Developing the JPL Engineering Processes

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This p aper briefly r ecounts t he r ecent h istory o f p rocess reengineering a t t he N ASA J et Propulsion Laboratory, with a focus on the engineering processes. The JPL process structure is described and the process development activities of the past several years outlined. The main focus of the paper is on the current process structure, the emphasis on the flight project life cycle, the governance approach that lead to Flight Project Practices, and the remaining effort to capture process knowledge at the detail level of the work group.

I. Background

The top level processes were established about 1995 in preparation for initial International Standards Organization (ISO) 9000 certification. See Fig. 1. The mission-oriented processes were Develop Needed Technology (DNT), Generate Scientific Knowledge (GSK), and Develop New Products (DNP). These were supported with other institutional processes Align and Integrate, Communicate With The Public, Guide and Govern, Provide Enabling Services and Acquire, Nurture and Deploy People. All mission and system development for space projects occurs in DNP. In retrospect, the lower level procedures developed during this "rush to ISO" where not uniformly structured, varied in quality and not well integrated.

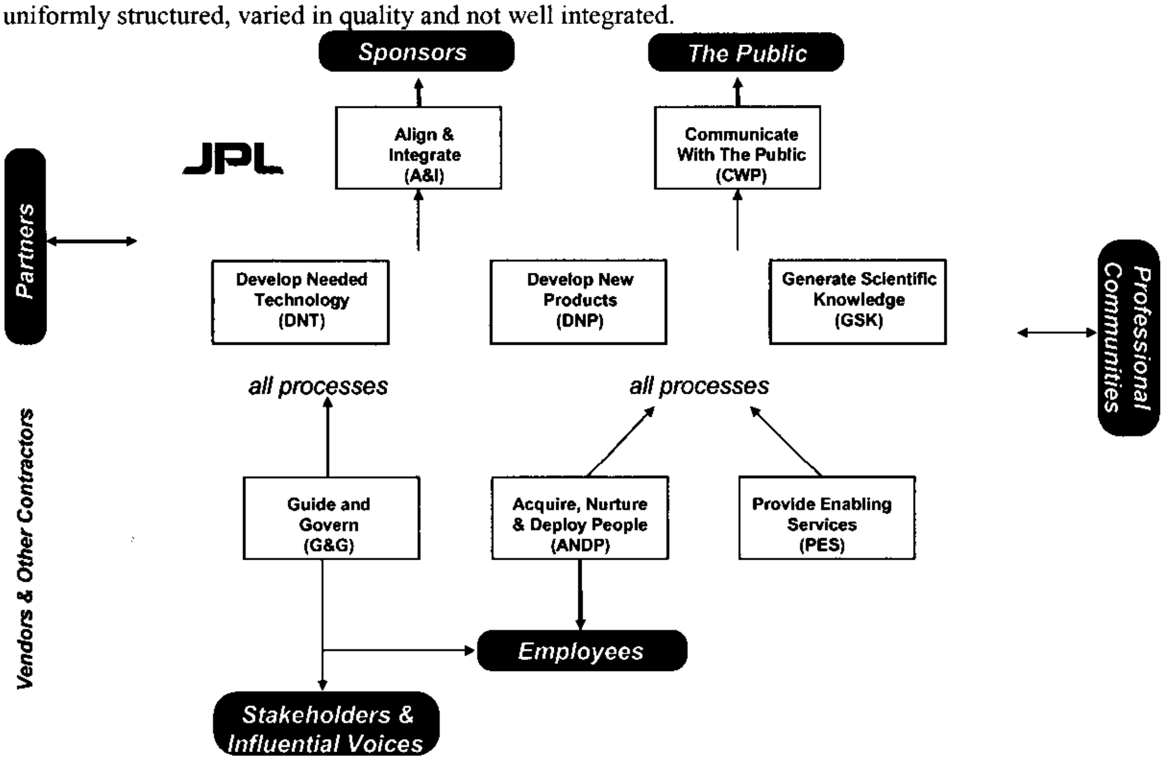

Figure 1. JPL Top Level Processes

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The number of missions at JPL has grown substantially, from 3 in 1983 to over 45 in 2003. The Mars '98 failures of the Mars Climate Orbiter and the Mars Polar Lander led to insightful Board Reviews and Reports. Among these findings was the following from the Young Committee:

> "..JPL has not completely made the transition to FBC [Faster, Better, Cheaper]. They have not documented the policies and procedures that make up their FBC approach; therefore, the process is not repeatable. Rather, the project managers have their own and sometimes different interpretation. This can result in missing important steps and keeping lessons learned from others who could benefit from them."

During 2001, the subsystem level DNP processes were established, followed by development of procedures for assembly and component level development activities. These procedures were designed to capture the required "best practices" that define how employees do work.

