Georgia Tech Manufacturing Institute

CAIIAC

Consortium for Accelerated Innovation and Insertion of Advanced Composites (CAIIAC)

WORKSHOP #1 : ROADMAPPING

November 5, 2014

Georgia Institute of Technology

About this Document

The National Institute of Standards and Technology (NIST) ran a competition for planning awards to support industry-driven consortia in developing research plans and charting collaborative actions to solve high-priority technology challenges and accelerate the growth of advanced manufacturing in the United States. This Advanced Manufacturing Technology (AMTech) Program aims to spur consortium-planned, industry-led R&D on long-term, pre-competitive industrial research needs. Major objectives also include eliminating barriers to advanced manufacturing and promoting domestic development of an underpinning technology infrastructure.

In May 2014, the NIST awarded the Consortium for Accelerated Innovation and Insertion of Advanced Composites (CAIIAC, pronounced “KAYAK”) to work on issues that hinder bridging the gap between research and commercialization in advanced composites.

The overall vision of CAIIAC is to create an innovative domestic manufacturing ecosystem to significantly shorten the time required in manufacturing development cycles and provide “right-the-first-time material yields” for broad-based composite processes. Guided by this vision, the three-fold mission is to:

1) accelerate innovation and assist in speeding up the development and deployment of advanced composites;
2) develop broad-based applications for advanced composites; and
3) encourage “invent here, build here” in the United States to improve competitiveness of the U.S. composites industry and sell advanced composite products globally.

On November 5, 2014, the Georgia Tech Manufacturing Institute welcomed 45 industry leaders and top manufacturing researchers to convene the first CAIIAC workshop. The goal of the meeting was to introduce the consortium to the invited guests and to gain input on its direction. This report is a summary of the discussions that occurred at this workshop. The Agenda and Participants list are attached in appendix.

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Grand Technical Challenges

The roadmapping effort started with the identification of the Grand Technical Challenges that the consortium would tackle. The six CAIIAC Grand Technical Challenges have been developed with input and information from:

- Phone interviews of industry experts
- Surveys from industry partners
- Technical reports and roadmaps

And include:

1. *Standardized composite design and testing for faster and more affordable certifications:* Defining design guidelines and best practices is the way to standardize composite design. Integrated Computational Materials Engineering (ICME) is immature in composites, because of the large variety of composites designs and IP issues on materials and process data required to fill the models. Extending ICME to discovery and development seems easier than extending it to certification.

2. *Quick and reliable joining and repairs:* Although most composites components and damages are unique, a standardized approach to similar types of repairs could make the process faster and easier. Automation and inspection of repairs technologies are to be developed as well.

3. *Scalable and reproducible out-of-autoclave processes and affordable tooling:* There is a critical need for high-rate composite manufacturing technologies, but this requires overcoming challenges such as understanding materials and process data to enable smooth scale-up from lab to large scale production, and developing automation, process monitoring and control.

4. *Structural health monitoring (SHM) of life cycle performance:* SHM methods for composites are still in their infancy and must be accounted for at the very initial design steps.

5. *Recycling and reuse of composites:* The development of cost-effective recycling technologies that can recover high quality constituent materials, as well as the identification of applications that could actually use these recycled materials, are the key drivers towards increased composites recycling.

6. *Inclusion of nanomaterials for improved performance:* Large scope of research, but few applications, integrating nanomaterials into composites should improve performance and cost-effectiveness without impairing manufacturability.

