidth of 6 Mbps but plans have been initiated to increase this to 100Mbps.

CSC developed a process to integrate new sites into the DICE environment. Documentation was presented to the DICE review board for approval. This process was designed to be used to incorporate DICE node sites at Pacific Northwest National Laboratories and at Sandia National Laboratories. Modifications to the project reporting process were made. Two members of the technical review board must review project final reports and an oral presentation before the board is required before project sign-off. CSC also developed an intern process that was presented during the second call for projects. The intern process provides the ability for student interns to be located at the vendor site in Springfield.

The Avetec DICE team with support from CSC held its second annual conference for stake holders in the DICE project. The event, titled DICE Alliance was held May 7-9, 2007. CSC supported the agenda for the first day of the conference and participated in a Workload Management session during the second day. Seven case study briefings based on DICE projects were presented and a panel discussion on current data intensive challenges was held. DICE personnel also used the event to issue a second call for projects and described project requirements to attendees.

Active projects and there status as of the current reporting period are shown below in Table 7.

Table 7. DICE Project Status for 2nd Quarter 2007.

Project Title	Organization	DICE Challenge Area	Status
Center for Performance Evaluation of Cluster Networking and I/O Technologies (PECNIT).	The Ohio State University	Network Protocols and Applications	Dr. Panda's team has received completed their testing of the PCI-X Single Data Rate (SDR) Infiniband testing at the ASC site.

			The ASC cluster will be modified to use the Quadrics Interconnect in the month of July. His team will begin using the AVETeC cluster first for SDR PCI-Express testing and then modify it for Double Data Rate (DDR) testing during the next quarter.
Data Location Awareness in the Grid Scheduling Process.	Platform	Intelligent Job Schedulers	Platform has completed the first phase of their project. They plan to return in late July to test with an updated version using a 2 and 3 site configurations.
3D Visualization and CELL BE processor	Mercury Computer Systems	Remote Visualization	Mercury has withdrawn their project, but DICE is still planning to implement their system to be used at NASA. The Mercury gear is not scheduled to arrive at NASA until July 20^{th}.
Global Data Sharing and Enabling of Site Agnostic Resource Management and Job Scheduling Across Geographically Distributed Environments.	Yotta Yotta	Global Data Sharing	Yotta Yotta began performance testing and discovered a network performance issue over the WAN from ASC to NASA. Once this issue is resolved, Yotta Yotta will complete their project.
Explore Technology for Dynamically Establishing SN Extensions, on an As-needed basis, to Collocated Storage	NASA/University of Maryland	Distributed and Parallel File Systems	NASA/UoM have completed their project and currently developing their final report.

Resources			
GrADS	NASA	Remote Visualization	Continues to test over the WAN from ASC to NASA with different TCP window sizes. This project is nearly complete and the report is due in the next quarter.
OpenSMS for HSM using the XFS file system	Sun/Intivity (GrovesTech)	Data Staging	Intivity has completed their project and is finalizing their report for submission
ViON	NASA	Distributed and Parallel File Systems	ViON has completed their project and the report is scheduled for submission and review in August.
NAS Evaluation	ASC MSRC	Distributed and Parallel File systems	The Network Attached Storage (NAS) evaluation has completed the first phase with the Isilon storage and will begin the second phase in late July/early August.
Linking a file system in WAN	OSC-Pete Wycoff	Distributed and Parallel File systems	After a delay for collaboration agreement and NDA signings, this project is ready to begin. The estimated start for this project is the week of July 9th
IGRID	Crosswalk	Distributed and Parallel File systems	Crosswalk has completed their site survey and is now working with LSI and EMC to provide storage for their project.

2.2.18.5. CSC Accomplishments, July – September 2007

During the third quarter of 2007 the DICE environment was used to continue project work. The cluster at the ASC/MSRC was down for a short period of time to install a Quadrics interconnect necessary for evaluation in one of the projects. Near the end of the quarter a security vulnerability was addressed for 64 bit kernels and as a result, operating system kernels were patched and rebuilt. There was an incompatibility between the new kernel build and the IBRIX file system client on the ASC/MSRC cluster. CSC continued to address this issue.

The team achieved better network performance in the connection between NASA and ASC over DREN. This was accomplished by changing VPN encryption protocol from AES to 3DES and by additional tuning. During the testing DREN supported only OC-12 (622 Mbps) peering between DREN and the Max Gigapop. This was identified as a limiting factor in network speed.

CSC worked with the DICE team to define a 192 node IBM cluster that uses dual socket quad core processors for a total of 1536 compute processors rated at 14.5 Teraflops. This cluster was planned for a DICE node located at the Pacific Northwest National Laboratories in Richland Washington.

A total of twenty project proposals were received as a result of the second year project call. The DICE team with support from CSC reviewed project proposals and recommended eleven projects for consideration to the DICE Governance Board. Resource requirements to support the projects were identified.

The team conducted planning and coordination activities for participation and hosting a booth at the annual Supercomputing Conference and Exhibition.

Project status for projects operating in the DICE environment during the reporting period is shown below in Table 8.

Table 8. DICE Project Status for 3rd Quarter 2007.

Project Title	Organization	DICE Challenge Area	Status
Center for Performance Evaluation of Cluster Networking and I/O Technologies (PECNIT).	The Ohio State University	Network Protocols and Applications	Dr. Panda's team has received completed their first phase testing of PCI-X technologies at ASC His team will begin using the AVETeC cluster first for SDR PCI-Express testing and then modify it for Double Data Rate (DDR) testing during the next

			quarter.
Data Location Awareness in the Grid Scheduling Process.	Platform	Intelligent Job Schedulers	Platform has completed their project and are in process of creating their final report
Global Data Sharing and Enabling of Site Agnostic Resource Management and Job Scheduling Across Geographically Distributed Environments.	Yotta Yotta	Global Data Sharing	YottaYotta is scheduled to complete their testing in the third week of October.
Explore Technology for Dynamically Establishing SN Extensions, on an As-needed basis, to Collocated Storage Resources	NASA/University of Maryland	Distributed and Parallel File Systems	NASA/UoM has created their report and is awaiting final approval before posting.
GrADS	NASA	Remote Visualization	NASA has completed their testing and is process of generating their report.
OpenSMS for HSM using the XFS file system	Sun/Intivity (GrovesTech)	Data Staging	Intivity has completed their report and is awaiting final approval before posting.
ViON	NASA	Distributed and Parallel File Systems	ViON has completed their project and is currently generating their report.
NAS Evaluation	ASC MSRC	Distributed and Parallel File systems	The Network Attached Storage (NAS) evaluation team is finalizing their second phase of their testing and is expected to complete their project in November.
Linking a file system in WAN	OSC-Pete Wycoff	Distributed and Parallel File systems	The DICE environment is currently re-configuring for this project and the

			expected start date in October.
IGRID	Crosswalk	Distributed and Parallel File systems	Crosswalk has recently gone out of business and this project has been terminated.

2.2.19. Generic Engine Model Verification and Validation

Dr. Jeff Dalton continued prior research and development collaboration with the Air Force Research Laboratory Propulsion Directorate in generic turbine engine modeling and simulation under contract to Avetec shortly after the company was founded in 2005. This work continued under NALI phase II funding and was summarized in a paper presented at the 42nd AIAA Joint Propulsion Conference in Sacramento in 2006. The remainder of this section summarizes the research.

Modeling and simulation technologies have developed to the point that they provide necessary tools for the engineer designing new weapons systems. Systems are so complex that some element of modeling and simulation is necessary to complete designs. As system complexity continues to increase and system interactions become harder to understand, we believe modeling and simulation will play an increasingly important role. The use of virtual engine testing using modeling and simulation techniques has been suggested by Dr. Charles Skira at AFRL as a means for reducing the required testing while managing acceptable risk in new engine development programs. In order for product developers to have the necessary confidence in the answers provided in a system simulation, verification and validation (V&V) are key elements in any simulation model development.

There are several ways to do engine modeling and simulation. Traditional approaches have a long history of development using FORTRAN or other 4th generation languages to calculate thermodynamics cycle parameters associated with the design and performance prediction of gas turbine engines. These cycle decks have been used extensively by developers of gas turbine engines and their customers to understand the behavior of jet engine designs prior to, during, and after the development of the physical engines. Beginning in the mid to late 1990's an effort was undertaken by NASA Glenn Research Center scientists to modernize the way that cycle deck simulations of engine designs are produced. The NASA Numerical Propulsion System Simulation (NPSS) code development effort focused on the use of object-oriented software development practices to develop a very flexible means for capturing the physics of engine components and encapsulating component behavior in configurable, reusable modules[2]. NPSS also contains features for coupling components and completing integrated engine systems designs and automating the test and analysis of these designs. NPSS provides a modern, object-oriented method for producing customer cycle decks that predict engine behavior. In addition to NPSS, MATLAB, Simulink, and associated tools have been applied in the development of detailed, physics-based, turbine engine models capable of execution on real-time hardware simulators.

NPSS and Simulink based models are complementary in nature. NPSS combines object-oriented techniques for component encapsulation, mechanisms for interconnecting components and establishing communications linkages between the components to perform iterative solutions of coupled systems. Simulink provides an easy-to-use, graphical, modeling and simulation development environment for developing time-based simulations in a broad range of applications. Both NPSS and Simulink are capable of code generation using associated tools. Add-on tools available from the MathWorks, Inc. enable the production of real-time code from Simulink models for execution on specialized, real-time, computing hardware. Turbine engine modeling software for modeling low-bypass ratio, augmented, turbofan engines has been developed for both Simulink and NPSS.

To mitigate engine and control system development costs and operational costs, the Propulsion Directorate's Turbine Engine Division of the Air Force Research Laboratory has been engaged in the development of real-time, integrated, simulation models of both modern turbine engines and their respective control and health management systems. As a result of this work, a real-time simulation capability called the Turbine Engine Dynamic Simulator (TEDS) has been developed for the purpose of supporting research in advanced turbine engine controls and health management. TEDS, operating as a virtual test cell, enables a user to investigate "what-if" scenarios at a fraction of the cost of an engine test cell or research aircraft. This simulator benefits researchers by offering a shared resource to support advanced controls and health management research in a real-time simulation environment. Non-linear, component-level, engine and engine control models that are physics-based are used to model the operation of a generic, gas turbine engine.

The TEDS virtual test cell is composed of two dSPACE Inc.-based hardware simulators with specialized analog and digital I/O modules for interconnection between simulators or interfacing to external hardware. The function of each simulator is determined by real-time model software compiled on a host PC and downloaded onto the simulator for real-time execution. MathWorks, Inc. MATLAB, Simulink, and Real-Time Workshop with dSPACE, Inc. ControlDesk software running on host computers are used to do rapid system development of real-time models for deployment in the virtual test cell. TEDS simulators have been used to perform real-time simulations of gas turbine engine and engine control systems.

To facilitate turbine engine and control system modeling and simulation, generic engine and control models implemented in Simulink have been developed. The history of this development is briefly described here to set the context for the current work. Dr. Zane Gastineau conducted initial model development for his Ph.D. dissertation in August 1998. His thesis titled, "Robust, Multivariable, Quantitative Design of an Adaptive Model-Based Control for Jet Engines," served as the basis for a generic engine and generic engine control system and led to the development of the concept of a real-time control capability to support real-time modeling and simulation of gas turbine engines. This was further developed into an intelligent controls research capability by government and contracted researchers to provide a real-time simulation and analysis platform for the investigation of modern turbine engine and control system behavior. Enhancements for the generic engine model (GEM) including updated control system modeling and the development of hardware simulation components including real-time model environment have been completed.

Two separate simulation systems are used to provide the high-fidelity, virtual operating environment. The first system simulates the plant, i.e. the engine model, complete with all related sensors and actuators. The second system simulates the engine controls, complete with all logic, switching, inputs and outputs. Data transfer between the two systems is via a set of electrical cables, which carry the actual physical signals that exist in an operating aircraft engine. This architecture resulted in a tool that can be used not only to simulate an engine Full Authority Digital Electronic Control (FADEC), but also to interconnect the real and virtual components of the propulsion systems at will. The versatility of these simulators also allows operational testing of individual engine and control components such as sensors, actuators, and valves. Taken as a whole, TEDS represents a significant improvement in the ability of the Propulsion Directorate to characterize the performance of propulsion systems and components in a timely manner.

The generic engine model (GEM), as developed by SMI, uses a standard thermodynamics package to do engine cycle performance calculations for a two-spool, non-augmented, high-bypass ratio turbofan. The model also includes modules for modeling mechanical shaft dynamics as well as gas dynamics in the engine. These modeling objectives enable GEM to combine both steady-state performance calculations and transient analyses in the same simulation model. Mink lists two goals associated with the development of the generic engine model: 1) to provide a capability for independent testing, V&V of propulsion system components and 2) to provide a non-proprietary model suitable for use by researchers in propulsion systems. The use of real-time hardware with analog sensor interfaces enables the development of hardware-in-the-loop (HIL) testing capabilities.

Requirements established for the modeling and simulation approach included: 1) real-time engine simulation, 2) operation over the entire flight envelope, 3) accurate steady-state behavior, 4) credible transient behavior, 5) easily modified for other engine cycles, 6) capable of hardware interfacing for testing and validation, 7) simulated engine sensor measurements, 8) Environment, PLA, and engine load user inputs, and 9) non-proprietary, accessible model structure.

Development based on these requirements has resulted in an extremely flexible design was used in several capacities for HIL testing. The generic model features a 0-D model of the thermodynamics associated with an engine cycle. It is physics-based and component-based so that parts of the model may be reused in other engine simulation and modeling experiments. Model behavior may be customized by tuning any of over 100,000 data points (including component map points, geometry, and other parameters) in the underlying MATLAB workspace.

Since its completion, a number of possible uses for the generic engine model have been suggested. These include: 1) V&V of actuators, engine controllers, and advanced control algorithms, 2) integration of the generic engine model with models of other propulsion system components, 3) evaluation of engine health management algorithms, 4) engine performance trending, and 5) parameter fitting for specific engine types. When considering new potential uses of the modeling and simulation technology it is important to quantify assumptions that can be made in considering the new use and balance the need for V&V steps during the development and the risk associated with not performing V&V steps.

Although GEM is a powerful research tool, there are several aspects of the model which make it difficult to apply in applications listed above. The model features a comprehensive set of subsystem components that are available for reuse. However, these components have not been delivered in library form, making their reuse more difficult. Common subsystems are reused within the model. However, in many cases slight variations on the subsystem components are required in each application. A library structure with more complete encapsulation of component parameters is required to make the components more easily reused. Documentation regarding the use of components including underlying assumptions of the design is in progress and has recently become available. V&V efforts of GEM have been limited and informal due to time and budget constraints.

The risks associated with limited V&V activity have been deemed acceptable in terms of the original intended uses of the GEM, which are to provide a reasonable model for HIL testing and provide a non-proprietary model for researchers. However, in considering more advanced uses of the model, a more formal V&V process must be completed. Methods for tuning model parameters for matching specific engine behavior are not fully documented and the degree to which derivatives of GEM can be used to model individual engine behavior have not been completely quantified. The original generic engine design assumed subsonic operation, and associated assumptions must be revisited prior to using the model in applications involving modern fighter engines that operate in flight envelopes including supersonic Mach numbers.

A framework for verification and validation of engine model simulation results was proposed and is shown below in Figure 17.

