1st Workshop on U.S. Undergraduate Systems Engineering Programs

Colorado Springs, Colorado
April 7-8, 2010

Workshop Report

Sponsored by

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and
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Workshop Report

Introduction

On April 7 and 8, 2010, more than 60 professionals from academia, government, and industry assembled for a workshop at the United States Air Force Academy (USAFA) in Colorado Springs to examine the state of undergraduate programs in systems engineering (SE) in the United States. The USAFA and the Department of Defense Director of Systems Engineering co-sponsored this first of a kind workshop, which had three goals:

1. Explore the characteristics, successes, and challenges of U.S. bachelor's degree programs in SE
2. Build a sense of community among U.S. faculty who operate undergraduate SE programs in order to facilitate future exchanges of information and willingness to work together to refine and implement the high-level proposals developed by the workshop attendees
3. Develop high-level proposals for how to reinforce the strengths of those programs and address their challenges, increasing their value to students and prospective employers in a way that is practical in today's challenging educational environment

The workshop achieved the first goal. The second goal, of course, is a journey, which began at the workshop. The final goal, which builds on the first two, was also begun, but requires more than the two days allotted to the workshop. However, several key issues that need to be addressed to achieve Goal 3 were identified and next steps to address them are presented in this report.

Summary of the State of Undergraduate Systems Engineering Programs in the United States

Workshop attendees represented 23 universities, 8 companies, and numerous organizations within the Department of Defense. They deliberated for two days. Their insights, conclusions, and recommendations are based on many years of experience (a) creating, leading, and participating in undergraduate SE programs; (b) employing graduates of undergraduate SE programs; and (c) employing engineers who become systems engineers on the job. Based on the information presented and discussed at the workshop and the conclusions drawn by those assembled, the workshop organizers[1]

[1] Dr. Donald Gelosh, Deputy Director Workforce Development in DDR&E Systems Engineering, and Lt Col Paul Lambertson, Director of Systems Engineering at the Air Force Academy, were the General Co-Chairs of the workshop. Dr. Art Pyster, Stevens Institute of Technology, led the Program Committee with the two General Co-

believe the state of U.S. bachelor's degree programs in SE is characterized by the following eight observations:

1. ***Strong Demand.*** Both industry and government have a strong demand for trained, experienced systems engineers, especially those who can think holistically about complex problems, are comfortable with the increasing complexity of systems that address those problems, can manage the uncertainty and complexity of the environment in which those systems are being built, and can respond to demands to shorten the time to deliver systems to the field. Government, government contractors, and those who educate them dominated the workshop population. Hence, the workshop population was not fully representative of the entire U.S. industry and all who might hire systems engineers. Nevertheless, the population was diverse enough to indicate there is a strong demand for trained, experienced systems engineers. However, the demographics of the workshop attendees made it hard to draw conclusions about the real demand for those coming out of undergraduate SE programs. *(Recommendation: Conduct research to understand the demand in both the defense community and the broad U.S. economy for graduates of undergraduate systems engineering programs.)*
2. ***Distinction Lessens Over Time.*** Companies routinely hire engineers with bachelor's degrees in disciplines other than SE and then develop them into systems engineers through a combination of in-house training and on-the-job experience. They also hire engineers with bachelor's degrees in SE, but in far fewer numbers. In either case, new hires are treated as apprentices, not as journeymen or experts. Yet, at the workshop, only a rough picture emerged of how those new hires are deployed and which competencies developed during their undergraduate education are most valued. During the first two years after graduation, the distinction between a SE and a non-SE degree is sharpest. By the end of four years of work experience, when the apprenticeship period is often ending, there is little distinction between engineers who learn SE on the job and those who first learn it as an undergraduate. *(Recommendation: Conduct research to understand the jobs that graduates with a bachelor's degree in SE hold during their apprenticeship period, to understand the competencies valued most by employers during that period, and to understand the relative performance of those with an SE degree and those with an engineering degree other than SE.)*
3. ***Real Engineers.*** Undergraduate SE programs generally produce "real" engineers. Such programs are Accreditation Board for Engineering and Technology (ABET) accredited. The curricula incorporate classical engineering courses in physics, circuits, mathematics, mechanics, chemistry, etc. Graduates of these programs would generally be prepared to sit for the Fundamentals of Engineering Exam required in most states to become certified as Engineers in Training. *(Recommendation: Conduct research to understand how many graduates of SE programs go on to become certified Engineers in Training and eventually certified Professional Engineers. Determine why graduates seek or forgo certification.)*
4. ***Systems vs. Domain Centric.*** There are dozens of undergraduate programs that include the phrase "systems engineering" in their titles. All but 11 do so in combination with other disciplines, most notably industrial engineering, but also biological, computer, and other engineering disciplines. The 11 programs without other disciplines in their titles are called

Chairs. Jim Anthony, Ann Birdsall, Art Cartwright, AnnMarie Choephel, and Dona Lee completed the workshop organizing group.

Systems Centric; the others are called *Domain Centric.*[2] Over the last decade, the number of undergraduate SE programs has mushroomed from 19 to 55. However, virtually all the growth has been in Domain Centric programs. No study has looked in detail at what is being taught in the Domain Centric SE programs to understand the balance between SE and the domain in the programs.[3,4] *(Recommendation: Conduct additional research to understand what SE is being taught in Domain Centric SE programs and where the graduates are being employed.)*

5. ***Distinction Is Fuzzy.*** The distinction between Systems Centric and Domain Centric SE programs is not as sharp as the names imply. Systems Centric programs generally require students to specialize in an application area such as finance, or in an additional discipline such as electrical engineering. The effect is that the Systems Centric programs are often a hybrid of a "pure" program in systems engineering and a Domain Centric program. *(Recommendation: Hold a workshop to sharpen the understanding of the similarities and differences between Systems Centric and Domain Centric SE programs.)*
6. ***Industrial vs. Systems Engineering.*** The distinction between Industrial Engineering and Systems Engineering is unclear. As an example, the Industrial and Systems Engineering Department website at Texas A&M University states "Industrial engineers deal with **systems**. They can design, implement or improve integrated systems comprised of people, materials, information or energy." This sounds remarkably similar to what can be found on the Systems Engineering and Operations Research Department website at George Mason University: "Systems Engineers determine the most effective ways for an organization to use all of a given system's components -- people, machines, materials, information, and energy. Systems engineers plan, design, implement and manage complex systems that assure performance, safety, reliability, maintainability at reasonable cost and delivered on time." *(Recommendation: Hold a workshop to sharpen the understanding of the similarities and differences between Industrial Engineering and SE.)*
7. ***Top Four Challenges.*** The top four challenges for successful undergraduate SE programs are: (a) understanding and meeting customers' needs within curriculum constraints, (b) sustaining technical and societal relevance, (c) incorporating sufficient real-world problem solving into the curriculum, and (d) identity-communications-community of practice. For example, the third challenge may be manifested in having a sufficient number of strong senior design projects that are sponsored by companies and that have the right complexity and scale. The fourth challenge may be manifested in the lack of visibility many students have in SE or their failure to appreciate the importance of SE, making it hard to recruit them into SE programs. *(Recommendation: Hold a workshop to elaborate more fully on these challenges and develop a sharper roadmap to address them.)*
8. ***Program Offices Are No Different.*** The undergraduate educational requirements for systems engineers who will work in U.S. government program offices are quite similar to those

[2] Fabrycky, W.J., "Systems Engineering: Its Emerging Academic and Professional Attributes," the Proceedings of the 2010 American Society for Engineering Education Conference and Exposition, Lexington, KY, June 20-23, 2010.

[3] Brown, D. E. & Scherer, W. T. (2000). A comparison of Systems Engineering Programs in the United States. Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 30(2), 204-212.

[4] Squires, A. (2010) DRAFT: Measuring the Value of Remote Online Systems Engineering Education, PhD Dissertation, Stevens Institute of Technology.

who graduate from a “typical” Systems Centric SE program; e.g., the graduates should first be an engineer, then be a systems engineer, as described in point 3, *Real Engineers.* They should be educated in systems analysis, requirements management, life cycle choices, trade-off analysis, and other concepts typically taught in Systems Centric SE programs.

The eight observations above include a number of recommendations. Those recommendations are elaborated in the final section of this report together with a proposal that a second workshop on U.S. undergraduate systems engineering programs be held in spring 2011.

Workshop Structure

The workshop was divided into three main parts. Part I, which took place on the morning of the first day, set the stage for the rest of the workshop by offering keynote perspectives from industry, government, and academia on the need for systems engineers and how universities are responding to that need. Part II, held during the rest of the first day, offered three panels in plenary session, each addressing a different specific question. These panels built on the themes presented earlier by the keynote speakers. During Part III on the second day, each workshop participant joined one of four breakout sessions to examine a specific question and provide recommendations to the entire workshop body. Those four breakout sessions built on the insights from the panels and keynote addresses.

Part I. Stage Setting

The four speakers were:

1. Mr. Stephen Welby, *Director, Systems Engineering, Defense Research and Engineering*, who described the Department of Defense’s need for systems engineers
2. Mr. Charles Toups, *Vice President and General Manager, Network and Tactical Systems, Boeing Network and Space Systems,* on what industry looks for from entry-level systems engineers and how those systems engineers are used during the first four years after being hired
3. Lt Col Paul Lambertson, *Director, Systems Engineering, USAFA,* who described the Academy’s systems engineering program – its history, its successes, its challenges, and its future.
4. Dr. Art Pyster*, Distinguished Research Professor, Stevens Institute of Technology,* described the Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE^{TM}) Project and an analysis of U.S. undergraduate programs in systems engineering

The full set of viewgraphs used by all four keynote speakers are in Appendices A-E of this report.

Stephen Welby

Mr. Welby’s five key points were:

- The U.S. military must field new capabilities much more rapidly than in the past to counter new and emerging threats. Systems engineering plays a key role in speeding up such fielding.
- The Administration and the Congress both strongly encourage more effective systems engineering as evidenced by the Weapon Systems Acquisition Reform Act of 2009.
- Four key challenges: (a) create the tools to enable rapid capability delivery; (b) expand the aperture of SE to address 21st century technical challenges; (c) embrace complexity; and (d) expand the SE human capital resource base.

- Systems engineers need to have breadth (understand system life cycle and processes, know product domains, …), depth (extensive expertise and experience in one or more engineering disciplines and one or more product domains), and leadership skills (comfort in dealing with complexity, capability to make tough technical decisions, …)
- Undergraduate engineering programs should prepare people to be systems thinkers (understand the role of the system in its operational context, think holistically about complex systems, …)

He listed five key issues for undergraduate SE education:

- What are the critical educational requirements for entry-level systems engineers?
- What is the real market, in both government and industry, for undergraduate systems engineers?
- What is the proper mix of classical engineering instruction and application domain focus in a bachelor's degree in SE?
- Is the undergraduate curriculum a zero-sum game – and if so, what do we displace with SE coursework and related projects?
- Is a bachelor-level SE degree appropriate and effective as a terminal degree?

The workshop directly discussed these five key issues as evidenced in the breakout session summaries in Appendices F-I.

Mr. Welby also cited four challenges to the workshop:

- Is a bachelor-level SE degree an adequate replacement for a degree in a traditional engineering discipline?
- What is the correct body of knowledge for entry-level SE and how should it be delivered?
- How can we develop better instructional materials to support modern SE education?
- What can we do to enable and promote the acceleration of experience for systems engineers?

The workshop considered the first, second, and third challenges as evidenced in the other keynote presentations and in the breakout session summaries. However, the fourth challenge did not receive significant attention.

Charles Toups

Mr. Toups' key points were:

- Boeing has a strong need for young systems engineers.
- Boeing has an in-house development program for systems engineers in which new employees (a) complete an in-house SE overview course, (b) learn the career roadmap and select specific SE skills of interest; (c) review the technical competencies required for the chosen SE skills; (d) obtain the necessary training; (e) obtain the necessary on-the-job experience, including through a mentoring program; and (f) pursue a graduate degree in SE

Paul Lambertson

Lt Col Lambertson's key points were:

- The SE program at the USAFA places a strong emphasis on classical engineering foundation such as chemistry, electrical circuits, physics, and differential equations.
- All new engineers (not just systems engineers) take ten introductory engineering courses and six basic science courses.
- There are seven major concentrations for SE, including electrical, computer, and aeronautical systems.
- Of the 47 academic courses that the USAFA aeronautical engineering curriculum requires, 41 are required for SE with the remaining six advanced aeronautical engineering classes replaced with six SE courses, including an introduction to SE, project management, and introduction to human factors.
- The USAFA develops officers capable of systems thinking who can use introductory SE processes and tools
- With strong institutional focus and support, USAFA SE program achieved full six-year ABET accreditation the first time USAFA sought SE accreditation.

Art Pyster

Dr. Pyster presented two related talks – the first on the BKCASE Project, the second on a study of undergraduate SE programs. Dr. Pyster's key points for BKCASE were:

- BKCASE is a large community project, global in reach, that will produce what is expected to be the authoritative body of knowledge in SE and a reference curriculum for SE master's programs
- BKCASE is supported by the Department of Defense, the International Council on Systems Engineering (INCOSE), the Institute for Electrical and Electronics Engineers (IEEE), the Association for Computing Machinery (ACM), and the National Defense Industrial Association (NDIA) Systems Engineering Division.
- The body of knowledge and reference curriculum are being delivered in three iterations, with the first iteration due later in 2010. All versions will be freely available on the Internet (www.bkcase.org).

Dr. Pyster's key points for the study of undergraduate SE programs were:

- There has been a healthy growth in the number of U.S. SE programs at both the undergraduate and graduate levels.
- There are two broad types of programs: *Systems Centric*, where the concentration is designated as SE; where SE is the intended major area; and *Domain Centric,* where SE education and training are integrated into the teaching of another engineering discipline such as biological engineering or industrial engineering.
- Nearly all the growth in undergraduate SE programs is in Domain Centric programs.
- Survey of 15 undergraduate SE programs revealed some common practices including ABET accreditation, required capstone course, optional internship program, small number of tenure/tenure-track faculty, much employment by government and government contractors. Small sample size could skew reported findings.
- There were few common strengths or weaknesses cited among undergraduate SE programs.

Part II. Panel Discussions

Part II, held on the afternoon of the first day, included three panel sessions, each addressing a different question:

1. What are the best practices in teaching systems engineering to undergraduates?

   Systems engineering is about getting requirements right, deciding the right life cycle model, understanding customer needs, ensuring the right blend of specialty engineers are working together, and a myriad of other activities, often conducted with teams that are geographically distributed and working for multiple organizations. What are the best practices used to teach undergraduates about these many activities given the limitations in the experiences of a typical undergraduate?

   Panelists: Michael Smith (chair), Drew Hamilton, Seshadri Mohan, Armen Zakarian

2. Should systems engineering degrees only be offered at the graduate level?

   The sheer existence of undergraduate degree programs in systems engineering is controversial. Because systems engineering is inherently multidisciplinary and requires many complex judgments, some academics and practicing professionals believe that anyone should first practice one or more specialized engineering disciplines for several years before *earning any SE degree. Those academics and practitioners believe that systems engineering degrees and certificates should be offered only at the graduate level. Yet this workshop is bringing together many successful offerers of undergraduate systems engineering degree programs. How can those two views be reconciled?*

   Panelists: Dinesh Verma (chair), Dennis Barnabe, Thomas Mazzuchi, Timothy Trainor, Brian Wells

3. How much classical engineering and domain focus should be in a bachelor's degree in systems engineering?

   A classical undergraduate engineering degree is highly structured with few electives. Students usually have a common focus in the first two years on mathematics, design, chemistry, mechanics, electronics, and physics, somewhat independent of their engineering specialty. The last two years typically focus on advanced topics and team projects within the engineering specialty. Should students earning a bachelor's degree in systems engineering have their program structured much as a classic engineering undergraduate? Should they learn about systems engineering in the context of another engineering discipline such as industrial, chemical or biological engineering? Should students learn about systems engineering in the context of a particular application domain such as finance, telecommunications, or naval weapons systems?