CAIIAC Methodology

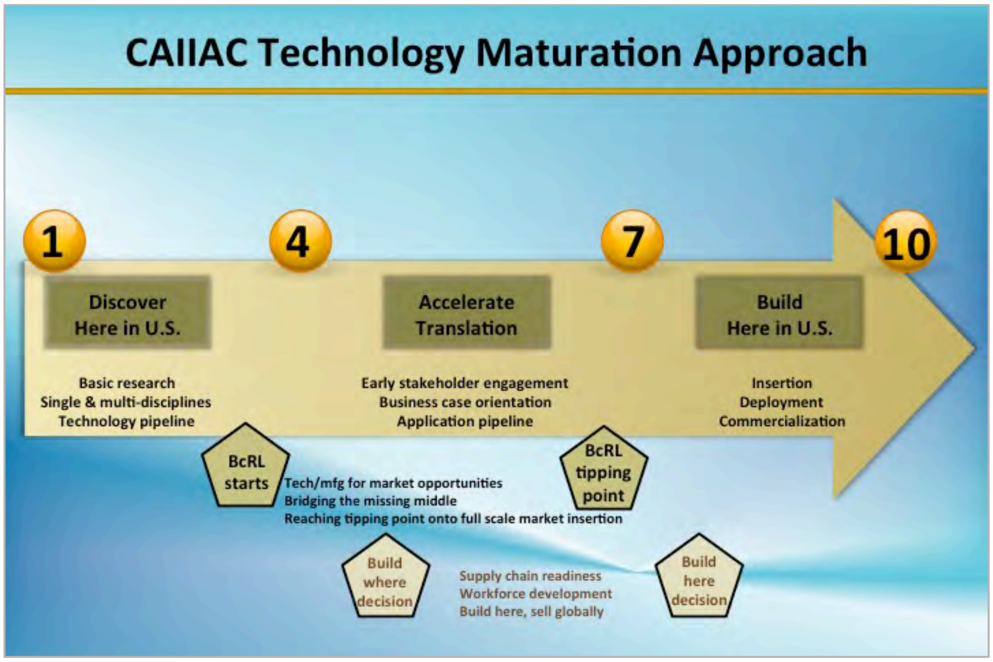
Despite the growth of the composite industry over the past 30 years, broad-based commercial adoption of lightweight composites has been slower than expected. Industry has yet to be convinced of the superior “system-level” performance and “life-cycle” cost benefits. In addition, the U.S. leadership in composite technologies has been seriously challenged by other countries, particularly those in Europe.

The U.S. composites industry is highly fragmented, and includes approximately 3,000 companies. It is primarily composed of small and medium enterprises and many of them struggle to reach the critical mass that would enable them to invest in cost effective, rapid manufacturing and other emerging technologies. No single company has the financial resources or technical depth to successfully tackle the challenges in the near future.

Building on these ascertainments, the CAIIAC initiative wants to introduce the following practices to the composites industry:

- Technology maturation – the concurrent maturation of Technology Readiness Levels (TRL), Manufacturing Readiness Levels (MRL), business cases and an ecosystem to accelerate innovation and insertion, as well as to ensure that the new technology is "invent here, build here in the US"
- Full value chain engagement - involve small- and medium-sized enterprises that support Original Equipment Manufacturers (OEMs) in a wide range of sectors
- Innovative technology – use of a fully integrated experimental and computational approach to dramatically reduce the "time to full readiness" of using new technologies or processes, e.g., novel nanomaterials, out-of-autoclave processes, rapid certification and recycling of composites

Starting with an industry-led road-mapping process, the new consortium aims to identify and validate emerging crosscutting lightweight composite technologies that offer benefits across multiple industries. The consortium will generate and prioritize major technical projects to address these technical gaps and challenges, as well as others to be included in the consortium’s technology roadmap. In order to effectively evaluate technical projects, the consortium will incorporate and institutionalize and “xRL” scheme that will include TRL, MRL, Business Case Readiness Levels (BcRL) and Ecosystem Readiness Levels (ERL) across all project teams.



CAIIAC Technology Maturation Approach

1

Discover Here in U.S.

Basic research
Single & multi-disciplines
Technology pipeline

4

BcRL starts

7

Accelerate Translation

Early stakeholder engagement
Business case orientation
Application pipeline

Tech/mfg for market opportunities
Bridging the missing middle
Reaching tipping point onto full scale market insertion

BcRL tipping point

10

Build Here in U.S.

Insertion
Deployment
Commercialization

Build where decision

Supply chain readiness
Workforce development
Build here, sell globally

Build here decision

The roadmapping process that will be used is meta-roadmapping. Meta-roadmapping is a technology-mining method that involves analysis of existing roadmaps/expert opinions/reports, scientific publications and patents to derive useful information about the emerging technologies. Results from this analysis will be combined into a list of emerging technologies. This will become a starting point for the development of a meta-roadmap categorized by subject experts. This approach differs from a traditional roadmapping process in that it can provide an idea about the technology under study from different perspectives in a single meta-roadmap.