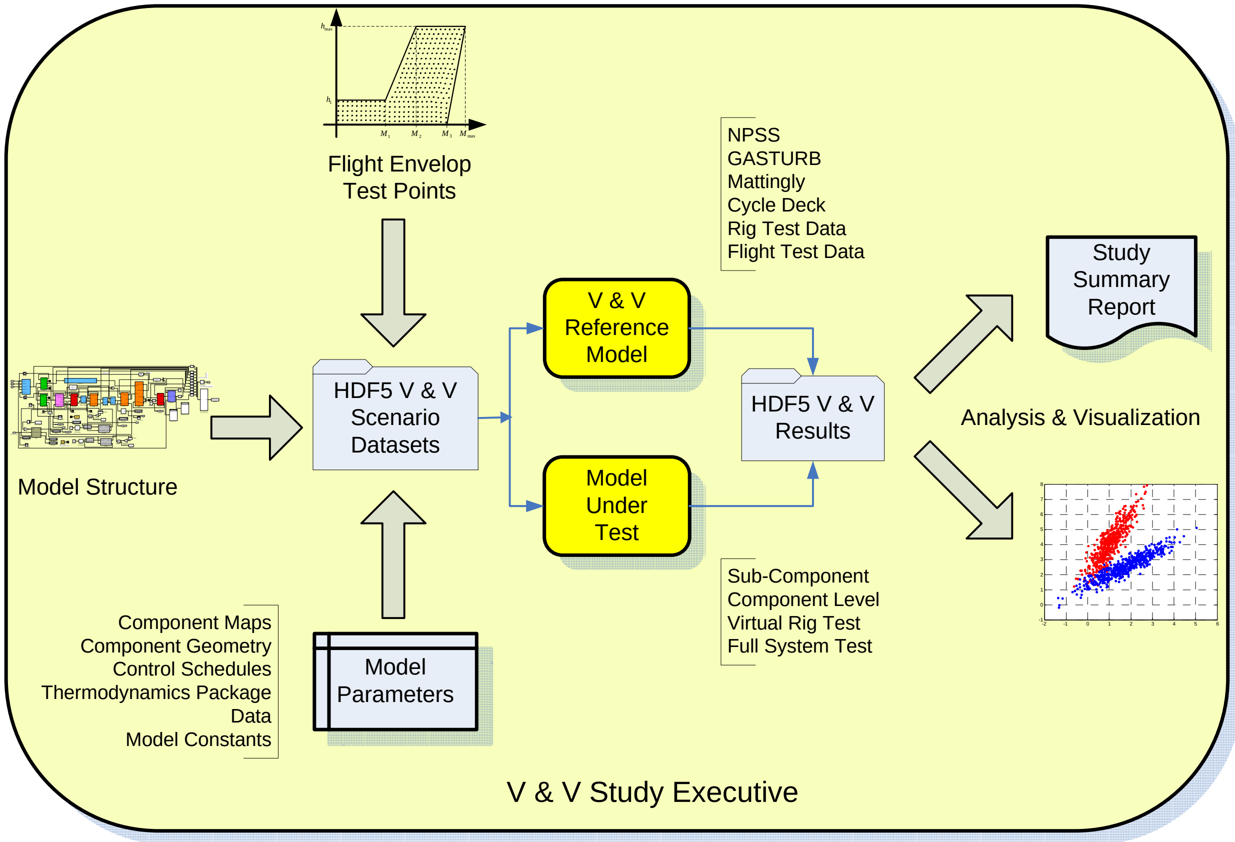


Figure 17. Concept for Engine Model Verification and Validation

2.2.20. Integrated Modeling and Simulation Framework

Dr. Jeff Dalton conducted collaborative research with representatives of the Air Force Research Laboratory Propulsion Directorate in both the Turbine Engine Division and the Power Division with the objective of using modeling and simulation for system level trades in the preliminary design stages of advance air vehicle based weapon systems development and acquisition. Partial results of this work were published in the 43rd AIAA Joint Propulsion Conference in Cincinnati. The remainder of this section summarizes this work.

Modern air weapon systems acquisition programs face integration challenges that are increasingly difficult to manage. Contributing factors to these challenges include higher levels of overall system complexity, tighter coupling and stronger interaction between subsystems, the need to optimize at the integrated vehicle system level, and the distributed nature of the subsystem design process. In conventional system design, vehicle performance and operational objectives are established early in the process. These vehicle-level specifications drive the performance and design requirements. Interface control documents are produced and the development of subsystems begins. The systems engineering that is required to develop the platform is so complex that, by necessity, the design has been decomposed into individual subsystems. Examples of subsystems that have been designed in relative isolation include the gas turbine engine itself, the fuel subsystem, engine auxiliary subsystems, secondary power for actuation, avionics, flight and engine control, and thermal management subsystems for supplying vehicle-level cooling.

In recent acquisition programs the system design work has been distributed to individual contractors which in turn form a tiered supplier design chain. The prime contractor then is called upon to assume the responsibility and risk associated with the integration of the various subsystems. This approach is contrary to historical approaches where the prime contractor assumed responsibility for most of the design work and then distributed the manufacturing through a supply chain. A disadvantage to the current approach is that although individual subsystems are optimized, when completed and integrated into the vehicle, the result may be a finished product that is at best sub-optimal and in the worst case inoperable. As a result, costly redesign may be required late in the acquisition process, if at all possible. An integrated approach to modeling and simulation provide many advantages over traditional approaches. Apart from providing a means of accurately measuring a system's performance, the purpose of using simulation tools is also to link the economic factors, such as productivity and total costs, as well as the sustainable factors, such as natural resource and energy consumption of a system. The simulation results prove quantitatively and visually that sustainability is not only 'free' but is, in fact, a far better proposition for cost and safety, as well as performance for propulsion systems than traditional forms of management. The difference between prior programs where the prime contractor was the primary developer and trends for emerging programs is shown below in Figure 18.

It is our view that a sophisticated modeling, simulation and analysis framework can be used to evaluate the designs, guide decisions made for individual subsystem components and development needs, track changes that result as a normal part of the design process, capture interactions among components and subsystems, and check for system operability. This framework can be exercised early in the design process to conduct trade studies which correspond to multi-objective optimization and divert potential operational problems down the line. Strategies and implementations for the multiple levels of control can be developed within the framework. It can also be used as the vehicle design develops, and as individual components are available, to test both component compliance and integration. Hardware test results can, in turn, be used to increase the fidelity of the models and simulations.

The objective of the research was to outline the required framework and suggest steps that can be taken to utilize such a modeling, simulation and analysis capability which merges thermal, power, and propulsion simulation models to benefit Air Force weapon systems development. A general framework and a specific implementation of a software environment for model prototyping, simulation and optimization are presented. This paper provides an overview of an integrated simulation environment, discusses the model-integrated computing philosophy, and illustrates the high-level modeling concepts being developed in the Air Force Research Laboratories (AFRL) for embedded systems design and evaluation.

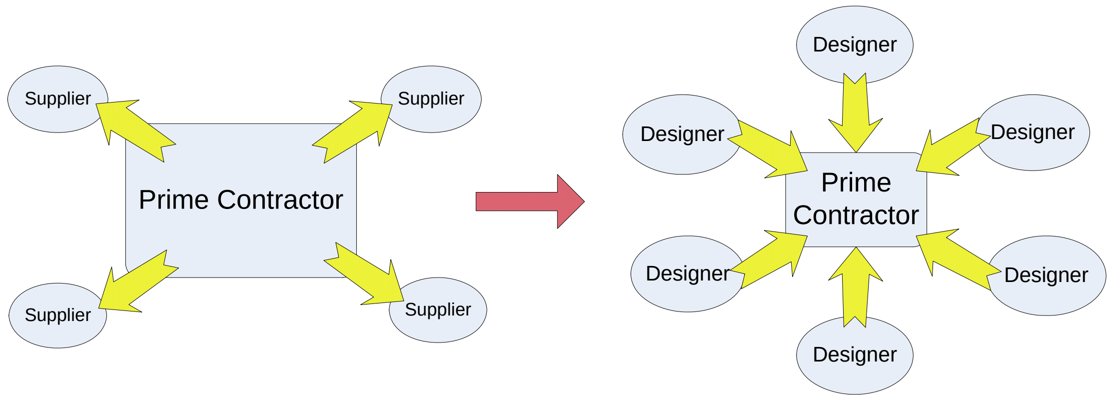


Figure 18. Transition from Supply Chain to Design Chain

2.2.21. Conference Participation of the Avetec Research Team

Under sponsorship of the NALI phase II funding Avetec research teams were able to participate in aerospace industry related research conferences and other events. Examples of these are documented in this section of the report.

Avetec researchers attended the International Gas Turbine Institute (IGTI) Turbo Expo Conference and Expositions held in Barcelona Spain in 2006 and in Montreal Canada in 2007. The IGTI Turbo sponsored by the American Society of Mechanical Engineers (ASME) is the premier international conference within the industry featuring both technical research components and industry exhibitions. Avetec research was featured as a key part in the 2006 conference as documented in the NALI phase I final report previously submitted. Avetec collaborators also presented NALI sponsored work in the 2007 conference.

In addition to IGTI, Avetec researchers also participated in the 2006 and 2007 AIAA Joint Propulsion Conference and the 2007 AIAA Annual Sciences Meeting. Avetec researcher Dr. Ian Halliwell has served as the organizer for AIAA student design competitions in turbine engine design and also has served in various capacities on AIAA technical committees related to turbine engine design research and development.

Dr. Jeff Dalton, in collaboration with Ernie Hodge of Modelogics, Atlanta Georgia, presented aircraft system related modeling and simulation efforts underway at the 2007 MathWorks Aerospace and Defense Conference. The presentation featured early NALI program results in the development and application of aircraft thermal management modeling and simulation tools.

Dr. Jeff Dalton prepared and presented an overview of gas turbine engine propulsion concepts at the National Test Pilot's School in Mojave CA. The presentation was an invited presentation for flight test pilots and flight test engineers in a year long course at the school.

2.2.22. Engine Health Management System Research

Early in the development of Avetec Research programs, Turbine Engine Health Management was identified as a strategic area of interest for future work with the U.S. Air Force Research Laboratories. Through collaborative efforts, Avetec established several research efforts with the objective to apply results from modeling and simulation efforts through other collaborations in the area of engine health management.

Under the direction of Dr. David Loda, Avetec researchers completed a pilot study that used off-the shelf components to implement an engine health management system designed for real time data collection and archiving from a moving automobile as an analog to future possible health management systems for air vehicles. The demonstration attached a streaming data collection unit to the standard OBD II data port common in late model automobiles. The data collection unit and a GPS receiver in the vehicle were connected to a microserver integration unit that contained a cell phone transmitter. The integrated unit enabled real-time engine and location information to be sent via cell phone switches back to a database server on the Avetec network. Tests were conducted to collect, store, and process vehicle health data.

As a result of this preliminary work, Avetec researchers set out to develop a unified modeling and simulation framework that could be used to test and analyze performance of future engine health management systems. Under NALI phase II funding. Allen Revels at Avetec developed a project plan for the development of the framework as shown below in Figure 19. The project was selected for funding under later NALI phased funding.

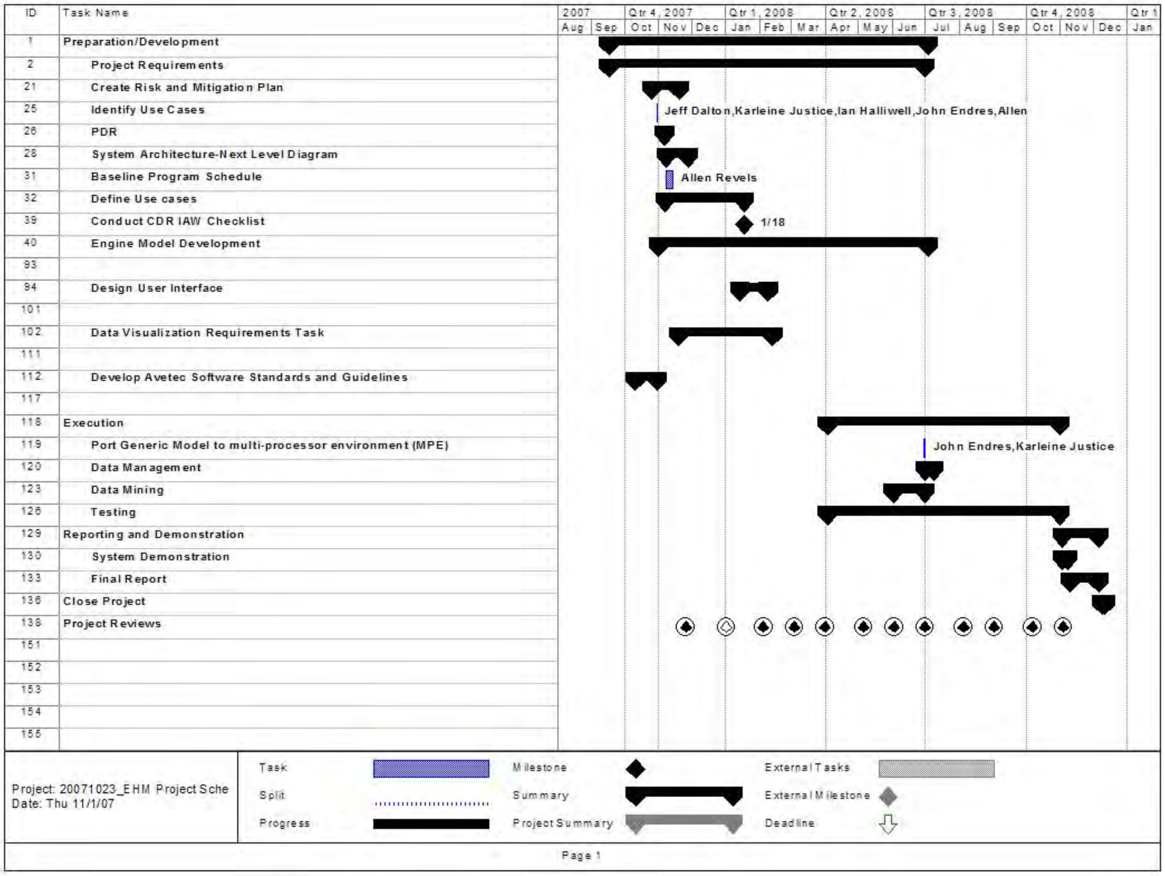


Figure 19. Engine Health Management System Evaluation Framework Project Plan

2.2.23. Micro Turbine Heat Exchanger Modeling

Karleine Justice joined the Avetec Research group in 2006 while a graduate student in Mechanical Engineering at Wright State University. NALI phase II funding was provided to Karleine in support of her Master's degree research in micro-turbine power generation with application to air vehicle auxiliary power systems. As a result of that support Karleine completed her Master's degree, presented intermediate results at local conferences and published a related paper at the 43rd Joint Propulsion Conference in Cincinnati in 2007. Her research is summarized in the remainder of this section.

The introduction of distributed generation for electrical power is the result of changing market forces, energy security issues and advancement in energy technology. A few of the driving forces behind distributed generation are the ever increasing need for reliable digital systems with quality power, the overburdening of the transmission and distribution grid of the nation, and energy security with efficient and productive use of domestic resources. Environmental concerns

also play a big role in distributed generation. Near zero emissions and ultra-high efficiency help to compel today's electric production market towards distributed generation.
Hybrid fuel cell designs under development and consideration include a high temperature fuel cell with a gas turbine generator, a fuel cell with a reciprocating or more commonly referred to as a piston engine, and designs that incorporate different fuel cell technologies. Hybrid systems have proven to generate high efficiency with essential low levels of pollutant emissions at greater fuel energy savings than non-hybrid systems. Fuel cell hybrid systems that incorporate gas turbine technology in the form of microturbines that generate power on the scale of 10 kW to 50 MW are envisioned to participate in the new market for distributed generation.

It is very important to properly match and integrate the fuel cell with the gas turbine portions of the cycle. A complete shut down of the turbine can be damaging to the fuel cell and other system components. Temperature response analysis allows for the validation study of the mathematical modeling of the hybrid power system. A fuel cell may take up to three hours to reach steady operating conditions. Depending on the size of the heat exchanger, the heat extraction from the hot flow may take several hours before enough is extracted to provide appropriate heat to the turbine for power extraction.

