If You Want Good Systems Engineers, Sometimes You Have To Grow Your Own!

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Abstract—Given the ever increasing number, scope and complexity of systems today, it is vital to have a cadre of highly trained and skilled systems engineers to ensure that those systems are developed and operated successfully. But from where will those systems engineers come? The Jet Propulsion Laboratory (JPL) has come to the conclusion that if you want them, sometimes you have to grow your own.

The JPL Systems Engineering Advancement (SEA) project was launched in FY2004 to advance the practice of systems engineering at JPL, and to address the three key aspects of change: people, process and technology. A significant major portion of the People component of the SEA Project is devoted to a systems engineering on-the-job training (OJT) program. The SEA OJT program will train 50 systems engineers over a five year period according to a three-pronged systems engineering competency model. This competency model includes technical domain knowledge, understanding of systems engineering standards, processes and practices, and highly valued behavioral attributes. The behavioral attributes fall into four broad categories: leadership, communication, problem solving and systems thinking, and attitudes and attributes.

The SEA Project wrestled with determining the best way to train potential systems engineers along each axis of the competency model, especially how best to inculcate the behavioral attributes. Ultimately, they determined a range of activities that would accomplish their objectives. This mix includes classroom training, hands-on project experience, mentoring and coaching, shadowing, 360 degree feedback, and attending conferences and workshops. This paper provides an overview of the JPL SEA OJT Program including the candidate selection criteria, selection process, training approach and activities, and lessons learned.

1. INTRODUCTION

About JPL

The Jet Propulsion Laboratory (JPL), located in Pasadena, California, is a non-profit federally funded research and development center which is operated by the California Institute of Technology under a contract with the National Aeronautics and Space Administration (NASA). JPL is part of the U.S. aerospace industry, and is NASA’s lead center for robotic exploration of the solar system. In addition to its work for NASA, JPL performs tasks for a variety of other federal agencies, such as the U.S. Department of Defense, the Department of Transportation, and the Department of Energy. JPL is organized into nine directorates as follows:

1. Office of the Director
2. Business Operations Directorate (BOD)
3. Engineering and Science Directorate (ESD)
4. Solar System Explorations Directorate (SSED)
5. Office of Safety and Mission Success (OSMS)
6. Mars Exploration Directorate (MED)
7. Astronomy and Physics Directorate (APD)
8. Earth Science and Technology Directorate (ESTD)
9. Interplanetary Network Directorate (IND)

The organizational structure within a directorate includes groups, sections, divisions and then directorate. JPL uses a matrix organizational structure where the technical divisions within the ESD supply products, services and people to the program and project offices within the programmatic directorates. JPL has approximately 5000 employees; 4000 in the technical divisions of ESD and the programmatic directorates and 1000 in the administrative divisions of BOD. Its annual budget is approximately $1.5 billion.

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2 IEEAC paper #1522, Version 4, December 8, 2006
Background

Motivated by some highly visible failures resulting in mission loss (e.g., Mars ’98) and by a NASA-wide systems engineering initiative, JPL undertook an effort to advance the way it practices systems engineering. Another driver was the large increase (almost a factor of ten) in the number of projects being implemented simultaneously, compared to the era in which JPL’s traditional practice of systems engineering was developed. The Lab’s senior management formed the Systems Engineering Advancement (SEA) Project in order to “significantly advance the practice and organizational capabilities of systems engineering at JPL on flight projects and ground support tasks.”

2. SEA Project Summary

The scope of the SEA Project includes the systems engineering work performed in all three dimensions of a program, project, or task:

1. the full life-cycle, e.g., concept through the end of operations
2. the full depth, e.g., Program, Project, System, Subsystem, Element (SE Levels 1 to 5)
3. the full technical scope, e.g., the flight, ground and launch systems, avionics, power, propulsion, telecommunications, thermal, etc.

The SEA Project realizes that major change initiatives must address the three aspects of change – people, process, and technology (see Figure 1) – and that proactively deploying those changes is essential [10]. It does this by utilizing customer relationship management (CRM) and organizational change management (OCM) to ensure that it is reaching its true target audience and that the desired changes are being adopted [4], [6], [7], [8], [12].

The SEA Project is structured in a way that addresses these aspects of change and is comprised of the four components described below [13].

1. The SEA Project Management manages the SEA Project and all its activities, and communicates with JPL senior management and with other external interfaces.
2. The Process, Product, Tools and Technology (PPTT) Element captures, defines, and refines repeatable systems engineering procedures and practices for project use. It also identifies existing and emerging technology and tools which support systems engineering activities, especially those that provide model-based engineering capabilities.
3. The People Element supports the recruiting, selection and development of systems engineers via strategic hires, career path planning, SE competency model, seminars, classroom training, mentoring and on-the-job training (OJT).
4. The Deployment Element promotes communication and infuses practices into project use; measures the project’s progress toward its objectives and requirements; and provides the infrastructure for the SEA Project.

