The Systems Engineering Upgrade Initiative at NASA's Jet Propulsion Laboratory

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Abstract. JPL is implementing an initiative to significantly upgrade our systems engineering capabilities. This Systems Engineering Upgrade Initiative [SUI] has been authorized by the highest level technical management body of JPL and is sponsored with internal funds. The SUI objective is to upgrade system engineering at JPL to a level that is world class, professional and efficient compared to the FY04/05 baseline. JPL system engineering, along with the other engineering disciplines, is intended to support optimum designs; controlled and efficient implementations; and high quality, reliable, cost effective products. SUI technical activities are categorized into those dealing with people, process and tools. The purpose of this paper is to describe the rationale, objectives/plans and current status of the JPL SUI.

CONTEXT AND RATIONALE

Rationale. Since JPL was established as a NASA Center, its assigned role as the Lead Center for planetary robotic exploration has required the Laboratory to design and implement first-of-a-kind, highly complex systems. JPL developed its system engineering capabilities the hard way, as a response to a string of failures during the Ranger program in the mid-sixties. After that, JPL conducted challenging and sophisticated missions for over two decades without a single major failure, other than those attributable to the launch vehicle. This is a remarkable record and, as a result, JPL's system engineering capability was viewed, internally and externally, as a world-class core competency. Looking back on those "early years", systems engineering at JPL can be viewed as a personality driven behaviour of a few individuals employed on big projects and a spacecraft development sub-specialty.

During the 1990s many changes occurred, most notably, three JPL-managed missions to Mars failed. Although there were many contributing causes to these failures, in their aftermath Project Managers began to express concerns about a perceived decline in the quality of the system engineering support they were receiving. It appeared that what had been viewed as a particular strength of the Laboratory had seriously eroded.

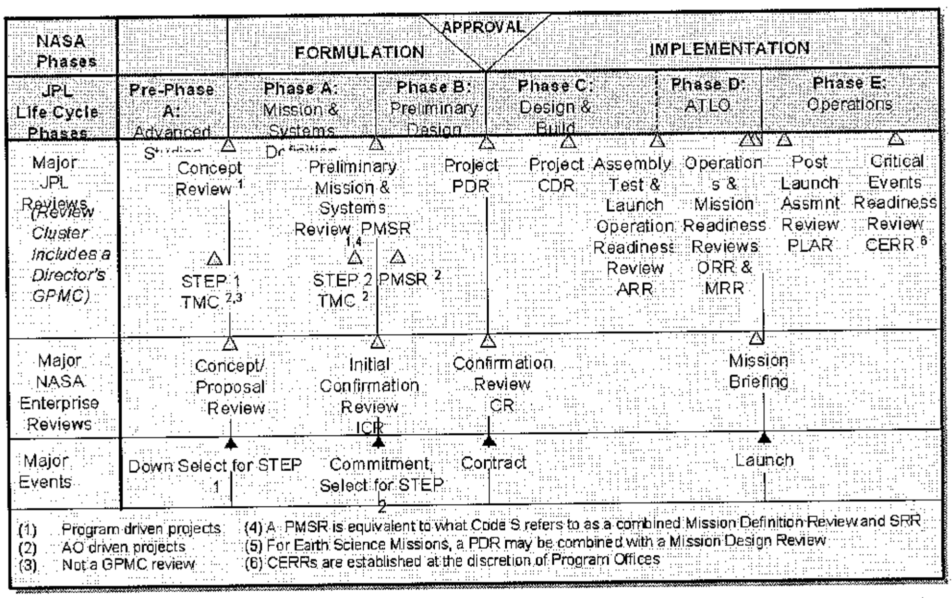
Another change from the "early years" is that now there are many more projects being implemented simultaneously than in the era in which the JPL system engineering culture was first created. The number of simultaneous projects means that the past process of training apprentice system engineers "at the knee" of a very few "masters" is no longer a workable approach to training.

In addition to the Mars mission failures and the increase in the number of projects, there are several additional forces which argue for an upgrade of system engineering at JPL. The product line has changed from only flybys and orbiters to flybys/orbiters and systems for in-situ investigation [rovers&probes] and large flight systems for astrophysical investigations. Projects also contain more intelligence, autonomy and software. These changes call for more complex design trades. There is also a re-emphasis on engineering rigor and process. Finally, the world of system engineering beyond JPL has moved on and it is clear that JPL is neither conversant nor practicing many modern system engineering tools, techniques and processes.

The JPL System Engineering Upgrade Initiative [SUI] has been created in response to these issues.

