Synthesis of Engineering Best Practices and ABET AC2K into a New Mechanical Engineering Curriculum

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Abstract

Aggressive competition for global technological markets is driven by engineering breakthroughs in manufacturing and processing (micro/nano-electronics, data/information and materials), combined with new strategies that reduce risk, cost and time to market. This highly dynamic scenario is assisted by improved distribution systems like E-commerce, among others. Industry is aware that mergers and acquisitions by themselves do not guarantee world-class competitiveness but a great deal depends on their investment in a highly skilled workforce. As a consequence, industry is very interested in working with universities to raise their level of awareness on those competencies sought in new engineering graduates.

Engineering programs seeking to be relevant and responsive to industry and government agencies involved with hiring engineering graduates have no difficulties recognizing that, these employers represent an important component of their constituency. However, this group is not the only constituency that engineering programs seek/need to satisfy. Other constituencies are represented by alumni, professional associations, accreditation boards, departmental advisory boards, school directives, as well as, the students themselves. All members of the program constituency do not agree universally on the priorities and which outcomes are better than others. Furthermore, less agreement exists on how to meet the challenges brought up by each.
This paper discusses the elements considered and the approach taken by the faculty of the Mechanical Engineering Department at Alabama A&M University, to synthesize into a new ME curriculum the ABET accreditation criteria 2000, the “best practices” recommended by the American Society of Mechanical Engineers, the recommendations of the Society of Manufacturing Engineers, the National Research Council recommendations and also those that have evolved from Boeing / University Key Schools Workshops.

As part of the competitive strategy, and to become relevant to regional needs, the concept for the new curricula was formulated with two specializations; one is focus on manufacturing and the other, is geared to propulsion systems. In both options areas such as; system performance, reliability, safety, concurrent engineering, teamwork and communication are given special attention.

I. Background

Alabama A&M University, (AAMU) was granted the authority to offer two new engineering programs in August 1, 1995. The mechanical and electrical engineering programs became a part of a larger legal desegregation law suit resolution in the civil case CV 83-M-1676. This situation brought to AAMU both a challenge and a unique opportunity to develop two engineering programs from “a clean sheet of paper” perspective. Dr. Arthur J. Bond, Dean of the School of Engineering and Technology, formed a team to develop both the electrical and mechanical curricula. This paper describes some of the elements that influenced the design of the new curricula for the Mechanical Engineering Program.

The first author was selected as a member of the team in 1996 and the co-authors joined the team in 1998. The program was approved in its entirety in October 1997. The court order forced a distinct and innovative focus to the program by requiring strict observance in its design, to be non-duplicative of any existing engineering programs in the state of Alabama. Two years after initial approval, the EE program graduated four students, and the ME program graduated two students that entered the program as transfer students from other institutions. Therefore, the ME program produced their first graduating class two years ahead of schedule. The two ME graduates hold manufacturing engineering positions in different local companies in the Huntsville area. There were approximately ninety students enrolled in the ME program at the initiation of its third year.

II. Problem Definition

The task of designing an innovative non-duplicative curricula for mechanical engineering is both a challenge and an opportunity to utilize the engineering design experience. This task was viewed as a multi-year project with a goal; to produce a competitive engineering program.
As in the case of new product development, it was essential to answer typical questions such as:
a) What should be the key features; b) How to establish specifications; c) How to establish 
resource allocations; d) How to describe it; e) Who are the customers; f) How much would it 
cost; g) What should be the competitive strategy; h) What is the schedule and i) What are the 
risks and critical issues. Providing answers to these questions resulted in an effort to develop 
a synthesis of engineering best practices with ABET AC2K within the new mechanical 
engineering curriculum.

III. The Big Picture; Converging Views for a New Engineering Curricula.

A series of documents emerged by the mid-nineties that represented a national view on the 
subject of engineering education. These documents are enlightening and were helpful in 
developing the new ME curricula. A few points from them are discussed briefly herein.

National Research Council

In 1995, a report was issued on a new study conducted by the Board of Engineering Education 
(BEEd), of the National Research Council in cooperation with the National Aeronautics and 
Space Administration (NASA), the U.S. Department of Energy, the National Academy of 
Engineering, The Boeing Company, and Xerox Corporation.