![Figure 1 How the SEA Project Addresses the Three Key Aspects of Change](image)

The SEA Project was able to build on some previous process improvement activities at JPL in the 1980’s and 1990’s, including Total Quality Management (TQM), Process-Based Management (PBM), ISO 9000 certification, and the Software Resource Center (SORCE). In addition, significant leverage has been gained from the work of the Software Quality Improvement (SQI) Project initiated in FY 2002 [11]. They also conducted several benchmarking trips to aerospace organizations that have achieved high maturity level ratings against SEI’s Capability Maturity Model Integration (CMMI) to study and observe their approach to systems engineering and process improvement.

SEA On-The-Job Training Program

A significant portion of the SEA People Element is the SEA On-The-Job Training (OJT) Program. The SEA OJT Program responds to a strategic initiative at JPL to increase the number of highly trained systems engineers at the Lab. The objective of the program is to identify and enhance the competency of the next generation of systems engineers for JPL flight projects. The goal is to establish a systems engineering development program and to identify engineers currently at JPL to go through training, mentoring, shadowing, and internship. The SEA Project also funds
mentors to work with each protégé and to share their expertise. The SEA OJT program will select 10 engineers each year for five years.

Training personnel is really not optional as some might think, and worrying about employee turnover is no excuse either. As leadership expert John Maxwell likes to say, “The only thing worse than training someone and having them leave is NOT training them and having them stay!”

The remainder of this paper focuses on the SEA OJT Program. It includes a description of the systems engineering competency model and an overview of the SEA OJT program itself, including the candidate selection criteria, selection process, training approach and activities, and lessons learned.

3. SE COMPETENCY MODEL

The SEA Project developed a systems engineering competency model along three axes that includes Technical Knowledge, Process Knowledge, and Personal Behaviors (see Figure 3). The Technical Knowledge axis represents systems engineering knowledge in the ~20 product domains used in JPL flight projects [23], [24]. The Process Knowledge axis encompasses the ten systems engineering functions. The Personal Behaviors axis encompasses four clusters and 14 behaviors. These behaviors are similar to those found by Davidz and Maier [3], [16]. Each of these axes is discussed in more detail below. This competency model will be used to screen candidates for external hire, to conduct internal assessments of systems engineers, and to drive training content and active career management.

Technical Knowledge Axis

Good systems engineers at JPL have a technical grasp of, and appreciation for, system engineering at all levels. They are usually a generalist in nature, but with proven technical depth in one or two product domains, e.g., Flight System, Mission Operations System (MOS), Radar, Avionics, Software, etc. The list of hierarchical JPL flight project levels and the ~20 corresponding flight project product domains is shown in Table 1. Good SEs have technical knowledge of both flight and ground systems. They know when a technical solution is obvious, and when a more formal decision process is warranted. They know how to engage specialists for their technical knowledge and abilities. They know what their peers and counterparts are doing in the field of Systems Engineering. Lastly, they may speak at conferences or hold memberships in technical organizations.

Process Knowledge Axis

The Processes axis encompasses the ten systems engineering functions listed below.

1. Develop System Architecture
2. Develop and Maintain Requirements
3. Develop and Maintain Interfaces
4. Analyze and Characterize the Design
5. Verify and Validate
6. Conduct Technical Reviews
7. Manage Technical Resources
8. Participate in Risk Reviews
9. Manage and Control the Design
10. Manage the Systems Engineering Task

Note that the SE functions tend to fall into two broad categories – life-cycle dependent activities and management and oversight activities. The first category consists of life-cycle dependent activities such as developing the system architecture, developing requirements, characterizing the design, and verifying and validating the system. The second category consists of management and oversight activities such as conducting reviews, managing technical resources and risk, managing and controlling the design and even managing the SE task itself. Note that these 10 SE functions can and should be practiced at all five levels of the flight project. Good systems engineers have proven knowledge of these systems engineering functions. They understand the essence of the JPL Design Principles and the Flight Project Practices and understand appropriate deviations based on specific circumstances.

Personal Behaviors Axis

The SEA Project utilized a rigorous process to identify a list of highly valued personal behaviors of systems engineers [5]. The process was performed by a person from the Leadership and Organizational Development Group in the Human Resources Professional Development Section who is trained in psychology and organizational behavior. She interviewed and “shadowed” nine highly regarded systems engineers. Then she analyzed common themes and grouped information into clusters of competencies with associated behaviors. She also reviewed and sought concurrence with the interviewees on the overall competencies. The behaviors identified fell into the clusters shown below.