In this research a parametric Simulink model of a microturbine generator was created to model performance of an auxiliary power generation system. The simulation model was used to understand detailed system level behavior of microturbine generation systems. A top level view of the Simulink model is shown below in Figure 20.

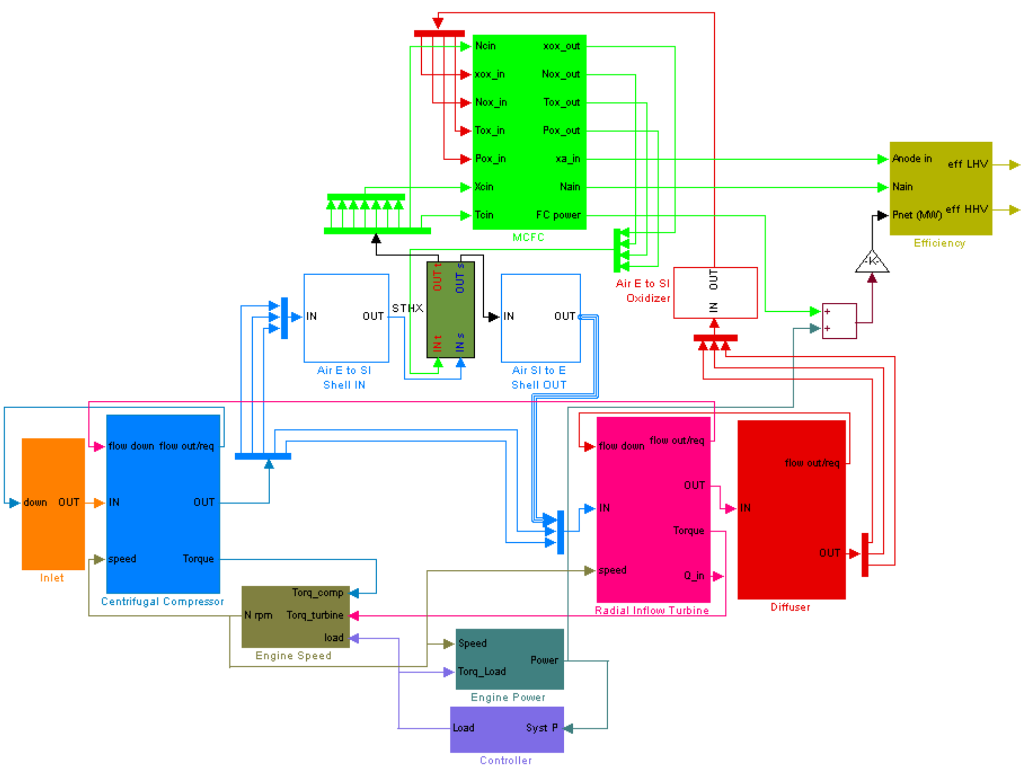


Figure 20. Simulink 0-D Microturbine Generator Model of a Hybrid Generation System

2.3. Task III - Transition Next Generation Manufacturing Technologies

NALI activities under this task have continued to expand the application of lasers and photonics technology to manufacturing and overhaul & repair of advanced power systems. Other emerging next generation manufacturing technologies, such as those pertaining to reverse engineering and metrology, have been initiated. Accomplishments include:

Laser and Photonics Technology Project Summaries

2.3.1. Laser Processing of Ceramic Matrix Composites (CMC's)

The Laser Applications Laboratory (LAL) Team has continued to working with OEM and AMPI CMC focal point, Pratt & Whitney on the processing of CMC's for advanced engines. This has included cutting trials with a high power fiber laser for cutting trials for Physical Sciences Inc. (PSI) which is working on an AMPI program with ATK on the development of a laser based workcell for CMC materials. These results were included as part of presentations at the last two AMPI TIM meetings. The LAL team has been asked to possibly participate in follow-up efforts in this area. The LAL has also worked with Triton (a small MA based company) working on a SBIR; Phase I effort to produced turbine components with cooling holes. The LAL Team provided test holes in un-fired and fired specimens using both standard Nd:YAG and pulsed fiber lasers. The LAL Team has been asked to participate in a Phase II effort on this effort as well and would be partially funded for its participation. Outside of NALI funding, the LAL Team has been funded to evaluate a Netherlands based excimer laser for its ability to process CMC materials. This also falls partially under "Short Pulse Laser Hole Drilling" (discussed below) but the goal is to leverage this effort against data collected under NALI funding to better determine the potential to use advanced lasers in the processing of CMC's.

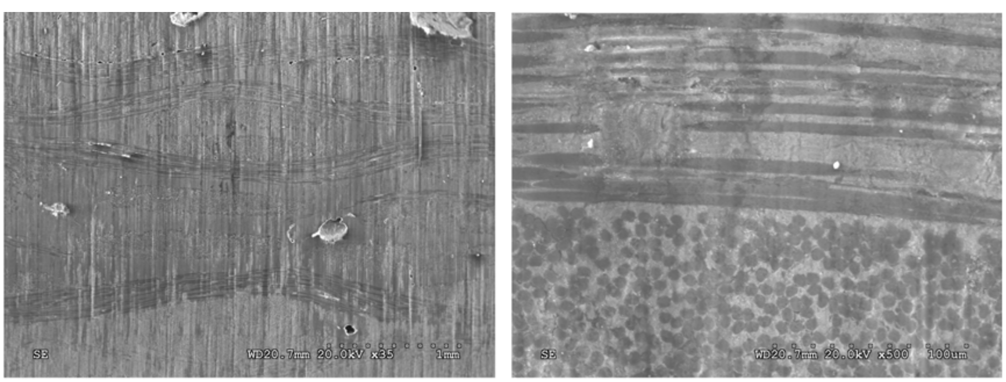


Figure 21. NCLR laser cut surface of the 6mm bar ripped from the edge of the CMC panel. (Left) 50X (Right) 500X

CCAT also continues to work with Physical Sciences Inc. (PSI) and there AMPI and SBIR efforts. CCAT was able to demonstrate with its fiber laser the ability to cut CMC's at high velocities which altered the direction that PSI was going with respect to equipment.

2.3.2. Laser Additive Manufacturing

The LAL Team was to consider the acquisition of equipment to all for laser additive manufacturing (LAM) as part of its NALI efforts. After reviewing the availability of systems in the CT area and the obstacles for implementing this technology, the LAL Team has determined that it may best not to acquire LAM equipment but utilize existing systems and develop processes and monitoring equipment to be used to produce acceptable materials. With this redirection of efforts, the LAL Team is determining which organizations to work with and in what fashion.

2.3.3. Quasi-Real Time Acoustic Monitoring and Control for Laser Hole Drilling

The LAL Team was very successful with this effort over the last 12 months. The Team was able to determine a method to acoustically monitor the drilling process and stop the laser from drilling in real time. This was demonstrated on components that “mimicked” drilling of blade and vane components. The system was also demonstrated to be able to monitor break through when drilling on the fly. The technology has reached a state where it is being marketed to potential companies that may have an interest in commercializing it. Pratt & Whitney has purchased the hardware to place a version of the system on its production equipment to monitor a hole drilling operation. This may lead to using the system to control the laser program to 1) decrease the chance for back strike damage and 2) to improve air flow consistency. These efforts have also been shared with an SBIR; Phase II effort led by Triton Systems (a MA company) and its team (GE Aviation, Pratt & Whitney, and Rolls Royce) which is looking at developing a “suite” of technologies to control hole size. This SBIR team is looking at using acoustic and spectral monitoring (from GE) to determine break through. In a related effort, the LAL team has also worked with Scientific Applications & Research Associates (SARA), Inc of CA, which is working on a real time hole “quality” system that will examine and measure a hole and related the data to an air flow value. SARA was using the data from the acoustic monitoring system to trigger when to measure the hole size. The LAL Team has also been working with Pratt & Whitney and the University of Missouri Science and Technology (UMS&T) on another break through monitoring system and using the acoustic monitoring system as a “bench mark” to determine capability.

Figure 22. Image of Prima/LASERDYNE 795 which is equipment that was consigned to CCAT LAL Team. Equipment is being used for a number of SBIR, AMPI, and NALI funded programs including acoustic monitoring of laser drilling process

Due partially to the LAL teams success in laser drilling and its acoustic monitoring work, a number of companies have been willing to place equipment at the CCAT facilities on a "no cost loan" agreement. This has included a DMG Lasertec 80 and 130 drillers, a LASERDYNE Systems 795, a Flow Systems bench flow testing stand, and a HABCO AF 100 bench flow testing stand. This equipment represents almost $3 million in value. The DMG Lasertec 130 driller was used with the acoustic monitoring efforts already and the LASERDYNE 795, the Flow Systems, and a HABCO flow testing equipment will be used on the program for the remainder of 2009 and into 2010. The DMG Lasertec 130 driller, which was used and demonstrated under this effort, was actually sold to Acucut who is a supplier to the OEM's.

2.3.4. Laser Cutting for Helicopter Skin Material

The LAL Team was approached by OEM, Sikorsky, and asked to assist in the developing a controlled process (and validation) for laser cutting helicopter skin materials, Al Alloys 2024 and 7075, with 2nd through 4th tier suppliers. Sikorsky presently does not have a specification that will allow its suppliers to provide lower cost parts that have been laser cut. The ability to provide lower cost laser cut parts would be of interest to the USAF for legacy aircraft. Past efforts by Sikorsky has indicated that laser cut aluminum parts have lower fatigue performance versus mechanically cut parts due to HAZ and cracking. Sikorsky had hoped to have funding available to support testing of trials that would be conducted by the LAL Team as part of an effort to develop a laser cutting specification but funding was not available. However the LAL Team worked with Sikorsky to establish a Capstone (senior project) within the Institute of Materials Sciences to examine the metallurgical differences between various cutting systems. The LAL Team coordinated with the laser system companies (Trumpf and Prima) to provide cut specimens and advised the students on possible areas that need examination.

2.3.5. Laser Hybrid Welding

The LAL Team, in its evaluation of advanced laser systems, has been working with Triton Systems (a MA company working on a Phase II SBIR Award) in the developing of laser hybrid welding techniques for structural Ti Alloy components. This was accomplished using a high power fiber laser and an industrial robot system. The power supply system (Lincoln 455) was provided as a "no cost loan". The deliverable is to produce structural components for three point bend testing. The five beams (and additional specimens) that were fabricated at CCAT were tested. The beams were three point tested. All of beams met the targeted load (140,000 lbs) with beams reaching 190,000 lbs.

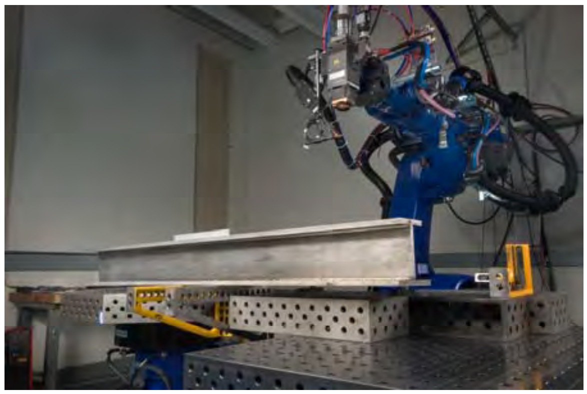


Figure 23. Image of hybrid system (IPG Fiber laser, Precitec head, Kuka robot, and Lincoln GMAW power supply) with fabricated Ti-6-4 "H" beam

2.3.6. Laser Marking in Support of DoD UID

The LAL Team was able to establish under NALI I a "state of the art" in the area of laser marking. Through a Design of Experiments (DOE) approach it was able to determine "acceptable" work envelopes on COTS laser markers. Additional work has been accomplished to determine the cause of some "variability" in the marking process which appeared to be related to the lasers and/or the scanning systems. This information will be important to understand how best to improve the repeatability of the equipment and prevent "over processing" on critical components.

2.3.7. Laser Generation of Crack-Like Features

Using the knowledge developed under the "Laser Marking in Support of DoD UID" effort, the LAL Team has continued its efforts in developing the ability to place "crack-like features" into test specimens for fatigue testing. This has included methods for the quickly evaluating the depth and length of the features without metallographic processing. The LAL Team has worked with a number of Pratt & Whitney facilities on the production of potential test specimens for testing in this area. The LAL team has also been asked to participate in an NSF funded program that would develop this technology further with the goal of making it a standard method for introducing pre-crack features in fatigue specimens. At the close of the NALI Phase II, the LAL Team funded a “Senior Project” at University of Connecticut (UConn) to investigate the further the advantages of laser induced cracks for fatigue testing. The results are due in June 2010.

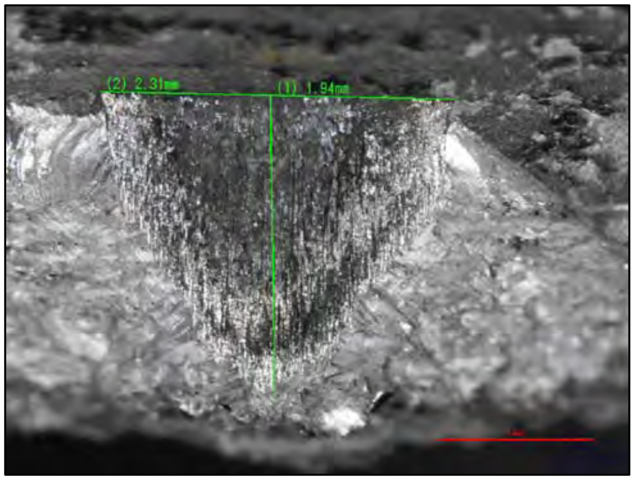


Figure 24. Image of exposed “thumbnail notch” produced by laser machining in aluminum test specimen.

2.3.8. Laser Welding of Dissimilar Metals for Fuel Cells

Efforts with GenCell, a CT Small Business involved in stationary fuel cell systems, were suspended in 2009. This was due to the fact that GenCell was purchased and it is not cleared when or if this effort may re-start. The LAL Team is monitoring potential other partners in this area.

2.3.9. Laser Machining

After efforts with ARCOR Laser Services, a CT Small Business, and its efforts to demonstrate the ability to laser machine an F119 rotor broach tool, the LAL Team has been working on developing a basic understanding of the laser machining process for such large structures. This includes determining how parameters (i.e. pulse energy, pulse frequency, scan speed, over lap, etc.) impact the removal rate and also the surface roughness. These efforts have focused to date on using the existing equipment within CCAT. The LAL team has also been working with other laser manufacturers to determine if recent advances in lasers may be able to 1) increase the removal rates, 2) result in improve surface quality, and/or 3) decrease the HAZ during processing. The LAL Team has also worked with GE Global. GE Energy, GE Aviation, UTRC, Pratt & Whitney, and Reflexite on laser machining for various applications. These efforts have developed into commercial programs outside of the NALI program.

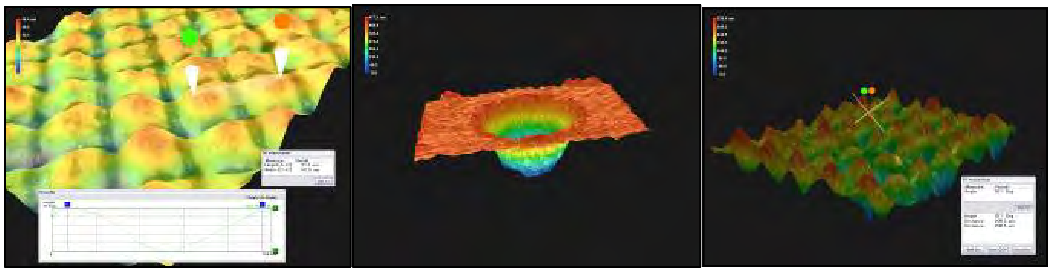


Figure 25. Three dimensional images showing the results of laser machining on a variety of materials and shapes.