For the authors, this report highlights emphasizing the view that engineering education should 
be that of a systems perspective requiring fluid and continuous interaction among school 
faculty, administration, professional societies, federal agencies, accrediting bodies and industry 
to produce the desired educational outputs.

Pertinent to curriculum design issues we can extract the following points:

- Development of a highly adaptable and flexible system
- Integration of both fundamentals with exposure to engineering practice and design
- Larger exposure to design principles, team projects, business perspective and 
societal issues.
- Training to perform well with interdisciplinary teams
- Tailoring to local circumstances keeping a global perspective.
- Assessment ready and open to industry’s feedback
- Reinforce communication skills experiences and training for life long learning.

In academe, gaining approval to curricular changes is at least a two year effort. As a 
consequence, meaningful changes will take approximately two to three years to have any 
influence to speak of. Since engineering programs are not required to show a return on 
investment in two or three years as industry is, it would be most advantageous to build-in 
flexibility and adaptability in the design of engineering curricula.
Some engineering programs here in the U.S. still debate the wisdom of the proposed changes given that: *It worked before, nothing has fallen off the table, if it isn’t broke don’t fix it, principles are non-changing, why should we.* However, if the engineering program is viewed as part of a dynamic system and every thing changes around it, then it would be reasonable to expect reflections of these changes in the curricula. Paradoxically in some nations of the Pacific rim engineering programs are more aggressive in promoting rapid innovation and early specialized training.

**ABET**

By December of the same year, the Accreditation Board for Engineering and Technology (ABET) Board of Directors approved the Engineering Criteria 2000 for a two year period comment that began in January 1996. ABET Engineering Accreditation Criteria 2000 (AC2K) was approved for a three year phased implementation starting in the 1998-1999 accreditation cycle. AC2K provides guidelines for engineering programs to document: where they are now, and where improvements can be made in their programs. The interpretation of AC2K as a driver of innovation, reform, quality, and responsiveness to a constituency is still debated at the “trenches”; however those more acquainted with the industry’s efforts to remain competitive can note the parallelism between statistical control processes (SCP), and outcomes based assessment (OBA) predicated in AC2K.

ABET will still require one year of mathematics and basic science, a half year of humanities, and one and a half years of engineering topics as well as a capstone design experience.

Pertaining to the curriculum, ABET program criteria states: *Graduates most have demonstrated:*

a) knowledge of chemistry and calculus-based physics with depth in at least one;

b) ability to apply advanced mathematics through multivariate calculus and differential equations;

c) familiarity with statistics and linear algebra;

d) ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems”

AC2K has established in Criteria 3, eleven engineering competencies to be met. These are:

1 an ability to apply knowledge of mathematics, science, and engineering;

2 an ability to design and conduct experiments, as well as to analyze and interpret data;

3 an ability to design a system, component, or process to meet desired needs;

4 an ability to function on multi-disciplinary teams;

5 an ability to identify, formulate, and solve engineering problems;

6 an understanding of professional and ethical responsibility;

7 an ability to communicate effectively;

8 the broad education necessary to understand the impact of engineering solutions in a global/societal context;

9 a recognition of the need for and an ability to engage in life-long learning;

10 a knowledge of contemporary issues; and,

11 an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
AC2K also requires documentation that program outcomes and educational objectives have been met. ABET suggests use of: student portfolios, including design projects; nationally-normed subject content examinations; alumni surveys that document professional accomplishments, career development activities, employer surveys, and placement data of graduates.

ASME

Also in December of 1995, The American Society of Mechanical Engineers (ASME), issued a report entitled: Integrating the Product Realization Process (PRP) into the undergraduate curriculum. The report was documented by questionnaires sent to both industry and academe to determined what was considered as best practices utilized for the PRP. It also attempted to assess preparedness gaps as perceived by the industry. For most of the twenty-best practices in PRP, the responses tend to aggregate around preparation rated OK (Marginal).

The part that likely, provided more insight to the industry’s views is the one section on comments from respondents on specific skills deficiencies perceived in new BS graduates. However, it is important to note that there is no indication to show that if this survey had been conducted five, ten, or fifteen years earlier that the results would be substantially different from those reported in 1995.