1. Leadership Skills
   - Has the ability to influence
   - Has the ability to work with a team
   - Has the ability to trust others
   - Communicates vision and technical steps needed to reach implementation
   - Mentors and coaches less experienced systems engineers

2. Attitudes and Attributes
   - Has intellectual self-confidence
   - Has intellectual curiosity
   - Has ability to manage change
   - Remains objective and maintains a healthy skepticism
3. Communication
  - Advances ideas and fosters open two-way discussions
  - Communicates through storytelling and analogies
  - Listens and translates information

4. Problem Solving and Systems Thinking
  - Manages risk
  - Thinks critically and penetrates a topic in a methodical manner

She also administered the Myers-Briggs Type Indicator (MBTI®) to each of the highly regarded systems engineers in order to identify their personality or psychological type. (The MBTI consists of four temperaments and 16 types. See Table 2 for more information on the MBTI [27].) They all fell into two of the four basic temperaments – Rational (Intuitive Thinking, NT) and Guardian (Sensing Judging, SJ). Within those two temperaments, they were identified with the following seven types: INTJ (Forseer/Mobilizer), ENTP (Inventor/Improvisor), INTP (Inventor/Designer), ENTJ (Director/Commandant), ISTJ (Overseer/Inspector), ISFJ (Provider/Nourisher), and ESFJ (Provider/Caretaker). See Figure 4 for these preliminary MBTI results for JPL SEs in graphic form.

In addition, she found that good systems engineers typically view the system or subsystem as a non-linear web of “connects” or “disconnects” to be solved. They have the ability to view the big picture, zoom in to pin-point the “disconnect”, and then zoom back out to the big picture, while at the same time looking at the interrelationships and patterns in the system or design. They have a high degree of curiosity mixed with self-confidence and persistence and are achievement-oriented. They may describe themselves as having extraordinary physical insight to see the connections and interrelationships between what they are doing and the world around them. They are drawn to the challenge of solving complex problems and are creative in the midst of numerous constraints. These findings are consistent with the literature on highly successful and effective people [1], [2], [17], [18], [19], [20]. Now the SEA Project is working with line managers to inculcate these valued behaviors into members of their systems engineering community and to utilize this list in their interviewing process.

4. SEA OJT SELECTION PROCESS

**SEA OJT Selection Criteria**

The selection criteria for SEA OJT candidates include:
- **Career Phase:** Is in early or mid-career phase (~5 to 15 years of relevant professional experience)
- **Potential:** Has the potential of being among the best systems engineers in their organization
- **SE Functions:** Appreciates the value of implementing the SE functions
- **SE Behaviors:** Has many of the preferred SE behaviors
- **SE Experience:** Has had some systems engineering work experience
- **Project Experience:** Has had flight project delivery experience (software or hardware) e.g., Cognizant Engineer, Integration and Test Engineer, ATLO (Assembly, Test and Launch Operations) Engineer, or mission operations
- **Flight Project Product Domains:** Is representative of a cross section of the 20 flight project product domains.

**SEA OJT Selection Steps**

Enrollment in the Systems Engineering OJT program is a competitive process. The total lead time for the selection process is approximately three (3) months (mid-August to mid-November). The selection process includes the following eight steps.

1. The Director for the Engineering and Science Directorate (ESD) and the SEA Project Manager issue an e-mail call to invite interested individuals and their managers to participate in the OJT program. Either the individuals notify their managers, or managers may notify individuals of interest.
2. Division managers in ESD and OSMS nominate individuals based on specified criteria, write a recommendation letter for each candidate, and prioritize the candidates from their division.
3. The SEA Project confirms the selection criteria and schedules interviews for about 30 candidates who meet them.
4. The SEA Project interviews the confirmed candidates and screens for the highly valued SE behaviors.
5. The SEA Project ranks the candidates and makes recommendations for down-select and follow-on interviews based on interview results and consensus rankings.
6. Formulation Phase and Implementation Phase teams conduct follow-on interviews with SEA OJT candidates.
7. The SEA Project down-selects to the top ten candidates and then notifies the selected participants.
8. The selected individuals must accept the SEA OJT selection and make a commitment to spend an average one day per week on the program for the duration of their time in it.
9. The SEA Project publicizes the selection of the SEA OJT participants.
SEA OJT Interview Process

The interview process for the SEA OJT program is conducted in two rounds. In round one, four interviewers representing various areas of technical expertise including systems engineering and software engineering, as well as behavioral components, conduct one-hour interviews of all candidates who meet the stated selection criteria.

The interview questions explore numerous aspects, such as the nature of the candidate’s interest in the program, their technical experience and educational background, technical and professional expertise, technical writing, productivity, and behavioral aspects. An interview question that helps characterize the candidate’s technical depth and understanding is, “Tell us one of the most difficult problems you had to solve. What was it and how did you go about solving it?” An example of a question that addresses the behavioral aspect of working on a team would be, “Tell us a time when you had to build consensus with different team members. Step us through how you did it.”