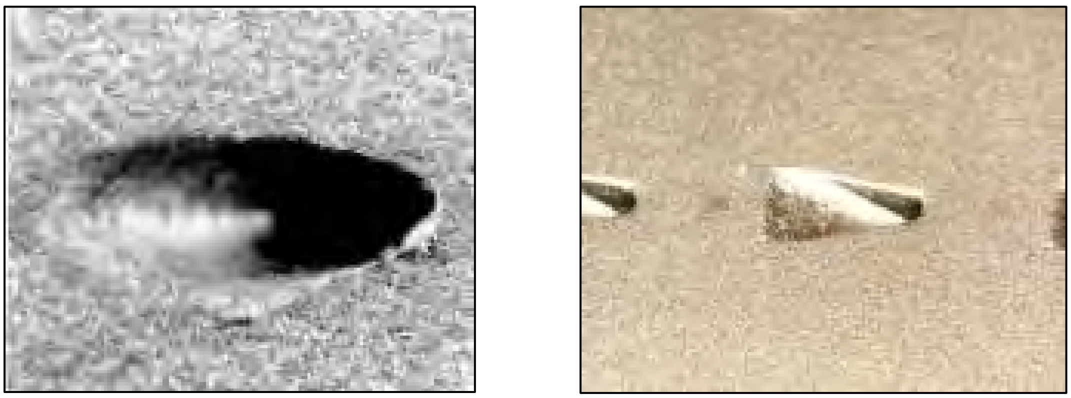


Figure 26. Left image is of a typical laser drilled hole. Image at right is a laser machined diffuser.

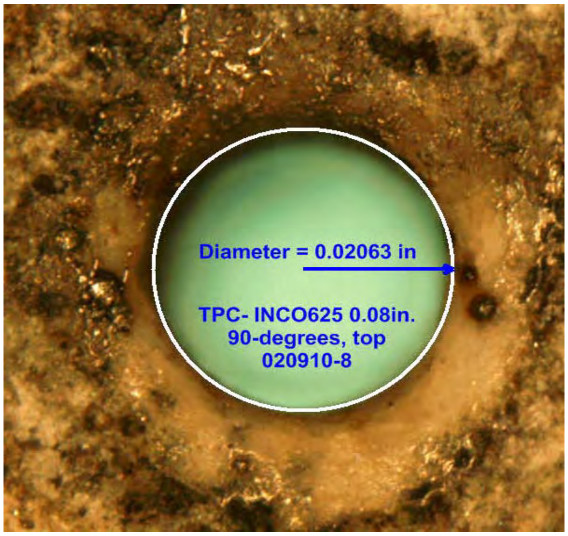
- Shaped Hole Laser Drilling

  The LAL team has been active in this area over the past year. As a result of a referral from ARCOR Laser Services, a CT Small Business, the LAL team was contacted by the Virginia Polytechnic Institute and State University (Virginia Tech) to help in the production of a test specimen of a "blade like" feature with cooling holes for wind tunnel testing. A successful specimen was produced and supplied to Virginia Tech. The LAL team has also been working with Pratt & Whitney a two stage process in support of the F135 engine (for the JSF). During the past year, DMG has placed a Lasertec 80 Driller at CCAT on a "no cost loan" basis which has allowed the group to demonstrate for Pratt & Whitney the ability to drill and shape cooling holes and sharing probing data between the two systems.

2.3.10. Fiber Laser Hole Drilling

The LAL Team has been able to develop software and hardware that has allowed for hole drilling with the 10 kW fiber laser at CCAT. Hole drilling with the fiber laser differs from the "traditional" lamp pumped Nd:YAG laser by 1) the fiber laser is uniform power distribution vs. Gaussian which may be important in back strike applications, 2) the fiber laser is delivered by fiber which may allow for a major change in the design and cost for laser hole drilling systems,

3) the quality of the hole may be improved, and 4) because the pulse frequency can be very high may allow for single pass hole drilling on the fly. Initial high speed video trials and drilling rates indicated major difference between the fiber laser and the Nd:YAG laser systems. Some of this work was derived as part of a University of Hartford student's master's thesis. It is hoped that these results will be found of interest by the OEM's and laser systems builders and result in a program outside of the NALI effort.



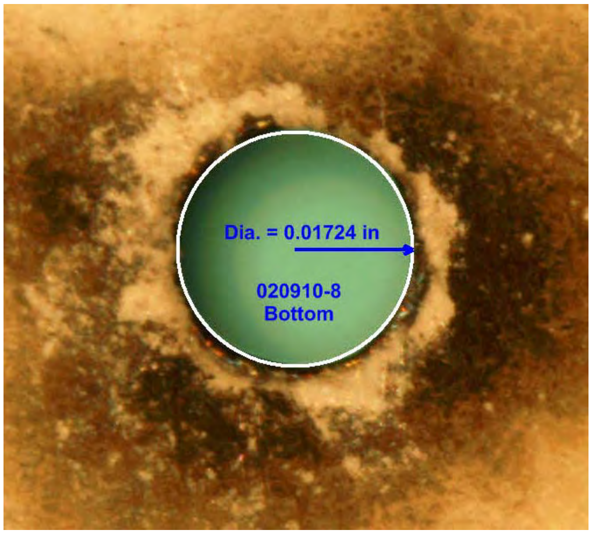


Figure 27. Left image is the entrance of a fiber laser drilled hole in a 0.080" thick Inconel 625 with Thermal Barrier Coating (TBC) that was drilled "on-the-fly" at 40 ipm. Image at right is the exit hole.

2.3.11. Short Pulse Laser Hole Drilling

While it has already been demonstrated that "short pulse" (and ultra short pulse lasers) result in little to no heat affected zone due to very high peak power (very small pulse durations), the low average power and reliability of such systems coupled with the high complexity in system architecture and high capital cost has prevented the use of this technology in manufacturing environments. As mentioned under the "Laser Machining" section, the LAL Team continues to examine other potential lasers that may be used for laser machining. As result of this, the LAL team is being funded outside of NALI by Pratt & Whitney to examine a Netherlands based excimer laser with short pulse width and shorter wavelength. It is hoped that this information will be leveraged against other data collected by the LAL Team in the area of laser machining and drilling of metals, TBC coated materials, and CMC materials to determine the potential of using this laser in production.

2.3.12. Application of Lean Principles to Laser Manufacturing Processes

The LAL Team still supports "lean principles" and has worked with other groups within CCAT on these efforts. Over the last year the LAL Team worked to conclude the a continuing analysis at Pratt & Whitney, North Berwick for laser drilling of F135 Combustor Panel Liners.

2.3.13. Laser Safety Program

The CCAT Laser Safety Program continues to updated/refresh its procedures and practices to meet ANSI (and LIA) standards.

Non-Laser Technology Project Summaries

The activities in Reverse Engineering and Metrology have been initiated. The M&S team has been assessing the latest scanning technology available and the software to accept the data, and convert the measured data into feature based solid models. Currently implementing low cost scanning tools for evaluation and potential value to SMEs metrology and reverse engineering applications.

2.3.14. Reverse Engineering

Team
- CCAT – Tom Scotton, Nasir Mannan, Bob Memmen
- CCSU – Prof. Paul Resetarits

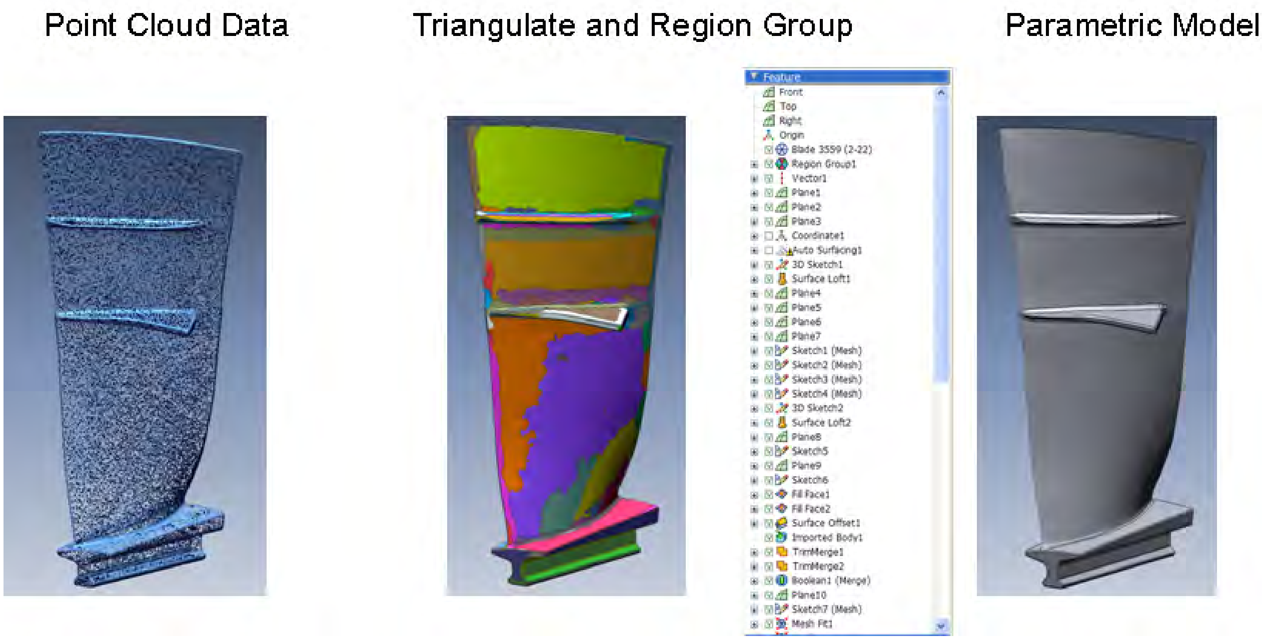
Software Solutions
- Inus Technology – Rapid Form XOR2
- Inus Technology – Rapid Form XOV2
- Inus Technology – InspectWorks
- Feature Based Recognition –
  CimSkil, Elysium, Formatworks, Anark

Goals/Objectives
- Identify and evaluate software tools to support 3D Imaging of real parts and the conversion from COP to Feature Based Solids

Expected Benefits
- Faster time to market for manufacturing of parts not originally designed in 3D CAD
- Rapid generation of NC programs

Status to Date

Under NALI Phase II the M&S team continued to ramp up our capabilities to conduct the process of reverse engineering with the software tools that we had available. The effort included a continual surveying of new technology to identify COTS solutions that make the process of converting the Cloud of Points data into the polygonalized surface data and then converting this to geometric. Parametric feature based solid CAD models as shown in the images below.



The CCAT Applications Engineering staff engaged in ramping up their skills for applying the Rapid Form and Inspect Works software that was selected as our first software tool for acquisition because of its direct interface available with our CAD tool of choice SolidWorks. A CCAT AE is now certified to be a trainer of both of these software modules.

Over the course of this phase, over 25 different parts have been scanned and reverse engineered in support of technology demonstrations for the following companies: ACT Robotics, B&E Manufacturing Co, BNB Manufacturing, HMR Associates, PWA, UTRC, Sikorsky Helicopter, TCI MRO, Schwerdtle, Unilever, University of Hartford. In several cases parts were reverse engineered to support other efforts in the area of machining process optimization. In these scenarios, structured white light systems were used to scan cutting tools for input into the ThirdWave Production Module software as well as the raw castings of parts that were to be machined in the manufacturing process.

Central Connecticut State University (CCSU)

The Next Engine Laser Scanner system installed at CCSU under the Phase I program is still being used in their CAD/CAM laboratory.

2.3.15. Metrology

Team
- CCAT – Tom Scotton, Bob Memmen, Nasir Mannan

Software Solutions
- PAS Technology – Automated CMM Programming

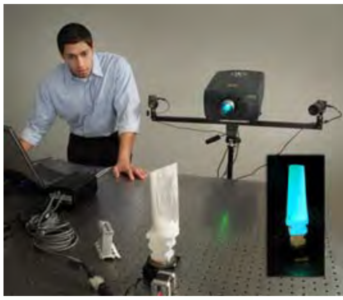
Hardware Solution
- Internally Custom Developed Systems
- MicroScan3D – MicroScribe G2LX Arm
- CMM – TBD

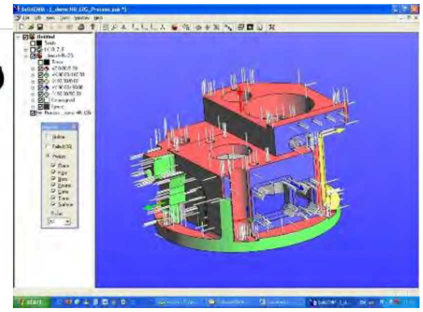
Goals/Objectives
- Investigate COTS software solutions for programming of CMM machines
- Investigate 3D Metrology software solutions for inspecting parts based on 3D scan data

Expected Benefits
- Identification of COTS software tools that will reduce the time to create DMIS CMM inspection code
- Optimize the inspection process by minimizing CMM motion path distance traveled.
- Decrease inspection time by utilizing automatic non contact inspection systems

Status to Date
The focus of the team under this Phase of the program was to identify COTS solutions that can be applied by manufacturers to improve their ability to inspect parts more efficiently and effectively. In support of this, we initiated the implementation of our Metrology lab to test out technology and to evaluate the application for affordability and ease of use.

- Building low cost, easy to operate 3D scanner systems for advanced optical inspection.
- Acquired InspectWorks Software to receive COP's
- Upgraded to Rapidform XOV2 for automated 3D inspection based on 3D scan data.
- Completed assessment of off the shelf software for programming CMM's offline.
- Received and installed demonstration software for Automated CMM programming from PAS Technology
- CCAT staff received informal training for PAS software
- Companies Engaged: ACT Robotics, B&E Manufacturing Co, BNB Manufacturing, HMR Associates, PWA, UTRC, Sikorsky Helicopter, TCI MRO, Schwerdtle, Unilever, University of Hartford




2.3.16. Gap Filler Removal

CCAT collaborated with CTC to evaluate new methods for removing gap filler on military aircraft such as the F-22. Gap filler is used to eliminate surface discontinuities between segments or panels on the exterior of aircraft. The gap filler must be removed and replaced during some maintenance procedures and when the gap filler contains defects. The current method for removing gap filler involves maintenance personnel who use hand-held chisels to chip away the gap filler. This is a time consuming and labor intensive process which has the potential to cause damage to panels and/or surrounding substrates. Improved methods for removing gap filler will allow for faster repair times, increase the availability of aircraft, and reduce damage and/or the potential for damage to the substrate.

The use of laser energy for coating removal is a technology that is environmentally acceptable and less labor intensive than current removal methods. Previous and current United States Air Force (USAF) efforts have proven that laser technology can successfully remove conventional and rain erosion coatings from metallic and composite substrates; however, the removal of specialty coatings, such as gap fillers, is dependent on the specific properties of the coating. Hence testing of different types of lasers, settings, parameters, and control technologies, such as color recognition and thickness measurements, were recommended to be investigated further.

The ultimate goal of this project was to identify a candidate method for removing the gap filler, devise a test plan, and conduct a demonstration. The candidate methods identified were a portable hand-held 150 Watt (W) neodymium-doped yttrium aluminum garnet (Nd:YAG) laser system with a stylus, provided by the distributor, Adapt Laser Systems, and a skive blade tool, which was used to supplement the laser removal method. The identified substrates in the test plan included an aluminum (Al) plate and an Al panel with graphite epoxy strips attached (herein referred to as the Al/GE panel).