The list of twenty best practices opened for comments for the survey are:

<table>
<thead>
<tr>
<th>No.</th>
<th>Practice</th>
<th>No. of comments generated</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Teams/Teamwork</td>
<td>167</td>
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<tr>
<td>2.</td>
<td>Communication</td>
<td>118</td>
</tr>
<tr>
<td>3.</td>
<td>Design for Manufacture</td>
<td>116</td>
</tr>
<tr>
<td>4.</td>
<td>CAD Systems</td>
<td>106</td>
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<tr>
<td>5.</td>
<td>Professional Ethics</td>
<td>43</td>
</tr>
<tr>
<td>6.</td>
<td>Creative Thinking</td>
<td>64</td>
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<tr>
<td>7.</td>
<td>Design for Performance</td>
<td>16</td>
</tr>
<tr>
<td>8.</td>
<td>Design for Reliability</td>
<td>129</td>
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<tr>
<td>9.</td>
<td>Design for Safety</td>
<td>75</td>
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<tr>
<td>10.</td>
<td>Concurrent Engineering</td>
<td>129</td>
</tr>
<tr>
<td>11.</td>
<td>Sketching/Drawing</td>
<td>159</td>
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<tr>
<td>12.</td>
<td>Design for Cost</td>
<td>159</td>
</tr>
<tr>
<td>13.</td>
<td>Application of Statistics</td>
<td>89</td>
</tr>
<tr>
<td>14.</td>
<td>Reliability</td>
<td>83</td>
</tr>
<tr>
<td>15.</td>
<td>Geometric Tolerancing</td>
<td>132</td>
</tr>
<tr>
<td>16.</td>
<td>Value Engineering</td>
<td>120</td>
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<tr>
<td>17.</td>
<td>Design Reviews</td>
<td>140</td>
</tr>
<tr>
<td>18.</td>
<td>Manufacturing Processes</td>
<td>142</td>
</tr>
<tr>
<td>19.</td>
<td>Systems Perspective</td>
<td>124</td>
</tr>
<tr>
<td>20.</td>
<td>Design for Assembly</td>
<td>39</td>
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</tbody>
</table>
It is logical to expect that respondents will be willing to be more vocal on subjects that are more often encountered in their workplace. It is somehow interesting to note that respondents will be almost twice as motivated to discuss views on Design for Reliability than plain Reliability. The most surprising from the list above is to find that the minimum number of comments go to Design for Performance. This data suggests that there may be a weak connection between reliability and performance which is certainly not true.

SME

On August 1996 the Society of Manufacturing Engineers (SME), launched its Manufacturing Education Plan. As a result in 1997 SME and its Education Foundation produced a report entitled: Manufacturing Education Plan: Phase I Report. In this report the question of competency gaps among recent manufacturing engineering graduates and technologists were approached directly. SME has stated its interest in providing guidance on what, and how manufacturing topics should be taught.

Through a series of workshops the following top fourteen major competency gaps were identified and ranked:

1. Communication Skills (presentation skills, listening abilities, graphic software usage)
2. Teamwork (conflict resolution, interpersonal relations, team member, accountability)
3. Personal Attributes (leadership, sensitivity to others, consciousness of the big picture, ability to both teach and learn from others, analytical skills, and consensus building.)
4. Manufacturing Principles (lean manufacturing, concurrent engineering, constrains)
5. Reliability (Process and products, FMEA principles, testing for expected life cycles.)
6. Project Management (resource deployment, cross functionality, planning, monitoring)
7. Manufacturing Processes (gaps between “book learning” and application of principles)
   - CAD/CAM
   - Product Engineering
   - Blue Print Reading
   - Hydraulics
   - Process Improvement
   - Jig and Fixture Design
   - Geometric Dimensioning and Tolerancing
   - Materials
   - Metrology
   - Electronics
   - Tool Design
   - Troubleshooting
8. Business Skills (Cash flow, ROI, customer focus, risk analysis/management, etc.)
9. Quality (ISO 9000 compliance)
10. Change Management (long and short term perspectives, product configuration, control and documentation, acting as a change agent.)
11. Statistics and Probability
12. Ergonomics (human factors, safety and work station/tool design)
13. Materials (materials selection, manufacturability and utilization)
14. Continuous Learning or Lifelong Learning
It is commendable that SME has sustained the research regarding competencies. In their latest publication, ten professional and technical competencies have been identified. The list is: “business knowledge/skills, project management, written and oral communications, and international perspective, on the professional side; supply chain management, manufacturing process control, manufacturing systems, and quality on the technical side.”