As the candidate discusses his/her work experience, characterizes the system on which he/she worked and describes the nature of the types of problems faced and tradeoffs made, it becomes apparent the degree to which he/she views things from a systems perspective and how broadly and deeply he/she grasps systems engineering concepts and approaches. Following each interview, the interviewed candidate is evaluated on a scale of one to five.

Throughout the month-long interview cycle, the candidates are periodically ranked as a whole into three categories: high, medium and low. Only those candidates who are ranked as high are then called back for the second round of interviews. In round two, the candidates are evaluated by personnel from the formulation phase and the implementation phase. Then these remaining candidates are ranked again and a final selection of the top ten is made.

5. SEA OJT Training Approach

The SEA OJT program works as follows:

1. A “5 Party Agreement” is signed by the SEA OJT Participant, his/her Technical Group Supervisor, Project Element Manager, Mentor, and SEA Manager to ensure all parties agree to their participation in the program.

2. The SEA Project Manager, JPL HR Professional Development, and the SEA OJT participant together create an individual “Development Plan”

3. Participants are funded an average of eight (8) hours per week.

4. Participants spend on average approximately one hour per week with their mentor.

5. The SEA Project holds Monthly Protégés meeting with all the participants.

6. The SEA Project and HR Professional Development hold monthly meetings with each participant to update his/her individual Development Plan and to track progress.

SEA Training Activities

The SEA Project wrestled with determining the best way to train potential systems engineers along each axis of the competency model, especially how best to inculcate the behavioral attributes. Ultimately, they determined a range of activities that would accomplish their objectives. This mix includes classroom training, hands-on project experience, mentoring, shadowing, 360 degree feedback, attending conferences and workshops, etc. However, the program does not use a “cookie cutter” approach to training in which everyone takes the same classes or SE opportunities. Instead, upon selection each participant completes an individualized OJT implementation plan based on any gaps in their SE abilities and on the 360 degree feedback. Each of the training activities is discussed in more detail below.

Classroom Training

Classroom training falls into four main categories: general systems engineering classes, technical product domain classes, SE function classes, and SE domain overview classes also called “Lunch and Learn” seminars. The classes available in each category are listed below.

General systems engineering classes include:
1. NASA Systems Engineering
2. JPL Systems Engineering
3. Mission Architecting

Technical Product domain classes include:
1. Project Systems Engineering
2. Flight System
3. Mission Operations System (MOS)
4. Ground Data System (GDS)
5. Flight Software
6. Guidance and Control
7. Power
8. Telecommunications
9. Avionics
10. Mechanical
11. Thermal
12. Instruments and Introduction to Flight Science Instruments
13. Electric Propulsion
SE function classes include:
1. Concepts of Model-Based Engineering (MBE)
2. State Analysis
3. Requirements Analysis & Management Using DOORS
4. UML: A Comprehensive Hands-On Introduction

SE “Lunch and Learn” Domain Overview Seminars include:
1. Ground Data System
2. Software
3. Telecommunications
4. Spacecraft Power
5. Avionics
6. Mechanical Systems Engineering
7. Thermal Systems Engineering
8. Propulsion Systems Engineering
9. Planetary Protection Systems Engineering
10. Flight Software

Hands-On Project Experience

Project experience can be gained by attending and observing activities in various phases of the system life-cycle such as formulation, development and/or operations. Formulation phase activities could include participating on a proposal team, observing a Team X study, attending a JPL Frontliners monthly meeting or participating in Program Office Directed Studies. Development phase activities could include attending major reviews for a flight project, such as a System Architecture and Requirements Review (SARR), Preliminary Design Review (PDR), Critical Design Review (CDR), ATLO Readiness Review (ARR), Environmental Test Readiness Review (ETRR), or Critical Events Readiness Review (CERR). Operations phase activities could include spending some time observing a mission operations team from a major flight project in action, such as the Cassini mission to Saturn, the Mars Reconnaissance Orbiter (MRO) mission, the Mars Exploration Rover (MER) mission, or the Spitzer Space Telescope mission. Lastly, additional experience could be gained by serving as a recording secretary for a meeting of the JPL Engineering Board (JEB) at which major systems issues are discussed and resolved.

Conferences and Workshops

SEA OJT participants are encouraged to attend relevant conferences, workshops and symposia such as the International Council on Systems Engineering (INCOSE) International Symposium, Ground Systems Architecture Workshop (GSAW), Conference on Systems Engineering Research (CSER), National Defense Industry Association (NDIA) Systems Engineering Conference, IEEE Aerospace Conference, etc.