Table 1 lists a set of sample data for major key areas of advanced composites, which can be used for meta-roadmapping of composites:

Keywords	No. of Publications (Source: Compendex; Time Span: 1995-2014)	No. of Patents (Source: Derwent Innovations Index; Time Span: 1995-2014)
Composite Design	117,371	8,752
Composite Manufacturing	57,141	37,043
Composite Repair and Joining	12,702	5,882
Composite Non-Destructive Evaluation/Inspection/Testing	6,580	272
Composite Structural Health Monitoring	3,699	54
Composite Recycling	9,653	2,178
Composite Certification	985	66
Nanocomposites	75,760	4,024

Workshop Technical Discussions Outcomes

The six topics identified were thoroughly discussed at the workshop during the five featured presentations given by industry experts and the breakout sessions. The five featured presentations included:

- *Integrated Computational Materials Engineering*, by Chuck Ward, Air Force Research Laboratory
- *Standardized Design*, by Robert Yancey, Altair Engineering, Inc.
- *Scalability*, by Don Klosterman, University of Dayton
- *Composite Manufacturing*, by Bob Stratton, Stratton Composites Solutions
- *Composite Repairs*, by Ray Kaiser, Delta Airlines, Inc.

Two simultaneous breakout sessions were held, focusing on “ICME and Standardized Design” and “Scalability and Composite Repair.” The following summarizes the outcomes of these presentations and breakout sessions.

1. Standardized composite design and testing for faster and more affordable certifications

Standardized composite design can be defined as generating confidence in the model and enforcing consistent practices. Standards for composites and their applications are unique and are proprietary to each organization. Therefore, composite design standards should not be universal. Universal standardized composite design is unrealistic; materials, structure or application have to be considered for each specific case. Defining design guidelines and best practices would be more effective.

It is difficult to purchase some materials in small quantities to test: a materials database is useful and work in this area should continue. Databases for standardized composite design mostly exist in the aerospace industry. But as the data is proprietary, most of the aerospace companies have their own database. And, they won’t trust the data coming from others. The barriers for developing a composite design database come from IP issues and the lack of funding for testing.

<u>Integrated Computational Materials Engineering</u>:
ICME is currently not used on a day-to-day basis for composites in aerospace and automotive industries because it is still in the research phase. For example, mature models for damage mechanisms in composites are available. The OEMs are used to design with isotropic materials (e.g. metals). But, when it comes to anisotropic with interfaces, ICME becomes very immature. The process is not integrated yet, and it is used in an ad-hoc fashion and/or as a last resort. A potential exception is for small fiber composites, where ICME is further advanced, e.g. simulation packages for injection molding of short fiber-filled thermoplastics. Integrating ICME into composites development is a paradigm shift.

The simulation software industry has done a poor job of setting expectations. The expectations are to have tools to predict performances and help understand the trends that indicate where the issues are, but not necessarily providing actual numbers. This kind of information would help to solve general issues.

The major barrier for developing and deploying effective ICME tools is the lack of confidence that a standardized method would apply to different designs. Accurate and efficient ICME models are needed for this purpose; but there are IP issues on materials and processes. Moreover, not a single company can provide complete data; this creates the need to define the data format. The standardization in protocol is required before a transfer to the whole industry can happen. But there is a lack of cross industry collaboration. IP is the largest issue; companies do not want to share their internal know how. Also, for small companies, ICME software licensing is expensive and, therefore, prohibitive.

ICME for composites would generate a tremendous amount of data such as how to run a large number of simulations and analyze them quickly, and to visualize and process the data. The problem does not come from the computer hardware, but from the software licensing and the difficulty to run numerous simulations in parallel.

ICME to Reduce the Time and Cost of Composite Certification and Qualification:
New materials qualification costs are high and have to be borne by companies. Every change in the process requires re-qualification. Many good manufacturing improvements are not available for industry because of the qualification cost. Computational methods can reduce the cost to obtain necessary data. They have decreased the cost of certification. However, this depends on the industry. In the automotive industry, data is acquired through simulation and only final tests are done for regulation, while in the aerospace industry, tests dominate in the certification process.

Given these examples, extending ICME to discovery and development is easier than obtaining certification. The validity of the model does not need to be as robust. More uncertainties are acceptable as there are lower risks. Test areas are of higher concern because not every point must be tested.

There are no mature ICME and standardized design tools for composite joining (composite to composite or composite to metal). It is an art in which surface preparation is key and needs to be done properly. Non-destructive evaluation is a necessary tool for adhesive bonding.

2. Quick and Reliable Joining and Repairs

There are a variety of composite joining and repair (CJAR) approaches and most damages are unique. However, having a standardized approach to making similar types of joining and repairs could make CJAR faster and easier. The major challenges in CJAR are the joining/repair of complex contour structures, the kissing bonds, and the repeatability of joining and repairs. There is no standard patch size for composite repair since the shapes are complex and unique. Automation and inspection of joining and repair is difficult, but desirable, as well as monitoring and control of joining and repair quality.

