Space Systems Engineering
Professional Development & Certification

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ABSTRACT

In the mid-1990s, the Federal Government pursued "Acquisition Reform," which resulted in significantly reduced government technical oversight of contractors. This caused less technical personnel to be hired in the government program offices for the last ten years. Recent investigations of space problems have recognized the need to revitalize the systems engineering workforce within the government program offices. Two years ago, the National Reconnaissance Office (NRO) embarked on the development of a professional development and certification program for space systems engineering. The NRO workforce is heterogeneous; it is comprised of military and civilian members of all DoD services as well as several intelligence community agencies. Our objective was to develop a program that maximized the synergy with parent-agency programs and avoided any redundant training requirements. A three-level certification program was established that required technical education, systems engineering experience, and systems engineering training. The training selected is a combination of existing NRO courses, off-the-shelf academic courses, commercial training classes, and newly developed classes. After the first year, over 375 employees have attended at least one training class and we are certifying systems engineers at the rate of 10-12 per month. The success of this program has led to potential expansion into other areas of the government.

1. Background

The aerospace industry and especially the national security space arena have enjoyed a high degree of competence in both the industry and government workforce. With the start of the space race, there was a tremendous surge of scientists and engineers being produced by our universities. Working in the aerospace arena was exciting and important to national security.

Three events greatly altered the workforce composition in the 1990s. First, the collapse of the Soviet Union removed the immediate threat to the United States and prompted reductions in budgets for military and space systems and reductions in our military forces. Second, the rise of the "dot-com" enticed our college students to study computer and information technology fields. The dot-coms were paying much higher, albeit unsustainable, salaries than the aerospace industry. Third, Congress instituted Acquisition Reform. Government project offices were supposed to trust the contractors to do the right thing. The former practices of technical oversight were discouraged. Secretary of Defense, William Perry, cancelled the majority of military standards. One of the first casualties of this new policy was MIL-STD-499B, Systems Engineering, which was to be a major revision to the 1974 499A. A blue-ribbon government committee spent 30 months developing this new version. The reduced emphasis on the technical oversight led to a reduction in the hiring of government engineers. Twelve years later, we have a government workforce with a lack of engineers and scientists capable of assessing the quality of their contractor's efforts.

Today, in the post-9/11 era, our need for technical competence is perhaps the greatest in history. The nature of the current terrorist threat requires much more sophisticated space systems than in the past, when we were dealing with a traditional military threat. In addition, our systems are no longer stovepipes. They must operate in a complex system of systems environment, where the system under development must interface with many other complex systems, with existing and evolving capabilities.

To summarize, the table below shows NRO risks over time.

Table 1. NRO Risk Over Time

Era	Time Frame	NRO Willingness to take Risk	Oversight Tolerance for Failure
Intelligence Imperative	1960-1970	High	High
Technology Driven	1970-1990	Medium	Medium
Peace Dividend	1990-2002	High	Low
War on Terrorism	2002 -	Medium	None

2. Recognizing the Problem

The aerospace field is a high-risk environment. Missiles and satellites take many years to design, build and field. Because the systems take so long to implement, the designers push the technology envelope as much as possible. This will ensure the maximum capabilities once in operation. However, stretching for new technologies has a high risk. The early days of the rocket research in the US was littered with failures. One early program had eleven failures before succeeding. The uncertainties were understood and each failure was looked at as an opportunity to learn and get closer to success. Today, Congress would have cancelled the program after the second or third failure.

In the late 1990s, the failure rate for satellites and launches had a significant increase. The government recognized this and asked several panels of greybeards to investigate. Some of the key findings are:

- National security space acquisition process is seriously flawed
- Cost estimates for space programs should be made at the 80% confidence level, instead of 50%

- The government must retain adequate talent to be a "smart buyer"
- Requirements growth is a major cause of cost growth and schedule delays
- Many of the technical problems occurred because of the failure to conduct adequate systems engineering studies
- Previous attempts at "acquisition reform" had the unintended consequence of focusing on cost versus mission success

This recognized lack of systems engineering practitioners prompted calls for reinvigoration of systems engineering. DoD policy called for implementation of "robust systems engineering." In addition, DoD required the development and implementation of a new government planning document, called the Systems Engineering Plan (SEP). The key values of the SEP are: a) it must be updated at each milestone decision point; b) it must be approved by the Milestone Decision Authority; c) it must describe the actions the government program office is taking to assure mission success. The National Reconnaissance Office recognized the need for systems engineers and embarked on a major effort to rebuild their technical staff.

