

Unique Education & Workforce Development for NASA Engineers

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Abstract

NASA engineers are some of the world's best-educated graduates, responsible for technically complex, highly significant scientific programs. Even though these professionals are highly proficient in traditional analytical competencies, there is a unique opportunity to offer continuing education that further enhances their overall scientific minds. With a goal of maintaining the Agency's passionate, "best in class" engineering workforce, the NASA Academy of Program/Project & Engineering Leadership (APPEL) provides educational resources encouraging foundational learning, professional development, and knowledge sharing. NASA APPEL is currently partnering with the scientific community's most respected subject matter experts to expand its engineering curriculum beyond the analytics and specialized subsystems in the areas of: understanding NASA's overall vision and its fundamental basis, and the Agency initiatives supporting them; sharing NASA's vast reservoir of engineering experience, wisdom, and lessons learned; and innovatively designing hardware for manufacturability, assembly, and servicing. It takes collaboration and innovation to educate an organization that possesses such a rich and important history—and a future that is of great global interest. NASA APPEL strives to intellectually nurture the Agency's technical professionals, build its capacity for future performance, and exemplify its core values—all to better enable NASA to meet its strategic vision—and beyond.

NASA Engineering Education

Responsible for technically complex, highly significant scientific programs, it is only fitting that NASA employs some of the best and brightest engineers in the world. These graduates of accredited university programs have to exhibit a high level of technical competency before they are even hired. From a knowledge and skill standpoint, NASA already has a very competent and well-trained workforce in place, but continuing education is equally important. NASA offers several career enhancing opportunities for its staff, such as facilitating enrollment in university-provided master's and doctoral programs. But other essential educational options exist internally through the NASA Academy of Program/Project & Engineering Leadership (APPEL). NASA APPEL is managed by the Office of the Chief Engineer at NASA Headquarters in Washington, D.C. APPEL contributes to NASA's mission by promoting individual and team excellence in program/project management and engineering through the application of integrated learning strategies, methods, models, and tools in a practical manner.

Recognizing the necessity of offering blended educational opportunities that address a full range of learning styles and modes, NASA APPEL supports individual practitioners, as well as project and program teams, at every level of development. It does so through four primary business lines: curriculum; knowledge sharing; performance enhancement; and research and advanced concepts. Curriculum lies at the heart of NASA APPEL's approach to building the Agency's

program/project and engineering capabilities. Its courses are designed using project management and systems engineering competency models, and focus on what the participants need to enhance their own capabilities, knowledge, and skills. NASA APPEL utilizes best practices and unrivaled subject matter experts to ensure the best and most appropriate leadership and technical education is available to NASA professionals.

NASA APPEL's curriculum consists of a core curriculum and a wide array of in-depth courses, all of which leverage real-world experiences to reinforce learning and provide an additional means of obtaining requisite skills. The core curriculum develops and enhances the essential skills and knowledge necessary to successfully perform in NASA's established project environment. NASA APPEL in-depth courses are comprised of an extensive collection of project management, systems engineering, and engineering topics that provide more detailed, specialized education to augment the skills and knowledge gained through the core curriculum. This paper focuses on how—through its in-depth engineering course offerings—NASA APPEL is developing and offering unique coursework that enhances the Agency's engineering workforce.

With both a strong undergraduate analytical foundation and higher education opportunities available to NASA engineers, NASA APPEL's mission is to focus on areas in engineers' training that may have been understated or simply lacking during their formal education. In particular, it strives to offer a unique curriculum that specifically supports those with NASA engineering careers. To accomplish this, NASA APPEL reviewed current engineering undergraduate degree requirements and surveyed numerous engineers and engineering managers throughout the Agency. From this data, it identified several areas in NASA's technical workforce's educational background regarded as weak. As a result, NASA APPEL is currently incorporating educational best practices and partnering with some of the scientific community's most respected subject matter experts to expand its engineering curriculum beyond the analytics and specialized subsystems by developing courses in these three key areas:

- I. Understanding NASA's overall vision and its fundamental basis, and Agency initiatives supporting them (Why? Such knowledge is, after all, the primary purpose behind the all work NASA engineers do).
- II. Sharing NASA's vast reservoir of engineering experience, wisdom, and lessons learned (Why? It is imperative to impart this real-world engineering wisdom from seasoned experts to the next generation of NASA engineers).
- III. Innovatively designing hardware for manufacturability, assembly, and servicing (Why? Engineers should "think outside the box" to develop inventive, creative solutions, while mindfully not increasing program risk and cost).