The demonstration was completed on March 25, 2009, at the CCAT facility in East Hartford, Connecticut. The results from this demonstration showed that laser technology can successfully remove the gap filler and maintain a substrate temperature of less than 180ºF. A skive blade tool was successfully used following the laser removal to remove portions of the gap filler when the material was at elevated temperatures, and was assisting the laser to achieve improved strip rates. However, the tool was not sturdy enough for use when the gap filler material was at room temperatures – the tip would break and require re-sharpening. Use of the skive blade tool was attempted briefly during each of the trials.

A visual assessment of the panels after laser coating removal, showed no burning or warping of the substrates. Use of a 10x magnification device was used after each test trial on the Al/GE panel and no damage to the composite substrate could be seen from either process. The coating removal rates achieved from using both the laser and skive blade tool were around 15 minutes for a 12-inch gap. The removal rates are expected to increase as the laser system power, parameters, and process (i.e., use of blade) is optimized.

2.3.17. Crack Detection in Low Observable Coatings

CCAT collaborated with CTC to evaluate new methods for detecting cracks in low observable (LO) coatings. Visual inspection of LO coated panels on F-22 aircraft in service under the Low Observable Health Assessment System (LOHAS) program indicated that some panels exhibited hairline cracks on the painted surface.

The objectives of this project were to: a) fabricate an LO coated aluminum substrate specimen using an unclassified version of LO coating and thermally and mechanically stress the specimen to induce visible hairline surface cracking damage in the paint, and b) inspect the specimen using flash thermography nondestructive inspection (NDI) to demonstrate the capability to rapidly detect and display indications of cracking.

Small coating cracks were easier to detect using processed flash thermography images versus standard visual inspection. Additionally using flash thermography, distinction between substrate corrosion and non-corrosion damage under coatings is straight-forward.

Recommendations for future work include discussing priority LO coating cracking and corrosion under paint issues and NDI needs with potential clients on site to establish a plan to collect data using flash thermography for select applications. Data collected would be analyzed to evaluate the effectiveness of flash thermography to detect defects. Once proven effective, plans should be established to transition flash thermography NDI to replace or supplement current inspection protocols.

Opportunities for future efforts include a demonstration and evaluation of a portable hand-held 300 W Nd:YAG laser system for coating removal of the gap filler on actually composite coupons followed by the performance of mechanical and non-destructive evaluations to confirm that substrates and composite edges are not damaged during the removal process.

The use of hand-held laser technology for the removal of gap filler has a high potential for near-term technology transition. The portable hand-held laser systems are a commercial-off-the-shelf technology that is currently available. The skive blade tool would only need minor modification to be ready for application.

2.4. Task IV - Total Supply Chain Enterprise Effectiveness

2.4.1. Manufacturing and Supply Chain (led by CCAT)

In support of NALI objectives, CCAT's Manufacturing & Supply Chain Initiative team interacts with SMEs in three thrusts; Productivity Improvement, Workforce Development, and Market Expansion. CCAT strengthened SMEs listed in by focusing on the following activities:

- Productivity Improvement
  Needed for global competitiveness, productivity improvement has been achieved by assisting SMEs with the planning and execution of process improvement activities (lean/six sigma & technology insertion projects) that make a measurable impact on operating efficiency.

- Workforce Development
  Needed for growing the skills required by advanced product and processes technologies, Workforce Development has been addressed through resource listings and calendar of events on the CCAT website and periodic Information Exchange Workshops on topics requested by our industry partners.

- Market Expansion
  Market Expansion is the top-line growth and diversification of the business needed to ensure SMEs are financially sound, able to weather the periodic down-turns of cyclic aerospace & defense procurement, and maintain a production readiness level needed to respond quickly to DoD demand.

2.4.2. Supply Chain Management

Team
- CCAT – Don Balducci, Wayne Sumple, Bob Torrani, Susan Coffey, Tom Scotton
- Comparison International – Neil Cambridge

Period – 1/08 to 12/09

Overall Summary of Task
CCAT is evolving as the go-to resource for the USAF, OEMs, and SMEs for supply chain services and support. The MSCI team routinely visits regional manufacturers to understand their capabilities, inform them of available resources, assess improvement opportunities, and refer these opportunities to the other CCAT initiatives.

Introduction

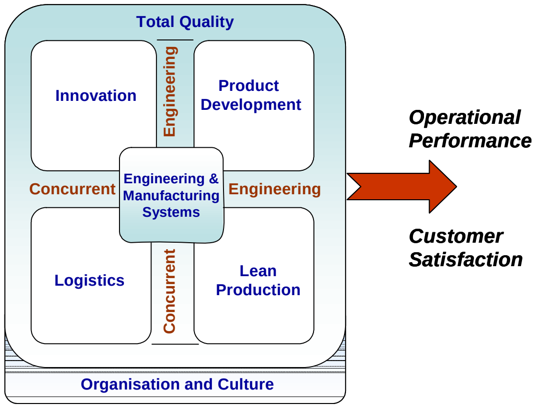
CCAT has conducted extensive site visits and engaged with various companies in workforce development, market expansion, and productivity improvement. Starting in December 2008, CCAT piloted a new service, benchmarking, to assist SMEs. The benchmarking pilot using a tool PROBE for Manufacturing engaged seven SMEs in CT and ME. Each company received their own customized results which were incorporated into an aggregation for the cluster. The project has identified the follow results for this small cluster:

- On average the cluster shows a good balance of best practices and performance for world class with an overall requirement to focus on "excellence" to push it further toward world class,
- Consistent with historical findings in PROBE data for SMEs, the pilot companies best practice weaknesses are greater in number than those of performance,
- The overall competitiveness in practice vs performance for the cluster is placed in the "en route" zone for World Class Manufacturing,
- Skilled labor, shortage of cash, and the ability to implement change quickly are predominant inhibitors to achieving company vision within the pilot cluster.

Methods / Procedures

One of the goals of NALI is to strengthen the U.S. Aerospace Manufacturing Supply Chain, particularly SMEs. Benchmarking is one method of identifying competitive positioning and areas of strengths and weaknesses. Comparison International has developed a process for generating competitive assessments that is called "PROBE for Manufacturing Microscope". Through implementation of this process, information on "Competitive Positioning", "Business Practice and Performance", and "Weakest and Strongest Elements" can be obtained.

PROBE is a 360^{o} assessment of business practices and performance at the company level which is aggregated to a cluster analysis. The assessment and analysis are produced against a framework of world class manufacturing. As a result of this work participating firms receive a diagnostic and recommendation for improvement. A diagnostic is also created at the cluster level pinpointing current strengths and weaknesses. These diagnostics provide participating firms and the NCAL, at the cluster level, with a picture of competitiveness for world class performance and growth.

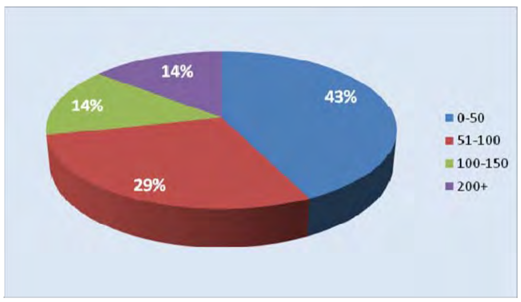


Achieving world-class status is based upon the proposition that the adoption of best practice in manufacturing management leads to strong manufacturing performance, which in turn leads to superior business performance. **'Practice'** refers to the established processes and procedures that an organization has in place to design, manufacture, deliver and measure its products and services. **'Performance'** refers to what is achieved, with an emphasis on operational aspects including product and service quality.

MSCI and Comparison International partnered to perform benchmarking with seven SMEs. The benchmarking evaluations required that CCAT, Comparison International, and participating SMEs each commit to contributing time and personnel to support the efforts. MSCI and Comparison International facilitated a one day meeting with a cross-functional team at each of the seven SMEs to respond to a series of questions to determine how the SME compares to the global competition.

The seven SMEs serve the A&D sector as follows:

Employee Size Distribution



The Type of Manufacturing

MAJOR CATEGORIZATION	
SIC	Description
D_3721	Aircraft & Related
D_3499	Fabricated metal products, NEC
D_3491	Industrial valves
D_3541	Machine tools, metal cutting types

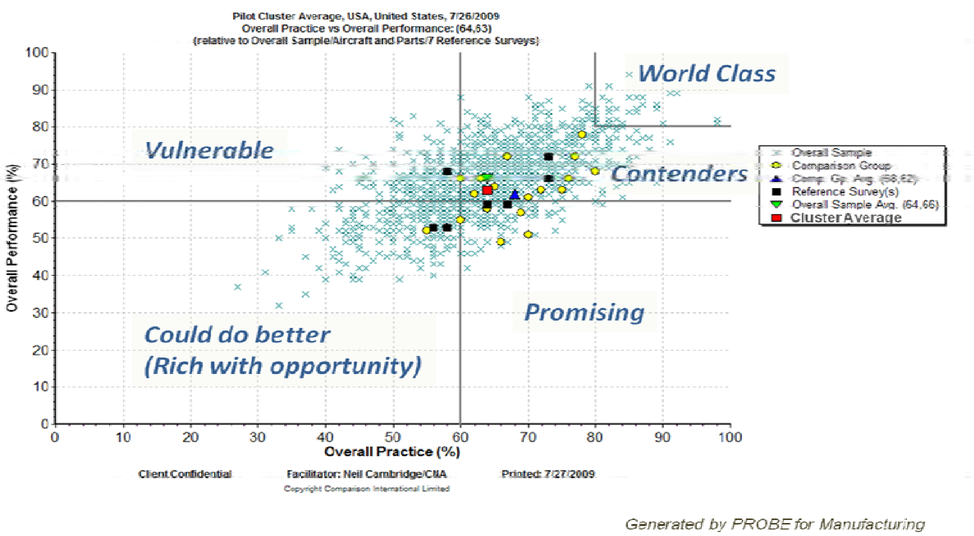
SUB CATEGORIZATION
Precision machined components
Helicopter flight components
Electronic valves & operators
Metal fabrication & machining helicopter parts
Robotics

Benchmarking Process

Summary of process (link to details):

1- 5-7 team members representing various levels and responsibilities of the organization are selected & one member is identified as the team leader,
2- team members spend ~1 hour independently completing the PROBE for Manufacturing questionnaire,
3- team leader conducts brief (1 hour) pre-meeting to discuss what the organization wants to achieve from the benchmarking exercise and their role,
4- team participates in facilitated session,
5- team and management receives feedback (same day as facilitated session) and written report within 2 weeks.

Benchmarking Results
- Scatter Diagram



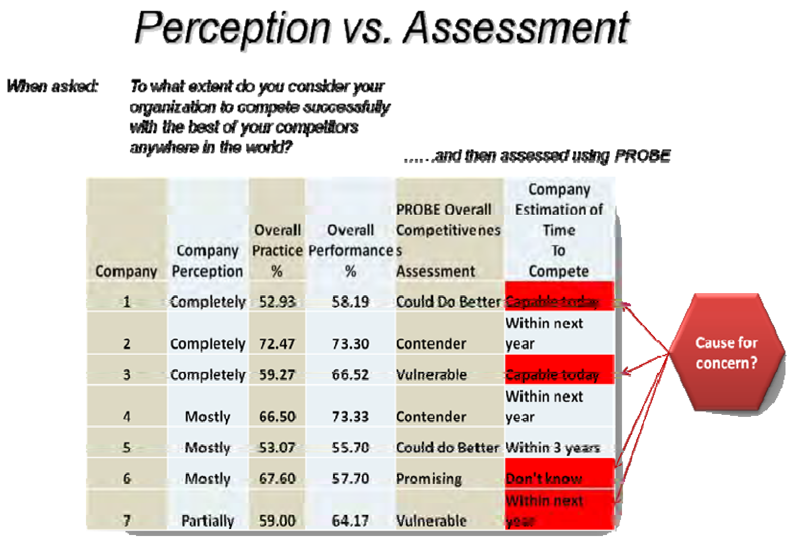
This scatter diagram is constructed by taking the consensus scores for all the practice questions in the questionnaire and assigning an index of Overall Practice for the organization; similarly, an index of Overall Performance is calculated. These indices are then plotted on the scatter diagram, with practice on the horizontal scale and performance on the vertical scale. The resultant position in isolation says much about the organization:

- Scores in excess of (80 practice, 80 performance) place the organization in the 'World Class' or 'Leaders' category, and those between (60,60) and (80,80) are labelled as 'Contenders' or 'Potential Winners'.
- Organizations with a practice score above 60 and performance below 60 are considered 'Promising' because they appear to have invested in sound practices but have yet to realize the performance they deserve from their investment. The improved performance can reasonably be expected to materialize in due course.
- Those with performance above 60 and practice below are considered 'Vulnerable'. They appear to be achieving good performance, but it is not underpinned by equivalently good practices. This may reflect some sort of protected situation for the organization, historically or currently. It might suggest that individuals rather than the processes are maintaining the performance. Clearly, a reduction in the level of protection or the loss of key personnel would be likely to have a serious impact on performance, hence the vulnerability tag.
- Organizations below (60,60) have the potential to do substantially better. A key challenge may be prioritising a large number of opportunities for improvement.

On the scatter diagram, the red square shows the position of this PROBE survey and the green triangle the position of the overall sample average – the average of all the green crosses. The yellow circles identify other organizations that are in a particular comparison group (such as a sector: the comparison group is identified in the bottom row of the chart's title), and the blue triangle is the average for the comparison group. In this case, the comparison group is 'Aircraft & Parts'.

Perception vs. Assessment

The combined results of the pilot positions the average of the cluster in the 'Contenders' zone of the world class model, with a practice index of 64% and a performance index of 63%. The individual company scorings are shown by the black squares. There is an interesting correlation to be made between these individual results and assumptions of competitiveness by the company prior to the PROBE assessment as shown by the adjacent chart.