3. The First Step

Our first step was to develop a basic systems engineering training program. We looked at off-the-shelf programs from several training companies, as well as university programs. After an analysis of their offerings against our requirements, we selected the California Institute of Technology's Industrial Relations Center program. It offered a 64-hour program over eight days. Two of our primary objectives related to this training were: a) minimize the business impact of the student's training; and b) ensure that the training is interactive and that credit is not given for merely attending the classes. The class was broken into two teams. The teams were given a specification for a space system. Over the course of the eight weeks, the student teams were expected to carry the design of their system through preliminary design. They were assigned a deliverable at the end of each class. The results of the team work were presented at the start of the following class. The classroom day were separated by at least two weeks to provide time for team interaction. Deliverables in this program include a system specification, system architecture, work breakdown structure, life cycle cost analysis, and a formal one-hour Preliminary Design Review presentation.

This program, which we refer to as SE-501, Acquisition Systems Engineering, has been very successful. We have trained over 150 students. After each class, we review the student comments and adjust the curriculum as appropriate. Here are some of the changes that we have made:

1. The class schedule has been changed from eight days over 14 weeks. The new schedule runs five consecutive days covering the basics of systems engineering. The teams are then given four weeks to develop their design and produce their deliverables. The instructor meets with each team at least once per week to check on progress and provide guidance. This format minimizes the impact on employee business needs.

2. The class was originally held in an unclassified format. By changing it to a classified format with cleared instructors, the students were able to discuss program-related problems. This has proven to be a real benefit to the students.

3. A final day has been added to the program. It provides lessons learned from actual NRO programs. The presenters for this day are Chief Systems Engineers from the programs. The inclusion of these lessons learned personalize the training to the students own work environment.

Variants of this program are being used by several major prime contractors for their internal systems engineering certification program.

The success of SE-501 and the growing need for qualified systems engineers spawned a requirement to expand to a multi-level systems engineering professional development and certification program. The NRO workforce is heterogeneous. It is comprised of military and civilian members of all Department of Defense (DoD) services as well as several intelligence community (IC) agencies. Our objective was to develop a program that maximized the synergy with parent-agency programs and avoided any redundant training requirements. As a result, our first action was to research the certification programs of those agencies as well as those of professional societies.

The International Council on Systems Engineering (INCOSE) developed a formal certification program over a three-year period. This author was an active participant in that development and was able to learn from the issues and roadblocks encountered. We met with the certification points of contact for several intelligence agencies to understand their approach to systems engineering training and certification. Most of their programs were based on systems engineering graduate courses and a syllabus set up by the university.

The DoD program results from the Defense Acquisition Workforce Improvement Act (DAWIA). The DAWIA program certifies at three levels in 13 different areas, one of which is systems engineering, and is called System Planning, Research, Development and Engineering – Systems Engineering (SPRDE-SE). Its requirements are summarized below in Table 2[1].