(I) A Better Understanding of What NASA Does

To satisfy this first area of engineering educational needs, it is important to understand the unique requirements related to NASA missions which are described in NASA's Vision Statement: "To understand and protect our home planet, to explore the Universe and search for life, and to inspire the next generation of explorers...as only NASA can." In the development of its engineering courses, NASA APPEL is able to meet the needs of its workforce along with developing three courses that closely support the Agency's vision statement.

NASA APPEL “Earth, Moon, and Mars (EMM)” course: “To understand and protect our home planet...”

Most engineering majors in academia are not required to take a course in geology. At NASA, engineers are tasked with exploring our own planet, the Moon, and Earth’s closest neighbor Mars. Therefore, it is crucial that the engineers who are designing the hardware to accomplish these complex, technical goals understand how our planet works; and also what to expect when the spacecrafts they design and build actually land on the Lunar or Martian surfaces. In order to prepare these engineers who are tasked to achieve such lofty goals, NASA APPEL has developed the *Earth, Moon, and Mars (EMM)* course that explains the formation of the Universe, our solar system, and our planet.

The goal of the EMM course is to reveal the remarkable discoveries of how planetary bodies are formed and the kinds of geologic processes that continue to operate on them today. Participants also learn about the unique geologic properties and the challenges that the Moon and Mars pose to future exploration.

Learning methods include interactive lectures and small-group discussions. The course begins with a study of how the Earth "works." It shows how competing processes such as tectonic formation and erosion continue to battle over Earth’s surface. Participants have an opportunity to examine the current ideas about the structure, dynamics, and composition of the Moon and Mars. The evidence comes from meteorites, satellite remote sensing, and previous NASA missions (manned and robotic) to their surfaces. These lessons are directly applicable to identifying the signatures of ancient life that might still remain on Mars.

After attending this course, participants should be able to:

- Describe systems that continue to shape our planet and how they impact life on Earth (energy sources, water availability, climate change, natural hazards);
- Explain the important influences that life exerts in changing Earth’s surface, as well as how these processes can apply to other planetary surfaces;
- Debate hypotheses about the formation and history of Earth, Moon, Mars, and other planetary bodies;
- Identify the forces that continue to change Earth, Moon, and Mars, as well as the geological conditions that humans will face as they continue to explore them; and,
- Describe how planetary compositions may affect Lunar and Martian landings and roving vehicles.

The *Earth, Moon, and Mars* course is taught by Dr. Michael Wyession, Associate Professor of Earth and Planetary Sciences, Washington University in St. Louis.

NASA APPEL “Essentials of Astronomy for Engineers” course: “...to explore the Universe and search for life...”

Engineers have a specific, well-defined market or industry in which they work, and their product designs focus on well-known, understood attributes of a specific area of interest. To a NASA engineer their “industry” or “market” is the Universe. Therefore, it is sensible for every NASA engineer to possess a foundational understanding of astronomy, since their daily work is

ultimately connected to cutting-edge exploration activities that attempt to answer fundamental questions. NASA APPEL believes it is not only critical to illustrate and explain the Universe to its engineers so they can more fully appreciate the scope and rationale of the work they are involved in, but also vitally important to impart a deeper appreciation for the majesty of the worlds they are tasked to explore through their engineering abilities.