360 Degree Feedback

Each SEA OJT participant is given a 360 degree feedback opportunity. This is a process which enables a person to receive confidential, anonymous feedback from a number of people around him/her, e.g., from his/her managers, peers, customers and team members regarding the degree to which he/she demonstrates the highly valued SE behaviors. Figure 2 shows the sources of feedback and Table 2 shows the differences between 360 degree feedback and a typical annual performance evaluation. The benefits of the 360 degree feedback process are described below.

1. The process allows the participant to see a more complete picture of his/her strengths and development needs.
2. Perception is reality and this process helps individuals understand how others perceive them.
3. Confidentiality allows professionals to hear feedback without becoming defensive or feeling publicly exposed.
4. The anonymous nature allows people to communicate feedback they may have felt uncomfortable sharing otherwise.
5. Participants can better manage their own performance and careers.
6. Feedback is essential for learning.

The outcome of the process is a gap analysis between how the person sees himself/herself and how others perceive him/her.

![Figure 2 Sources of 360 Degree Feedback](image-url)
provide information to help improve the participant’s performance, such as relevant articles or books, e.g., [17], [18], [19], [20].

*Mentoring and Coaching*

SEA OJT participants are each assigned a mentor who models the highly desired SE behaviors. The protégé meets with his/her mentor several times per month to discuss the SE behaviors and to be coached in applying them. This is based on the assumption that some things are “better caught than taught.”

In his book *The 360 Degree Leader* [16], author and leadership expert John Maxwell, defined a good five-part process for on-the-job training as follows.

1. **I DO IT.** The process begins with knowing how to do something myself.
2. **I DO IT AND YOU WATCH.** After I have mastered the process, I take you with me and ask you to watch.
3. **YOU DO IT AND I WATCH.** At some point, you jump in and actually try it. My role is to encourage you, gently correct you and redirect you as needed.
4. **YOU DO IT.** I step back and give you some room so that you can master it.
5. **YOU DO IT AND SOMEONE ELSE WATCHES.** I help you find someone else to develop, and encourage you to get started. You never really know something until you teach it to someone else.

This is also a good description of the approach used in the SEA OJT program. Mentors and protégés discuss a wide range of topics, everything from the role of SE in risk decisions to problem solving, fault protection, models, architectural decisions, SE behaviors, areas of improvement from the 360 degree feedback, how to deal with different personalities, overall career path and career development [14].

In addition, the OJT participants work with a coach from JPL Professional Development to address the results from their 360 degree feedback. The coach helps the individual to understand the feedback and keep a balance of positives and negatives. The coach also helps to build a realistic view of the development needs. Together they establish a practical development plan, and the coach and OJT participant meet monthly to review progress.

*Shadowing SE Masters*

JPL has identified a number of systems engineering experts or “masters.” The SEA OJT participants are given an opportunity to “shadow” these experts or “masters” in order to observe their behavior on the job and to see good systems engineering modeled in a true life environment. The opportunity to observe master SE’s conducting real work and observing real-time behaviors is worth a thousand words. Participants are asked to observe a particular behavioral trait and then discuss with their mentor what they observed. Participants ground their learning by asking questions about what was observed. What motivated the mentor to behave in a particular manner? What were they hoping to accomplish? Did they achieve the result they were looking for? These questions help to ground the learning with the mentor. This also gives the mentor an opportunity to reflect on his/her own behavior.

*Process Training*

Process training includes reviewing the ten SE practices and then meeting with each of the ten SE Function Masters for at least an hour in order to understand how to apply that function on the job. It also includes reviewing the applicable SE procedures for their SE domain.

Lastly, the SEA OJT candidates are given an opportunity to have lunch with the Director of the JPL in order to get to know JPL Senior Management and to better understand the strategic direction of the Laboratory.

**6. SEA OJT Lessons Learned**

The lessons learned on the SEA OJT Program fall into two broad categories: lessons from the selection process and lessons from the training implementation process.

*Selection Lessons Learned*

1. Conducting interviews with each of the candidates who meet the criteria is an essential element in the selection process. A person’s resume can look good, but it’s impossible to determine if a candidate has the desired personal behaviors without face to face contact and interaction.
2. Having people with different technical backgrounds and perspectives conducting the interviews ensures that each candidate is evaluated fairly and accurately.
3. It’s important to keep the end goal of developing the next generation of systems engineers in mind. Otherwise, one can be swayed by education or analytical ability alone which is a necessary, but not sufficient, part of the equation.

*Implementation Lessons Learned*
4. OJT participants need to take ownership of the program and make it a priority to attend training events. They get out of it only what they put into it. They need to be self-motivated and disciplined.

5. The 360 degree feedback is a very valuable component of the program since it gives a person an accurate reflection of how others perceive him/her and serves as the basis for growth and improvement.