Table 2. SPRDE - SE Requirements

Level	**Education**	**Experience**	**Training**
1	Baccalaureate degree in engineering, physics, chemistry, biology, mathematics, or a related field or At least 10 years of acquisition experience in SPRDE	1 year of acquisition experience in science or engineering	ACQ 101 – Fundamentals of System Acquisition Management
2	Same as Level 1 required plus Desired MS in engineering, physics, chemistry, biology, mathematics, operations research, management or a related field plus Desired 9 semester hours form accounting, business finance law, economics, industrial management, quantitative methods or organization and management	2 years (4 desired) of acquisition experience in science or engineering	ACQ 201 – Intermediate Systems Acquisition SYS 201 – Intermediate SPRDE
3	Same basic requirements as Level 1 plus Desired advanced degree in engineering, physics, chemistry, biology, mathematics, operations research, management or a related field	4 years of acquisition experience in science or engineering plus 4 additional years of experience in acquisition	SYS 301 – Advanced SPRDE

	plus Desired 12 semester hours as specified in Level 2	positions of increasing responsibility and complexity	

Our concerns with the SPRDE-SE program are the small number of years of experience, which does not have to be in systems engineering, and the lack of any specific requirements for systems engineering training.

4. The NRO Program

Based on the INCOSE, IC and SPRDE-SE programs, as well as reviews of certification approaches used by other professional societies, the NRO Deputy Director for Systems Engineering (DDSE) published NRO Instruction 65-4, *Systems Engineering Professional Development and Certification Program.* It established a 3-level certification based on education, systems engineering experience and systems engineering training. All levels require a baccalaureate degree in physics, mathematics, engineering or a related field. All levels require experience in actual systems engineering related activities. Those requirements are: 2 years for Level 1, 4 years for Level 2 and 7 years for Level 3. To assist the applicants, the 65-4 provides a list of systems engineering roles based on Sarah Sheard's 12 roles of systems engineers[2], with some others added. We do not require that the systems engineering experience be confined to government service. Any post-baccalaureate systems engineering experience is applicable. Many NRO engineers have significant prior experience in industry.

The NRO training requirements are significantly different than other programs. We require specific systems engineering-related training. Level 1 requires SE-501, discussed above, and SE-502, Space Systems Design. SE-502 is a comprehensive five-day course based on Space Mission Analysis and Design[3]. These two courses provide new systems engineers with a basic understanding of the field as well its application to space.

Level 2 training was selected based on observed needs identified in greybeard studies of the NRO workforce. Our objective, at Level 2, was to provide experienced systems engineers with additional training in specific areas related to their job responsibilities. We offer six classes, each two to three days long. The applicants can select any four of the six classes that best apply to their job. The classes offered are:

- Risk Management
- Requirements Development
- Concepts and Architecture
- Integration, Validation, and Verification
- Decision Analysis
- Measurement and Analysis Workshop

The classes above are variations of off-the-shelf courses from government and private training organizations plus two newly-designed courses. Two of these are also offered by one of the parent agencies and eliminates duplicate training. Each has now been offered twice during FY05. Student feedback has been analyzed and slight adjustments have been implemented.

Level 3 training has not been defined yet. Our objective is to provide new material for the senior level engineers to assist them in managing the highly complex development activities. We do not want to duplicate any lower level training. This is the subject of an FY06 task. However, we will award Level 3 certification to any NRO engineer that achieves INCOSE certification. The INCOSE certification requires no specific systems engineering training, but does require experience and education, as well as requiring the applicant to pass a comprehensive standardized exam on systems engineering, based on the INCOSE systems engineering handbook[4].

In order to provide synergy with other IC programs, the NRO permits the applicant to substitute six graduate semester hours of systems engineering-related training for any level's training requirements. This serves to encourage pursuit of a systems engineering masters degree as well. An applicant with a minimum of 18 graduate credits and the required seven years systems engineering experience will be certified at Level 3. Therefore, anyone with an MS or PhD in systems engineering will be certified at a level commensurate with their systems engineering experience.

When one initiates a certification program, there will usually be a number of very senior practitioners, to whom training would be superfluous and insulting. They could probably teach the courses. Many of the professional societies have provided some form of "grandfathering" for the highly experienced people. The NRO approach to this issue was a Legacy Certification option. It provided a one year window from the start of the program in which experienced systems engineers could apply for Legacy Certification. The legacy experience requirements are 4, 8 and 12 years versus the 2, 4, and 7 years for normal certification. Although legacy applicants do not have to fulfill normal training requirements, all must attend a three-day, SE-801, Systems Engineering Executive Overview. SE-801 is a shortened version of SE-501, substituting space-relevant case studies for the extensive student design activities. This class serves to baseline the systems engineering terminology and processes. The Legacy Program has expired now for most NRO engineers. However, it is still applicable to anyone who is within the first year of their initial assignment at the NRO and who is able to meet the legacy requirements. Table 3 summarizes the NRO certification requirements.