   Panelists: Don Taylor (chair), Paul Coffman, Brian Gallagher, Brett Peters, Ariela Sofer

All of these panel discussions directly fed the breakout sessions that were held on the second day of the workshop.

Part III. Breakout Sessions

On the second day, four breakout sessions took on different questions:

1. What are the primary undergraduate education requirements for SE personnel in government program offices?

2. What are the top five challenges to successful bachelor's degree programs in SE and how should those challenges be addressed?
3. Within the first ~~four~~ two years after graduation, what should someone with a bachelor's degree program in SE know and be capable of doing on the job? (The original question asked the group to explore a four-year timeframe. The group decided it was more important to explore the first two years after graduation.)
4. How much classical engineering (general, industrial, mechanical, electrical, etc.) and application domain focus (telecommunications, naval, medical, etc.) should be in a bachelor's degree in SE?

Each workshop attendee participated in a morning breakout session to answer its assigned question. In the afternoon, the leader of each breakout session reported to the entire workshop assembled in plenary. Appendices F-I provide details of each breakout session.

Next Steps

Throughout the workshop, participant energy was high and interaction was excellent. The workshop organizers could detect that Goal 2, building a sense of community among the faculty responsible for undergraduate SE programs, had begun. Reflecting the high participant energy at the end of the workshop, the closing discussions focused on next steps. Each of the recommended follow-on actions was discussed at the workshop, but only in a very abbreviated and nascent form. The workshop organizers fleshed out these proposed actions after the workshop ended. Also, after the workshop ended, the leaders of the four breakout sessions produced the summaries found in Appendices F-I. Those summaries contributed substantially toward the observations stated earlier in this report and the following actions.

Action 1. *The Second Workshop on U.S. Undergraduate Systems Engineering Programs* should be held in Spring 2011. The workshop should be somewhat larger than the first one, ranging up to 100 people with the explicit goal of adding more industrial participation outside the defense/aerospace sectors and adding more representation from DoD program offices and product center chief engineers. An East Coast civilian university should host the workshop, which will attract some different participants and help foster additional perspectives. The workshop agenda should directly address one or more of the recommendations cited above in the section on *The State of U.S. Systems Engineering Bachelor's Degree Programs*; e.g., holding a special session at the workshop to sharpen the understanding of the similarities and differences between Industrial Engineering and SE.

Action 2. A research project should be conducted to carry out the recommendation made as a result of observation 1, *Strong Demand;* i.e., conduct research to understand the demand in both the defense community and the broad U.S. economy *for graduates of undergraduate systems engineering programs*.

Action 3. A research project should be conducted to carry out the recommendation made as a result of observation 2, *Distinction Lessens Over Time*; i.e., conduct research to understand the jobs that graduates with a bachelor's degree in SE hold during their apprenticeship period, to understand the competencies valued most by employers during that period, and to understand the relative performance of those with an SE degree and those with an engineering degree other than SE.

Action 4. A research project should be conducted to carry out the recommendation made as a result of observation 3, *Real Engineers;* i.e., conduct research to understand how many graduates of SE programs go onto become certified Engineers in Training and eventually certified Professional Engineers. That research should determine why graduates seek or forgo certification.

Action 5. A research project should be conducted to carry out the recommendation made as a result of observation 4, *Systems vs. Domain Centric;* i.e., conduct additional research to understand what SE is being taught in Domain Centric SE programs and where the graduates are being employed.

Action 6. A workshop should be conducted to carry out the recommendation made as a result of observation 5, *Distinction Is Fuzzy*; i.e., hold a workshop to sharpen the understanding of the similarities and differences between Systems Centric and Domain Centric SE programs.

Action 7. A research project should be conducted to carry out the recommendation made as a result of observation 6, *Industrial vs. Systems Engineering;* i.e., hold a workshop to sharpen the understanding of the similarities and differences between Industrial Engineering and SE.

Action 8. In Fall 2010, a workshop should be held focused just on the undergraduate SE programs of the military service academies. This workshop should validate whether observation 7, *Top Four Challenges,* is correct for the Service academies, or modify them as appropriate. The workshop should further develop specific strategies and actions to be taken to address those challenges.

Appendix A

Perspectives and Challenges for Undergraduate Programs in Systems Engineering

Slides Presented During a Keynote Address by Stephen Welby, Director, Systems Engineering, Office of the Secretary of Defense

Perspectives and Challenges for Undergraduate Programs in Systems Engineering

7 April 2010

Stephen Welby

Director, Systems Engineering

Office of the Secretary of Defense

Department of Defense

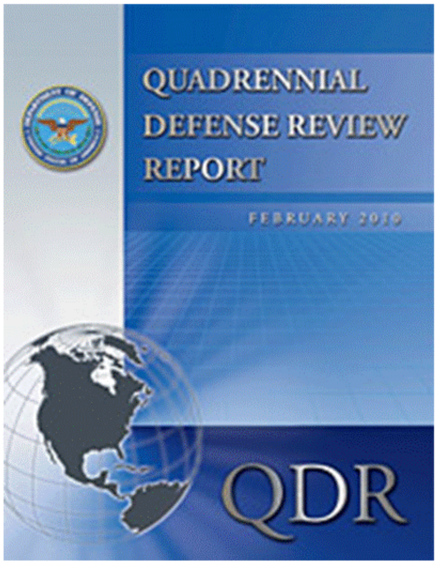
DISTRIBUTION STATEMENT A -- Cleared for public release by OSR on 5 Apr 2010 -- SR case number 10-S-1547 refers.

Key DoD Themes

1. Take care of our people
2. Rebalancing the Military
3. Reforming what and how we buy
4. Supporting our troops in the field

Secretary of Defense
HASC Budget Rollout Brief
February 2010

Rebalance the Force
2010 Quadrennial Defense Review

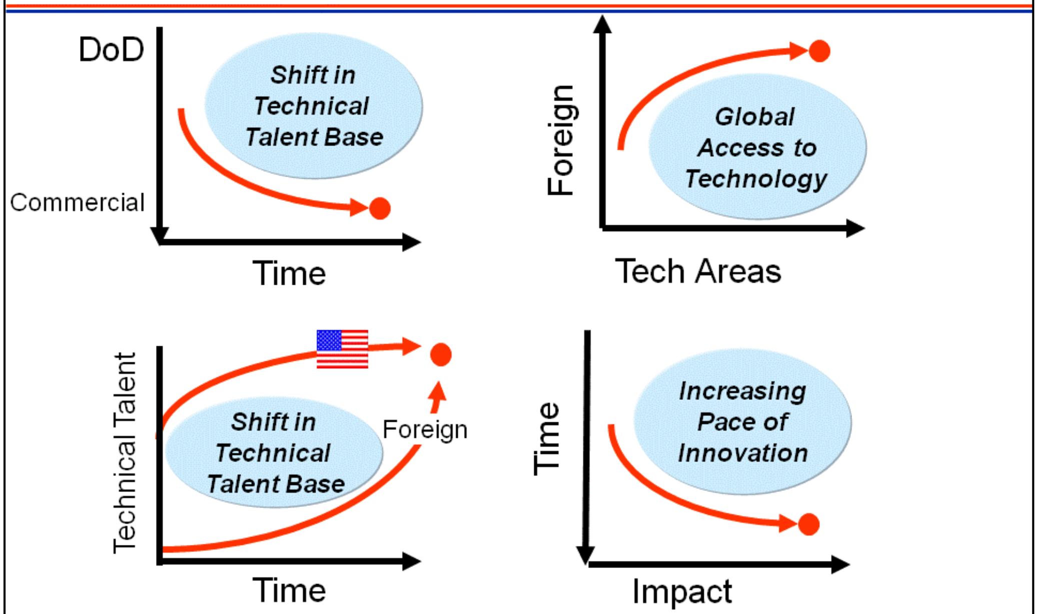


1. **Defend the United States and Support Civil Authorities at Home**
2. **Succeed in Counterinsurgency, Stability, and Counterterrorism Operations**
3. **Build the Security Capacity of Partner States**
4. **Deter and Defeat Aggression in Anti-Access Environments**
5. **Prevent Proliferation and Counter Weapons of Mass Destruction**
6. **Operate Effectively in Cyberspace**

Our Guidance

- **Quadrennial Defense Review Executive Summary, February 2010**
  - *Further rebalance the capabilities of America's Armed Forces to prevail in today's wars, while building the capabilities needed to deal with future threats*
  - *Further reform the Department's institutions and processes to better support the current needs of the warfighter; buy weapons that are usable, affordable and truly needed; and ensure that taxpayer dollars are spent wisely and responsibly*
  - *Preserve and enhance the All-Volunteer Force*
  - *Improve how it matches requirements with mature technologies, maintains disciplined systems engineering approaches, institutionalizes rapid acquisition capabilities, and implements more comprehensive testing*
- **Quadrennial Defense Review Report Preface**
  Secretary of Defense Robert M. Gates, February 2010
  - *United States needs a broad portfolio of military capabilities with maximum versatility across the widest possible spectrum of conflict*

Key Challenges to our Technical Base



DISTRIBUTION STATEMENT A -- Cleared for public release by OSR on 5 Apr 2010 -- SR case number 10-S-1547 refers.

Perspective for the Next Decade

1950 1960 1970 1980 1990 2000 2010 2020

National Security Challenges

Cold War

Vietnam War

Collapse of Soviet Union

Desert Storm

Bosnia

Kosovo

OIF

OEF

Irregular/Hybrid Warfare

Defense Capabilities

ICBM

Satellite comms

LGB's

GPS

Nuclear propulsion

C4ISR

Stealth

Precision Strike

UAV

Robotics

Night Vision

Human Terrain
Ubiquitous Observation
Contextual Exploitation
Scaleable Action

Enabling Technologies

Transistor

Solid state laser

Space tracking

Digital computing

Composite Materials

MEMS

Superconductors

Web protocols

VHSIC

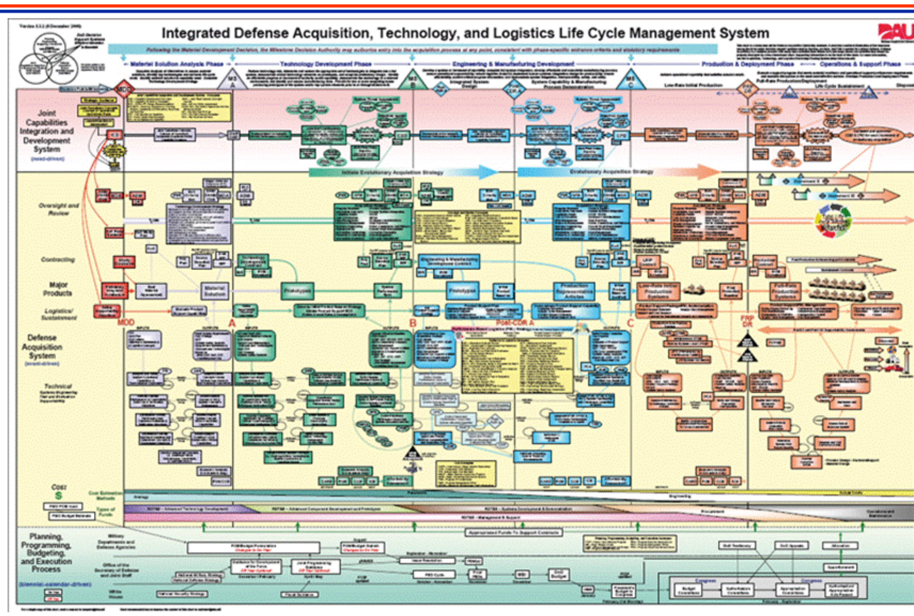
MIMIC

IR Sensors

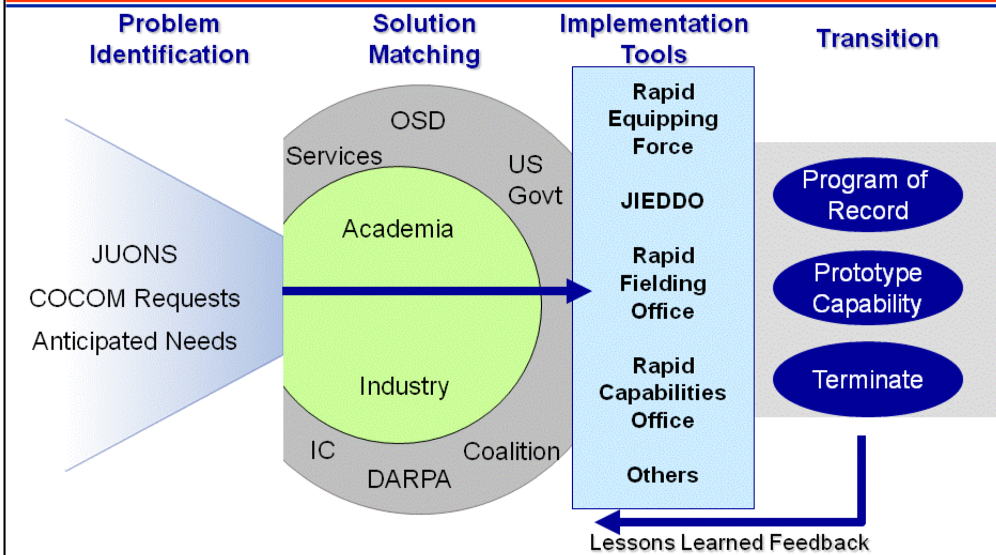
High Performance Computing

- Advanced Electronics, Photonics Algorithms, MEMS
- Nano; Meta; & New Materials
- Cognitive Computing
- Bio-Revolution

The DoD 5000.02 Process



The Challenge of Rapid Fielding



Role of Systems Engineering in Rapid Fielding?