6. The role and responsibility of serving as a mentor needs to be more clearly defined and agreed upon. In some cases, their time together could be more structured in order to maximize the opportunity together.

7. Mentoring training needs to be provided to the mentors prior to working with the OJT participants. Several of the mentors do not understand how to mentor. The training would include what makes a successful mentoring relationship and what are the avoidable derailment factors. In addition, this training would assist the pairs to focus on one or two behavioral goals which could be achieved within a 12-18 month timeframe.

8. OJT participants need to see additional SEs other than their own mentor exhibiting the desired behavioral competencies. They need to shadow several highly regarded SE’s in order to see varying approaches to reach a desired outcome. This allows the OJT participant an opportunity to gain greater awareness of how different people approach and solve problems. This also allows the participant to assess where his/her style falls in the spectrum of highly regarded SE’s.

9. It is difficult to find enough mentors since the really good SEs are already in demand and are usually overworked.

7. SUMMARY

In order to ensure that a cadre of highly trained and skilled systems engineers is available to successfully support systems being developed and operated, sometimes you have to grow your own. This growth process must be approached deliberately, systematically and methodically with the long view in mind. It takes several years to see the fruits of the investment, but it is worth the cost. It needs to be viewed as the cost of doing business and as an investment in the next generation.

Lastly, when training future systems engineers, all three axes of the SE competency model must be addressed – technical knowledge, process knowledge and personal behaviors – and the personal behaviors component is where the maximum leverage is gained. Knowing how successful systems engineers behave and sharing that information with the SE community establishes a standard for hiring, evaluation and personnel development.

8. ACKNOWLEDGEMENTS

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- SEA OJT Classes I and II – SEA OJT Protégés

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9. ACRONYMS AND ABBREVIATIONS

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>APD</td>
<td>Astronomy and Physics Directorate</td>
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<tr>
<td>ARR</td>
<td>ATLO Readiness Review</td>
</tr>
<tr>
<td>ATLO</td>
<td>Assembly, Test, Launch and Operations</td>
</tr>
<tr>
<td>BOD</td>
<td>Business Operations Directorate</td>
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<td>Caltech</td>
<td>California Institute of Technology</td>
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<td>CASE</td>
<td>Computer Aided Systems Engineering</td>
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<td>CDR</td>
<td>Critical Design Review</td>
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<tr>
<td>CERR</td>
<td>Critical Events Readiness Review</td>
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<td>CMMI</td>
<td>Capability Maturity Model Integration</td>
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<td>CRM</td>
<td>Customer Relationship Management</td>
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<td>CSER</td>
<td>Conference on Systems Engineering Research</td>
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<td>DNP</td>
<td>Develop New Products (process)</td>
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<td>DOORS®</td>
<td>Dynamic Object-Oriented Requirements System</td>
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<td>Deep Space Network</td>
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<td>EEIS</td>
<td>End-to-End Information System</td>
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<td>Entry, Descent and Landing</td>
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Table 1 Systems Engineering Levels and Domains

<table>
<thead>
<tr>
<th>#</th>
<th>System Levels</th>
<th>Flight Project Product Domains</th>
<th>Sub-Domains Included</th>
</tr>
</thead>
</table>
| 1  | Program       | ● Program                      | ● Planetary and Lunar Missions  
  |    |               |                           | ● Mars Missions          |
|    |               |                               | ● Earth Missions         |
|    |               |                               | ● Astronomy and Physics Missions |
|    |               |                               | ● Interplanetary Network  |
| 2  | Project       | ● Project                      | ● End-to-End Information System (EEIS) Systems Engineer  
  |    |               |                           | ● Project Software Systems Engineer (PSSE)          |
|    |               |                               | ● Entry, Descent and Landing (EDL) Systems Engineer   |
|    |               |                               | ● Fault Protection Systems Engineer           |
|    |               |                               | ● Mission Planning             |
|    |               |                               | ● Navigation and Trajectory Design |
| 3  | System        | ● Flight System/Spacecraft    | ● Payload Accommodation Systems Engineer |
|    |               | ● Payload                      |                                     |
|    |               | ● Mission Operations System (MOS) |                                 |
|    |               | ● Ground Data System (GDS)     |                                     |
| 4  | Subsystem     | ● Avionics                     | ● NA                        |
|    |               | ● Deep Space Network (DSN)     |                                     |
|    |               | ● Guidance, Navigation and Control (GN&C) |             |
|    |               | ● Mechanical Systems           |                                     |
|    |               | ● Planning and Execution       |                                     |
|    |               | ● Power Systems                |                                     |
|    |               | ● Propulsion Systems           |                                     |
|    |               | ● Radar Systems                |                                     |
|    |               | ● Science Instrument           |                                     |
|    |               | ● Software                     |                                     |
|    |               | ● Telecommunications           |                                     |
|    |               | ● Thermal/Fluid System         |                                     |
|    |               | ● Tracking System              |                                     |
Personal Behaviors