Table 3. NRO Certification Program

Level	Experience	Training
I	2 yrs. SE	SE-501 Acquisition Systems Engineering and SE-502 Designing Space Missions *or* 6 SE-related graduate credits
II	4 yrs. SE	Complete 4 from below: SE-601 Risk Management SE-602 Requirements Development/Management SE-603 Concept & Architecture Development SE-604 Integration, Verification & Validation SE-605 Decision Analysis SE-606 Measurement & Analysis Workshop *or* 12 SE-related graduate credits or 6 after Level 1
III	7 yrs. SE	INCOSE Certification or *or* 18 total SE-related graduate credits or 6 after Level 2

•All levels require a baccalaureate degree in engineering, physics, chemistry, mathematics, computer science or a related field.

5. Implementation

The most difficult part of establishing a certification program is getting the word out. To that end, we spent a great deal of time "marketing" it to the practitioners and their supervisors. We presented at staff meetings and all-hands meetings. We presented to senior managers at their regularly scheduled coordination sessions. We published articles in the internal newspaper and an internal magazine. In addition, we make an introductory presentation at each course offering, indicating where the course fits into the overall program, where they can find the program details and who they can contact for assistance. We also offer to review their draft application to ensure that they have complied with the requirements.

The application process is fairly simple. Separate application forms are provided for each level so that the requirements can be built into the forms. The forms and the instructions are provided on the DDSE home page on the internal NRO network. The applications are reviewed immediately upon receipt. If complete and qualified, they are entered into the certification database. Incomplete or unqualified applications are returned with and explanation and suggest actions. Once a month, the package of applications is sent to the certifying authority, the DDSE, for approval. Each successful applicant receives a framed certificate signed by the NRO Deputy Director as well as the DDSE. In addition they receive a congratulatory letter from the DDSE. The certificates and letters are sent to the applicants' supervisors, who are encouraged to deliver it to the applicants at a public forum of the applicants' coworkers so that their accomplishment can be recognized.

The first two applicants were given their certificates at a ceremony with the NRO Deputy Director and DDSE participating. Certification began in October 2004. Figure 1, below, indicates the number of certifications at each level. We are now experiencing an application rate of 10-15 per month and have certified 133 systems engineers in the first year of the program.