The goal of the *Essentials of Astronomy for Engineers* course is to foster a physical and philosophical understanding of our universe—and incite an interest in learning more. Most engineers earn undergraduate degrees without a foundational background in astronomy. This three-day, highly visual and thought-provoking course for non-astronomers builds fundamental knowledge of the universe and observational astronomy through the expertise of a well-respected subject matter expert.

Learning this overwhelming subject is innovatively accomplished by stepping through material “inside-out” via foundational modules, multi-media resources, and inspiring discussions. Main course topics include a brief history of astronomy; observing our solar system and beyond; the physics of astronomy; our solar systems’ planets, stars, galaxies, and other astronomical bodies; the origin, current state, and future evolution of our solar system; an overview of Space-Time including cosmology and the Big Bang; life as we know it and search for other life; and recommended resources for the astronomy hobbyist. Key NASA missions that are invaluable to the astronomy community are also included. This information is supported by scientific evidence, well-tested theories, vetted philosophies, observational data, and expert opinions.

Upon completion of this course, participants will be able to:

- Explain the high-level essentials of the history and science of astronomy including findings by the ancient philosophers, Newton, and Einstein;
- Discuss the physical creation, ingredients, timeline, scale, and physical evolution of the universe, Solar System, stars, and galaxies, as well as explain its current state and ultimate demise;
- Describe resources leveraged for space studies (telescopes, spacecraft, remote sensing instruments) and defend the importance of NASA’s exploring, monitoring, and analyzing our universe, including properties of the Moon and the Planets; comets and asteroids; the birth and death of stars; black holes and other end states; young and old galaxies; dark matter; dark energy; and more;
- Describe the basics of observational astronomy, including the calendar, seasons, and eclipses; and,
- Use, as an engaged hobbyist, recommended astronomy hardware, software, educational tools and resources, and be aware of local astronomy clubs and dark sky efforts.

The *Essentials of Astronomy for NASA Engineers* course is taught by Dr. Chris Impey, University Distinguished Professor and Deputy Head of the Astronomy Department, University of Arizona in Tucson.

NASA APPEL “NASA Missions: Engineering Exploration” course: “...to inspire the next generation of explorers...as only NASA can.”

As a federally funded government agency, NASA is involved in a wide variety of scientific research, development, and operational programs in both aerospace and aeronautics. In order to allow a workforce that is spread across the country to understand and appreciate the entire scope of NASA's work and the benefits it has brought to mankind, the *NASA Missions: Engineering Exploration* course is being developed. NASA is tasked numerous technical challenges and it is important that all NASA employees are not only aware of, but also well informed about the accomplishments of their Agency, and have an understanding of future plans. This course is being designed for NASA engineers and technicians who are anxious to gain an overall understanding of NASA's engineering in the service of exploration through a core knowledge of human spaceflight and robotic missions—past, present, and future.

The *NASA Missions* course will present detailed synopses of key NASA missions, focusing on what has been accomplished, current undertakings, and potential future endeavors from an engineering and personal passion stance. Learners will recognize how the driving forces behind Agency-wide successes are more than science and analytics, and how innovation, teamwork, and passion are also crucial components of an engineer's daily work. The goal is for attendees to apply this to their own daily thinking. They will also take away rationale for the endeavors that support the Agency's current vision, and will be able to personally craft and publicly convey the importance and purpose of America's space program in their own words with a strong sense of pride.

This three-day course will be conducted through a multi-media rich, thought-provoking, expert-led lecture. The course will include synopses of major NASA human spaceflight missions; major NASA robotic missions; overview and possible timelines of future NASA missions and technical challenges; importance of America's space program; conclusions in support of NASA's current programs and future vision; and recommended resources for continued learning. This knowledge sharing will be supported by historical knowledge and documentation; personal experiences, relationships, and interviews; and public information on NASA's plan for its future.