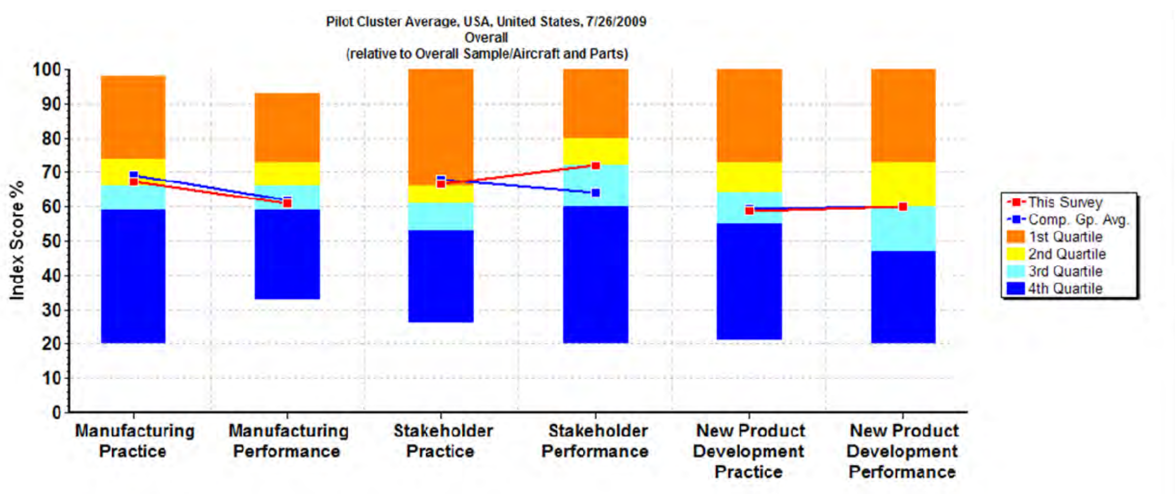
Perception vs. Assessment

When asked: *To what extent do you consider your organization to compete successfully with the best of your competitors anywhere in the world?*

.....and then assessed using PROBE

Company	Company Perception	Overall Practice %	Overall Performance %	PROBE Overall Competitiveness Assessment	Company Estimation of Time To Compete
1	Completely	52.93	58.19	Could Do Better	Capable today
2	Completely	72.47	73.30	Contender	Within next year
3	Completely	59.27	66.52	Vulnerable	Capable today
4	Mostly	66.50	73.33	Contender	Within next year
5	Mostly	53.07	55.70	Could do Better	Within 3 years
6	Mostly	67.60	57.70	Promising	Don't know
7	Partially	59.00	64.17	Vulnerable	Within next year

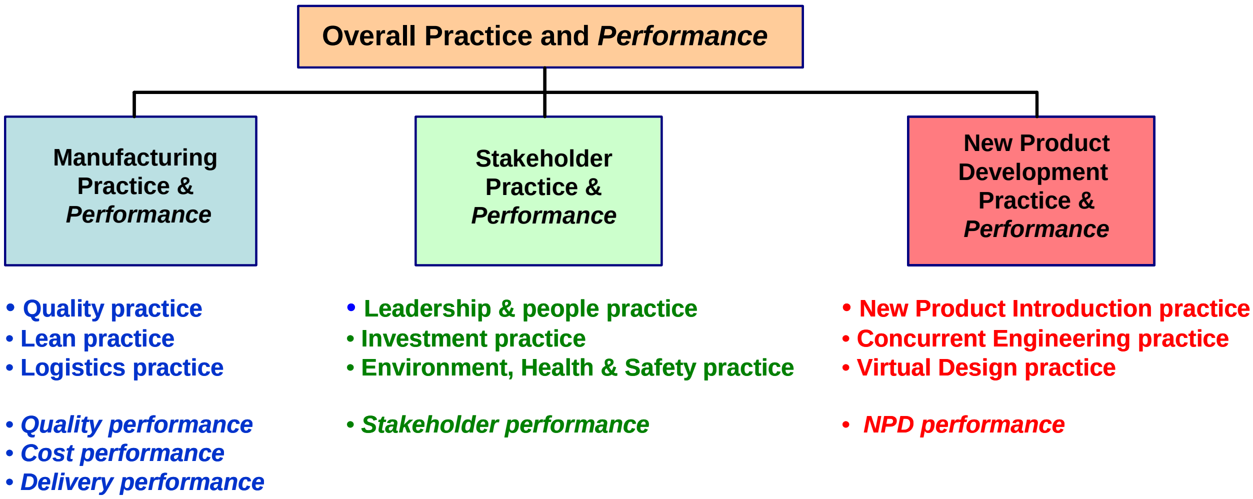
- Overall Practice and Performance Quartiles Chart



The Quartiles Charts are constructed by taking a group of scores that relate to a particular theme and calculating an index for that theme. The chart shows, across the page, several indices that have been calculated in this way. The range of values for each index for the entire sample is plotted lowest to highest, and that range is divided into four color coded quartiles. For example the first (top) quartile is displayed in orange, 25% of benchmarked organizations are contained within it and their range of scores is indicated by the height of the orange bar. Superimposed over the quartiles bars, the red square indicates the position of the cluster companies and the blue square indicates the position of the comparison group average.

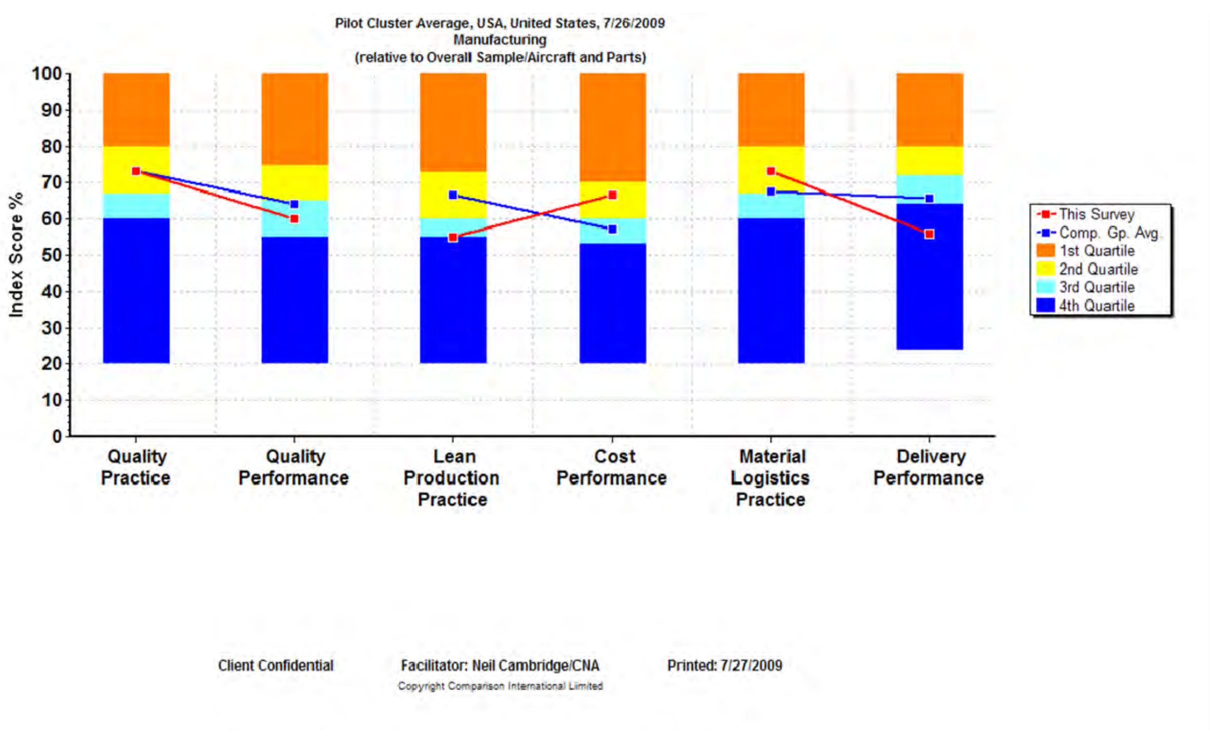
The Overall Quartiles chart benchmarks this organization against others in the sample across the broad themes of:

- Manufacturing Practice and Performance,
- Stakeholder Practice and Performance,
- New Product Development Practice and Performance (if applicable).



A balanced pair of indices (practice and performance) for a topic indicates that the organization is achieving a level of performance commensurate with its investment in practices. Two possibilities occur when practice is higher than performance. If the practices are a recent investment the situation is promising; if not, it would suggest that the practices may be inappropriate or not well implemented, because they are not being effective. If performance exceeds practice the situation may be described as vulnerable for the reasons explained in an earlier section of this report.

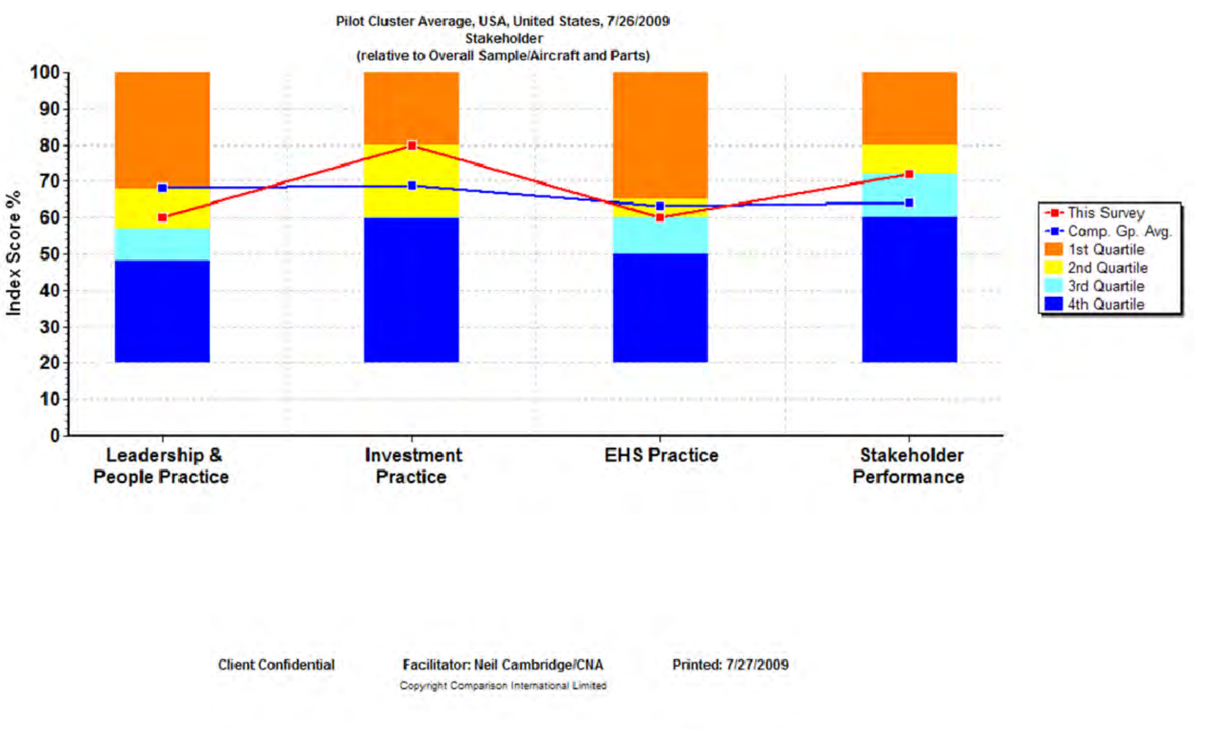
Manufacturing Practice and Performance Quartiles Chart



The Manufacturing Quartiles chart is constructed in the same way as the Overall Quartiles chart but now breaks Manufacturing into three pairs of topics:

- Quality Practice and Performance,
- Lean Production Practice and Cost Performance,
- Material Logistics Practice and Delivery Performance.

Stakeholder Practice and Performance Quartiles Chart



A stakeholder may be considered to be anyone who is in any way impacted by the activities of an organization. As a key stakeholder group, customers' interests are a focus of the 'Quality, Costs and Delivery' performance considerations within the 'Manufacturing' theme of PROBE's analysis. The Stakeholder Practice and Performance Quartiles focus on the needs of several other important stakeholder groups:

- employees,
- investors/shareholders,
- and the broader society that is affected by the organization's activities.

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- employees,
- investors/shareholders,
- and the broader society that is affected by the organization's activities.

Weakest and Strongest Elements

The final two charts are created by comparing the scores given to individual PROBE questions with the average of the scores given to the same questions by other organizations in the comparison group/the overall sample.

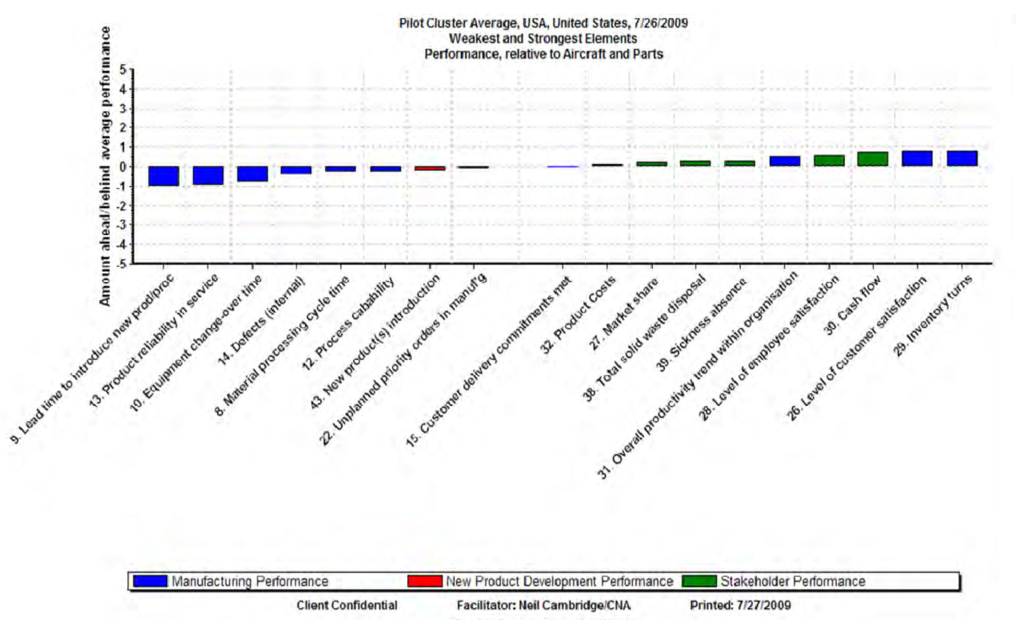
Ten ‘Strongest Elements’ are plotted to the right hand side of each chart. These are the (up to) ten performance aspects and the ten practices for which the organization’s score is furthest ahead of the average.

In contrast, the left-hand side of each chart shows (up to) ten ‘Weakest Elements’. These are the practices or performance aspects for which the organization’s score is below average, or in some cases is only slightly ahead of average.

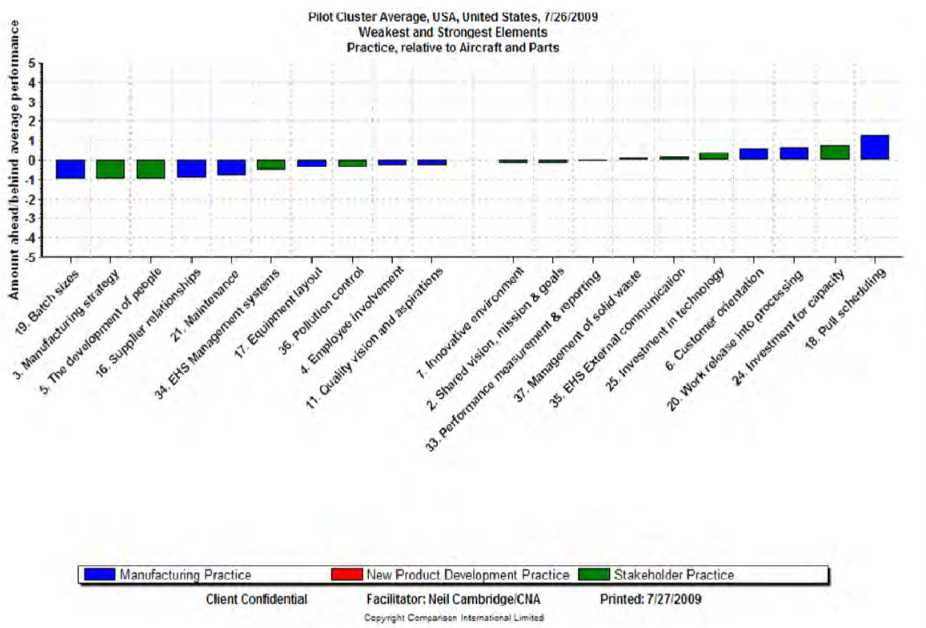
The bars on these two charts are color coded, linking the ‘performance’ and ‘practice’ questions to the themes of Manufacturing, Stakeholders and New Product Development. The question numbers are included on the charts for ease of reference. The scale refers to the amount by which the organization’s score is above or below the average.

The objective of these two charts is to help prioritize the topics for attention:

- The highlighted performance strengths should be protected. They represent the aspects of performance which most clearly differentiate this organization from other organizations in the comparison group.
- A feature of leading organizations is that they know what their strengths are and understand clearly how those strengths are achieved and maintained. Examination of the ‘practice strongest elements’ might help to deepen this understanding.
- The highlighted performance weaknesses should be reviewed and consideration given to their relevance and importance to the organization. Which are the highest priorities for improvement?
- Perhaps the greatest emphasis should be placed on the ‘practice weakest elements’; since it will generally follow that improved performance can only be achieved via improved practices.