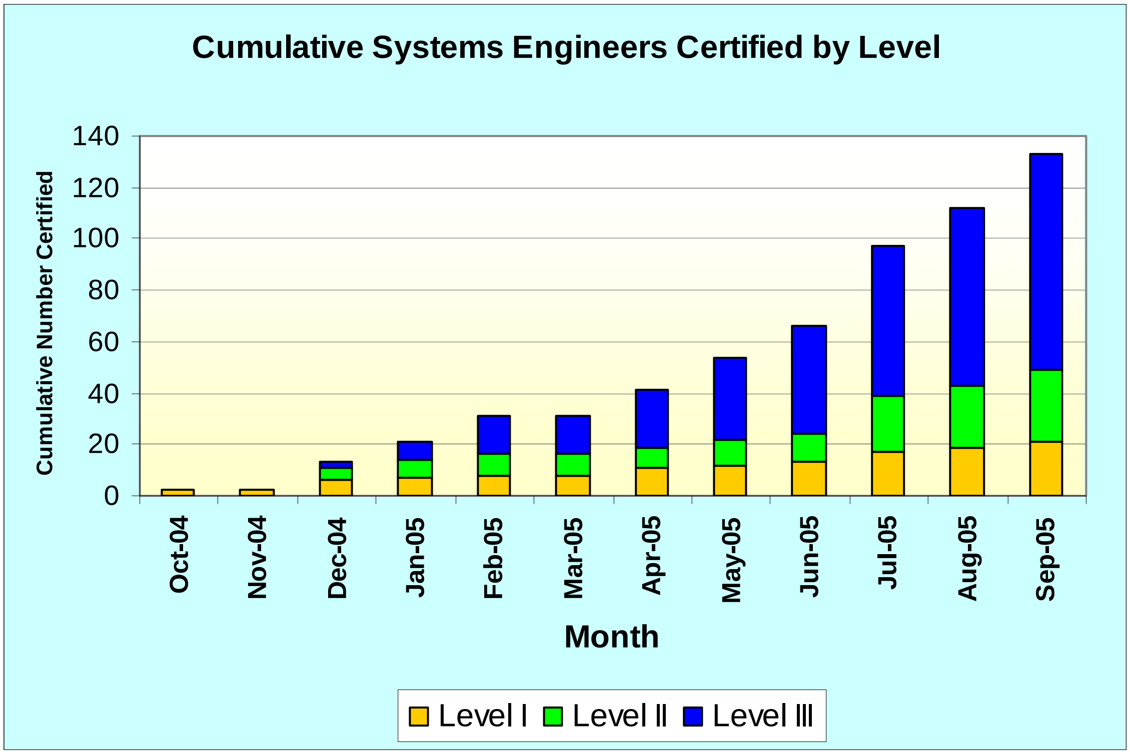

Figure 1. Systems Engineers Certified

6. The Next Step

Training and certifying systems engineers has been very successful. However, there are other areas of professional development that we would like to address in the future. Systems engineering is a hybrid profession. It requires detailed scientific domain knowledge, domain experience, and a strong ability to technically manage a project. In addition, lessons learned and best practices enhance the systems engineer's effectiveness. DDSE has started collecting best practices and lessons learned and is in the process of developing a means of making them available to the workforce. One method of passing on this systems engineering lore is mentoring. We hope to develop a systems engineering mentoring program in FY06.

As mentioned above, we hope to motivate pursuit of advanced degrees in systems engineering. Because of the heavy workload of NRO engineers and their frequent travel, it is very difficult for them to commit to graduate school. Now there are ways to accommodate these issues. Most universities now offer distance learning options via video teleconferencing (VTC). By setting up VTC receive sites in the NRO offices, no travel would be required to attend classes. Most distance learning programs also record their classes and make them available on the web for later viewing by registered students. This accommodation relieves the travel concern. We hope to develop this capability in the future.

Finally, successful programs only occur when there is a strong partnership between the Chief Systems Engineer and the Program Manager. They have similar goals, but approach them from a different aspect. The systems engineer is the "technical conscience" of the Program Manager and needs to ensure decisions are based on sound technical judgment in addition to cost and schedule. We are considering development of a joint systems engineer and program manager class to teach that teamwork and appreciation for the others' responsibility.

7. Biography

Gerard H. Fisher is a senior systems engineer with The Aerospace Corporation, who supports the NRO Deputy Director for Systems Engineering. Mr. Fisher conceived, developed and now administers the NRO's Systems Engineering Professional Development and Certification Program. Mr. Fisher is in his 40th year as a systems engineer. His experience includes roles as Chief Systems Engineer on complex system developments for military customers in the guided missile, space and anti-submarine warfare arenas. He spent 25 years with IBM Federal Systems prior to joining The Aerospace Corporation. Mr. Fisher has a BS in Physics from St. Bonaventure University and an MS in Systems Engineering from Virginia Tech.

8. References

[1] Defense Acquisition University, 2006 Catalog, www.dau.mil/catalog/default.aspx

[2] Sheard, Sarah, Twelve Systems Engineering Roles, Proceedings of the 1996 INCOSE Symposium.

[3] Wertz, James R., and Wiley J. Larson, Space Mission Analysis and Design, Third Edition, 1999, Microcosm Press.

[4] INCOSE Systems Engineering Handbook, INCOSE-TP-2003-016-02**,** Version 2a, June 2004.