Support for Change

Weapon Systems Acquisition Reform Act of 2009 (Public Law 111-23)

- Establishes *Director, Systems Engineering* as principal systems engineering advisor to the SECDEF and the USD(AT&L)
- Requires Congressional reporting on Systems Engineering Capabilities and MDAP achievement of measurable performance criteria
- WSARA signed into law 22 May 2009
- Director, Systems Engineering on board 21 Sep 2009
- Implementing DTM signed by USD(AT&L) 4 Dec 2009; Acquisition Guidance on-line 31 Jan 2010
- DoD Directive formalizing responsibilities of Director, Systems Engineering in development
- First annual WSARA SE / DT&E Joint Report delivered to Congress 31 Mar 2010

President Barack Obama hands a pen to U.S. Rep. Robert Andrews (D-NJ) as he signs the Weapons Systems Acquisition Reform Act in the Rose Garden at the White House Friday, May 22, 2009. Standing from left are: Andrews, Rep. John McHugh (R-NY), Sen. Carl Levin (D-MI), Rep. Ike Skelton (D-MO) and Rep. Mike Conaway (R-TX). Official White House Photo by Samantha Appleton

MDAP - Major Defense Acquisition Program (USC 2430)

Systems Engineering Mission

- **We execute substantive technical engagement throughout the acquisition life cycle with major and selected acquisition efforts across DoD**
- **We apply best engineering practices to:**
  - **Help program managers identify and mitigate risks**
  - **Shape technical planning and management**
  - **Support and advocate for DoD Component initiatives**
  - **Provide technical insight to OSD stakeholders**
  - **Identify systemic issues for resolution above the program level**
  - **Support Knowledge Based Decision Making**

We are the "E" in DDR&E

Director, Systems Engineering

Director, Systems Engineering
Stephen Welby

Terry Jaggers, Principal Deputy

Systems Analysis Kristen Baldwin	Major Program Support James Thompson	Mission Assurance Nicholas Torelli
Addressing Emerging Challenges on the Frontiers of Systems Engineering	**Supporting USD(AT&L) Decisions with Independent Engineering Expertise**	**Leading Systems Engineering Practice in DoD and Industry**
Analysis of Complex Systems/Systems of Systems Development Planning/Early SE Program Protection/Acquisition Cyber Security University and Industrial Engineering Research	Engineering Assessment / Mentoring of Major Defense Programs Program Support Reviews OIPT / DAB / ITAB Support Systems Engineering Plans Systemic Root Cause Analysis	Systems Engineering Policy, Guidance, and Standards Specialty Engineering (System Safety, Reliability / Availability / Maintainability, Quality, Manufacturing, Producibility, Human Systems Integration (HSI)) Technical Workforce Development

Providing technical support and systems engineering leadership and oversight to USD(AT&L) in support of planned and ongoing acquisition programs

Systems Engineering Contributions to Acquisition

- Systems-level technical leadership
- Risk identification and management
- Interface management
- Life cycle focus
- Robust exploration of the need
- Achievable system design
- Integration of technical disciplines

SE Research Needs

- Flexible system design
  - Agile systems/products/architectures
  - Flexible systems engineering processes and methods
  - Capture agility, adaptability, responsiveness as design attributes
- Education and Workforce accelerants: at individual, corporate and national levels
- Early systems engineering and development planning
  - Melding of ops requirements with early systems engineering to highlight promising technical solutions: the "art of the possible"
- Engineering System of Systems
  - Addressing the challenge of complexity

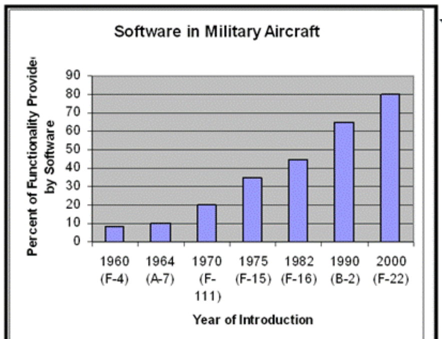
Challenges Ahead

- **Create the tools to enable Rapid Capability Delivery**
  - Shorten the time to deliver life-saving and war-winning technologies – without compromising SE integrity
- **Expand the aperture of SE to address 21st century technical challenges**
  - Security, software-intensive, etc…
- **Embrace complexity**
  - Systems of Systems / Complex Adaptive Systems / Emergent behaviors
- **Expand the SE human capital resource base**
  - Reflect new insights in curricula to grow the next "crop" of SE

Systems 2020

NEW INTELLIGENT TOOLS & APPROACHES

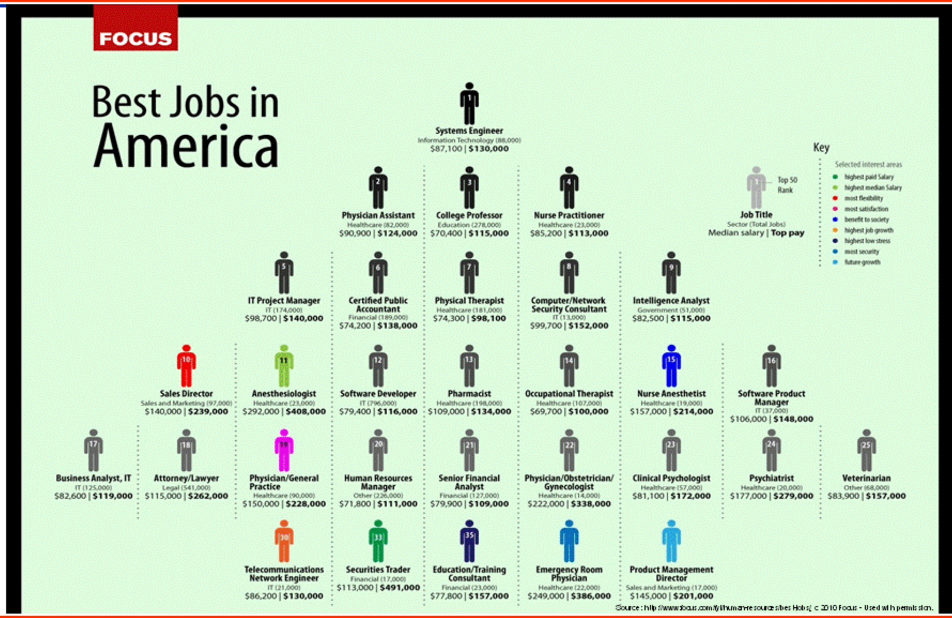
- Engineering Design
- Test
- Construction



"Crouching Dragon, Hidden Software: Software in DoD Weapon Systems", Jack Ferguson, IEEE Software, vol. 18, no. 4, pp.105-107, Jul/Aug, 2001.

- Trusted
- Assured
- Reliable
- Interoperable

Systems Engineer - The Best Job in America?



Source : http://www.focus.com/fyi/human-resources/best-jobs/ c 2010 Focus - Used with permission.

What Are Our Expectations of Our Systems Engineering Workforce?

- **Breadth**
  - Awareness of and appreciation for other functional areas,
  - Understanding of the system lifecycle and processes
  - Knowledge of other engineering disciplines and how they integrate into the system solution
  - Knowledge of product domains
- **Depth**
  - Extensive expertise and experience in one or more engineering disciplines and in one or more product domains
- **Leadership**
  - Ability to motivate and inspire individuals and teams
  - Comfort in dealing with complexity
  - Focused on underpinning decisions with data
  - Capability to make tough technical decisions

Systems Thinking in Undergraduate Engineering

- **Preparing students to:**
  - Think holistically about complex problems
  - Understand the role of the system in its operational context
  - Understand the parts of the system in the larger context of the system
  - Understand both the interactive nature of the system and the role of feedback in the system
  - Understand the impact of changes to the system and how system behavior can evolve over time
  - Understand common models of life-cycle capability delivery: conceptualization, requirements definition, design, development, production, deployment, operation and retirement
  - Appreciate the societal context in which we deliver capability: economic efficiency, environmental stewardship, and safety of life and property

Undergraduate Systems Engineering Issues

- **What are the critical educational requirements for entry-level Systems Engineers?**
- **What is the real market, in both government and industry, for undergraduate systems engineers?**
- **What is the proper mix of classical engineering instruction and application domain focus in a bachelor's degree in systems engineering?**
- **Is the undergraduate curriculum a zero-sum game – and if so what do we displace with systems engineering coursework and related projects?**
- **Is a Bachelors-level systems engineering appropriate and effective as a terminal degree?**

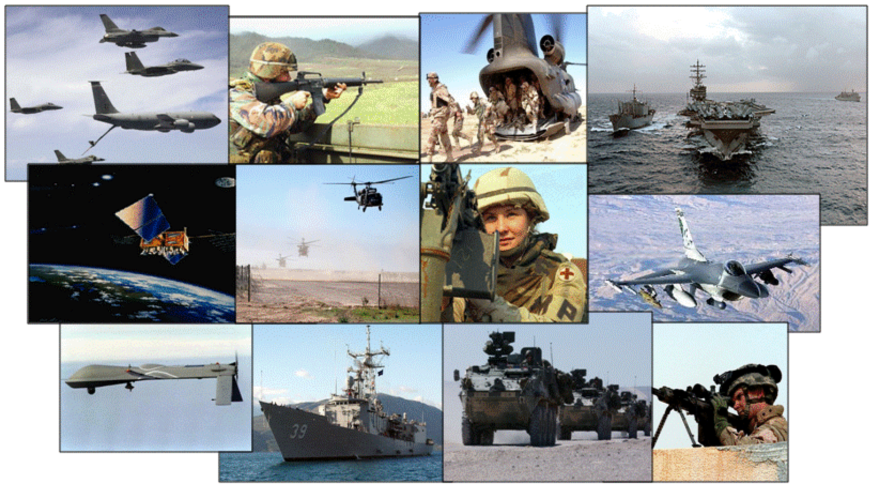
Challenges to this Workshop

- **Is a Bachelors-level Systems Engineering an adequate replacement for a degree in a traditional engineering discipline?**
  - What is gained and what is lost?
  - What is the role of working experience in developing effective system engineers?
  - Should Systems Engineering only be offered as a graduate level specialization?
- **What is the correct Body of Knowledge for entry-level Systems Engineering and how should it be delivered?**
- **How can we develop better instructional materials to support modern Systems Engineering education?**
- **What can we do to enable and promote the acceleration of experience for Systems Engineers?**

Opportunities

- **Acquisition reform efforts have recognized criticality of strong Systems Engineering focus for program success**
  - ***Systems Engineering toolkit focused on identifying and managing risk – development risk, production risk and life-cycle***
- **Growing focus on addressing "early-acquisition" phases - requirements definition, development planning, and early acquisition systems engineering support**
  - ***Leading to more informed decisions at MS B***
- **Our development processes need to evolve to provide faster product cycles, more adaptable products and address emerging challenges**
- **Future US Defense capabilities depend on a capable US engineering workforce in and out of government**
  - ***Need to create opportunities to grow future "Engineering Heroes"***

Systems Engineering: Critical to Program Success



Innovation, Speed and Agility

Appendix B

The Boeing Company: Developing Our Systems Engineers

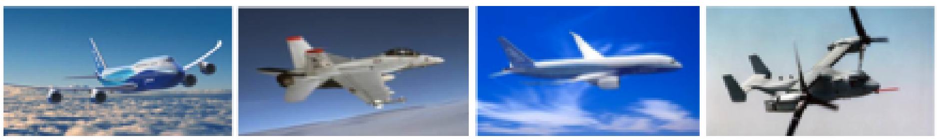
Slides Presented During a Keynote Address by Charles Toups, Vice President and General Manager of Network and Tactical Systems, The Boeing Company

BOEING

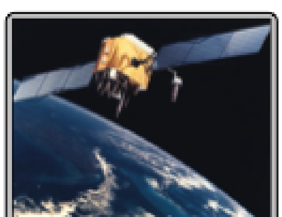
The Boeing Company

Developing Our Systems Engineers

Charles Toups
VP/GM Network & Tactical Systems



Complex Products In A Changing World



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www.boeing.com/vision

Vision 2016

People working together as a global enterprise for aerospace leadership

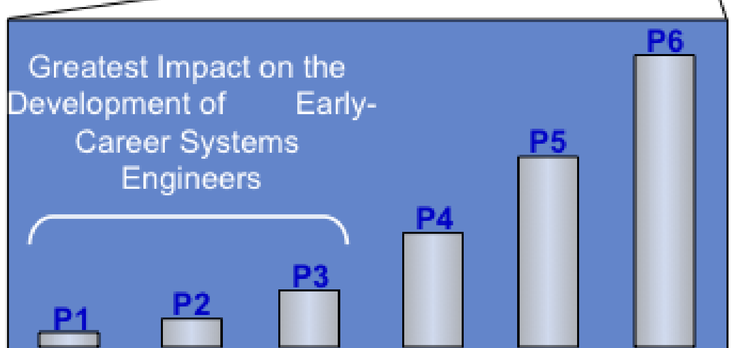
Strategies
- Run healthy core businesses
- Leverage strengths into new products and services
- Open new frontiers

Core competencies
- Detailed customer knowledge and focus
- Large-scale systems integration
- Lean enterprise

Values
- Leadership
- Integrity
- Quality
- Customer satisfaction
- People working together
- A diverse and involved team
- Good corporate citizenship
- Enhancing shareholder value

Boeing Systems Engineering Development

Occupation	Discipline	Job Family	Job Family Level	Skill Code
Engineering (6)	Systems Engineering (K)	Systems Engineering Engineer (8C)	P1-P6	16 Choices



	P1	P2	P3	P4	P5	P6
Bachelors	0	2	5	9	14	20
Masters	-	0	3	7	12	18
Doctorate	-	-	0	4	9	15

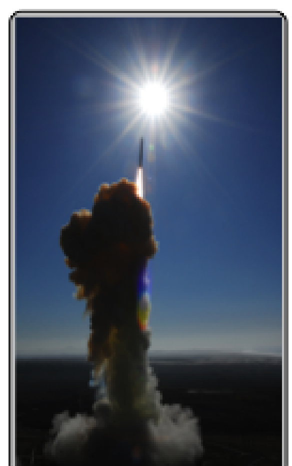
Undergraduate Systems Engineer Development

1. Complete Systems Engineering (SE) overview course
2. Develop understanding of SE Career Roadmap and select SE skill of interest
3. Review the technical competencies required for the SE skill chosen
4. Review Boeing training mapped to the SE skill chosen
5. Establish training curriculum with manager
6. Attend training courses per curriculum
7. Gain on the job experience
   a. Sign up for a Rotation Program
   b. Join the Boeing Mentor Program
8. Pursue a graduate degree in SE

Dynamic and Flexible SE Development Options

Embedding Systems Thinking

- All new engineers take a Systems Engineering course that answers the following questions:
  - **What is systems engineering?**
  - **How does SE impact me?**
  - **How and when do I apply SE principles?**
  - **How do my activities fit into the larger SE picture?**
  - **Where can I go for more information and help?**



Setting Clear SE Expectations Across the Boeing Enterprise

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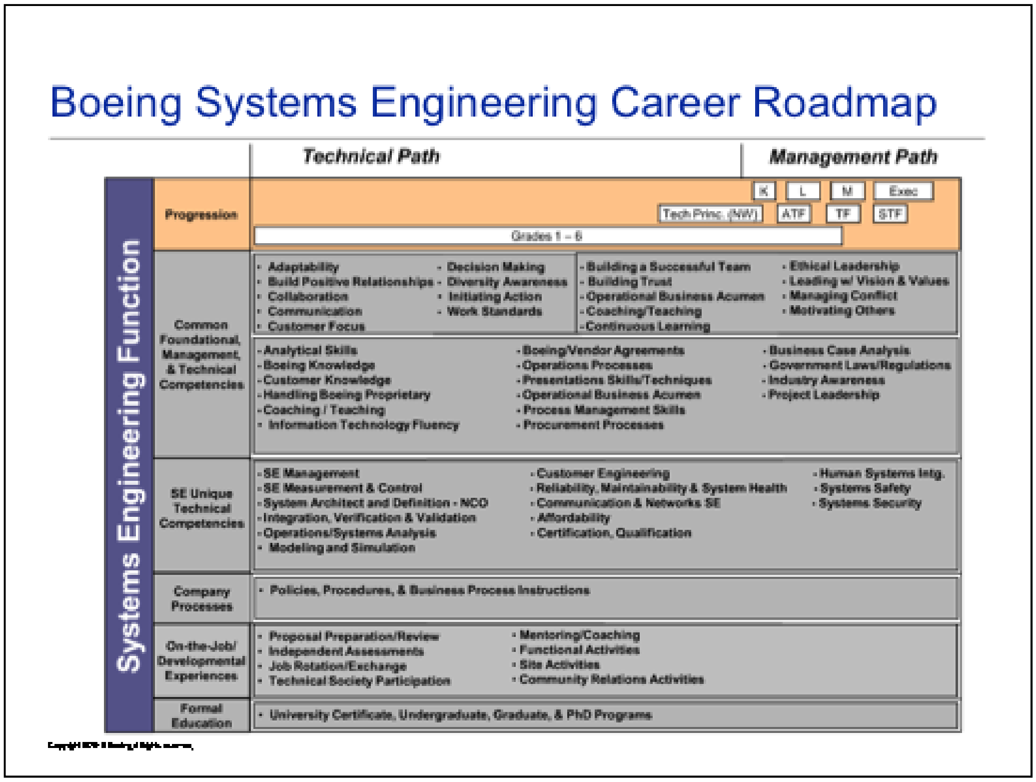