Context. In order to understand the SUI, it is helpful to understand its context at JPL. While there are many types of work going on at JPL, the SUI is aimed at systems engineering for our flight projects. Projects have a depth, a breadth and a length. Figure 1 presents the JPL flight project life cycle, i.e. the project length. Systems engineering is practiced during all phases from pre-Phase A through Phase E. Figure 2 presents one view of the architecture of a generic JPL flight project. The view of the architecture shown in figure 2 has two dimensions. The first

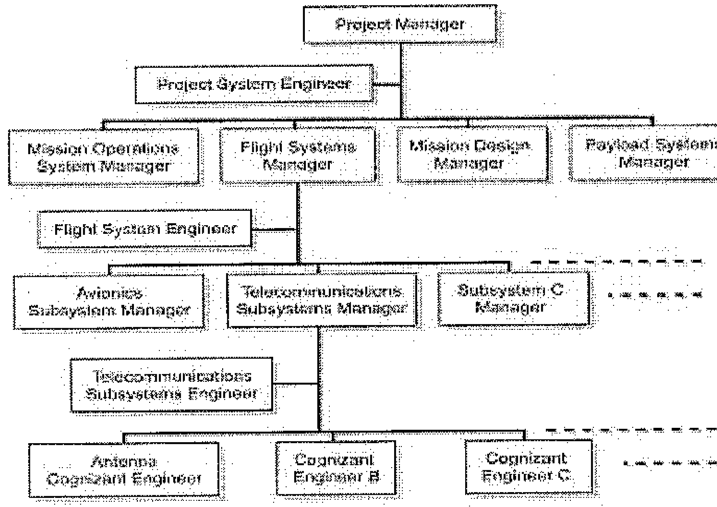
Figure 1. JPL Flight Project Life Cycle



dimension is the project "depth" which is a hierarchal dimension. Figure 2, displays four levels of the project hierarchy. The first level is the "project level" which is where the Project Manager and Project System Engineer reside. In JPL terminology, the project level is called level 2. Level 1 is called the program level and is not shown in figure 2. Level 3 is called the "system" level and is where the major implementing subsystems of the project reside, called "systems". For each level 3 system there is a level 3 system engineer; one for the flight system, one for the mission operations system and so forth. Level 4 is called the "subsystem" level and in general there is a system engineer or someone performing the system engineering functions for each level 4 subsystem.

System engineering on JPL flight projects is performed across the project "breadth", across all

Figure 2. JPL Flight Project Architecture

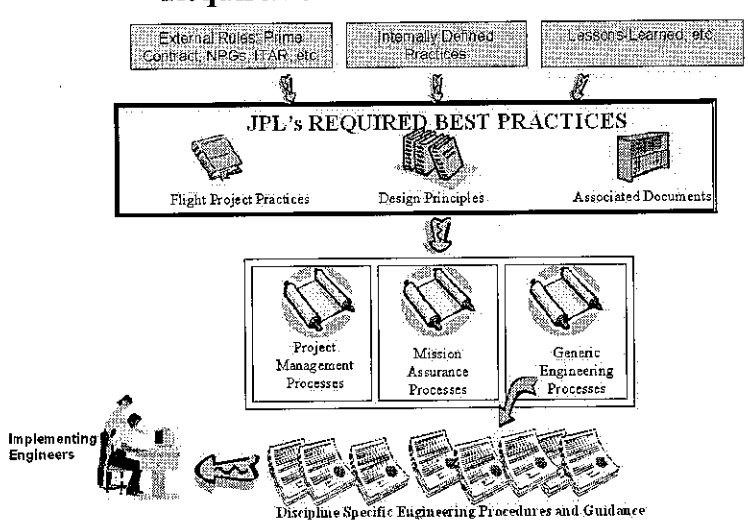


the level 3 implementing systems; throughout all levels of the project from level 2 through 4 [and perhaps lower] and across all phases of the project from pre A to E.

Understanding where system engineering is performed on JPL flight projects [depth, breadth and length] is necessary; however not sufficient to provide the context for the SUI. A working definition of system engineering as practiced at JPL is also necessary. To this end, system engineering at JPL has been defined in terms of nine technical functions: 1) develop system architecture, 2) develop & maintain requirements, 3) develop & maintain interfaces, 4) manage technical resources, 5) analyze and characterize the design, 6) verify & validate, 7) manage risk, 8) conduct peer reviews and 9) manage & control the design.

A final element of context is the JPL approach to capturing and documenting our internal policies, requirements and procedures. Figure 3 present an overview of our environment for internal policies, requirements and procedures.

Figure 3. JPL Environment for Internal Policies, Requirements and Procedures



OBJECTIVES

The overall SUI objective is to upgrade system engineering at JPL to a level that is world class, professional and efficient compared to the FY04/05 baseline. The motivation for this objective is not just to upgrade systems engineering for the sake of doing so; but to contribute to increasing efficiency [decreasing costs] and decreasing the risk associated with the implementation and operation of JPL's flight projects. The next level of objectives is presented in table 1. These are the objectives which will drive task definition and implementation and funding allocations. The SUI has been authorized for duration of 3 years starting in fiscal year 2006.