The aforementioned documents represent hundreds of man-hours of work among industry, academia, accreditation agencies and government agencies interested in providing assistance, and guidance in establishing where engineering education was back in 1995 with regard to industry’s evolving needs.

The thrust of these efforts did not just happen almost simultaneously by accident, the National Science Foundation (NSF) funded several engineering school coalitions in the early nineties, to re-engineer the way engineering was taught. In a parallel effort, The Boeing Company launched in 1994 a series of initiatives to enhance engineering education. Boeing has sustained a high degree of involvement with the academic community via: internship summer programs, university/industry workshops and by appointing Boeing Executive Focal persons to work with “key” schools in the development of engineering competencies, that favor viewing engineering design as the central focus in engineering education.

IV. Regional issues and local constituency

ALABAMA A&M UNIVERSITY is located in Huntsville, AL., a region of major industrial manufacturing, technology transfer and research endeavors in space transportation and propulsion. AAMU is one of two Land Grant Universities in Alabama. A few highlights on the history of the state provides insights to activities that draw community support for engineering and research activities.

- Orville and Wilbur Wright carved part of aviation history in March 29, 1910 with their first flying school in Montgomery.
- Alabama is the home of the Tuskegee Airmen;
- Huntsville is the home of the Redstone Arsenal and the U.S. Army Aviation and Missile Command (AMCOM)
- Dr. Von Braun’s team based in Huntsville, used a modified Redstone rocket to put America’s first orbiting satellite into space.
- Alabama is the home of NASA’s George C. Marshall Space Flight Center where the Mercury-Redstone vehicle was developed, and successfully launched Admiral Alan B. Shepard to a sub-orbital flight; making him America’s first astronaut.
- NASA MSFC is a national center for propulsion research, space transportation and micro-gravity. Where the space station freedom started to be built.
V. Definition of the New Mechanical Engineering Curriculum

As a result of the consideration of the information discussed herein. It was concluded that, the resulting curriculum had to:

1. Meet accreditation criteria
2. Address national trends, while becoming locally relevant
3. Allocate space for university core requirements,
4. Stay as a four year program to be completed within 128 to 130 semester credit-hrs.
5. Provide flexibility
6. Be focused on teaching and instruction that reflects real engineering practice.
7. Be a competitive and cost effective program.

As part of the competitive strategy and to become relevant to regional needs, the concept for the new curricula was formulated with two specializations; one focused on manufacturing and the other geared to propulsion systems. To provide additional adaptability a third option was included as the general option with a group of elective courses to be defined as the system evolve. In both options areas such as; system performance, reliability, safety, concurrent engineering, teamwork and communication are given special attention.

As a means to illustrate the engineering practice, it is required that all engineering courses have at least one project. The projects are developed by students working in teams. The projects require a report and an oral presentation that has weight in assigning the final grade.

The design practice is integrated during the four years and culminates with two sequential senior level courses in mechanical engineering design.

Training for life long learning is achieved by teaching students about learning at different levels of complexity, as discussed by Bloom et all.

The new curricula is intended to reduce the time industry and government usually takes in the "re-training" of new engineering graduates to become part of a production team.

Two 200 level courses required in electrical engineering aim to facilitate the interdisciplinary work that mechanical engineers are faced on a daily basis.

The specializations provide sixteen semester-credit hours of course study in the specialized area. The work that students carry out is augmented by five semester credit hours of senior design in the respective specialization, bringing the total focus to twenty one credit hours of scholarly work in either the manufacturing or propulsion options.
Specially designed courses include: a) Introduction to Mechanical Engineering; b) Concurrent Engineering; c) Quality and Reliability Assurance; d) Design for Manufacture and Reliability; e) Economic Evaluation of Design Projects; f) Operations Planning and Scheduling; g) Power Systems Integration; h) Power Plant Performance; i) Analysis and Synthesis of Gas Turbine Components; j) Gas Dynamics; and k) Rocket Propulsion.