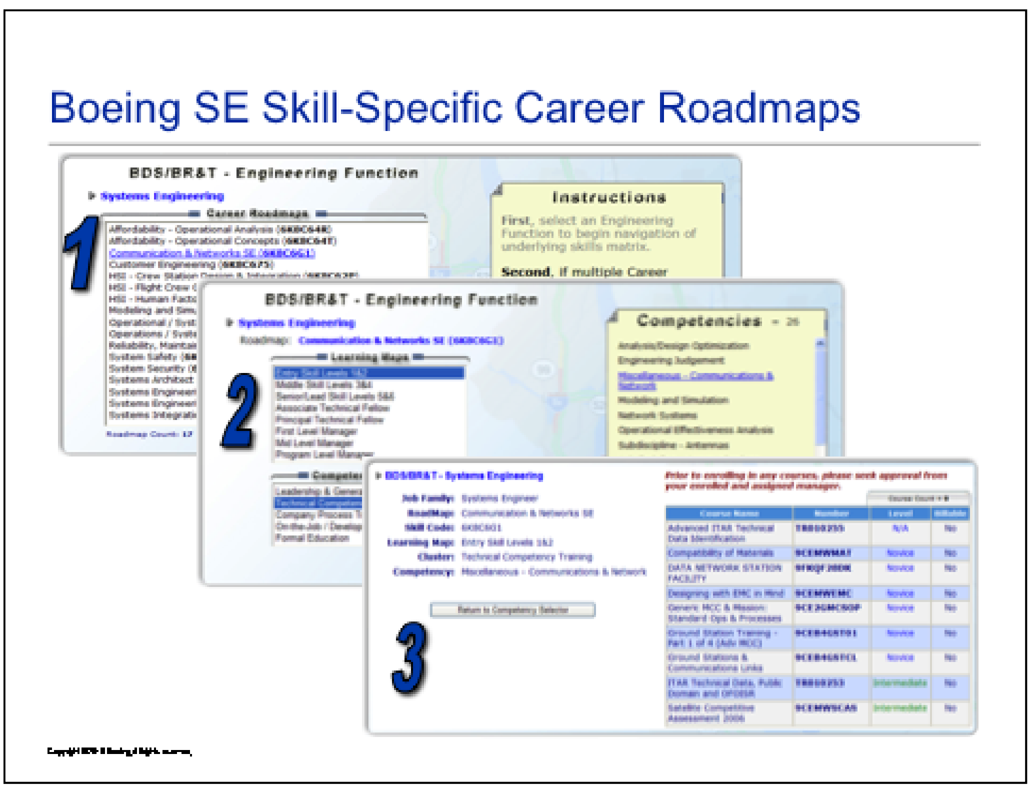

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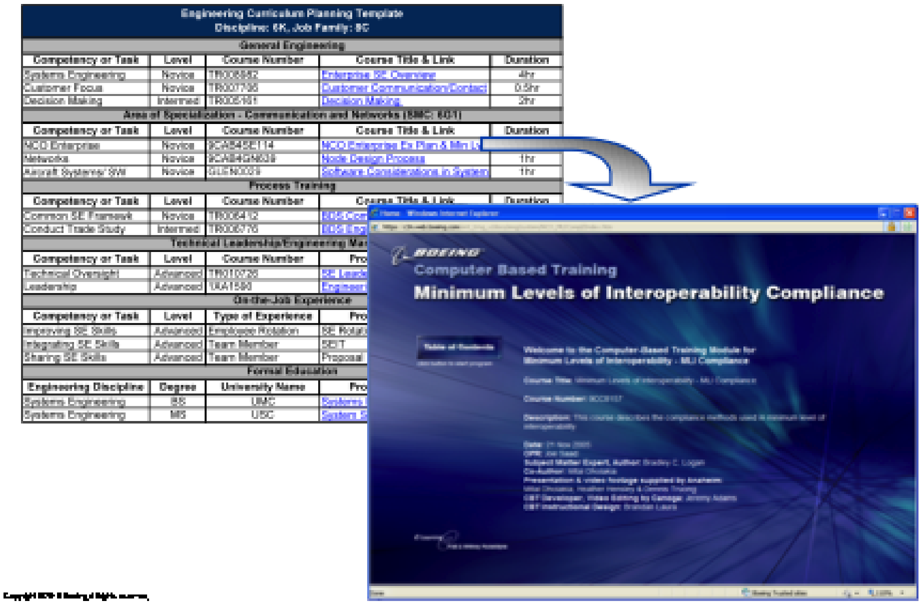
Establish Plan and Complete Training



Undergraduate Systems Engineer Development

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   a. Sign up for a Rotation Program
   b. Join the Boeing Mentor Program
8. Pursue a graduate degree in SE

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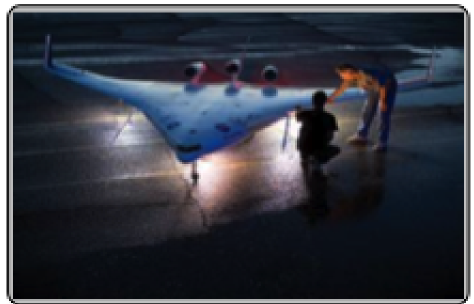
Thank you

- Developing Systems Engineers is critical to:
  – Boeing
  – Industry
  – Our Nation
- This is a great new forum and we need you to be successful!



Systems Engineers Solve Society's Most Demanding Problems

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Appendix C

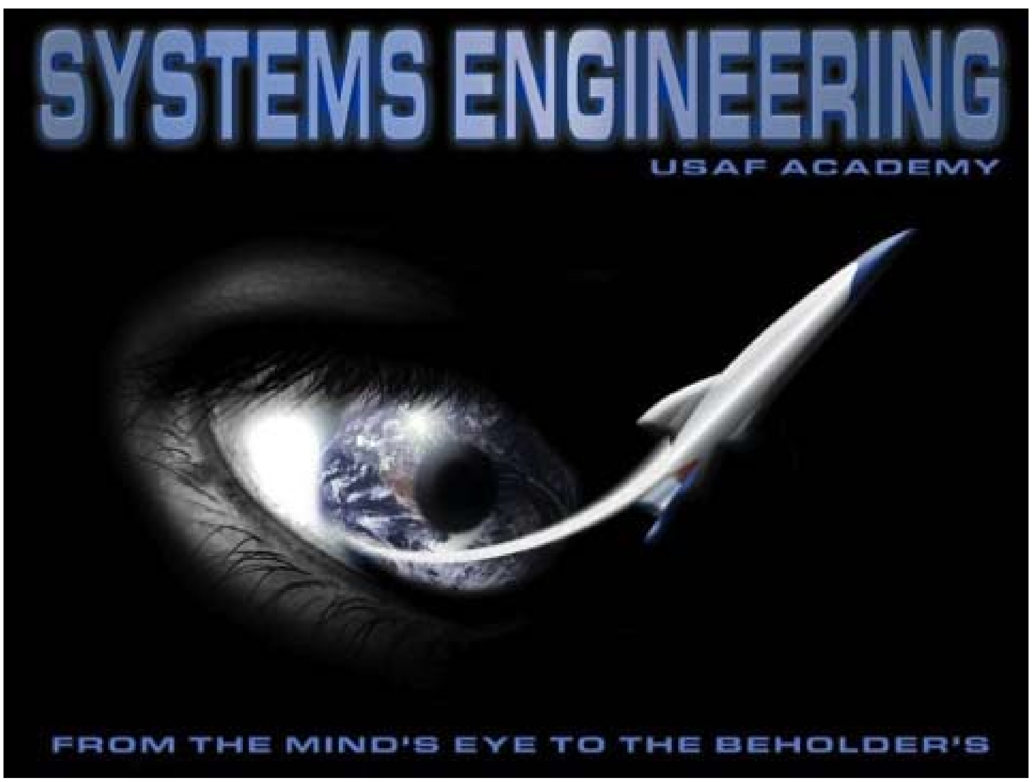
The United States Air Force Academy Systems Engineering

Slides Presented During a Keynote Address by Lt Col Paul Lambertson, Director, Systems Engineering, U.S. Air Force Academy

Integrity - Service - Excellence

The United States Air Force Academy
Systems Engineering

Lieutenant Colonel Paul Lambertson
Director, Systems Engineering



Purpose

- To inform on the history, challenges and successes in developing the United States Air Force Academy's Systems Engineering program

Integrity – Service – Excellence

What is USAFA sE

- USAFA Systems Engineering = sE

  "s" => systems engineering processes and tools
  laid upon a firm
  "E" => classical engineering foundation

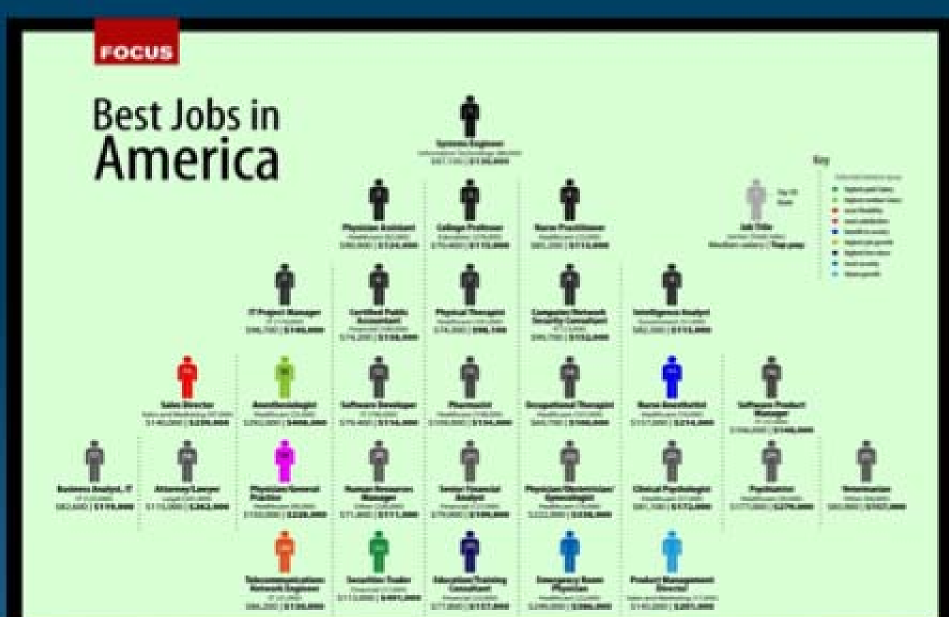
- sE major has seven concentrations
  - sE-Aeronautical Systems
  - sE-Computer Systems
  - sE-Electrical Systems
  - sE-Human Systems
  - sE-Information Systems
  - sE-Mechanical Systems
  - sE-Space Systems

Integrity – Service – Excellence

sE Mission

- To develop officers…leaders…of character capable of systems thinking utilizing introductory systems engineering processes and tools

Integrity – Service – Excellence



HISTORY

sE Program Genesis

- The USAF desperately needs…"airmen and a vibrant civilian workforce with science, technology and *systems engineering skills*"
- "Then, at the suggestion of John Jumper (USAF Chief-of-Staff), we are creating a major at the U.S. Air Force Academy in systems engineering – *not to raise systems engineers* but to make sure that our future pilots, the officers in our air operations centers, battle managers and many others, *think in systems engineering terms*. Because the technology of our service grows and grows and we must be able to master it if we are going to have a comparative advantage over any potential enemy"

-- August 2002 Dr. Roche, Former Secretary of the Air Force

Dr. Alex Levis
Former Chief
Scientist
of the Air Force

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sE History

- 2003 - USAFA Dean & Permanent Professors developed & launched the Systems Engineering & Systems Engineering Management majors
  - Systems Engineering & Systems Engineering Management majors
  - Systems Engineering Steering Committee comprised of 5 Permanent Professor Department Heads with a Lt Col Working Committee Head (from the Department of Behavioral Sciences and Leadership)
- 2006 - Systems Engineering moved to Department of Aeronautics due to numerous resources issues; Steering Committee replaced by Systems Engineering Working Group (SEWG) headed by the Lt Col Aeronautics Department Deputy Head for Systems Engineering

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sE History con't

- 2008 - Systems Engineering program elevated by the USAFA Dean from the Aeronautics Department to the Engineering Division (College of Engineering)
  - "Deputy Head" reporting to Aeronautics Department Head now "Director" reporting to the Engineering Division Chair
- 2008 - Systems Engineering Management housed solely in the Department of Management with continued SEWG representation
- 2009 – Systems Engineering major accredited by ABET (November 2008 visit)
  - Full 6 year accreditation with maximum ABET allowed 2 year back-accreditation
  - ABET Visitor – "Best Practice" from his experience

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sE History con't

- 2009 – USAFA sE Director and Distinguished Visiting Professor asked to function as senior subject matter experts for systems engineering across the USAF
- 2009 – The Weapon Systems Acquisition Reform Act establishing a 3-Star General equivalent to lead all systems engineering efforts for the Department of Defense
- 2009 – USAFA sE Director further asked to serve as a systems engineering senior subject matter expert for Department of Defense

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USAFA sE Data Points

- sE program has large enrollment each class year
  - Survey of Systems Engineering declared cadets indicates a large number selected a STEM major solely because Systems Engineering was offered
  - Four resident upper-classes surveyed over two years

CLASS YEAR	2006	2007	2008	2009	2010	2011
sE CONCENTRATIONS	32	43	51	41	38	34

sE - 2nd Largest of 10 USAFA Engineering Majors in 2010

sE Gained 38 Engineering Majors (of 133 surveyed) = 29%

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SENATE 454 - WEAPON SYSTEMS ACQUISITION REFORM ACT OF 2009

- Sy... ...gineering - Section 101
  - ... important step necessary to address high ... acquisition programs is "a viable ... the beginning"
  - "... ...d its systems engineering ... last twenty years. The o...

"...establish organizations and develop skilled employees needed to fill any gaps in such capabilities" sect 101

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sE/SEM Confusion

- Systems Engineering Management (SEM) is a Department of Management major that includes the six "core" systems engineering courses
- SEM stops at Calc II and has limited engineering beyond the systems engineering courses
- SEM is an excellent major targetting Management students who want more engineering than the traditional Management degree
- sE works closely with SEM to ensure cadets and advisors understand the differences

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CHALLENGES

Challenges

- How do you operate & sustain a "non-department" department?
  - Systems Engineering Working Group (SEWG) – Matrixed across eight different departments
  - sE Memorandum of Understanding
  - Faculty Operating Instruction (in work)
- ABET "concern": "understaffed"
  - USAFA Superintendant briefed by ABET Team Chair
- Current sE requirement is 4 positions (billets)
  - 2 Military / 2 Civilian
  - 4 full time equivalents (FTEs) determined through ABET self study analysis at current student enrollment – as discussed previously, we anticipate this enrollment will increase

What Does USAFA Produce?