Leadership Skills
- Has the ability to influence
- Has the ability to work with a team
- Has the ability to trust others
- Communicates vision and technical steps needed to reach implementation
- Mentors and coaches less experienced systems engineers

Attitudes and Attributes
- Has intellectual self-confidence
- Has an objective and comprehensive view of the SE job
- Maintains a healthy skepticism with an attitude of “prove it”
- Has intellectual curiosity and seeks interrelationships
- Has ability to understand and manage change

Communication
- Advances ideas and fosters open two-way discussions
- Communicates through storytelling and analogies
- Listens effectively and translates information

Problem Solving and Systems Thinking
- Manages risk
- Thinks critically and penetrates a topic in a methodical manner

Processes
- Has proven knowledge of systems engr. practices
1. Develop the system architecture
2. Develop and maintain requirements
3. Develop and maintain interfaces
4. Manage and allocate technical resources
5. Analyze and characterize the system design
6. Verify and validate the system requirements and designs
7. Identify, manage and mitigate risks
8. Organized technical peer reviews
9. Manage the design process
10. Manage the systems engineering task

Technical Knowledge
(domain/discipline specific)
- Successfully expresses a technical grasp of system engineering at all levels
- Is a generalist in nature, with proven technical depth in one or two SE disciplines

Program Systems Engineering
Project Systems Engineering
Flight/Spacecraft/Payload Systems Engineering
Mission Operations System (MOS) Systems Engineering
Ground Data System (GDS) Systems Engineering
Avionics Systems Engineering
Deep Space Network (DSN) Systems Engineering
Entry, Descent and Landing (EDL) Systems Engineering
Guidance, Navigation and Control Systems Engineering
Instrument Systems Engineering
Mechanical Systems Engineering
Planning & Execution Systems Engineering
Power Systems Engineering
Project Software Systems Engineering (PSSE)
Propulsion Systems Engineering
Radar Systems Engineering
Software Systems Engineering (SSE)
Telecommunications Systems Engineering
Thermal/Fluid Systems Engineering
Tracking System Systems Engineering

Figure 3 Systems Engineering Competency Model
### Table 2 Myers-Briggs Type Indicator (MBTI) Mental Processes and Orientations [27]