The proposed new curriculum became one that meets university core requirements, a core of common engineering courses until the third year and a senior specialized courses with a capstone design sequence. The curriculum is shown in the next page.
# THE MECHANICAL ENGINEERING PROGRAM AT AAMU

## Freshman Year

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<tr>
<td>ORI 101 Survival Skills</td>
<td>1</td>
<td>1 ENG 102 Communication Skills II</td>
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<td>¹ENG 101 Communication Skills I</td>
<td>3</td>
<td>MTH 126 Calculus II</td>
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<td>MTH 125 Calculus I</td>
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<td>PHY 105 Physics I</td>
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<td>CHE 101 General Chemistry I</td>
<td>3</td>
<td>⁴EGC 101 Computer Programming</td>
<td>3</td>
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<td>CHE 101L General Chemistry I Lab</td>
<td>1</td>
<td>ME 101 Intro to Mechanical Engineering</td>
<td>1</td>
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<tr>
<td>³Health Science</td>
<td>2</td>
<td>ME 101L Intro to Mechanical Engineering Lab</td>
<td>1</td>
</tr>
<tr>
<td>⁴EGC 101 Eng. Drawing &amp; Graphics</td>
<td>3</td>
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¹ENG 103, or ENG 104 may be taken by international students.
²FAS 101, HED 101, or NHM 103
³The equivalent general engineering course can be substituted with the corresponding ME course.

## Sophomore Year

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<tr>
<td>MTH 227 Calculus III</td>
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<td>MTH 238 Differential Equations</td>
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<td>PHY 106 Physics II</td>
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<td>HIS 102 World History II</td>
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<td>HIS 101 World History I</td>
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<td>ME 210 Material Science</td>
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<td>EE 201 Linear Circuit Analysis I</td>
<td>3</td>
<td>ME 206 Dynamics</td>
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<td>ME 205 Statics</td>
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<td>ME 210L Material Science Lab</td>
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⁵PHL 201, PSY 201, SOC 201, or GEO 213.

## Junior Year

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<tr>
<td>ECO 200 Basic Economics</td>
<td>3</td>
<td>EE 203 Analog Circuit Des/Anal.</td>
<td>3</td>
</tr>
<tr>
<td>ME 231 Strength of Materials</td>
<td>3</td>
<td>EE 203L Analog Circuit Des/Anal. Lab</td>
<td>1</td>
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<tr>
<td>ME 310 Thermodynamics</td>
<td>3</td>
<td>ME 300 Math. Meth. in Mech. Engin.</td>
<td>3</td>
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<tr>
<td>ME 320 Kinematics/Dynamics of Mach.</td>
<td>3</td>
<td>ME 301 Anal. &amp; Instrum./Phys. Syst.</td>
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<tr>
<td>ME 360 Fluid Mechanics I</td>
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<td>ME 301L Anal. &amp; Instrum./Phys. Syst.L</td>
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<tr>
<td>ME 360L Fluid Mechanics Lab</td>
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<td>ME 312 Heat and Mass Transfer</td>
<td>3</td>
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## Senior Year Common Courses

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<tbody>
<tr>
<td>ENG 203 Humanities I</td>
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<td>ENG 204 Humanities II</td>
<td>3</td>
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<tr>
<td>ME 451L Automatic Control Systems L.</td>
<td>1</td>
<td></td>
<td>9</td>
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<tr>
<td>ME 470 Mech. Engin. Design Project</td>
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VI. Conclusion

A new curricula in mechanical engineering at AAMU has been designed with vertical and horizontal integration. Its design is intended to provide as much responsiveness to all the constituencies identified in the system. It aims to develop to some extent, in the ME students, part of the engineering competencies sought by industry and government, during a four year effort. The coursework includes training in design for: manufacture, performance, cost, reliability, safety, communications and team/teamwork skills.

The approach to building engineering competencies is promoted by hands on project development and specialized lectures and group exercises. Students seem appreciative of the characteristics of the program and have demonstrated a higher level of interest in pursuing their academic work.