- Does USAFA graduate Systems Engineers?
  - Many engineering programs utilize the Fundamentals of Engineering (FE) exam to become an Engineering Apprentice
  - Add 4 years experience to qualify for Professional Engineer (PE)
  - The International Council on Systems Engineering (INCOSE) follows a similar process
  - Apprentice Systems Engineering Professional (ASEP)
  - Add 5 years experience to qualify for Certified Systems Engineering Professional (CSEP)

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SUCCESSES

Successes

- Full (6 year) ABET accreditation with back accreditation to 2006! "Unprecedented" – USAFA Dean
- Briefed program to Deputy Assistant Secretary of the Air Force for Acquisition and Requirements
  - We got more than we asked for…
  - He was *very* pleased with our identifying a "hole" in his policy and focused on shoring that breach
  - Designated *significant* monetary support for three years
    - NDAA Section 852 now funds 50% of the USAFA Systems Engineering manning requirement until 2012
    - WSARA could extend/expand this critical support
- Developing INCOSE ASEP-ACQ prep course (re USAFA FE prep course) which already has USAF SPRDE equivalency credit – USAF training leveraging education

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sE Program Relevancy

- #1 USAF Engineering Need (Air Force Materiel Command)
- July 2005 – AF Science Advisory Board (SAB) Report (p1) – "*what was previously only a development practice has evolved to become a science and engineering discipline*"
- Sep 2008 - Deputy Assistant Secretary of the Air Force for Acquisition and Requirements & USAF Director of the Center for Systems Engineering (CSE) agree the "*quality and quantity of systems engineers is insufficient for USAF needs – the USAFA program directly addresses this problem*"
- 2008 Nat'l Research Council Report - The USAFA SE program has important value… important that USAFA work with the Air Force Personnel Center so USAF capitalizes on grads' SE training

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Early Benefits

- USAF enjoying early benefits from USAFA sE graduates
  - 2nd Lt Rachel Grant sE-Aero, 2006
    - F100 AFSO21 LEAN event
    - "My boss saw that I understood the propulsion challenges, but also all the systems engineering aspects. As a 2nd Lt, I was selected as the engineering-side manager over more senior civilian engineers…reporting directly to the Propulsion Group Commander [Colonel]"

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F100 LEAN Event

- Some big picture numbers
  - There are 3,195 engines in the F100 fleet, valued at $11.2B
  - The fleet is distributed over seven USAF Major Commands comprising 33 bases
  - 2nd Lt Grant personally managed Systems Program Office (SPO) engineering input on 27 cell designs for 5 engine modules, incorporating 1000+ parts

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LEAN Event Results

- High Pressure Turbine Module Repair flow days went from 45 to 13 days - a **71%** improvement
- Annual Distance Travelled for various parts
  - Exhaust Case: from 238 miles to 32 miles – 206 miles (**87%**) of routing cut in lean cell redesign
  - Shaft: from 357 miles to 137 miles – 221 miles (**62%**) of routing cut in lean cell redesign
  - Rear Turbine Hub: from 387 miles to 16 miles – 371 miles (**96%**) of routing cut in lean cell redesign

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LEAN Event Results con't

- Process Improvement for 3rd Stage Air-seal Support repair
  - Originally 23 steps were accomplished, and of those only five were necessary: 18 unnecessary steps were cut
  - Originally part went through 21 ownership changes: All 21 ownership changes eliminated

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USAFA'S APPROACH

USAF Academy Approach to Systems Engineering Curriculum

- Define what education is required for an undergraduate engineering degree using ABET standards
- USAFA's approach lays a rigorous *classical engineering foundation* upon which *systems engineering process and tools are erected*

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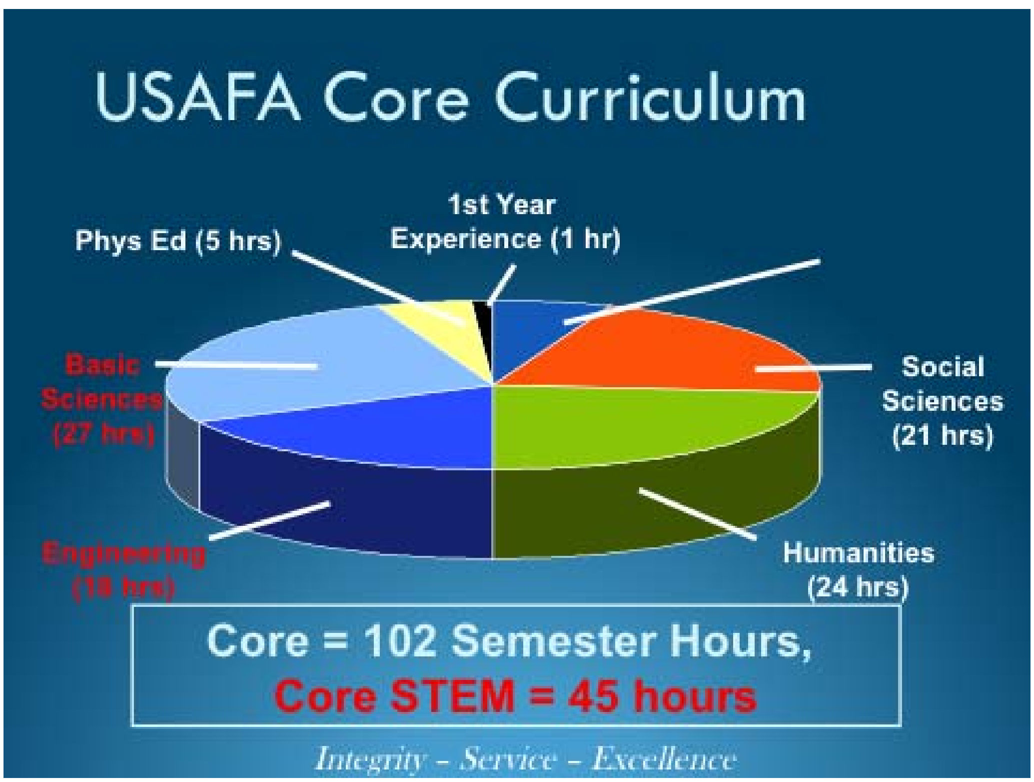
Systems Engineering Concentrations

- As previously stated, all Systems Engineering majors must chose a classical engineering concentration:
  - sE-Aeronautical Systems
  - sE-Computer Systems
  - sE-Electrical Systems
  - sE-Human Systems
  - sE-Information Systems
  - sE-Mechanical Systems
  - sE-Space Systems

Integrity – Service – Excellence



Classical Engineering Foundation

Aeronautical Engineering 315 Fundamentals of Aeronautics
Astronautical Engineering 410 Introduction to Astronautics
Biology 315 Introductory Biology with Laboratory
Chemistry 100 Applications of Chemistry I
Chemistry 200 Applications of Chemistry II
Computer Science 110 Introduction to Computing
ECE 231 Electrical Circuits and Systems I
Engineering 101 Introduction to Air Force Engineering
Engineering Mechanics 220 Fundamentals of Mechanics
Math 141 Calculus I
Math 142 Calculus II or Math 152 Advanced Placed Calculus II
Math 243 Calculus III
Math 245 Differential Equations
Math 356 Probability & Statistics for Engineers
Physics 110 General Physics I
Physics 215 General Physics II

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Method

- Each concentration closely mirrors its classical engineering "host"
- The following chart demonstrates the similarities between sE Aeronautical Systems and Aeronautical Engineering

Integrity – Service – Excellence

COURSE	AERONAUTICAL ENGINEERING	SE - AERONAUTICAL SYSTEMS
Biology 315 Introductory Biology with Laboratory	✓	✓
Chemistry 100 Applications of Chemistry I	✓	✓
Chemistry 200 Applications of Chemistry II	✓	✓
Computer Science 110 Introduction to Computing	✓	✓
Physics 110 General Physics I	✓	✓
Physics 215 General Physics II	✓	✓
Aeronautical Engineering 315 Fundamentals of Aeronautics	✓	✓
Astronautical Engineering 410 Introduction to Astronautics	✓	✓
Engineering 101 Introduction to Air Force Engineering	✓	✓
Engineering Mechanics 220 Fundamentals of Mechanics	✓	✓
ECE 231 Electrical Circuits and Systems I	✓	✓
Math 141 Calculus I	✓	✓
Math 142 Calculus II or Math 152 AP Calculus II	✓	✓
Math 243 Calculus III	✓	✓
Math 245 Differential Equations	✓	✓
Math 356 Probability & Statistics for Engineers	✓	✓
Aeronautical Engineering 241 Aero-Thermodynamics	✓	✓
Engineering Mechanics 320 Dynamics	✓	✓
Aeronautical Engineering 341 Aero Fluid Mechanics	✓	✓
Aeronautical Engineering 351 Aircraft Perf & Static Stability	✓	✓
Aeronautical Engineering 352 Aircraft Stability and Control	✓	✓
Aeronautical Engineering 361 Propulsion I	✓	✓
Aero Engr 481 Intro to Aircraft & Prop Sys Design (Capstone I)	✓	✓
Aero Engr 482 (or 483) Aircraft Design (Capstone II)	✓	✓

Differences

- Six courses from the Aeronautical Engineering curriculum are changed to the Systems Engineering "core" courses
  - Introduction to Systems Engineering
  - Project Management
  - Introduction to Human Factors
  - Programming for Engineering and Scientists (MATLAB)
  - Systems Analysis
  - Probabilistic Models

Integrity – Service – Excellence

COURSE	AERONAUTICAL ENGINEERING	sE - AERONAUTICAL SYSTEMS
Biology 215 Introductory Biology with Laboratory	✓	✓
Chemistry 100 Applications of Chemistry I	✓	✓
Chemistry 200 Applications of Chemistry II	✓	✓
Computer Science 110 Introduction to Computing	✓	✓
Physics 110 General Physics I	✓	✓
Physics 215 General Physics II	✓	✓
Aeronautical Engineering 210 Fundamentals of Aeronautics	✓	✓
Astronautical Engineering 310 Introduction to Astronautics	✓	✓
Engineering 101 Introduction to Air Force Engineering	✓	✓
Engineering Mechanics 220 Fundamentals of Mechanics	✓	✓
ECE 231 Electrical Circuits and Systems I	✓	✓
Math 141 Calculus I	✓	✓
Math 142 Calculus II or Math 152 AP Calculus II	✓	✓
Math 243 Calculus III	✓	✓
Math 245 Differential Equations	✓	✓
Math 356 Probability & Statistics for Engineers	✓	✓
Aeronautical Engineering 341 Aero-Thermodynamics	✓	✓
Engineering Mechanics 320 Dynamics	✓	✓
Aeronautical Engineering 341 Aero Fluid Mechanics	✓	✓
Aeronautical Engineering 351 Aircraft Performance & Static Stability	✓	✓
Aeronautical Engineering 352 Aircraft Stability and Control	✓	✓
Aeronautical Engineering 361 Propulsion I	✓	✓
Aero Engr 481 Intro to Aircraft & Propulsion System Design (Capstone I)	✓	✓
Aero Engr 482 or 483 Aircraft Design (Capstone II)	✓	✓
Systems Engineering Option		✓
Computer Science 211 Programming for Engineers & Scientists		✓
Operations Research 310 Systems Analysis		✓
Operations Research 321 Probabilistic Models		✓
Sys Engr 310 Introduction to Sys Engr		✓
Behavioral Science 373 Intro to Human Factors		✓
Systems Engineering 301 Project Management		✓
Structures and Materials Elective	✓	
Aeronautics Elective	✓	
Math 346 Engineering Math	✓	
Engineering Mechanics 330 Mechanics of Deformable Bodies	✓	
Aeronautical Engineering 471 Aeronautics Laboratory	✓	
Aeronautical Engineering 342 Computational Aerodynamics	✓	
Aeronautical Engineering 442 Advanced Aerodynamics	✓	

Where the sE Courses Fit

Systems Engineering Option	Structures and Materials Elective
Computer Science 211 Programming for Engineers & Scientists	Math 346 Engineering Math
Operations Research 310 Systems Analysis	Aeronautical Engineering 342 Computational Aerodynamics
Operations Research 321 Probabilistic Models	Engineering Mechanics 330 Mechanics of Deformable Bodies
Sys Engr 310 Introduction to Sys Engr	Aeronautical Engineering 471 Aeronautics Laboratory
Behavioral Science 373 Intro to Human Factors	Aeronautics Elective
Systems Engineering 301 Project Management	Aeronautical Engineering 442 Advanced Aerodynamics

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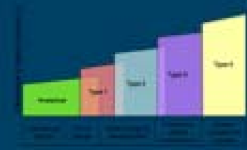
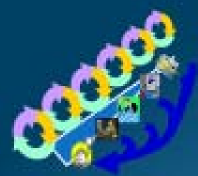
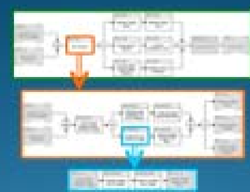
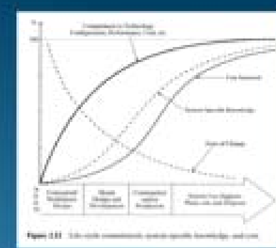
Intro to Systems Engineering









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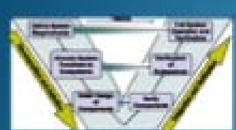

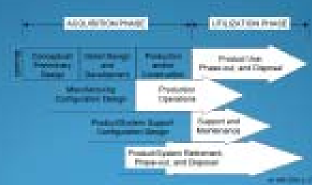

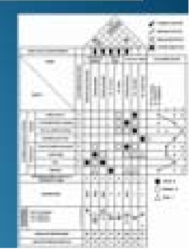

Conclusion

- Systems Engineering is critical to successful USAF acquisition
- USAFA Systems Engineering program is effective and meets USAF constituency needs


Integrity - Service - Excellence

Appendix D

BKCASE™: Body of Knowledge and Curriculum to Advance Systems Engineering

Slides Presented During a Keynote Address by Art Pyster, Distinguished Research Professor and Deputy Executive Director of the Department of Defense Systems Engineering Research Center, Stevens Institute of Technology

BKCASE™

Body of Knowledge and Curriculum to Advance Systems Engineering

Art Pyster

Distinguished Research Professor and
Deputy Executive Director of The Department of Defense
Systems Engineering Research Center

Stevens Institute of Technology

7 April 2010

art.pyster@stevens.edu

www.bkcase.org

What is BKCASE?

- Project to create:
  - Body of Knowledge in systems engineering (SEBoK)
  - Graduate Reference Curriculum in Systems Engineering (GRCSE™)
- Started in September 2009 by Stevens Institute of Technology and Naval Postgraduate School with primary support from Department of Defense
- Project will run through 2012
- Intended for world-wide use

7 April 2010 2

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Edward Ghafari, ICES Corporation and Defense Information Systems Agency, US	Alice Squires, Stevens Institute of Technology, US
Richard Grzybowski, Corning Incorporated, US	Massood Towhidnejad, Embry-Riddle University, US
Tom Hilburn, IEEE Computer Society and Embry-Riddle University, US	Guilherme Travassos, Federal University of Rio de Janeiro, Brazil
Scott Jackson, University of Southern California, US	Mary VanLeer, Arkansas Scholarship Lottery, US
Michael Krueger, ASE Consulting, US	Brian Wells, Raytheon, US

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Our Partners

BKCASE

Also seeking partnership with Project Management Institute and Brazilian Computer Society

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BKCASE Vision and Objectives

BKCASE

Vision

"Systems Engineering competency models, certification programs, textbooks, graduate programs, and related workforce development initiatives around the world align with BKCASE."