Performance Strengths and Weaknesses



Practice Strengths and Weaknesses

Conclusions

As a pilot it is important to remember that statistically we cannot use these results as a final conclusion for policy, investment or education. This is too small a sample statistically for it to be representative of the region and/or sector. However, 29 out of 52 questions averaged 3 or less; hence there is lots of room for improvement

The pilot has shown how a diverse set of factors (size, production process, commodity, specialty, etc.) can be normalized into peer level understanding. It has provided a micro picture of competitiveness for world class manufacturing in the target industry. For most of the companies team members expressed this was the first time they had either individually or as a team stepped back and viewed the manufacturing business as a whole. As a result there was shared learning – "a rising tide floats all boats." While the aggregated data is not statistically sufficient to make decisions at the cluster level, the individual company results have served to provide direction for continuous improvement. The process has provided the individual companies with a framework that can be repeatedly called upon for ideas and examination.

For CCAT and the AF, the project has provided an insight not readily available and a small microcosm of what potential issues might exist in the aerospace supply chain overall. It has provided a baseline of measurement that can be expanded upon to create the basis for which future policy and investment could be drawn.

What is clear from the project is that for many of the pilot companies they cannot make the journey of world class on their own. A few are on their way as can be seen in overall practice vs performance chart. However, what should be noted here is that the higher performing companies were part of larger group of companies (network of independent Connecticut-based aerospace companies; a non-profit partnership that is part of Connecticut's Industry Cluster Initiative). Consequently this could, although not guaranteed, lead to more depth in support and investment. For the rest who are smaller, one owner/family run companies, the investments to improve come much harder. These are the companies who in particular would be served well by outside support and assistance. They are making in many cases critical parts in the supply chain. The business environment is highly competitive and the room for error in price, quality, agility and delivery is virtually non-existent.

This project witnessed companies at the high and the lower end of the world class spectrum. What was clear from all was a dedication to compete at all levels and be a preferred supplier to their customers. The difference was for a few the investments in optimization of their facilities and production process is paying off. For others the business is delivering but not at an optimized level and is more susceptible to competition. The common finding from all seven companies is the need more effort in the area of manufacturing strategy and the development of people.

The next steps for this task are to:

- focus on six additional companies from the aerospace cluster noted above,
- extend the benchmarking analysis to these companies to expand the sample size and provide individual baselines for improvement,
- assist the six companies with action planning to capitalize on strengths and close the gaps between current state and processes needed to effectively satisfy customer demands,
- development of internal capability (a company resource) to keep the process improvement thrust going forward without the reliance on high-priced consultants,
- begin implementation of the action plan through a sufficient number of projects to demonstrate the return-on-investment.

2.4.3. Supply Chain Service Center SCSC

Team
CCAT – Wayne Sumple, Don Balducci, Mark Johansen, Tom Scotton

Period: 6/09 – 12/09

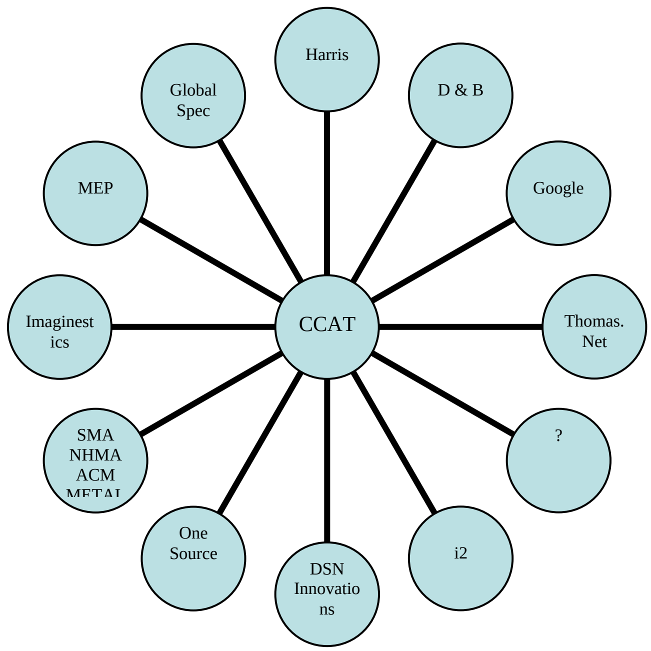
Overall Summary of Task
Develop a Supply Chain Service Center that, upon request, identifies regional (pilot will initially cover Connecticut & Western Massachusetts) companies that meet certain manufacturing requirements - including process and equipment capabilities, production capacity, quality certifications and delivery schedules. This project will develop the general structure of the service, evaluate and assess through interviews and surveys the need for the service and assuming the need is confirmed, conduct a pilot program to demonstrate that the process works.

Introduction
Locating suppliers with specific capabilities is time consuming and expensive. This is true for both small start up companies and large established OEMs. This service will save time and money for those manufacturing customers that don't have extensive purchasing and/or engineering resources on the payroll, or the technical expertise to transform an R&D company to a manufacturing company, or in the case of OEMs, the time to find a supplier with specific capabilities.

Methods/Procedures
CCAT will set up a Supply Chain Service Center. This center will receive requests via phone calls, email and the CCAT website for parts to be made. CCAT will evaluate if enough information is available to pass on to suppliers that have the capability to make the parts. For those parts that are missing information, CCAT will evaluate if technologies exist (reverse engineering, modeling, alternative processes such as additive manufacturing) to complete a technical data package. Once CCAT feels there is enough information to manufacture the part, we will poll multiple databases/services to locate the best available supplier. CCAT will offer 4 Levels of service, each one more detailed than the previous according to what the customer needs.

Why this service works – CCAT is not creating a database. Creation and maintenance of a database of the magnitude required is not practical. CCAT will rely on multiple, large recognized, existing services to maintain database accuracy. Most SMEs do not know about or have access to these databases. With multiple levels of service, CCAT will offer as much or as little support as the customer would like. And because CCAT is considered an unbiased manufacturing resource, the targeted customers should be willing to work with us on this type of effort.

Diagram 1.0 – Linkage to Existing Databases



Tasks

1. Establish Definitions
    a. Scope – define boundaries and next level of detail
        i. Manufacturing Companies (SIC code, NAIC code, location in CT & Western Mass, # of employees, sales volume)
        ii. Customers (Original Equipment Manufacturers (OEM), government, entrepreneur, Defense Logistics Agency (DLA), US Air Force, Tinker AFB, Hill AFB, Warner Roberts AFB, Procurement Technical Assistance Program (PTAP), Aerospace Component Manufacturers (ACM), Metro Hartford Alliance, National Institute of Standards & Technology's (NIST) Manufacturing Extension Partnerships (MEP), Connecticut Innovation (CI))
    b. Task – discuss with CCAT management and develop lists 1.a.i and 1.a.ii above
    c. Deliverable – quantify package for board approval in August including list of manufacturing companies, customers, final plan, schedule and cost estimates
    d. Resources – CCAT Manufacturing Supply Chain Initiative (MSCI) employees
2. Establish current practices. Confirm there is a need for this service.
    a. Scope - What do customers do now? How do they locate suppliers? Do they use in-house folks, or out source this? Do they use any on-line services? Is there a difference between small and large manufacturers? How about entrepreneurs? Do they see the value in a service like this? Would they use the service? Would they pay for it? How much? Conduct focus group.

    b. Task – develop questionnaire based on questions above. Interview 50 potential customers including 1st, 2nd and 3rd tier suppliers. Survey 200 potential customers including 1st, 2nd and 3rd tier suppliers
    c. Deliverable – Questionnaire, Interview Results, Survey Results and a Report with a recommendation to continue or not.
    d. Resources – CCAT MSCI employees, outside consultants
3. Define Resources to be used in search (Spokes on Diagram 1.0)
    a. Scope – evaluate 10-20 existing similar services and databases and choose which ones will be included in CCAT search. This will be the confidential part of the program.
    b. Task – Generate a report that summarizes each of the resources evaluated. Use Diagram 1.0 as starting point. This is heart of service. Concentrate on hard to find programs/services/databases. (for example CONNSTEP part location service) Include international databases. Look for new technologies (data mining capabilities at CCSU) that might help. Investigate CCAT's own IT capabilities. Include details on what will be required to develop partnerships like fee structures, non-disclosure agreements (NDA), memorandums of understanding (MOU), royalties and any legal considerations. Include the level of detail provided, availability, ease of use, cost, strengths, and weaknesses for each service and/or database.
    c. Deliverable – report including each item in Task above
    d. Resources – CCAT MSCI employees and outside consultants
4. Conduct Pilot
    a. Scope – evaluate effectiveness of SCSC. Success will be based on number and size of contracts won by SMEs through the pilot program
    b. Task - Find customer(s) willing to work with CCAT on Pilot by identifying 10 parts that need to be manufactured. Run parts through SCSC process. Generate a final report with determination to continue or not. Evaluate efficiency of service and make recommendations for improvement.
    c. Deliverable – Final Report with summary of SCSC successes and a recommendation to continue or not.
    d. Resources – CCAT MSCI employees, outside consultants
5. Develop Network
    a. Scope - find a means for maintaining a manufacturing capabilities repository
    b. Task - develop a new or choose an existing format for retaining manufacturing capabilities that are gathered during the pilot program. Include format developed by B Torrani for MSCI and program developed by MEP. Evaluate the effectiveness of maintaining a CCAT list of capabilities. What would a custom deliverable for the customer look like (i.e. 3 page printed company profile with a lot of information about 1 company or a summary of numerous companies)
    c. Deliverable – generate a report that provides a format for maintaining capabilities gathered from SCSC
    d. Resources – CCAT MSCI and IT employees
6. Project Management CCAT
    a. Scope – manage project
    b. Task – oversee project activities. Manage resources. Generate weekly reports

c. Deliverable – weekly reports
d. Resources – CCAT MSCI employees

Examples of SCSC Operation
Example A: Entrepreneur X wants to build wind turbines in Connecticut. He wants to outsource everything but the final assembly and testing.

> Deliverable: CCAT works with Entrepreneur X to develop a listing of the family of parts needed. CCAT performs a Level 1 search of its databases to identify potential suppliers. CCAT performs a Level 2 evaluation that includes website review and phone calls to confirm capabilities. CCAT performs a Level 3 assessment that includes site visits, lean, quality, capacity and delivery assessments. CCAT provides a report that identifies the best candidates with their capabilities and contact information. In this example CCAT could also provide modeling and simulation services to provide plant layout and value stream mapping of assembly process. Certain activities could generate revenue.

Example B: Customer X is introducing a new aerospace related Product A. Product A is made up of sub-assemblies A1 + A2 + A3. A1 is a small 1"H x .5"W x .75"L machined titanium part with +/- .001 tolerances. A2 is a large 4"H x 2"W composite ring 70" in diameter. A3 is a 5" plastic spherical part that needs to be injection molded. All three need to be made by suppliers with ISO9001 certification and the titanium part needs to be made and packaged in a class 100 clean room. Quantities are 50,000/yr, 25,000/yr and 100,000/yr respectively.

> Deliverable: Customer X provides CCAT with descriptions, specifications, drawings, quantities, delivery and cost requirements of the 3 items above. CCAT performs a Level 1 search of its databases to identify potential suppliers. CCAT performs a Level 2 evaluation that includes website review and phone calls to confirm capabilities. CCAT performs a Level 3 assessment that includes site visits, lean, quality, capacity and delivery assessments. CCAT provides a report that identifies the best candidates with their capabilities and contact information.. Certain activities could generate revenue.

Example C: The US Air Force needs to replace a number of obsolete parts on old airplanes. Drawings and Technical Data Packages are not available for these parts.

Example C1: USAF just wants to know who can make the part.

> Deliverables: CCAT performs a Level 1 search of its databases to identify potential suppliers. CCAT provides a report that identifies the best candidates with their capabilities and contact information.

Example C2: USAF wants someone to build small quantities/prototypes

> Deliverables: CCAT performs a Level 4 effort that includes working with the USAF to reverse engineer the parts including defining manufacturing processes, conversion of CAD to CAM, design of tooling and fixtures, qualification of the parts and manufacturing of the parts in a CCAT Manufacturing Application Lab (MAL). Certain activities could generate revenue.

Example C3: USAF wants production of 500 parts.

Deliverables: CCAT performs a Level 4 effort that includes working with the USAF to reverse engineer the parts including defining manufacturing processes, conversion of CAD to CAM, design of tooling and fixtures, qualification of the parts and turning over this data to a small & medium size enterprise (SME) capable of producing the parts. CCAT performs a Level 1 search of its databases to identify potential suppliers. CCAT performs a Level 2 evaluation that includes website review and phone calls to confirm capabilities. CCAT performs a Level 3 assessment that includes site visits, lean, quality, capacity and delivery assessments. CCAT provides a report that identifies the best candidates with their capabilities and contact information. CCAT works with the USAF and selected source to transition part to production. Certain activities could generate revenue.

Conclusions
In 2009, CCAT hired three consulting firms to investigate the feasibility of an SCSC and offer recommendations on its operation. All three agreed that some sort of crawling device that searches existing databases and company websites would best serve the project. During this investigative stage it was discovered that there may be a large number of SMEs without "good" websites. This has led to a separate task for MSCI to offer a "Website 4 Manufacturers" program.

Next steps are to launch a pilot program to demonstrate the effectiveness of SCSC. Success will be based on number and size of contracts won by SMEs through the pilot program. To support this pilot, CCAT is currently working with Imaginestics using their SCMN VizSeek and VizSpace software to match the needs of Oklahoma City Air Logistics Center OC-ALC to a hand picked number of CT aerospace manufacturers. CCAT expects this pilot will prove there is a need, a process, and companies that can provide solutions in the way of parts for the DoD.

2.4.4. Supply Chain Risk Workshop

Team
- CCAT – Dr. Thomas Maloney, Robert Torrani, Edward Marinko
- USAF Program Manager Supply Chain Risk Management – Mr. Bradley Bracher

Other participants
- Massachusetts Institute of Technology – Dr. Yossi Sheffi
- Auburn University – Dr. Brian Gibson, Dr. Wesley Randall
- The Supply Chain Council – Mr. David Morrow

Overall Summary of Task
Provide training on the theory and practice of Supply Chain Risk Management to personnel from the USAF Global Logistics Support Center and related organizations.

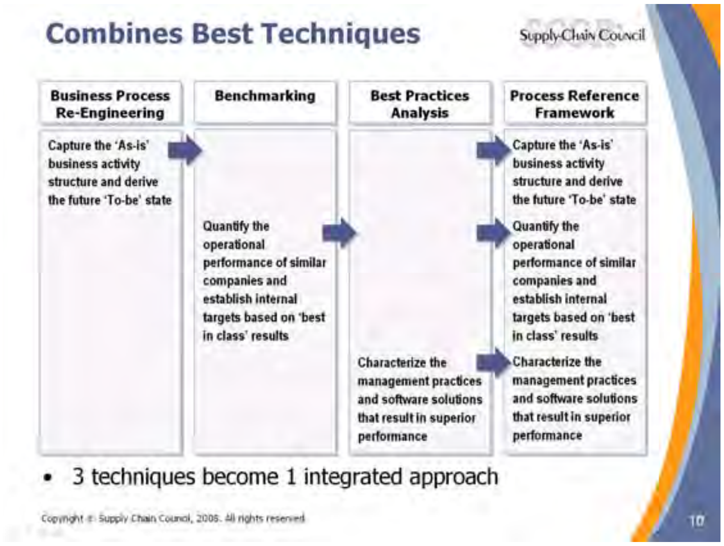
Introduction
Discussions with Bradley Bracher, USAF Program Manager Supply Chain Risk Management, revealed the need to make available specialized training on the theory and practice of Supply Chain Risk Management primarily to personnel from the USAF Global Logistics Support Center. The thrust of the program was threefold:

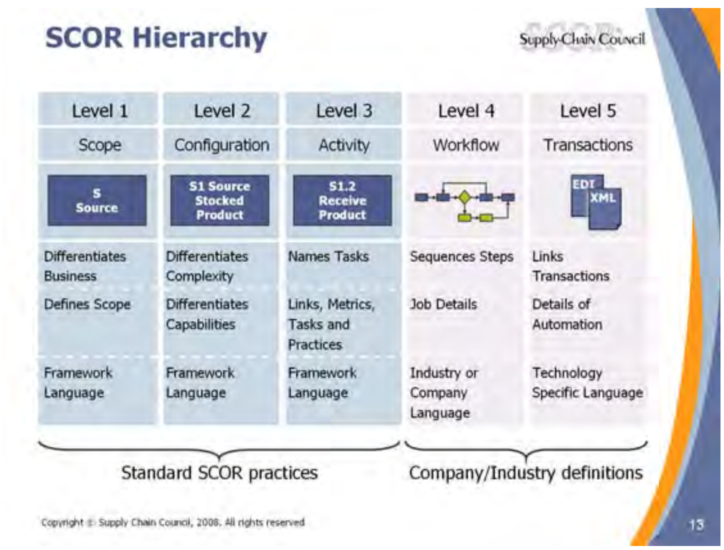
- First to present the latest thinking on supply chain management to practitioners within the group,
- Second to provide a framework for modeling best practices and managing supply chain processes, practices & performance, and
- Third to provide a solid foundation for an improved supply chain risk management program.