#	Objective	When
1	A common understanding of what SE is at JPL	'06
2	Procedures based upon the JPL SE definition	'06
3	All SE work is implemented via the procedures	'07
4	A SE tool and SW environment supporting "in house" SE	'07-'08
5	Understand the personal qualities that the JPL culture wants in lead system engineers	'06
6	Graduate trained lead SEs sufficient to meet demand	'07
7	JPL SE CMMI level 3 certified	'08
8	Fully integrate SUI activities into line management behaviors and activities	'08

Table 1: SUI Second Level Objectives

Objective #1 refers to the process of educating and enrolling all the systems engineering groups at JPL into the system engineer role and definition described in the preceding section. JPL is a matrix organization with a large directorate [the Engineering and Science Directorate] in which the majority of the engineers reside. These engineers are assigned to support flight projects which are managed by several program directorates. The Engineering and Science Directorate is comprised of 7 divisions and each division is comprised of 3 to 6 sections and sections are comprised of 4 to 10 groups and the working engineers reside in groups of about 10 people. There are about 20 groups whose primary business is system engineering at level 2, 3 or 4 and some portion of the project breadth, i.e. flight or ground system or project level. Objective #1 will be complete when all the engineers in these groups have the common understanding of JPL systems engineering.

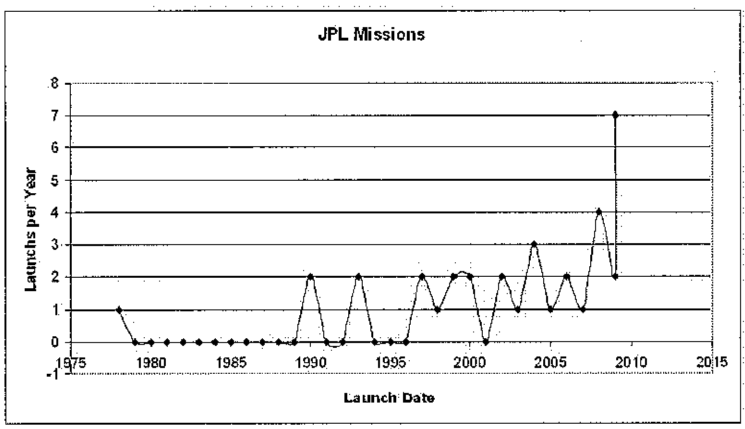
Objectives 2 and 3 follow directly from #1. As shown in figure 3, the working level engineers are to implement their work according to group level procedures. Objective #2 refers to having all the group level procedures in those 20 systems engineering groups consistent with the role and definition of JPL systems engineering, i.e. the 9 technical functions. Objective #3 is to ensure that the work be performed is being implemented consistent with the procedures.

The intent of objective #4 is to support the systems engineers in those 20 groups with tools that support their implementation of their procedure and to have a tool and software environment which will integrate all the systems engineering on a flight project across the depth, breadth and length of a flight project. Implicit in objective #4 is a tool and software environment which will support the 9 JPL systems engineering functions. Currently objective #4 is limited to the systems engineering which is performed "in house" at JPL, i.e. does not include the systems engineering performed by our contractors and partners at other NASA centers which are usually involved in our flight projects.

Objective #5 is fundamentally different from the prior four. Objective #5 refers to the "people" part of systems engineering. The JPL culture of system engineering recognizes that there is a "process" part of systems engineering and there is an intellectual, personality part of systems engineering or the systems engineer. Objectives 1-4 are aimed at the process part of systems engineering. Objective #5 is aimed at the intellectual, personality part of systems engineering. The JPL culture of systems engineering recognizes that the "process" part of systems engineering can be described, documented and taught to young engineers. Some of these young engineers are born with strengths in the intellectual, personality part of systems engineering and some are not. The intent of objective #5 is to clearly understand and identify those behaviours that the JPL systems engineering culture values and desires to see exhibited in our lead systems engineers.

Once we have identified the personal qualities we want in future lead systems engineers [objective #5] and the created the definition of the JPL systems engineering "process" [objectives 1-4], the intent of objective #6 is to train engineers, possessing those qualities, to implement the process. Objective #6 must train sufficient number of system engineers to meet the demand of the flight projects. Figure 4 presents the increase in the number of JPL flight projects which was referred to in the beginning of this paper. Based upon the data in figure #4, the projected demand for trained lead systems engineers is on the order of 40-60 per year depending upon the year post 2005.

Figure 4. JPL Forecast for Flight Projects Through 2009



Objective 7 should be unambiguous. The intent of objective 7 is to use the CMMI framework for systems engineering process as the standard against which JPL will measure its systems engineering processes and procedures. The objective of the SUI is to support and guide the systems engineering groups at JPL to become CMMI level 3 certified by the end of fiscal year 2008.