Objectives

1. Create a SEBoK that is globally recognized by the SE community as the authoritative BoK for the SE discipline.
2. Create a graduate reference curriculum for SE (GRCSE – pronounced "Gracie") that is globally recognized by the SE community as the authoritative guidance for graduate programs in SE.
3. Facilitate the global alignment of related workforce development initiatives with SEBoK and GRCSE.
4. Transfer stewardship of SEBoK and GRCSE to INCOSE and the IEEE after BKCASE publishes version 1.0 of those products, including possible integration into their certification, accreditation, and other workforce development and education initiatives.

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How We Got Here

BKCASE

In Spring 2007, 3 phase effort was proposed:

1. A reference curriculum for graduate software engineering with the "right" amount of systems engineering
2. A reference curriculum for graduate systems engineering with the "right" amount of software engineering
3. A fully interdisciplinary reference curriculum for systems and software engineering

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Phase 1 Primary Products

- Graduate Software Engineering 2009 (GSwE2009): Curriculum Guidelines for Graduate Degree Programs in Software Engineering
- GSwE2009 Companion Document: Comparisons of GSwE2009 to Current Master's Programs in Software Engineering
- GSwE2009 Companion Document: Frequently Asked Questions on Implementing GSwE2009


iSSEc

Graduate Software Engineering 2009(GSwE2009)

Curriculum Guidelines for
Graduate Degree Programs in Software Engineering

Version 1.0

Endorsed by INCOSE, NDIA SE Division, Brazilian Computer Society
Sponsored by DoD, IEEE Computer Society and ACM

www.GSwE2009.org

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SEBoK Value Proposition

1. There is no authoritative source that defines and organizes the knowledge of the SE discipline. Knowledge gap creates unnecessary inconsistency and confusion in understanding the role of SE and in defining SE products and processes.
2. Creating the SEBoK will help build community consensus on the boundaries of SE, including its entanglements with project management and software engineering.
3. A common way to refer to SE knowledge will facilitate communication among systems engineers and provide a baseline for competency models, certification programs, educational programs, and other workforce development initiatives around the world.
4. Common ways to identify metadata about SE knowledge will facilitate search and other automated actions on SE knowledge.

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SEBoK Content

BKCASE

1. The definition of fundamental terms and concepts and primary relationships between those concepts
2. A statement of the principles of SE
3. A description of generally accepted activities, practices, technologies, processes, methods, and artifacts of SE and how they relate to one another
4. How the knowledge of SE varies within individual application domains such as medicine, transportation, and telecommunications
5. References to books, articles, websites, and other sources that elaborate on the information in the SEBoK

Version 0.25 expected in Summer 2010

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GRCSE Value Proposition

BKCASE

1. There is no authoritative source to guide universities in establishing the outcomes graduating students should achieve with a master's degree in SE, nor guidance on reasonable entrance expectations, curriculum architecture, or curriculum content.
2. This gap in guidance creates unnecessary inconsistency in student proficiency at graduation, makes it harder for students to select where to attend, and makes it harder for employers to evaluate prospective new graduates.

GRCSE is being created analogously to GSwE2009 – in fact, using GSwE2009 as the starting text

Version 0.25 expected in Fall 2010

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Initial GRCSE Structure

BKCASE

- ***Guidance for Constructing and Maintaining GRCSE:*** the fundamental principles, assumptions, and context for the GRCSE authors
- ***Entrance Expectations:*** what students should be capable of and have experienced before they enter a graduate program
- ***Outcomes:*** what students should achieve by graduation
- ***Architecture:*** the structure of a curriculum to accommodate core material, university-specific material, and elective material
- ***Core Body of Knowledge (CBOK):*** material that all students should master in a graduate SE program – derived from SEBoK

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Expected Impact on Undergraduate SE Programs

BKCASE

SEBoK should directly influence what is taught in undergraduate SE programs by providing community-based consensus on the boundaries, principles, content, and key references of SE

GRCSE should help to better distinguish between graduate and undergraduate education in SE and influence undergraduate education by guiding what is taught in graduate programs

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Appendix E

An Analysis of U.S. Undergraduate Programs in Systems Engineering

Slides Presented During a Keynote Address by Art Pyster, Distinguished Research Professor and Deputy Executive Director of the Department of Defense Systems Engineering Research Center, Stevens Institute of Technology

Two Broad Types of Programs

STEVENS Institute of Technology

- Systems-Centric: where the concentration is designated as SE; where SE is the intended major area
- Domain-Centric: SE education and training that integrates the best SE practices within the traditional engineering disciplines… SE with biological engineering, SE with industrial engineering, etc.

Useful, but not perfect distinction – some programs have characteristics of both; e.g., Stevens has a master's of SE (SCSE), but offers a certificate in Space Systems SE (DCSE). Also, some programs integrate significant SE without using "systems engineering" in the name of their degree.

* Fabrycky, W.J., "Systems Engineering: Its Emerging Academic and Professional Attributes", to appear in the Proceedings of the 2010 American Society for Engineering Education Conference and Exposition, Lexington, KY, June 20-23, 2010.

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Program Population Growth

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There is healthy growth in the number of U.S. systems engineering programs at both the undergraduate and graduate levels

1999: 29 schools offered 58 programs at undergraduate and graduate levels – ***19 undergraduate programs***

2004: 75 schools offered 130 programs at undergraduate and graduate levels – ***43 undergraduate programs***

2009: 80 schools offered 165 programs at undergraduate and graduate levels – ***55 undergraduate programs***

Brown, D. E. & Scherer, W. T. (2000). A comparison of Systems Engineering Programs in the United States. Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 30(2), 204-212.

Fabrycky, W. J. and McCrae, E.A. (2005). Systems Engineering Degree Programs in the United States", in Proceedings of the 15th Annual International Symposium, INCOSE 2005, Rochester, NY, July, 2005 .

Fabrycky, W.J., "Systems Engineering: Its Emerging Academic and Professional Attributes", to appear in the Proceedings of the 2010 American Society for Engineering Education Conference and Exposition, Lexington, KY, June 20-23, 2010.

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2009 Program Distribution by Type

Type	B	M	PhD	Total
Systems Centric SE	11	31	14	56
Domain Centric SE w/ Biological Engineering	18	10	6	34
Domain Centric SE w/ Computer Engineering	7	5	3	15
Domain Centric SE w/ Industrial Engineering	17	17	13	47
Domain Centric SE w/ Management Engineering	1	2	0	3
Domain Centric SE w/ Manufacturing Engineering	1	8	1	10
Total	*55*	*73*	*37*	*165*

Parsing XX Systems Engineering important. Some programs are more about (XX Systems) Engineering rather than XX (Systems Engineering) – *more on this later…*

10-Year Trend

Type of SE Program	Degree Level	Brown & Scherer (2000)	Fabrycky (2010)	Increase Factor
Systems Centric	Bachelors	10	11	1.1
	Masters	10	31	3.1
	Doctorate	3	14	4.7
	Systems Centric	23	56	2.4
Domain Centric	Bachelors	9	44	4.9
	Masters	17	42	2.5
	Doctorate	9	23	2.6
	Domain Centric	35	109	3.1
All	Bachelors	19	55	2.9
	Masters	27	73	2.7
	Doctorate	12	37	3.1
All	All Degrees	58	165	2.8

Reference: Squires, A. (2010) DRAFT: Measuring the Value of Remote Online Systems Engineering Education, PhD Dissertation, Stevens Institute of Technology

Program Growth is Not Uniform

STEVENS Institute of Technology

- Over the last decade, strong growth for some:
  - Undergraduate DCSE grew from 9 to 44 programs (~5x)
  - Graduate SCSE grew from 13 to 45 programs (~3.5x)
- Least growth in undergraduate SCSE programs - from 10 to 11
- Overall growth is close to 3x, but has slowed significantly in the last 5 years

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Why The Disparity in Growth?*

STEVENS Institute of Technology

- This disparity may reflect the belief by many that SE is inherently experiential-based.
- Perhaps undergraduates, who largely lack experience, best learn SE in the context of another engineering discipline/application domain (DCSE) rather than as a "pure" SCSE.
- Perhaps graduates, who often enter a program with substantial industrial experience, can succeed in either a DCSE or a SCSE program.

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Survey Overview

STEVENS Institute of Technology

- To help ground discussion at this workshop, collected data from undergraduate SE programs
- 19 question survey responses collected in March
- 15 programs provided data:
  - 7 SCSE 6 DCSE
  - 2 not in Fabrycky's list (their degrees are not SE or *XX* SE, but integrate significant amounts of SE)
- Large enough sample to be interesting for workshop, but not large enough for definitive conclusions

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Short Version of First 11 Questions

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#	Question
1	Which undergraduate degrees do you offer in SE? …
2	In which academic units (departments, programs,…)?
3	In which year was your undergraduate degree in SE first offered?
4	How many students earned undergraduate degrees in past 5 years?
5	How many students are currently majoring in your program?
6	How many full-time faculty members teach your courses?
7	How many adjunct or part-time faculty members teach your courses?
8	In which industries do your graduates work?
9	Do you have an internship program?
10	Do you require a capstone design project?
11	Do you have strong ties to local government or industry?

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Remaining Questions

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#	Question
12	What are your core SE courses?
13	What is your primary goal for your students?
14	Are you ABET accredited?
15	Which other majors use your courses as required or electives?
16	What percentage immediately go on to graduate school?
17	What are the 3 strongest features of your program?
18	What are the 3 features needing most improvement?
19	Anything else you want to say?

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Commonly Reported Practices for Both DCSE and SCSE Programs

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1. ABET accreditation
2. A required capstone course
3. An optional internship program
4. Small number of tenure/tenure-track faculty
5. Little reliance on adjunct faculty
6. Industry/Government advisory councils
7. Relatively few students going directly on to graduate programs – only one program said more than 20%
8. Employment by government and government contractors

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Primary Program Goals of Three System Centric SE Programs

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Our students should be able to apply fundamental concepts of mathematics, science, IT, and engineering to contemporary and future systems, and to contribute to the development of systems using systems engineering methods, processes, models and tools.

Our goal is to provide our students with a strong background in mathematics, statistics, operations research, and computer science and to instill in them problem solving skills through systems thinking so that they can adapt themselves to any situation.

Our mission to prepare students with the knowledge and skills they need to design, model, analyze and manage modern complex systems.

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Educational Objectives of One SCSE Program

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The SE program is designed to provide a broad and solid education in the basics of mathematical modeling, software and information systems, and the treatment of uncertainty. Analytical thinking is stressed, in order to prepare the student for graduate education or productive professional employment. Simultaneously, the program is intended to develop the student's communication skills and awareness of the current professional world...

Program requires math, computer science, operations research, etc. + **5 cohesive courses in a specific domain such as electrical engineering, finance, or mechanical engineering**.

7 April 2010 *As reported on program website 13

Educational Objectives of Another SCSE Program

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Our educational program reflects the system engineer's unique perspective that considers all aspects of a system throughout the entire life time of that system…

Our program objective is to graduate students who are able to:

- Apply fundamental concepts of mathematics, science, information technology, and engineering…
- Participate meaningfully in the development of systems using systems engineering methods, models, and tools
- Achieve depth of knowledge in a technical area by completing a sequence of technical electives that constitute a concentration track.
- Work effectively as a leader and a member of … teams.
- Communicate effectively …

Program requires math, computer science, physics, chemistry, operations research, etc. + **3 specialization courses in either software intensive systems, telecommunications, etc.) cohesive courses in a specific domain**

7 April 2010 *As reported on program website 14

SCSE Programs Are not "Purely" Focused on the Discipline

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SCSE programs often expect students to learn about systems engineering in the context of a specialization with multiple specializations from which to choose.

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Primary Program Goals of Three Domain Centric Programs

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Our goal is to graduate X systems engineers with a solid understanding of Systems Engineering Design and how it is applied to hardware and software development

Be able to understand and apply the concepts of systems engineering

Our goal is for our graduates to understand the systems aspects of the various complex systems they will face across a variety of industries and be able to apply the appropriate methodologies, techniques, and tools to design, analysis, operate, and control those systems.

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Positioning of A DCSE Program Specializing in Industrial Engineering

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Industrial engineers figure out **how to do things better**… Systems engineering is a fundamental application of industrial engineering.

The industrial and systems engineer is synonymous with systems integrator – a **big-picture thinker**… A lot of engineers become disillusioned with the engineering profession because they get involved with minutiae or they end up on a CAD machine all the time and they never get out in the operating environment. ISE provides an opportunity for a challenging career working with people where you can have a direct impact on the success of an organization.

Program requires math, computer science, physics, chemistry, operations research, etc. + 17 credits in professional concentration areas including manufacturing, supply chain management, health care, human factors, information systems, general industrial engineering, and facility planning and development

7 April 2010 *As reported on program website 17

Positioning of A DCSE Program in Biological Systems Engineering

STEVENS Institute of Technology

The overall educational goal … is to graduate biological systems engineers to support sustainable production, processing, and utilization of biological materials and to protect natural resources. The BSE program seeks to prepare its graduates to become successful in the practice of biological systems engineering or in the pursuit of advanced degrees in BSE or other complementary disciplines… the program seeks to prepare its graduates:

- to solve engineering problems using the fundamental principles of science, mathematics, and engineering;
- to engage in life-long learning and professional development;
- to be effective communicators and team members; and
- to function in a professional and ethical manner.

Program requires math, computer science, physics, chemistry + many courses in biological systems. No course would be classically identified as SE per se. Phrases such as "requirements", "architecture", etc. are not on website.

7 April 2010 *As reported on program website 18

Commonly Required Courses

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Course	Program Type
Mathematics, chemistry, physics – classical engineering courses	Both
Introduction to Systems Engineering	SCSE
Simulation	Both
Senior Design or Capstone	Both
Operations Research	Both
Human Factors	SCSE
Project Management	SCSE
Information Technology/Computer Science	Both

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Elective SE Courses For Other Engineering Majors

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Most commonly mentioned elective courses are:

- operations research
- project management
- modeling and simulation
- engineering economics

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Program Strengths Across All Programs

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No single strength was commonly mentioned, but some were mentioned more than once

1. Cited individual subjects - SE thinking, mathematics, simulation, computer science, communication, …
2. SE is not taught as a separate subject but as an integrated approach to design
3. Capstone design course that requires students to solve real-world problem for a real client
4. Faculty with real-world experience

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Example Areas for Improvement Across All Programs

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Very little commonality across schools

1. More laboratories and hands-on projects
2. Better writing skills, mathematical skills, programming skills
3. More social science courses
4. More funding for faculty and other aspects of program
5. More courses on large-scale systems, systems design, and life cycle management
6. More on specific topics such as systems thinking, cost estimating, or requirements determination

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Conclusions

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1. Healthy growth in SE programs dominated by domain centric approach, especially at undergraduate level
2. Distinctions between DCSE and SCSE at undergraduate level is not as stark as categorization implies because of common practice to require specialization in SCSE programs
3. Relatively few common strengths or weaknesses cited among undergraduate SE programs
4. Larger data collection required to draw more definitive conclusions – but data as described should stimulate some thinking for this workshop

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Appendix F - Report of Breakout Session 1

What Are The Primary Undergraduate Education Requirements for SE Personnel in Government Program Offices?