There are several major issues for CJAR. For integrated structures, in-field repair will be an issue because they are heavy and complex structures. Joining and repairs in production facilities can potentially damage the primary structure. CJAR may have impact on downstream operations. For example, jointed or repaired structures may not survive in the high temperature processing environment (e.g. painting) after the assembly operation. In the wind power industry, the cost of repairing small wind turbine blades approaches the cost of a new blade. Therefore, few blades are repaired, but rather, they are replaced.

Computational models and design tools for CJAR are highly desirable. Currently, most of composite repair work is done based on experience with some basic inspection. Effective models/design tools for predicting bonding strength for CJAR can eliminate guesswork for joining and repair. Another important technology for effective CJAR is non-destructive evaluation/inspection (NDE/NDI) tools. Current NDE/NDI technologies are qualitative in nature and do not provide adequate results/data on bonding strength/effectiveness of CJAR. In addition, the work that needs to be done to provide effective joining and repair solutions for the composite industry includes reducing the variability of the joining and repairs, developing joining and repair automation equipment; and establishing shared material databases.

3. Scalable and Reproducible Out-Of-Autoclave Processes and Affordable Tooling

The increasing demand of composites in various applications including high demand production makes high-rate composite manufacturing technologies highly desirable. Composite scalability challenge lies in the fact that lab data cannot be easily extrapolated to large scale production. There is a lack of understanding of materials properties and process variables to scale up and this can only be solved by developing methodologies that would not only preserve the design intent but also scale into a repeatable production-based environment. The manufacturing is different from the lab but inherits of decisions made early on.

Currently, most composites manufacturing is done in autoclave. Going out-of-autoclave (OOA) requires good understanding of the processes and materials. Whether or not OOA can meet design requirements is a big question. The barriers for a widespread use of OOA include:

- Using OOA with prepreg, which is the common term for a reinforcing fabric that has been pre-impregnated with a resin system, has to be engineered to meet requirements under OOA conditions. Prepregs require partial impregnation, which is a proprietary process for manufacturers, thus leading to IP issues.
- There is no industry wide standard for materials and the lack of consistency of materials from vendor to vendor means that a unique process is needed for each material.

- A cost analysis is difficult to prepare ahead of time and the cost breakdown between overhead and operating costs is very different between autoclave and out-of-autoclave processes.
- There is a need for an education process to convince designers and users that OOA is as good as autoclave.

From the initial steps to the final assembly, the process should be fully integrated to avoid problems along the way. Because there are variations at every step of the process, manufacturing needs should be considered during the process development phase. Tools to accelerate the transition to OOA are needed in order to have the ability to identify, predict, measure and control properties of composites production scale-up. As a prime example, 3D printing is a good enabling technology for tackling possible prototyping stage issues, but at larger scales there are size and speed limitations. On the other hand, emerging composites 3D printing technologies for direct manufacturing of composite structures has great potential to fabricate complex composite structures with desired low cost and high efficiency.

3D properties resulting from 3D preforms are necessary for complex shapes. Analysis and online monitoring of 3D shapes of composites is highly desirable. Currently, we can design and build far more advanced 3D composite structures than we can analyze. This analysis gap is holding back the use of complex 3D preforms. In addition, inspections of special sections of preform structures such as corners and edges are especially difficult.

4. Structural Health Monitoring of Life Cycle Performance

With the increasing demand for improved performance in critical components using composites, Structure Health Monitoring (SHM) is becoming more desirable. Localized damage detection and assessment of composite structures, especially impact damage, is still in its infancy and no single technique used in isolation can provide reliable results. Nonetheless, reliable damage detection must be intrinsic to creating the structure and its cost-effectiveness. The challenge is to integrate this monitoring without compromising performance and manufacturability. The ability to repair structures needs to be accounted for in the design phase. Structures and materials groups need to collaborate at the beginning of the design process.

Workshop participants agreed on the need for a more collaborative environment in which academia will focus on problems that the industry views as important, as well as bring new ideas to the table. The audience also agreed that developing demonstration facilities for composites scalable manufacturing and repair R&D is needed. A geographical coalition is required so that resources can be close to the point of use. Existing test beds are not well served because large companies have their own facilities and small companies can’t afford the cost of paying for the test beds. Implementation grants would help small companies have access to the test beds at an affordable rate. Users have to be assured of the ability to protect trade secrets in a test bed environment. Initial agreement as to what is precompetitive as opposed to post competitive is required. In parallel, advanced composites training and education programs should be developed.