Upon completion of this course, participants will be able to:

- Understand and communicate the history and the engineering successes that were an integral part of major NASA human spaceflight missions, including Mercury, Gemini, Apollo, Saturn V, Skylab, Apollo-Soyuz, Space Shuttle, Shuttle-Mir, and International Space Station;
- Describe the remarkable accomplishments of major NASA robotic missions, including early near-Earth, Earth-observation, lunar, planetary, outer solar system, and astronomy missions;
- Discuss future NASA missions, technical challenges, and associated timelines for human spaceflight programs and robotic missions; and,
- Defend the rationale and importance of the NASA space program; what it means to education, exploration, national security, the economy, long-term survivability; and why the job they do is important for America and mankind.

The *NASA Missions: Engineering Exploration* course is taught by Andrew Chaikin, science journalist, author, speaker, and renowned authority on space exploration.

(2) Engineering Experience and Lessons Learned

The second area of engineering education NASA APPEL has developed involves cataloging and explaining the vast amount of proven technical “know-how” and lessons learned that NASA possesses as the world’s leading aerospace and aeronautic research agency.

For more than fifty years, NASA has had countless successes along with several tragedies and missteps. Relying heavily upon the lessons gained from over half a century of experience, NASA APPEL has developed two courses that help less experienced engineers gain valuable lessons from both NASA successes and mistakes. Using an extensive catalog of official case studies, NASA APPEL is able to convey key lessons learned and engineering wisdom from seasoned NASA engineers to a whole new generation.

NASA APPEL “Seven Axioms of Good Engineering (SAGE)” course:

NASA has learned tragically from its own past that engineering accomplishments require more than good technical skills. They require a strong dose of engineering wisdom, as well. Such wisdom is gained by appreciating historical achievements and understanding past mistakes. As the Scottish author, Samuel Smiles once wrote: “We learn wisdom from failure much more than from success. We often discover what will do, by finding out what will not do; and probably he who never made a mistake never made a discovery.”¹

The *Seven Axioms of Good Engineering* course takes a reflective look at numerous case studies, both from within NASA and the outside world, to discover where the root causes of most failures reside. Through the investigation of various examples, the attendees lead themselves to the discovery and application of axioms that bring a non-technical, yet crucial, sense of wisdom to the design process. These seven are: 1) avoiding a selective use of historical design data; 2) extrapolating existing data into unknown regions of the design space only with extreme caution; 3) understanding the design's sensitivity and robustness; 4) always testing against physicality; 5) guarding against unanticipated loads and/or failure modes; 6) avoiding highly coupled system unless a strong benefit is shown; and 7) ensuring human understanding of how the system works.

The purpose of SAGE is to promote good engineering design and project management decision-making via the study and discussion of case studies. Such discussions inspire and promote critical thinking, and help improve decision making among NASA engineers, technologists, program managers, and scientists.

The course is primarily taught using a case study format. Participants are given the opportunity to create their own design corollaries and case studies based upon their own experiences, and then present their cases incorporating the engineering axioms learned.

At the end of the course, each student should be able to:

- Demonstrate the value of case studies in critical thinking;
- Identify and explain the seven classical types of design errors, and how to avoid them;
- Explain the importance of non-analytical aspects involved in the design process;

- Integrate design data into design knowledge;
- Extract key decision-making aspects associated with engineering processes from case studies; and,
- Explain how to incorporate lessons learned into their everyday design processes.

The *Seven Axioms of Good Engineering* is taught by Dr. Tony Luscher, Associate Professor, Department of Mechanical Engineering, at the Ohio State University.

NASA APPEL “Space Systems Development: Lessons Learned (SSD)” course:

NASA APPEL took advantage of NASA’s extensive internal reservoir of engineering case studies when developing the *Space Systems Development: Lessons Learned* course. Two former, distinguished NASA engineers/managers review and critique more than 30 aerospace engineering examples in the classroom. Through the use of case histories such as Apollo 13 and the Space Shuttle Challenger “Normalization of Deviance” concept² to lesser-known examples from archives throughout the Agency, NASA engineers learn first hand from these highly experienced thought leaders who were there since the 1960’s, and worked through difficult feats and challenges to acquire invaluable experience.