Methods/Procedures
Our approach was to put together a four day program the first day of which involved a series of level setting, awareness heightening lectures providing key insights by leading scholars. Presenters included Dr. Yossi Sheffi from The Massachusetts Institute of Technology. Dr. Sheffi serves as the Director of the MIT Engineering Systems Division and the MIT Center for Transportation and Logistics. He is also the author of The Resilient Enterprise which focuses on minimizing risk in supply chains. Presenting, along with Dr. Sheffi were Dr. Brian Gibson, Professor Department of Aviation and Supply Chain Management at Auburn University and Dr. Wesley Randall, Assistant Professor Department of Aviation and Supply Chain Management at Auburn University. Dr. Randall is a former USAF logistics squadron commander, acquisition program manager, and operational logistician for numerous combat aircraft systems.

Areas covered on day one included a study of supply chain disruptions including an exploration of the types of disruptions likely to impact Air Force Material Command. A detailed exploration followed next covering the building resilience and flexibility into supply chains along with case study work focusing on disruption in the supply chain, its results and how participants would respond to it. The case study utilized was loosely based upon an actual scenario that affected the F-16. Participants were asked to closely review the case and using material from the earlier discussions, provide a detailed analysis of all the parameters related to the disruption including costs & quarterly funding impacts, short term mitigation strategies that could have been employed, as well as systems & techniques that could be used to avoid incidents like the one presented.

The next part of the program involved training with Mr. David Morrow from the Supply Chain Council. The Supply-Chain Council (SCC) is a global 800 plus member non-profit association. SCC counts both CCAT and the USAF among its member organizations. They have established the most widely accepted frameworks, SCOR[1,2] (*Supply Chain Operational Reference*) for evaluating supply chain activities and their performance.





Training centered on SCOR including the following subjects during days two and three:

- SCOR Processes and SCOR Modeling
  - Execution Processes (Source, Make and Deliver)
  - Planning and Control Processes (Plan and Enable)
  - Reverse Flow Processes (Return)
  - Modeling with SCOR
- Metrics, Best Practices and a SCOR Project Roadmap[3]
  - Strategic Metrics
  - Scorecards and Benchmarking
  - Best Practices and Benchmarking
  - A comprehensive SCOR project (SCOR Implementation preview)

The SCOR Project Roadmap Supply-Chain Council

Phase	Name	Deliverable	Resolves
	ORGANIZE	• Organizational Support	Who is the sponsor?
I	DISCOVER	• Supply-Chain Definition • Supply-Chain Priorities • Project Charter	What will the program cover?
II	ANALYZE	• Scorecard • Benchmark • Competitive Requirements	What are the strategic requirements of your supply-chain?
III	MATERIAL	• Geo Map • Thread Diagram • Disconnect Analysis	Initial Analysis – where are the problems?
IV	WORK	• Transactions • Level 3, Level 4 Processes • Best Practices Analysis	Final Analysis – where are the solutions?
V	IMPLEMENT	• Opportunity Analysis • Project Definition • Deployment Organization	How to deploy?

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By using SCOR tools, an organization can rapidly overcome the first difficult step in supply chain improvement – determining what processes to improve first and how much to improve them. SCC's SCOR models also help to guide the consolidation of internal supply chains and create standard processes and common information systems across units (*this can result in major cost savings, cycle-time and quality improvements*).

The final segment of the program once again focused on risk management. It looked at three areas or phases:

- Phase 1: Risk Identification – Looking at each single process with regards to potential disruptions that may negatively impact performance and which countermeasures are already in place.
- Phase 2: Risk Assessment: The likelihood / probability of a negative occurrence and the severity of an impact should it occur.
- Phase 3: Risk Mitigation: Both the controlling and monitoring of risks. This section focused on mitigation measures such as improved planning methods, alternative suppliers, response plans and building redundancy into an infrastructure.

Conclusions

A post program discussion with Bradley Bracher (USAF) indicated that the training program was effective in providing a common base of knowledge, useful supply chain risk management tools, and insights into best practices for the GLSC team. This is important as the team moves forward to help set program goals, metrics, determine schedules in addition to deploying standard risk management tools across the enterprise. They will also be utilizing these tools as they work not only to anticipate potential problems but to mitigate them before they impact operations.

Bradley Bracher has expressed interest in having CCAT organize training that would represent a logical next step for his team. This would likely focus around the SCOR training mentioned above and provide more extensive and hands on training in supply chain performance analysis, material flow analysis & work and information flow analysis and re-design. The Supply Chain Council offers such a program, which is two days in length and is available on a private basis. Mr. Bracher has suggested that such training could possibly be scheduled & offered in conjunction with an existing (to be determined) Supply Chain Management Conference. Ideal timing would fall sometime between May and July of 2010.

Follow up discussion also revealed the need for assistance in the GLSC's IT environment as they seek to better monitor vendor risks and trouble spots. Tom Maloney will be speaking with select vendor contacts who he feels may have software that could address some of the GLSC's needs. He also has suggested (and Mr. Bracher is in agreement) that if there is an effective match it may be sensible to look at integrating a pilot program into the existing bearing project CCAT is involved with. This is merely exploratory at the present time but may be a way to lend further assistance to the GLSC.

2.4.5. ALC Bearing Project

Team

- CCAT – Don Balducci, Bob Torrani, Tom Scotton, Tom Maloney
- SAF/IEL, Office of the Assistant Secretary of the Air Force – Doug Dynes
- Hill Air Force Base – Jeffrey Powell
- Timken Bearing, Bearing Inspection, Inc – Scott Radcliffe

Participating Companies

- Timken Aerospace
- Bearing Inspection, Inc

Period: 5/09 – 12/12

Introduction

Understand the requirements for bearings to reduce/avoid MICAP's by developing the capabilities within the USAF. Bearings are critical to the "National Defense" of the United States and have been deemed a strategic necessity. An understanding of the requirements, needs and current capabilities will be necessary to develop and implement a plan moving forward.

Methods/Procedures

Site reviews, GAP Analysis and understanding of current process capabilities at Hill (Utah) and Tinker (Oklahoma) Air Force Bases. Also gain understanding of USAF Supply Chain (see Figure 28. Supply Chain.).

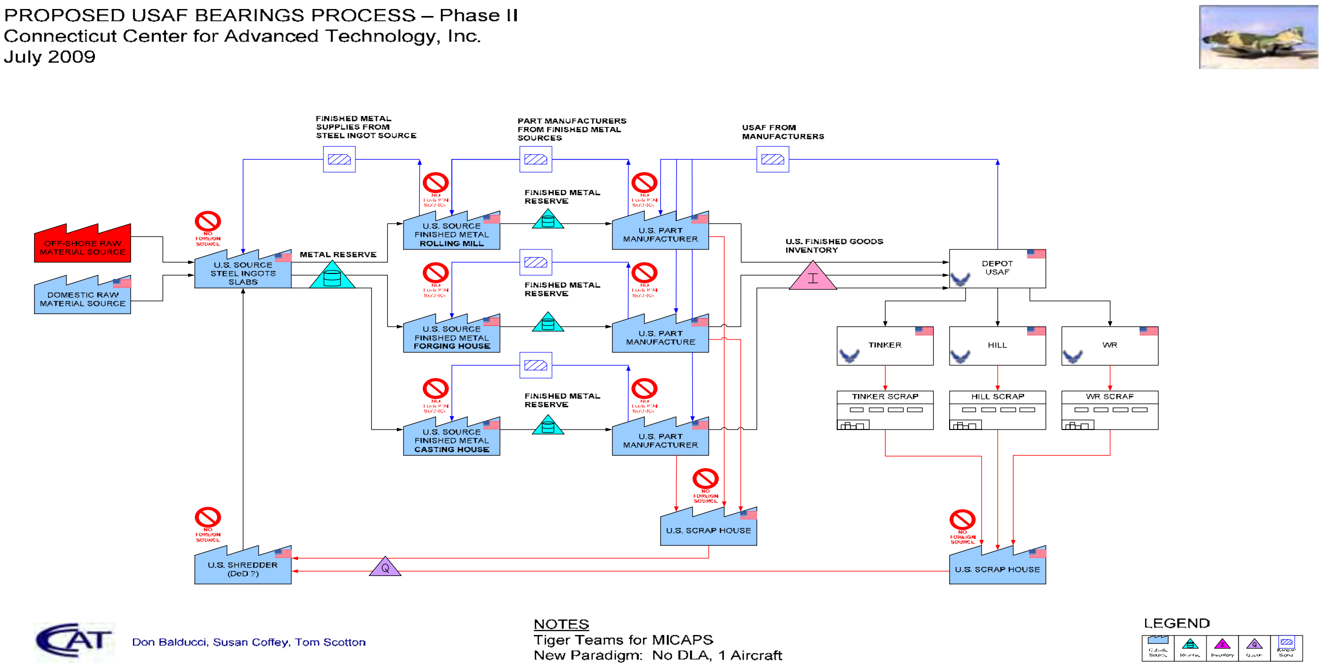

Figure 28. Supply Chain.

Tasks

1. Meetings to understand need of Air Force.
2. GAP Analysis to understand U. S. Air Force current capabilities versus U. S. Commercial capabilities.
3. Develop proposal with costs and timing to upgrade USAF facilities equal to U. S. Commercial capabilities.
4. Implementation of plan for upgrade.
5. GAP Analysis to understand necessary requirements for USAF bearing manufacturing
6. Implementation of plan to support bearing manufacturing on USAF Base.

Conclusions

In 2009, Connecticut Center for Advanced Technology, Inc. (CCAT) and Timken Bearing (Bearing Inspection, Inc.) signed an NDA. CCAT then contracted with Timken Bearing (Bearing Inspection, Inc.) to provide a GAP Analysis at both Tinker and Hill Air Force Bases for Level I & II capabilities at each base versus Timken Bearing Commercial Level I & II facility in Los Alamitos, CA. Next step will be an understanding and plan of action based on the findings of the GAP Analysis provided by Timken Bearing.

2.4.6. Manufacturing and Supply Chain (led by CTC)

Concurrent Technologies Corporation's period of performance for this phase was 1 Jun 2006 – 31 May 2007. CTC conducted research within the USAF and recognized the need for USAF organizations to achieve total asset visibility of items within the supply chain from war fighter to manufacturer. CTC analyzed these specific needs and determined the lack of supply chain visibility. In NALI Phase I, CTC initiated development of a visualization support tool prototype that may provide optimal supply chain management directed toward streamlined business processes, improved effectiveness, and reduced costs. Development continued in NALI Phase II. This tool is designed utilizing an open architecture that will provide total asset visibility of the supply chain from war fighter to manufacturer that can be synchronized and integrated with emerging Air Force systems. Accomplishments under NALI Phase II included:

- *Visualization Support Tool*

  Completed the development of the framework for the V*isualization Support Tool*. This tool can provide total asset visibility of the supply chain from war fighter to manufacturer that can be synchronized with emerging Air Force systems. *CTC* has discussed and demonstrated this application at the Air Force Transformation office in the Pentagon and the Purchasing Supply Chain Management office at Wright Patterson Air Force Base. Both agencies indicated an interest in this application.

- *Advanced Decision Support Tool*

  Continued the development effort for a Web-Enabled *Advanced Decision Support Tool*. This tool will enable decision makers throughout the USAF and aerospace industry supply chain to initiate actions to improve the effectiveness, efficiency, and responsiveness of the supply chain in meeting warfighter needs. Development of the Web-Enabled *Advanced Decision Support Tool* will provide the USAF with access to relevant supply chain information that will enable decision makers throughout the supply chain to implement a corrective action that will have a positive impact on the supply chain.

Further development of the visualization support tool will incorporate a more enhanced view of the Commodity Councils utilizing representative data. CTC will continue investigation into the USAF enterprise supply chain and possible resources that can be provided to enhance its effectiveness.

3. Closing Remarks

Work accomplished under Phase II of the National Aerospace Leadership Initiative has made a positive impact to the aerospace manufacturing community that supports the United States Department of Defense. Building upon and enhancing the capabilities of the first phase, the NALI Phase II efforts have contributed significantly to the NALI objectives of:

1. Strengthening the aerospace manufacturing supply chain
2. Transitioning next generation technologies to the aerospace manufacturers
3. Creating a workforce capable of using those next generation technologies

Under NALI Phase II, a focused effort was made to understand needs of the DoD, to interface with principal points of contact within the DoD, and apply the resources and capabilities of the NALI Consortium deliver solutions to those DoD needs. Efforts under the follow-on NALI Phases III and IV will continue to build upon the achievements made in this first two phases.

4. Glossary/Acronyms

ADE	Aerospace & Defense Initiative
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
ALC	Air Logistics Center
AMPI	Advanced Manufacturing Propulsion Initiative
APLC	Advanced Programmable Logic Control
BRI	Blade Row Interaction
C2E2	Common Collaborative Engineering Environment
CARL	Compressor Aero Research Laboratory
CBIA	Connecticut Business & Industry Association
CBM	Condition Based Maintenance
CCAT	Connecticut Center for Advanced Technology
CCSU	Central Connecticut State University
CFD	Computational Fluid Dynamics
CMSCI	Connecticut Manufacturing Supply Chain Integration
COTS	Commercial-off-the-shelf
CTC	Concurrent Technologies Corporation
DICE	Data Intensive Computing Environment
DMC	Defense Manufacturing Conference
DoD	Department of Defense
DSCR	Defense Supply Center
EDM	Electrical Discharge Machining
EHMS	Engine Health Management System
eVSM	Electronic Value Stream Mapping
GLSC	Global Logistics Support Center
HPC	High Performance Computing
IGTI	International Gas Turbine Institute
LAL	Laser Applications Laboratory
M&S	Modeling and Simulation
MAI	Metals Affordability Initiative
MRSO	Multiple Response Statistical Optimization
MSRC	Major Shared Resource Center
NACFAM	National Council for Advanced Manufacturing
NALI	National Aerospace Leadership Initiative
NCAL	National Center for Aerospace Leadership
NDIA	National Defense Industries Association
NGRMS	Next Generation Regional Manufacturing Center
OC-ALC	Oklahoma City Air Logistics Center
PLC	Programmable Logic Controller
SAR	Source Approval Reporting
SBIR	Small Business Innovation Research
STEM	Science, Technology, Engineering, and Mathematics
TECT	Turbine Engine Components Technologies

TMAC	Tool Monitor Adaptive Control System
VSA	Value Stream Analysis
VSM	Value Stream Map or Value Stream Mapping