5. Recycling and Reuse of Composites

As the composite industry grows, so will the need to recycle and reuse composite feedstock. Due to different chemical characteristics of their matrices, thermoplastic and thermoset composites have distinct recyclability. Thermoset composite materials are relatively difficult to recycle because of their chemical stability and the difficulty to separate the matrix and the fibers. Currently, the most common recycling or downcycling approach for thermoset composites is to shred retiring composites into fillers for downcycling applications. Thermoplastic resin composites are easier to recycle as they can be remelted and potentially reused as injection molding feedstock. That could make thermoplastic resin composites of interest for large-scale production parts, provided that recycling incentives and regulations are established.

In order for composites to be recycled, the recycling cost should be lowered, the recycled constituents' quality should be improved and the applications that could use the recycled feedstock should be identified and demonstrated.

6. Inclusion of Nanomaterials for Improved Performance

There has been a huge amount of research in nanomaterials composites, but no large-scale manufactured products have reached the market yet. Finding actual applications of nanomaterials in the marketplace is needed to move this field of research forward. Multifunctional composite structures for critical or high-end applications or self-healing composites could be achieved with nanotechnology. However, more research is required in these areas. Academic research on quick and even heating for rapid and balanced curing or joining of composites is desirable.

Nanomaterials can have applications for fracture toughness for composites. Out-of-autoclave would be a mechanism to embrace nanotechnology. In any case, while improving the performance, the inclusion of nanomaterials into composites should be cost-effective and should not impact the overall manufacturability.

Next Steps of CAIIAC

The next steps for the CAIIAC consortium will be to define:

- A complete and ready to implement technology transfer roadmap that clearly shows for each composite the TRL for transfer to key industrial markets and government
- An identifiable consortium organization that is ready to implement the CAIIAC mission
    - Identify key potential partners in the composites industry
    - Establish a database of potential partners to include composite expertise, market segments, and specialists who can work technologies into different businesses

CAIIAC will participate in the upcoming composites roadmapping workshop organized by the American Composites Manufacturers Association (ACMA) (January 20 - 21, 2015).

Two more CAIIAC workshops are planned for 2015 to enhance the roadmapping process. The completed CAIIAC roadmap(s) will be submitted to NIST at the end of the project.

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Georgia Tech | Manufacturing Institute

CAIIAC Workshop Agenda

November 5, 2014

Workshop Venue: Auditorium, Georgia Tech Manufacturing Institute Georgia Institute of Technology

Time	**Activity**	**Presenter/Moderator**
8:00 AM	Continental Breakfast	
8:30 AM	Call to Order	John Zegers, Master of Ceremonies
	Introduction of Provost Bras	Ben Wang, Executive Director, GTMI
	Welcome	Rafael Bras, GT Provost
8:45 AM	Introduction of Participants	All
9:15 AM	Workshop Agenda Overview	Les Kramer, AMPS
9:20 AM	Feature Talks on Challenges and Unmet Needs	
	• ICME	Chuck Ward, AFRL
	• Standardized Design	Bob Yancey, Altair
	• Scalability	Don Klosterman, U of Dayton
	• Composite Manufacturing	Bob Stratton, SCS
	• Composite Repairs	Ray Kaiser, Delta
10:40 AM	CAIIAC Vision, Goals, Mission and Deliverables	Ben Wang, GTMI
11:05 AM	Morning Break	
11:15 AM	GT Approach to Industry Partnership	Don McConnell, GT

CAIIAC Workshop Agenda (continued)