Last year two students graduated from this program. One of the ME graduates was awarded the Outstanding Scholar Award in the School of Engineering and Technology. Both graduates have positions of responsibility as manufacturing engineers in the Huntsville-Decatur area.

Bibliography/References:


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Ruben Rojas-Oviedo is Chairperson and Associate Professor of the Department of Mechanical Engineering at Alabama A&M University in Huntsville AL. Dr. Rojas-Oviedo has international engineering experience working both in academe and industry. He has an engineering consulting company and conducts applied research. He earned a Ph. D. In Aerospace Engineering from Auburn University, he has two Masters degrees one in Mechanical Engineering from N.C. State at Raleigh and the other in Applied Mathematics from Auburn. He earned a B.S. degree in Aeronautical Engineering from the National Polytechnic Institute – Escuela Superior de Ingenieria Mecanica y Electrica - in Mexico City, Mexico.

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Z.T. Deng is Assistant Professor of the Department of Mechanical Engineering at Alabama A&M University in Huntsville, AL. Dr. Deng has an extensive background and research experience in numerical simulation in particular high speed aerodynamics/flows with heat transfer phenomena. He earned his Ph.D., Aerospace Engineering, University of Tennessee, 1991., and his Bachelor of Science, Aerospace and Mechanical Engineering, from Beijing University of Aeronautics and Astronautics in 1985.

AMIR MOBASHER
Amir Mobasher is Assistant Professor of the Department of Mechanical Engineering at Alabama A&M University in Huntsville, AL. He holds a Ph.D. degree in Mechanical Engineering from University of Alabama in Huntsville. He has research interest in the areas of Computational Fluid Dynamics, Biomechanics, and Control and Automation. His primary area of interest at AAMU is Automation, Control and Fluid Dynamics. He has worked at U.S. Army Aeromedical Research Laboratory at Fort Rucker, Alabama on aircrew protection.

ABDUL JALLOH
A. Jalloh is Assistant Professor of the Department of Mechanical Engineering at Alabama A&M University in Huntsville, AL. Dr. Jalloh earned his Ph.D. in Mechanical Engineering, with a minor in Engineering Mechanics from the University of Arizona, he obtained his M.S. Mechanical Engineering also from the University of Arizona, and he holds a B.Eng. in Mechanical Engineering from University of Sierra Leone. His research interest is in areas of mechanical vibrations, structural dynamics, structural mechanics, applied elasticity, probabilistic design, finite element analysis, manufacturing and reliability.
Appendix 1. List of engineering competencies reviewed.

Teams/Teamwork
Communication
Design for Manufacture
CAD Systems
Professional Ethics
Creative Thinking
Design for Performance
Design for Reliability
Design for Safety
Concurrent Engineering
Sketching/Drawing
Design for Cost
Application of Statistics
Reliability
Geometric Tolerancing
Value Engineering
Design Reviews
Manufacturing Processes
Systems Perspective
Design for Assembly
Design of Experiments
Project Management Tools
Design for Environment
Solid Modeling/Rapid Prototyping
Systems
Design for Ergonomics (Human Factors)
Finite Element Analysis
Physical Testing
Total Quality Management
Design for Service/Repair

Product Testing
Process Improvement Tools
Tools for "Customer Centered" Design
Information Processing
Leadership
Statistical Process Control
Test Equipment
Industrial Design
Design for Commonality-Platform
Computer Integrated Manufacturing
Design Standards (e.g. UL, ASME)
Mechatronics (Mechanisms and Controls)
Testing Standards (e.g. ASTM)
Electro-mechanical Packaging
Conflict Management
Robotics and Automated Assembly
Design for Dis-assembly
Knowledge of the Product Realization
Process
Process Standards (e.g. ISO 9000)
Competitive Analysis
Project Risk Analysis
Budgeting
Manufacturing Floor/Workcell Layout
Bench Marking
Corporate Vision and Product Fit
Materials Planning--Inventory
Business Functions/(Mkt'g, Legal, etc.)

* List from ASME "Integrating the PRP into the Undergraduate Curriculum" 1995.