Objective 8 means that by the end of fiscal year 2008, the activities of the SUI will have become part of the JPL systems engineering culture as instantiated in the behaviours of line and project management and our formal documented processes and procedures. With the accomplishment of objective #8, SUI is complete.

CURRENT STATUS

As of the start of fiscal year 2005, the SUI is in the formulation phase. Alignment with the internal sponsors is incomplete, but progressing and the implementation plan for 06-08 is starting to be prepared. Fiscal 2005 will be spent: 1) completing alignment with top management, enrolling middle managers and communicating the objectives to the group level managers, 2) preparing the detailed implementation plan for '06-'08 and 3) starting some tasks in each of the 3 SUI subsystems. Those subsystems are people, process and tools with a leadership/management task responsible for the subsystems and overall management of the effort. The SUI will be reviewed by several review committees. Each subsystem will have a "blue team" of recognized experts in the subsystem from within and outside of JPL. The purpose of the "blue teams" is to advise the subsystem leaders of the best technologies, processes, people and tools to include in the subsystem developments. At the SUI project level, there will be an advisory committee with membership from each subsystem "blue team" and other systems engineering experts from beyond JPL including INCOSE, NASA and representatives from JPL's major system level contractors. There will be a JPL internal advisory committee which will represent top laboratory management, ensure that the resources are spent effectively and provide the necessary leadership to ensure cultural change when needed. Finally, there will be a JPL internal "red team" of working level managers whose role will be to challenge and question every aspect of the SUI. The remainder of this section describes some of the 2005 activities in the subsystems.

People. The people aspect of SUI is perhaps the most important. People implement procedures and tools support the people and procedures. SUI is committed to a training and education effort titled the System Engineer Development Program. The System Engineer Development Program's objectives are to provide: 1) a greater number of competent and effective system engineers, 2) systems engineers with a more comprehensive mix of skills, knowledge, and experience, 3) systems engineers with a modern set of attitudes, approaches, and tool ability and 4) a populated "pipeline" of selected engineers being trained to fill JPL's need for lead system engineers. During 2005, the System Engineer Development Program is implemented via pairs of protégés and mentors. The protégés are promising young engineers who have an interest in system engineering. The mentors are experienced systems engineers. The purpose of the pairing is to enable the informal face to face training of the young engineers. Additionally, during 2005, the people subsystem intends to engage a qualified contractor to study the JPL system engineering and management culture to identify those personal qualities and behaviors that are most valued in JPL system engineers.

Process. The SUI process activities in 2005 will center upon implementing the JPL systems engineering functions [1) develop system architecture, 2) develop & maintain requirements, 3) develop & maintain interfaces, 4) manage technical resources, 5) analyze and characterize the design, 6) verify & validate, 7) manage risk, 8) conduct peer reviews and 9) manage & control the design] into group level procedures. We will also investigate how these functions can be implemented in a model based systems engineering software environment and which SW tools are most effective at supporting this environment. The process subsystem will also support the development of processes and procedures intended to be CMMI compliant.

Tools. Currently, the only system engineering tool being used consistently at JPL is DOORS. Fundamentally, the tools subsystem will support the process and people subsystems. During 2005 we intend to evaluate CORE and CRADLE as examples of system engineering tools that have much more functionality than DOORS and which may be able to support some version of model based system engineering. We also intend to evaluate UML 2.0 tools such as Rhapsody. We will investigate whether CORE and/or CRADLE can interface to the JPL PDMS environment which is the Teamcenter Enterprise. The tools subsystem will also participate in the consortium which is working to develop a systems engineering language based upon UML, i.e. SysML and the ISO standards group working to create an international standard for information transfer between system engineering tools, i.e. AP233.

SUMMARY

NASA's Jet Propulsion Laboratory has embarked on an initiative to upgrade our systems engineering capability. The objective the Systems Engineering Upgrade Initiative [SUI] is to upgrade system engineering at JPL to a level that is world class, professional and efficient compared to the FY04/05 baseline. SUI technical activities are categorized into those dealing with people, process and tools. A summary of the context and objectives of the SUI is that systems engineering at JPL needs to evolve from: 1) a personality driven behaviour ....to a process based discipline practiced by specially trained and selected individuals, 2) a behaviour of a few individuals employed on big projects.....to a discipline that can be described, taught and practiced by many individuals on all our projects and 3) a spacecraft development sub-specialty......to a discipline practiced by many across the full project breadth [spacecraft, ground, payload, hardware/software], depth [level 2-4] and life cycle pre Phase-A to Phase E.

BIOGRAPHY

Ross Jones has a BS from Purdue and an MS from MIT in aeronautical engineering. Ross has been with JPL for 25 years and has been a technology developer, a system engineer at the spacecraft and project levels and a project manager. Ross has authored over 30 papers on various aspects of spacecraft design for planetary missions.