11:30 AM	Breakout I (Two Concurrent Sessions)	
	• ICME and Standardized Design (Auditorium)	Moderator: Don Klosterman Panelists: Andy Thomas, Bob Yancey and Chuck Ward Scribes: Tina Goldberg and Kevin Wang
	• Scalability and Composite Repair (Room 114)	Moderator: Jan Bremer Panelists: Tom Carstensen, David Herbert and Ray Kaiser Scribes: Les Kramer and Atiq Bhuiyan
12:30 PM	Working Lunch & Informal Discussion	
1:30 PM	Breakout II (Two Concurrent Sessions)	
	• ICME and Standardized Design (Auditorium)	Moderator: Ray Boeman Panelists: Brian Gardner, Jordan Shulman and Mia Siochi Scribes: Tina Goldberg and Kevin Wang
	• Scalability and Composite Repair (Room 114)	Moderator: Dan Coughlin Panelists: Bill Hooper, Jesse Hartzell and Bob Stratton Scribes: Les Kramer and Atiq Bhuiyan
2:30 PM	Afternoon Break	
2:40 PM	Breakout Report Back (Auditorium)	Session Moderator: Les Kramer
3:20 PM	Where Do We Go from Here?	Chuck Zhang, GTMI
3:30 PM	Concluding Remarks and Adjourn	Ben Wang, GTMI
3:35 PM	Unstructured Networking Opportunities	

Nov 5th Workshop Participants (1/2)

No.	Name	Organization	Organization Location
1	Atiq Bhuiyan	Georgia Institute of Technology	Atlanta, GA
2	Ray Boeman	Oak Ridge National Laboratory	Oak Ridge, TN
3	Michael Bray	ThyssenKrupp	Alpharetta, GA
4	Jan Bremer	BCT Steuerungs-und DV-Systeme GmbH	Dortmund, Germany
5	Billyde Brown	Georgia Institute of Technology	Atlanta, GA
6	Tom Carstensen	Sikorsky Aircraft Corporation	Stratford, CT
7	Dan Coughlin	American Composites Manufacturers Association	Arlington, VA
8	Steve Dickerson	Software Automation, Inc.	Atlanta, GA
9	Christina Drake	Florida Polytechnic University	Polk City, FL
10	Karen Fite	Georgia Manufacturing Extension Partnership	Atlanta, GA
11	Mark Francis	Sikorsky Aircraft Corporation	Stratford, CT
12	Brian Gardner	Chomarat	Williamston, SC
13	Tina Guldberg	Georgia Institute of Technology	Atlanta, GA
14	Tequila Harris	Georgia Institute of Technology	Atlanta, GA
15	Jesse Hartzell	Chomarat	Williamston, SC
16	David Herbert	Honeycomb Company of America, Inc.	Sarasota, FL
17	Charles Hill	Moog Components Group	Murphy, NC
18	William Hooper	ATK	Clearfield, UT
19	Steven Justice	Georgia Center for Innovation of Aerospace	Atlanta, GA
20	Ray Kaiser	Delta Airlines, Inc.	Minneapolis, MN
21	Kyriaki Kalaitzidou	Georgia Institute of Technology	Atlanta, GA
22	Don Klosterman	University of Dayton	Dayton, OH
23	Les Kramer	Advanced Materials Professional Services	Orlando, FL
24	Satish Kumar	Georgia Institute of Technology	Atlanta, GA
25	Richard Liang	Florida State University	Tallahassee, FL
26	Rob Maskell	Cytec Aerospace Materials	Tempe, AZ
27	Don McConnell	Georgia Institute of Technology	Atlanta, GA
28	Thomas Mensah	Georgia Aerospace	Atlanta, GA
29	John Morehouse	Georgia Institute of Technology	Atlanta, GA
30	Don Pital	Enterprise Innovation Institute	Atlanta, GA

Nov 5th Workshop Participants (2/2)

No.	Name	Organization	Organization Location
31	Zack Rubin	Generation Orbit Launch Services, Inc.	Atlanta, GA
32	Jordan Shulman	Generation Orbit Launch Services, Inc.	Atlanta, GA
33	Mia Siochi	NASA Langley Research Center	Hampton, VA
34	Robert (Bob) Stratton	Stratton Composite Solutions	Marietta, GA
35	Andy Thomas	Bell Helicopter Textron, Inc.	Fort Worth, TX
36	Rick Walker	Georgia Automotive Manufacturers Association & Falcon IP Capital	Atlanta, GA
37	Ben Wang	Georgia Institute of Technology	Atlanta, GA
38	Kevin Wang	Georgia Institute of Technology	Atlanta, GA
39	Chuck Ward	AFRL	WPAFB, OH
40	Sunny Wicks	Lockheed Martin	Bethesda, MD
41	Bob Yancey	Altair	Seattle, WA
42	Donggang Yao	Georgia Institute of Technology	Atlanta, GA
43	Yusheng Yuan	Baker Hughes	Houston, TX
44	John Zegers	Georgia Institute of Technology	Atlanta, GA
45	Chuck Zhang	Georgia Institute of Technology	Atlanta, GA