<table>
<thead>
<tr>
<th>Natural energy orientation</th>
<th>Extraverted (E)</th>
<th>Intraverted (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Face is directed towards the OUTER world of activities, excitement, people, and things.</td>
<td>Face is directed inward to the INNER world of thoughts, interests, ideas, and imagination.</td>
</tr>
<tr>
<td></td>
<td>• Act first, think/reflect later</td>
<td>• Think/reflect first, then act</td>
</tr>
<tr>
<td></td>
<td>• Feel deprived when cutoff from interaction with the outside world</td>
<td>• Regularly require an amount of “private time” to recharge batteries</td>
</tr>
<tr>
<td></td>
<td>• Usually open to and motivated by outside world of people and things</td>
<td>• Motivated internally, mind is sometimes so active it is “closed” to outside world</td>
</tr>
<tr>
<td></td>
<td>• Enjoy wide variety and change in people relationships</td>
<td>• Prefer one-to-one communication and relationships</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Way of perceiving or understanding and taking in information</th>
<th>Sensing (S)</th>
<th>Intuitive (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The Sensing side of our brain notices the sights, sounds, smells and all the sensory details of the PRESENT. It categorizes, organizes, records and stores the specifics from the here and now. It is REALITY based, dealing with “what is.” It also provides the specific details of memory and recollections from PAST events.</td>
<td>The Intuitive side of our brain seeks to understand, interpret and form OVERALL patterns of all the information that is collected and records these patterns and relationships. It speculates on POSSIBILITIES, including looking into and forecasting the FUTURE. It is imaginative and conceptual.</td>
</tr>
<tr>
<td></td>
<td>• Mentally live in the Now, attending to present opportunities</td>
<td>• Mentally live in the Future, attending to future possibilities</td>
</tr>
<tr>
<td></td>
<td>• Using common sense and creating practical solutions is automatic-instinctual</td>
<td>• Using imagination and creating/inventing new possibilities is automatic-instinctual</td>
</tr>
<tr>
<td></td>
<td>• Memory recall is rich in detail of facts and past events</td>
<td>• Memory recall emphasizes patterns, contexts, and connections</td>
</tr>
<tr>
<td></td>
<td>• Best improvise from past experience</td>
<td>• Best improvise from theoretical understanding</td>
</tr>
<tr>
<td></td>
<td>• Like clear and concrete information; dislike guessing when facts are “fuzzy”</td>
<td>• Comfortable with ambiguous, fuzzy data and with guessing its meaning.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Way of forming judgments and making choices and decisions</th>
<th>Thinking (T)</th>
<th>Feeling (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The Thinking side of our brain analyzes information in a DETACHED, objective fashion. It operates from factual principles, deduces and forms conclusions systematically. It is our logical nature.</td>
<td>The Feeling side of our brain forms conclusions in an ATTACHED and somewhat global manner, based on likes/dislikes, impact on others, and human and aesthetic values. It is our subjective nature.</td>
</tr>
<tr>
<td></td>
<td>• Instinctively search for facts and logic in a decision situation.</td>
<td>• Instinctively employ personal feelings and impact on people in decision situations</td>
</tr>
<tr>
<td></td>
<td>• Naturally notices tasks and work to be accomplished.</td>
<td>• Naturally sensitive to people’s needs and reactions.</td>
</tr>
<tr>
<td></td>
<td>• Easily able to provide an objective and critical analysis.</td>
<td>• Naturally seek consensus and popular opinions.</td>
</tr>
<tr>
<td></td>
<td>• Accept conflict as a natural, normal part of relationships with people</td>
<td>• Unsettled by conflict; have almost a toxic reaction to disharmony.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Action orientation towards the outside world</th>
<th>Judging (J)</th>
<th>Perceiving (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A Judging style approaches the outside world WITH A PLAN and is oriented towards organizing one's surroundings, being prepared, making decisions and reaching closure and completion.</td>
<td>A Perceiving style takes the outside world AS IT COMES and is adopting and adapting, flexible, open-ended and receptive to new opportunities and changing game plans.</td>
</tr>
<tr>
<td></td>
<td>• Plan many of the details in advance before moving into action.</td>
<td>• Comfortable moving into action without a plan; plan on-the-go.</td>
</tr>
<tr>
<td></td>
<td>• Focus on task-related action; complete meaningful segments before moving on.</td>
<td>• Like to multitask, have variety, mix work and play.</td>
</tr>
<tr>
<td></td>
<td>• Work best and avoid stress when keep ahead of deadlines.</td>
<td>• Naturally tolerant of time pressure; work best close to the deadlines.</td>
</tr>
<tr>
<td></td>
<td>• Naturally use targets, dates and standard routines to manage life.</td>
<td>• Instinctively avoid commitments which interfere with flexibility, freedom and variety</td>
</tr>
</tbody>
</table>
Figure 4 Preliminary MBTI Results for JPL’s Highly Regarded Systems Engineers
Table 3 Differences Between Development Process vs. Evaluation Process

<table>
<thead>
<tr>
<th>Development: 360 Degree Feedback Process</th>
<th>Evaluation: Performance Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Not used to identify performance issues</td>
<td>● Used to identify performance issues</td>
</tr>
<tr>
<td>● Addresses development in work related behaviors</td>
<td>● Addresses job specific skills, performance and accomplishments</td>
</tr>
<tr>
<td>● Optional</td>
<td>● Required by JPL on an annual basis</td>
</tr>
<tr>
<td>● Anonymous</td>
<td>● Tied to ranking, promotions and salary</td>
</tr>
<tr>
<td>● Ownership of the results rests with the participant</td>
<td>● Manager delivers feedback</td>
</tr>
<tr>
<td>● Requires a feedback coach</td>
<td>● Used for poor-performance</td>
</tr>
<tr>
<td>● Proactive</td>
<td>● Reactive</td>
</tr>
</tbody>
</table>

Figure 5 360 Degree Feedback Approach and Timeline

<table>
<thead>
<tr>
<th>Steps</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week 1</strong></td>
<td><strong>Participant nominates raters, Completes Self-Assessment</strong></td>
</tr>
<tr>
<td><strong>Weeks 1-4</strong></td>
<td><strong>Web-based Secure Survey Rolled out</strong></td>
</tr>
<tr>
<td><strong>Week 4-6</strong></td>
<td><strong>Data Analyzed &amp; Reports Prepared</strong></td>
</tr>
<tr>
<td><strong>Week 6-8</strong></td>
<td><strong>Individual Coaching &amp; Action Plans</strong></td>
</tr>
</tbody>
</table>

**Steps:**
- Web-based survey administered
- Participant nominates Feedback Providers
  - Managers
  - Peers
  - Customers
  - Team Members
- Self-Assessment Completed

**Outcomes:**
- Web-based survey administered to Feedback Providers
- Data Collected
- Reminder emails sent out
- Reports generated and provided to Professional Development
- Workshop conducted – “How to read and interpret your report”
- Feedback session conducted with Professional Development coach
- Action plans developed
- Follow-up w/ Feedback Providers