The goal of the SSD course is to examine the root causes of aerospace-specific mishaps, and the applicable lessons that can be derived from these historical incidents. The majority of space mishaps can be traced to easily recognizable and preventable reasons. Students will learn that implementing specific strategies and project principles are the best means of prevention in the demanding NASA environment.

The learning methods employed in the SSD course involve critical analysis of actual events by seasoned facilitators who possess thorough space system development understanding, as well as first-hand analysis experience. Many never-before-seen archival photographs and videos are included in the presentation, along with meaningful personal anecdotes.

At the conclusion of the course, attendees should be able to:

- Identify systems-specific lessons from selected historical cases treated;
- Demonstrate how normalization of deviance can effect decision points, and how to avoid it; and,
- Translate extracted lessons into concrete strategies for eliminating root causes of problems.

The *Space Systems Development: Lessons Learned* course is taught by Larry Ross, CEO of Aerospace Engineering Associates and former Director of NASA Lewis Research Center (now NASA Glenn Research Center) and Joe Nieberding, President of Aerospace Engineering Associates and former NASA Lewis Research Center Advanced Space Analysis Division Chief.

(3) Innovatively Design Hardware for Manufacturability, Assembly, and Servicing

By nature, engineers tend to be conservative. This is a necessary trait, especially in the aerospace community, where human lives and/or hardware worth billions of dollars are typically at stake in an engineer’s design. So, there are many times when this tendency overshadows an engineer’s

creativity. NASA APPEL's third area of engineering education supports the Agency's understanding that engineers need the freedom and inspiration to develop inventive, creative aspects within their discipline, but still do so in a crucial manner that does not increase risk and cost.

In addition, innovative design and creativity must be communicated effectively to the technicians who will manufacture and assemble the hardware. Too often there has been a disconnect between both of these critical stakeholders. Technicians possess years of valuable practical experience working with hardware that most engineers lack. NASA has seen the value of collaborating and sharing this knowledge via concurrent engineering.

NASA APPEL "Innovative Design and Engineering Applications (IDEAs)" course:
The key to product design and engineering success is to be able to think creatively. This is especially true for NASA engineers who must develop complex hardware that withstands the harshest of environments while generating critical data and mission successes for the space program.

In order to train its engineers to think creatively and always consider new ways to innovate engineering designs, NASA APPEL developed a three-day course entitled *Innovative Design and Engineering Applications (IDEAs)*.

The goal of this course is to make analytically minded engineers feel comfortable thinking differently, and give them training and tools to do so. This is accomplished through the introduction of several established problem-solving techniques used in other industries (such as the Pugh or TRIZ methods), and also by undertaking team projects in class where attendees must design a product with very limited resources.

The learning methods employed in the IDEAs course include an integrated case study comparing the Wright Flyer of 1903 to the Apollo Lunar Lander, which demonstrate the visualization of multi-disciplinary teamwork during the early stages of design. When employed as a whole, lecture materials, hands-on class exercises, case study videos, informal discussions, brainstorming, and group exercises allow participants to apply newly learned techniques to specific design problems and begin to "train their brain" to problem solve in a more innovative manner.

Upon completing this course, participants should be able to:

- Describe a short history of creative engineering solutions and effective methods for communicating new ideas;
- Explain the creative design process, then develop techniques for creative solutions and cost effectiveness;
- Identify appropriate tools for innovation, such as the Pugh or TRIZ methods, and apply them to existing NASA situations and challenges; and,
- Describe current industry best practices and relate them to real-world NASA program scenarios.

The *Innovative Design and Engineering Applications* course is taught by Mr. John Sturrock, Director of Strategic Development for Celerant Consulting.