Participants

- Cliff Whitcomb (session leader), Naval Postgraduate School
- Col Jim Collins, Air Force, AQR
- Maj Dan Doyle, Air Force, AQXD
- LtCol Scott Nowlins, Air Force, AQRT
- Martha Newman, Army RDECOM
- Col Tim Trainor, United States Military Academy
- Brian Gallagher, Northrop Grumman
- Dennis Barnabe, National Security Agency
- John Snoderly, Defense Acquisition University
- David Jacques, Air Force Institute of Technology
- Cihan Dagli, Missouri University of Science and Technology
- AnnMarie Choephel, OSD/DDRE Contractor Support
- Lt Col Paul Lambertson – United States Air Force Academy

After brief introductions by each group member, the group reviewed the question at hand, *"What are the primary undergraduate education requirements for SE personnel in government program offices?"* Initially, the group focused on defining "government program office"; however, the group felt it really depended on where the engineers were in the government and what they were doing in their positions. This was discussed in the context of a perceived need to establish the definition/scope of a program management office – whether in acquisition, requirements setting, T&E, logistic centers, warfare centers, labs – to include anyone who influences technical decisions on the government side. The Venn diagram in Figure 1 was sketched to define the intersecting relationships for the functions for government SE personnel. A point was made that it almost does not matter if you have an SE undergraduate degree for government positions; but there is a need for specific experience and proper mentoring in the end. The term "SE personnel" was then agreed to include any engineers who might work in a systems role, and not exclusively engineers trained and hired specifically as systems engineers. The definition was also meant to primarily define the role of government systems engineers. Contractors have similar roles for their SE personnel, but it was noted that there could be some differences - though these were not elaborated on in the breakout.

The group decided to focus on those who make decisions in a technical context versus a programmatic context - in other words providing a technically based perspective. For undergraduate education requirements the group considered the idea of looking at what competencies might be needed – but determined it would take too long to do this. Group members also noted that SE personnel may not always need an engineering degree (but should have hard sciences background), provided that have the competencies to make technically competent contributions to systems engineering recommendations.

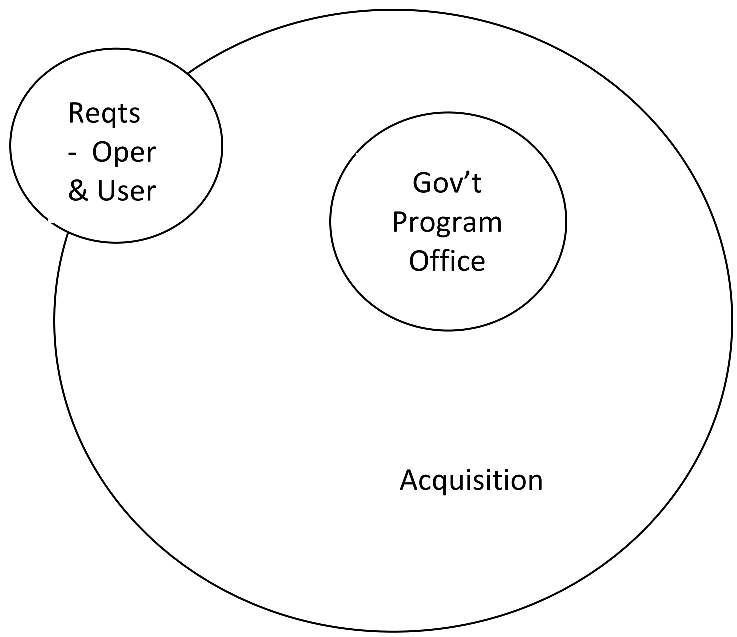

Figure 1. Venn Diagram to define the intersecting relationships for the functions for government SE personnel

The next discussion took the perspective: "On the day you arrive on the job – what do you need in the tool set?" Several perspectives were shown to the group in the form of PowerPoint slides. For graduate naval systems engineers at Naval Postgraduate School, COMNAVSEA has a set of Educational Skill Requirements (ESR) defined. A brief from Assistant Secretary of the Navy (Research, Development, and Acquisition) on the development time line for Chief SE was presented as an example. Not all agreed to that approach, especially the concept of waiting until a SE or engineer had 15 years of experience before taking a masters degree in SE - and members of the group stated from personal experience that they needed an SE masters degree much earlier in their career - with 5 to 7 years of experience being a more desirable time frame. An Office of the Secretary of Defense (OSD) SE Competency list – SE Technical and SE Technical Management - was also presented. The CDIO (conceive, design, implement, operate) curriculum for engineering education was also briefly discussed, though attendees decided it is too detailed for our level to use at this point. The group decided that using the ABET EAC undergraduate criteria (a) – (k) as a foundation of engineering competency was a good baseline, especially since it covers the "soft skills" - communications, etc, but any expanded forum in the future should also consider other competency work from NDIA, OSD, INCOSE, and others.

The group decided that members would each identify as many important characteristics for SE as they desired, put one concept per Post-it note, and post them on the blackboard. The group then used an Affinity approach to determine the categorization of the education needs at the high level (without getting into Blooms Taxonomy levels). The group ordered and re-ordered the slips of paper, and used a group consensus to identify, clarify, and classify any apparent redundant items. It was noted that the groupings were not really at the same level of granularity. Discussions included whether the focus would be on critical thinking or systems thinking. Computer skills should probably be assumed. The group also discussed that in the area of STEM, workers could have SE experience without necessarily having an undergraduate degree in SE or engineering and could augment their technical knowledge if they did not have a technical undergraduate degree. It was pointed out the education needs are not mutually exclusive; some are crosscutting and should be viewed as topics and not necessarily as courses. The initial and final results are listed below:

Initial categories after brainstorming:

- Economics
- Financial management
- Case studies
- Systems management
- Program management
- Conduct of design reviews
- Program and project management
- Contractor oversight and management
- Political
- World/national/local events
- Process knowledge
- Contract oversight and management

Crosscutting skills – critical thinking (problem solving)

- Unintended consequences
- Managing complexity

Analytical Skills

- Advanced math
- Optimization/stochastic processes; sequential – basic math modeling
- Statistical process control
- Probability and quantitative analysis
- Analysis of Alternatives/trade studies
- Decision analysis
- 'Ilities' – reliability analysis (growth, defect detection); functional allocation; reliability supportability; systems assurance – Reliability, Availability, Maintainability (RAM), SoS -ilities; modeling and simulation; human-system interface (HSI); systems integration (test and integration issues, interface management); risk (risk identification, risk and trade analysis, principles of risk analysis and mitigation); test and evaluation (T&E) – test processes, design of experiments; Requirements Management and Analysis – requirements management, analysis and decomposition, quality attributes definition; systems thinking – basics of systems engineering; computer skills /science basics – software/programming, architecture, mathematics lab, computer-aided design, Excel
- Elements of Systems architecting
- System life cycle – understand choices and consequences; environmental concerns, deployment and installation

Other

- Oral and written communication skills
- Domain engineering – engineering methods, general literacy in engineering

The group discussed that some people receive the title of systems engineer without being an engineer. The group agreed that a systems engineer should be "first an engineer" – and should have at least a hard sciences bachelor of science degree, and must have some advanced math.

Group members were then each assigned 5 points which they could assign across the elements they believed were the most vital education needs for SE personnel in government offices. The assigned numbers were totaled and ranked.

- General Engineering skills – 11
- Analytical skills – 8
- Project Management – 7
- Requirements – 5
- Risk – 5
- Systems Thinking – 4
- Systems Architecture – 4
- Modeling and Simulation – 3
- Systems Life Cycle – 3 (Basic SE course)
- Critical Thinking – 2
- Test and Evaluation – 1
- Systems Integration – 1
- System 'ilities' – 1
- Computer Skills – 0
- Teaching/Training - 0

The group then determined that this yielded a reasonable first cut at the question, and the final briefing included the results of this ranking exercise. General engineering skills received the most votes. The consensus was that systems engineers are engineers and that general engineering skills still make up the bulk of the educational needs for SE personnel. It was also noted that the list may reflect what was needed for government program offices, but additional research was needed to determine how the list would change for students going to work for other employers. One attendee also pointed out that their university students use these skills far beyond what is noted. One attendee questioned what was meant by the world/national/local events element. The response was that the group intended that to include such things as policy, funding, etc at national/state/local level. A final caution was noted on the limited voting that was used by the group in assigning numbers to determine priority, so this is necessarily a preliminary, but useful, outcome.

Appendix G - Report of Breakout Session 2

What Are the Top Challenges to Successful Bachelor's Degree Programs in Systems Engineering and How Should These Challenges Be Addressed?

Participants

- George Donohue (session leader), George Mason University
- Dona Lee (recorder), OSD, DDR&E Systems Engineering
- Col James Collins, SAF/AQR
- Daniel Livengood, Massachusetts Institute of Technology
- Kelly Miller, National Security Agency
- Seshadri Mohan, University of Arkansas at Little Rock
- Hiro Mukai, Washington University, St Louis
- Brett Peters, Texas A&M University
- John Pletcher, U.S. Air Force Academy
- Michael Smith, University of Virginia
- G. Don Taylor, Virginia Tech
- Gregory Tonkay, Lehigh University
- Jack Welsh, Booz Allen Hamilton
- Gary Yale, U.S. Air Force Academy
- Armen Zakarian, University of Michigan, Dearborn

Introduction

The topic of discussion for this group was the determination of the top challenges faced by programs offering bachelor's degrees in systems engineering and the specification of approaches that might be used to combat these challenges. The group had four hours to address the assigned topic, and had a set of guidelines to follow. First and foremost, the group was to provide answers that represented the consensus of the entire group. In cases where this was not possible, the group was instructed to discuss the reasons why no consensus could be reached or to provide a dissenting viewpoint when a strong minority position emerged. Second, the group was to clearly identify any underlying assumptions. Third, the rationale for each aspect of the answer should be clear and explicit. Fourth, the recommendations should cover not only academia, but also should be useful to government and industry. Finally, the answers should be presented at a subsequent summary session in a very concise format.

Assumptions

Breakout Group 2 first decided to establish the parameters affecting the discussion of challenges and several assumptions emerged. The first assumption was that SE was viable as an undergraduate program. Interestingly, this opinion was not universally held within the group, but the dissenting minority was very small and the view not passionately held, so the group moved forward under this assumption. Another important assumption was that undergraduate SE degrees should not ignore the word 'engineering' in the title. It should be a real engineering degree, complete with the appropriate basic sciences, mathematics, and engineering core curricula to be roughly equivalent to education in other mainstream branches of engineering. The degree should be able to be completed in 8 semesters (approximately 130 semester hours). The group also agreed as an assumption that SE can mean many things to many different constituencies, and that little help in terms of definition comes from either ABET or the many professional societies that participate broadly in the field of SE. Although the group felt that any undergraduate degree in SE should include curricula addressing "systems thinking", no consensus was reached on what specific topics should be included in this area. Finally, the group made the assumptions that our customer base was broad (including students, employers and society), and that adding SE content to other branches of engineering was outside the scope of our discussion.

Group Response

Although the group was tasked with finding the 'Top Five' challenges, it was determined that four challenges addressed the greatest of our concerns. The four challenges that emerged from the discussion include, in no prioritized order:

1. Understanding and meeting customer needs within curriculum constraints,
2. Sustaining technical and societal relevance,
3. Incorporating sufficient real-world problem solving into curricula, and
4. Identity-communications-community of practice.

Each of these challenges will now be discussed, along with the recommendations that emerged from group discussion.

Challenge 1: Understanding and Meeting Customer Needs Within Curriculum Constraints

In addition to developing curricula that have the right blend of classical engineering and SE courses, the group felt that it was important to help students to develop technical communications skills and to learn about leadership. SE graduates are expected to work in jobs that extend across several functional areas, making effective communication a necessity. Also, SE graduates are in a unique position to provide leadership to large projects and initiatives. They should leave SE programs armed with a tool set that helps them to exploit these opportunities to the benefit of their employer.

The breakout group recommends that at least 50 percent of SE courses contain requirements for written and oral presentation of course requirements, with feedback. This will assist students in building valuable communication skills that will assist in extending SE thinking across functional boundaries at their workplace. The group also recommends that each undergraduate SE program have mechanisms in place to capture feedback from customers (again including students, employers, and society) regarding the adequacy of the program. This feedback could include survey-based programs, student exit interviews at the time of graduation, etc. It almost certainly includes the development and use of strong external Advisory Boards that include representatives from key constituencies; government, major employers, program alumni, etc. Feedback should be obtained using appropriate metrics that enable SE undergraduate programs to measure their progress toward strategic goals.

Challenge 2: Sustaining Technical and Societal Relevance

This challenge is considered to be particularly important because of the general lack of understanding regarding the definition of SE, which is addressed in greater detail in the discussion of Challenge 4 below. It is essential that SE programs maintain adequate internal and external program funding. Internal funding for faculty and staff salaries and operational support are vital to the health of any program, but obtaining and maintaining ongoing internal funding depends upon academic administrative units understanding and appreciating the benefits of having an SE program. Increasingly, and particularly in state-supported colleges and universities that are faced with new funding paradigms in which state governments fund an increasingly small percentage of total operations, external funds that support vital research funding enable programs to remain viable, effective, and current. Thus, healthy SE undergraduate programs often will have ties to an effective graduate program. The group also felt that it is very important to provide opportunities for interdisciplinary experiences, again to solidify the idea that SE is a vital and valuable component of engineering curricula.

The breakout group recommends that SE programs find ways to encourage the sharing of emerging technical tools for a broader community. It is deemed important to develop interdisciplinary capstone projects for senior-level students, potentially even campus-wide or multi-university experiences. Also, it is recommended that SE programs vigorously solicit sponsorship from government and industry sources to support both research and educational objectives. Once again, external Advisory Boards can be leveraged to gain both feedback and assistance with proposals for external funds.

Challenge 3: Incorporating Sufficient Real-World Problem Solving into Curricula

At the heart of this challenge is attracting faculty members to SE academic programs who have system design experience. Many faculty members can teach the basic lessons of SE from textbooks, but only faculty members with experience as a direct employee or consultant can provide the benefits of their experience with large, complex, and often unstructured SE problems. The use of case studies of SE success and failures in multiple SE core classes would be very valuable, as would the use of strong capstone projects with good sponsors familiar with SE concepts.

The group recommends that faculty should engage industry practitioners in regular interactions. Even experienced faculty members will not be as familiar with the most current emerging issues in industry as practitioners. Faculty members should openly solicit companies for case study ideas and capstone projects. Practitioners should be encouraged to actively participate in case studies and capstone projects by direct mentoring of students. Funding should be sought to hire Adjunct Professors or to establish other scholar programs with leading engineers and managers from industry, the military or government to serve a time in residency on campuses. Student internships or cooperative education opportunities should be commonly used. National clearinghouses for case studies could provide a way to leverage the efforts of multiple universities for the common good. Furthermore, academicians should work with the various professional societies involved with SE to develop student competitions at the national or international level.

Challenge 4: Identity-communications-community of practice

Much more so than in other traditional branches of engineering, there seems to be a lack of understanding and awareness among high school students regarding SE. Perhaps this is because the physical manifestations of 'systems' are harder to visualize or define than in other branches of engineering. It is certainly easier to understand and visualize the actual design of a vehicle, a power grid, or a building than to understand and visualize the fact that each of these things are themselves systems, designed and built using more systems, and linked to additional systems and infrastructure in complex ways. Additionally, the all-encompassing nature of SE links the profession to multiple professional societies and makes seemingly simple issues like academic accreditation criteria difficult to define. All of these factors combine to make it difficult to attract the right students, that is, those with strong skills in mathematics, sciences, synthesis and creativity and communications.