NASA APPEL “Design for Manufacturability and Assembly (DMA)” course:

Perhaps one of the biggest changes that has taken place in the typical academic engineering program is the de-emphasis of drafting skills and manufacturing training. Prior to the World War II era, many engineers were former machinists who understood the products they fabricated so thoroughly that they were promoted to engineers. Today, this natural progression has migrated in the other direction, as all engineers must be degreed yet, too often, they lack the practical real-world knowledge and experience gained in the machine shop.

The *Design for Manufacturability and Assembly* course was developed with the input of engineers and craftsmen throughout the Agency. The DMA course finds the “middle ground” where NASA’s technical workforce—involved in the design, manufacturing, and assembly of major programs and hardware—is taught how to create a product that functions correctly and robustly. It also shares the “secrets of the trade” that facilitate manufacturing and assembly, along with an eye towards the inevitable need for future maintenance, servicing, and sustainability.

The goal for DMA is to provide students with the skills and insight necessary to design mechanisms, devices, and structural components that are produced quickly, of high quality, and cost effective.

Learning methods employed include a modular lecture with visuals, videos of key manufacturing processes, in-class demonstrations, examples, and exercises. Relevant case studies are also used in this course to enhance participant understanding.

At the conclusion of this course, each attendee should have:

- Better foundational knowledge of how integrated design, manufacturing, assembly process work;
- An understanding of the typical tolerances, surface finishes, and process times that are easily achievable, and those that are achievable only with significantly extra time, cost, and/or effort;
- A determination of major cost drivers;
- A standard set of design rules and guidelines associated with the process being considered;
- The ability to compare and select between several competing processes; and,
- An understanding of where to find additional knowledge about processes.

The *Design for Manufacturability and Assembly* course is co-taught by Dr. Tony Luscher, Associate Professor, Department of Mechanical Engineering, the Ohio State University and Mr. Richard Cournoyer, the group supervisor of the NASA Jet Propulsion Lab’s (JPL) Prototype and R&D Machining Services.

Conclusion

NASA APPEL has conscientiously worked to develop these innovative engineering courses, and continues to add more to its curriculum, by gathering input from internal NASA customers, academia, and industry. After finding and partnering with leading subject-matter experts as course developers and instructors, small-sized classes of up to 30 students are held across the Agency's Centers. The result of NASA APPEL's engineering workforce development efforts resonate at every level: young engineers become more well rounded through foundational courses; mid-career engineers build knowledge to lead programs and projects, and are encouraged to share their wisdom; and seasoned professionals are exposed to NASA's current areas of interest and help champion its vision while functioning as leaders and mentors. Overall, this NASA APPEL coursework offers unique professional development opportunities that enable participants to become and remain preeminent engineers. Moving forward, NASA APPEL plans to shape this engaging course content into eLearning-based education available to NASA professionals and the general public. It is also exploring partnerships with global academia and engineering organizations for modular inclusion within their standard engineering education.

While no formal testing is currently done after attending these engineering courses, feedback surveys are completed by every student for internal review purposes and course improvement. Various factors assessed include: what was learned that will be most valuable to current job responsibilities; what teaching methods contributed most effectively to learning; overall course content ratings; and instructor appraisal. When benchmarked against the entire APPEL catalogue, high marks are typical. All of NASA APPEL's engineering courses are currently being reviewed for American Council on Education (ACE) accreditation.

NASA only receives approximately 0.5% of the U.S. Federal Budget, with quite arguably the highest return on investment. Therefore, its engineers must remain well informed, innovative, and cost-effective to effectively perform and contribute. These courses fulfill the needs of the NASA APPEL curriculum, and goals the Agency itself, by strengthening an engineering workforce that is already well educated, motivated, and passionate. The engineering wisdom shared with participants through lessons learned, "big picture" foundations, and innovative engineering tools all further inspire NASA engineers to deliver the seemingly impossible. It takes collaboration and innovation to educate an organization that possesses such a rich and important history—and a future that is of great global interest. NASA APPEL strives to continually intellectually nurture the Agency's technical professionals, build its capacity for future performance, and exemplify its core values—all to better enable NASA to meet its strategic vision—and beyond.

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