The group made several recommendations to address these issues. Perhaps educational opportunities at this time are best focused on middle school, high school, and college freshman engineering students. Information sessions to assist students in understanding the nature of the SE profession would be very useful. In addition, adding SE content into high school science fair projects or the sponsorship of high school summer camp programs (perhaps with college credit) could provide very useful learning opportunities. This would involve a heavy commitment of time from SE academicians and perhaps also may involve the use of professional communications specialists, but may yield a high return as well. Collectively, these actions could help to establish the value proposition for SE undergraduate programs among students. Also, related professional activities could be very useful to the SE community. For example, the best SE academicians and practitioners could be encouraged to apply for jobs at funding agencies to increase SE visibility among key decision makers for the future of engineering. Systems engineers should also be encouraged to become ABET evaluators. Finally, systems engineers should be active in the professional societies (perhaps several) most relevant to their professional interests as an additional way to support SE in general.

Summary

The breakout group addressed the vital question of what challenges are most relevant in the quest to build successful undergraduate programs in systems engineering. The group identified challenges associated with identity, relevance, skills, and customer needs, and made several recommendations regarding how to address these issues and further our profession through undergraduate SE education.

Appendix H - Report of Breakout Session 3

Original Question: Within the first four years after graduation, what should someone with a bachelor's degree in systems engineering know and be capable of doing on the job?

Revised Question: Within the first <u>two</u> years after graduation, what should someone with a bachelor's degree in systems engineering know and be capable of doing on the job?

Participants

- Michael Papay (session leader), Northrop Grumman
- Ann Birdsall (recorder), Senior Systems Engineer, OSD, DDR&E Systems Engineering
- Laura Adolfie: Acting Director, DDR&E/STEM Development Office
- Paul Coffman: Specialist, J-2X Engine Project, Pratt & Whitney Rocketdyne
- Gerard Fisher: Senior Systems Engineer, The Aerospace Corporation (NRO)
- George Freeman: Technical Director, Air Force Institute of Technology
- 1Lt Rachel Grant: 552 ACSS/GFLA, Tinker AFB
- James Jamison: Chief Systems Engineer/Industry CTO/ IBM Distinguished Engineer, IBM
- Robert Judd: ISE Chair, Ohio University
- Steve Murray: Senior Scientist, SPAWAR Systems Center – Pacific
- 2Lt Ryan Pinner: F-15 Project Lead, Rqmnts and Plans Division, USAF SEEK EAGLE Office
- Maurice Sanders: Senior Technical Manager – Systems, General Dynamics-AIS
- Ariela Sofer: Professor and Chair, SE and Ops Research Dept, George Mason University
- Brian Wells: Chief Systems Engineer & VP of Engineering, Raytheon
- Douglas Westphal: Technical Director, BAE Systems

Assumptions

Assumption #1: Each participant in the group brought a diverse perspective and significant value to the discussion, so Dr. Papay proposed that the participants provide enough relevant information on their background to provide context and reference points for the ensuing discussion. The participants agreed, provided introductions, and related personal histories.

Assumption #2: During the discussion on each participant's background, common threads arose about each one's experience in systems engineering, which were documented on the white board and helped to guide the discussion to a successful conclusion. These common threads were:

- Ethics/Integrity
- Process: 6σ/Lean/etc.
- Tools

- Certifications
- Modeling and Simulation/Analysis
- Operations Research
- Communications Skills: written/verbal
- Safety
- Environmental Awareness
- Product Life Cycle
- Cost
- Making Good Decisions

Assumption #3: Because four years after graduation, a graduate will have spent as much time with an organization as they did in undergraduate school, and they will be trained and integrated into the organization, the question was refocused to look at the time period of two years after graduation, rather than four years.

Group Response

Within the first <u>two</u> years after graduation, what should someone with a bachelor's degree in systems engineering know and be capable of doing on the job?

- Have the foundational knowledge and skills to create deliverables in at least two of the 13 systems engineering roles as defined by INCOSE
- Be capable of performing quantitative analysis and trade studies using formal methods and tools to support decision making within the constraints of ethical, environmental and safety boundaries
- Perform a multi-disciplinary job by using modeling, simulation, and analysis with an understanding of product lifecycle, risk, and cost considerations
- Exhibit leadership qualities, written and oral communication skills, and the ability to operate within a collaborative workspace
- Know and apply the appropriate systems engineering processes and tools of the organization and identify potential improvements

Rationale/Discussion

The question was examined from a student perspective, from a government perspective, and from an industry perspective. It was then pointed out that a bachelor's degree is a degree in how to learn. The employees are trained and mentored on the job. Industry would rather train the SEs in their processes and culture. The participants offered considerable discussion and examples. That discussion could be generalized as: there is no "one size fits all." There was a difference in philosophy between the industry participants, but it was agreed that it was important to find the common denominator(s) that were critical to SE undergraduate knowledge.

Industry representatives noted that it is difficult to find "real world" problems for the new undergraduate systems engineers to work in industry. Industry is not hiring SEs out of college to be Lead systems engineers, just to do an important task and grow them over time to a leadership role. Some of the programs presented to the SE Undergraduate Workshop the previous day indicated that industry could take an undergraduate SE and put them to work on a program, just not in a lead role.

However, they must have skills so they can be put to work–skills such as electrical engineering, mechanical engineering, etc. They need to have skills they can apply immediately that is domain specific.

The discussion then became focused on what deliverables the systems engineers provide, and what differentiates the systems engineer from other engineers:

- The ability to create and operate within a collaborative space
- The ability to apply systems techniques to engineering problems
- The ability to think critically and at a systems level
- The responsibility to act in an ethical manner
- The ability to interact with domain experts
- The desire to continue education

After four years, the individual has to be producing for the employer. As an Engineering Manager evaluating a systems engineer, the systems engineer should be able to use Modeling and Simulation tools to produce a product; be capable of building a depth of experience; understand the organization and have developed a mentoring relationship; be soliciting advanced work; lead more graduates into the organization; and have growth expectation and a plan/path for future growth. There was general agreement that a highly technical background is needed regardless of the work application.

INCOSE (International Council on Systems Engineering) has identified 13 requirements for SEs. After two to four years on the job, the systems engineer should have some depth in at least two of those 13 requirements. INCOSE SE certification requires five years of work in SE with three areas of depth out of the 13 requirements.

General discussion about the need for the newly matriculated undergraduate systems engineer focused on the commonality being the deliverables. There are certain SE deliverables of which an undergraduate systems engineer is quite capable such as: writing a chapter on a subsystem, contributing to the System Engineering Management Plan, architecture, analysis, modeling and simulation and risk analysis. If not producing, they should at least be fully capable of significant contributions. As a novice, the systems engineer needs to understand what the models are depicting and be able to understand the results, for instance. Additionally, between zero and four years industry would usually have provided four ethics training courses and a course on the principles of systems engineering. There should be a blending of skills and abilities that might focus the deliverables into at least two separate areas.

Initially, an undergraduate systems engineer is expected to be able to talk knowledgeably as an engineer and then learn some applications of the engineering. There is some first day knowledge in the fundamental concepts and then there is the ability to apply those concepts. On day one they should have the foundational knowledge in whatever they are expected to be producing. A systems engineer would be expected to be able to do a functional decomposition at the unit level, for instance. Functional decomposition skills are generally taught during the second year of the SE curriculum.

The academic representatives pointed out the ABET point of view. What happens to the student four years down the road is important from the academic perspective.

Additional Recommendations

The main recommendation from Breakout Session 3 is: *There must be a tight phrase for identifying the work of the Systems Engineering undergraduate.* There are so many similar definitions and they are all long winded. The definition needs to be concise and universal. First, the systems engineer needs to be an engineer; have broad knowledge; be multidisciplinary; have good written and verbal communications skills along with active listening; and there needs to be an identification of universally agreed-upon core competencies.

In addition, future discussions should ensure that we recognize the difference between SE functions, the SE discipline, the SE job title, and the SE role.

Appendix I - Report of Breakout Session 4

How much classical engineering (general, industrial, mechanical, electrical, etc.) and application domain focus (telecommunication, naval, medical, etc.) should be in a bachelor's degree in systems engineering?

Participants

- Paul Componation (session leader), University of Alabama – Huntsville
- Jim Anthony (recorder), OSD, DDR&E Systems Engineering
- James Nemes, Penn State University, Great Valley
- Drew Hamilton, Auburn University
- Capt Kevin Rudd, United States Naval Academy
- Joel Sokol, Georgia Institute of Technology
- Col Timothy Trainor, United States Military Academy
- Darrell Wallace, Youngstown State University

Assumptions

To start, the group agreed to the following assumptions to guide their effort:

The undergraduate SE program reference curriculum would

- Be ABET accredited
- Prepare graduates to successfully sit for the Fundamentals of Engineering exam
- Meet stakeholder assumptions
- Use the T-model with the group's focus on the SE centric program
- A budget of 130 semester hours was adopted.

It was unanimously and emphatically asserted that all undergraduate SE programs should graduate "first an engineer" and that the core engineering curriculum above essential to this proposition.

The group used the "T" education model to visualize the three models. The width of the top of the "T" would represent the breadth of the SE education and the height of the column of the "T" would represent the depth of the domain education.

Discussion

Two extremes were noted: one extreme George Mason University (GMU) and the other USAFA.

Three different models of undergraduate SE programs were identified:

- Systems Centric programs built on basic sciences and mathematics with program tailored engineering courses; e.g. GMU
- Systems Centric programs built on "traditional" engineering core courses; e.g. USAFA
- Domain-focused engineering with tailored SE courses (Domain Centric programs).

To scope the conversation on undergraduate SE curricula, the group found it useful to subdivide a curriculum into three categories:

- General education
- Mathematics and sciences
- Engineering.

The US Military Academy's (USMA) program is similar to the USAFA; however their focus is different. The USMA is very comfortable with the GMU program since they chose to benchmark their program against GMU's program.

One participant stated he was struck by the differences between the mathematics requirements in undergraduate SE programs, adding

- Most programs require mathematics courses through differential equations
- Some stop at calculus
- Most include probability and statistics

The group then discussed the slide that provided the USMA's Primary Peer Group Comparison USMA SE Program (Academic Year 2010). All compared programs included statistics. Moreover, one participant stated that he would not call a program an engineering program without differential equations, an opinion shared by all participants. Similarly, there was unanimity that SE management is not an engineering program.

Subsequently, the ABET requirements were discussed. It was noted that ABET does not have any specific curriculum requirements for undergraduate SE, but that it has curriculum requirements for industrial engineering (IE) that are equivalent to the curriculum requirements for undergraduate general engineering (GE). Also, it was observed that Georgia Institute of Technology does not currently require differential equations in its undergraduate SE program and there is currently no ABET IE or GE requirement for differential equations in undergraduate SE, but that one may be added in the future. It was also stated that the Institute of Industrial Engineers (IIE) now accredits undergraduate IE programs and not ABET.

Discussion then shifted to the ABET Fundamentals of Engineering (FE) examination. For instance, the USMA requires its undergraduate SE cadets to sit the FE examination. However, the USMA prepares its undergraduate SE cadets to be officers / leaders with technical competence not disciplined engineers.

A remark was offered and obtained consensus that the ABET standard for undergraduate SE program accreditation is not high. Subsequently, an observation was made that GMU considers SE as a domain unto itself.

It was noted, with the possible exception of civil engineering (CE), many employers do not require successful completion of the FE examination, Professional Engineer (PE) examination, or professional licensing for their engineers. Consequently, these employees would not need to have taken the FE upon matriculation with an undergraduate engineering degree. Nevertheless, consensus was reached that every undergraduate engineering curriculum, including undergraduate SE, should enable an individual who received an undergraduate engineering degree to successfully sit for the FE examination.

It was stated that programs that do not require differential equations and thermodynamics might be perceived as "light-weight" programs. It was asserted that a fundamental and essential role of a systems engineer is to bridge the gap between the other engineering disciplines and other non-engineering disciplines required to successfully realize a system. To successfully perform this role, a systems engineer must have credibility and respect with the other engineering disciplines. Consequently, it was agreed that an undergraduate SE program should require the same core engineering undergraduate curriculum the other engineering disciplines share in common.

The group then started the task of developing guidance for the core engineering undergraduate curriculum. Three models of undergraduate SE programs were recognized: (1) a Systems Centric program, (2) a Discipline Centric program, and (3) a Domain Centric program. The following table presents the unanimous results for the undergraduate SE program reference curriculum:

Hours	Topics
40	Math/Science (Calculus, Differential Equations, Linear Algebra, Probability & Statistics, Chemistry, Physics)
33	General Education
	Engineering
21	FE - Circuits, Thermodynamics, Statics, Dynamics, Engineering Economics, Fluid Mechanics, Ethics
18	SE Core (SE, Program Management, Decision Analysis / Risk Management, Modeling and Simulation (M&S), Computational Tools (e.g. Mathlab?), Operations Research (OR), Human Systems Integration (HSI))
12	Discipline (IE, Civil Engineering, Mechanical Engineering, Aeronautical Engineering, Chemical Engineering, etc.), Industry (Medical, Transportation), Methodology (OR, HSI, M&S)
6	Capstone Project
130	Total

On completion of the undergraduate SE program reference curriculum, it was observed that graduates who spent their entire careers in the service, health, business management, financial, etc., industries may not need the FE courses.

The group in follow-on discussion noted the following items.

1. There exists confusion in the employment marketplace that is caused by the information technology domain's use of the title "systems engineer" for what might be more appropriately be called a "computer network engineer."
2. The strength of an undergraduate SE program is established by its science, mathematics, and engineering rigor and satisfaction of stakeholder (e.g., employers that hire a program's graduates) expectations with job performance of graduates.

3. It was stated that most, if not all, undergraduate SE institutions perform some assessment of the performance and effectiveness of their graduates in the workplace. However, it was widely acknowledged that the quality and adequacy of the measurement and testing of undergraduate SE graduates is not currently adequate. Consequently, it was recommended to initiate an investigation of establishing performance metrics for undergraduate SE graduates. Additionally, it was stated that measurement data for the metrics should not come from graduate self-evaluations but from employers.
4. Regarding, undergraduate SE graduate performance and effectiveness in the workplace, it was recognized that education must be coupled with employer training and experience to meet the performance the employer's expectations.

Future Issues for Undergraduate SE Programs

Additional academic instruction might be warranted to prepare graduates for the software-intensive character of many current and increasingly more future systems. It is asserted that the integration of software presents some unique problems (e.g., integration of functionally organized hardware with object-oriented software.)

It was observed that some undergraduate SE programs include applied statistics courses in their curriculum because this specific education instruction is highly valued by some employers of their graduates. It was recommended that other undergraduate SE programs consider including such similar instruction.

Two other subjects that might warrant education instruction consideration by undergraduate SE programs are (1) network /congested systems and (2) systems environmental management (e.g., ISO 14000).

It was recognized that the implementation of these curriculum recommendations might cause some problems with independence and identity of an undergraduate SE program within its parent academic institution. Therefore, further deliberation is desired and necessary.

It was observed that successful SEs in industry have education, training, and experience. Consequently, the appropriateness of permitting an individual graduating with an undergraduate SE BS degree directly starting a MS SE program was questioned. It was stated there is at least one academic institution that requires appropriate work experience to enroll in its master's of SE program.

It was recognized that co-op/internships provide valuable experience for undergraduates and enhances stakeholder support for undergraduate SE programs. However, their implementation is not without costs. Further investigation of improving the operation of co-op/internship with undergraduate SE programs would be useful.