II. The Develop New Products Structure

The DNP processes were originally defined to capture the JPL corporate knowledge and experience. In the past, the apprentice system worked well, but the recent changes (from a few large long term missions to many shorter missions) requires new ways to produce experienced leaders. Processes were proposed as the mechanism for documenting institutional knowledge and experience while providing the basis for standardization and continuous improvement.

JPL's approach to Flight Project Implementation is contained in processes. As shown in Fig. 2, these processes are divided into three categories: 1) Management, 2) Mission Assurance, and 3) Engineering. The Engineering Processes are further broken into Mission System, Flight System and Ground System processes. Process Owners and their Process Development Teams are responsible for the development of process definition, documentation, and improvement.

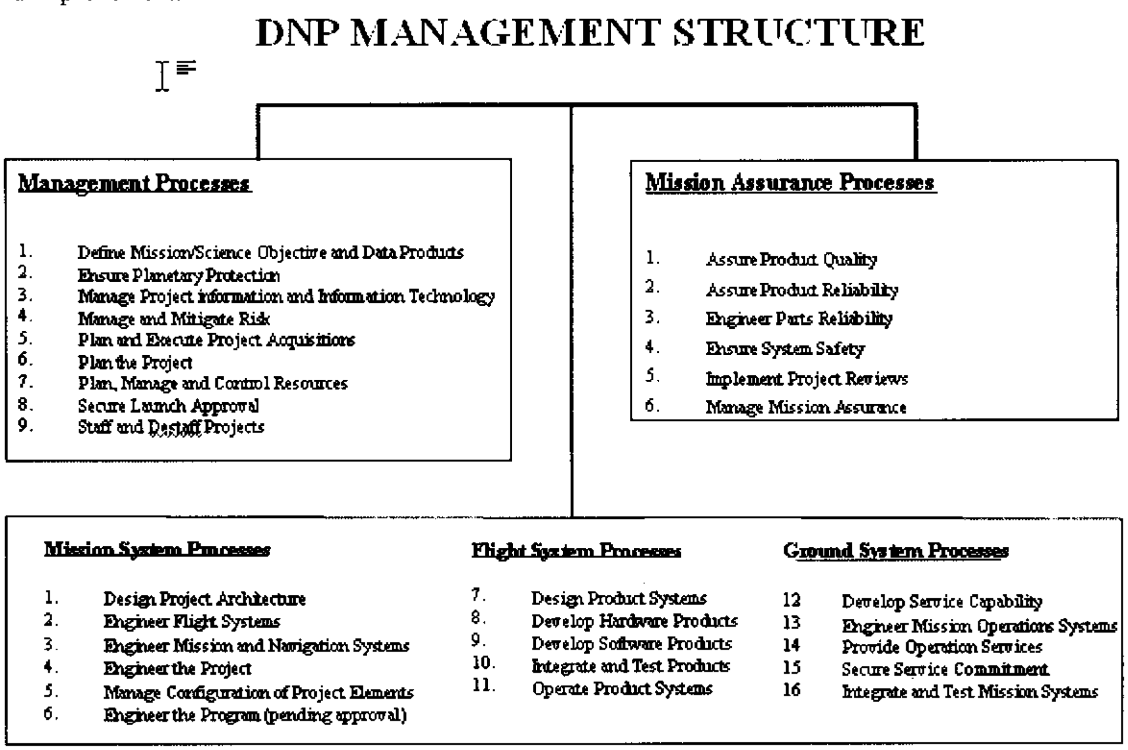

Figure 2. The Develop New Products Management Structure

The management processes generally are well defined and in place, with significant process support and training provided by Project Support Office. Many elements are being successfully used by projects.

The tension between viewing processes as "rules" versus viewing processes as "best practice and guidance" exists. There is a concern that engineering design is not formulaic and can't be mandated and there are significant differences at the level of product details. Procedures have aimed for the minimum necessary to satisfy external requirements and to assure mission safety and success by identifying activities and not engineering design rules. For example, most hardware development procedures require failure analysis during the design but don't specify a method and don't specify limiting values.

III. The JPL Flight Project Life Cycle

All processes and procedures are set in the Flight Project Life Cycle. See Fig. 3. Projects begin with the proposal opportunity and, upon selection, begin an Advanced Study Phase. The Pre-Phase A, and Formulation Phase (Conceptual Design and Preliminary Design) are periods spent improving the mission concept and gaining advocacy. Implementation Phase (Detail Design, Fabrication and Test) begins with formal project approval and assignment of a launch commitment. The life cycle includes the Operations Phase, but DNP and the Engineering Processes are concerned with development prior during the prior phases.

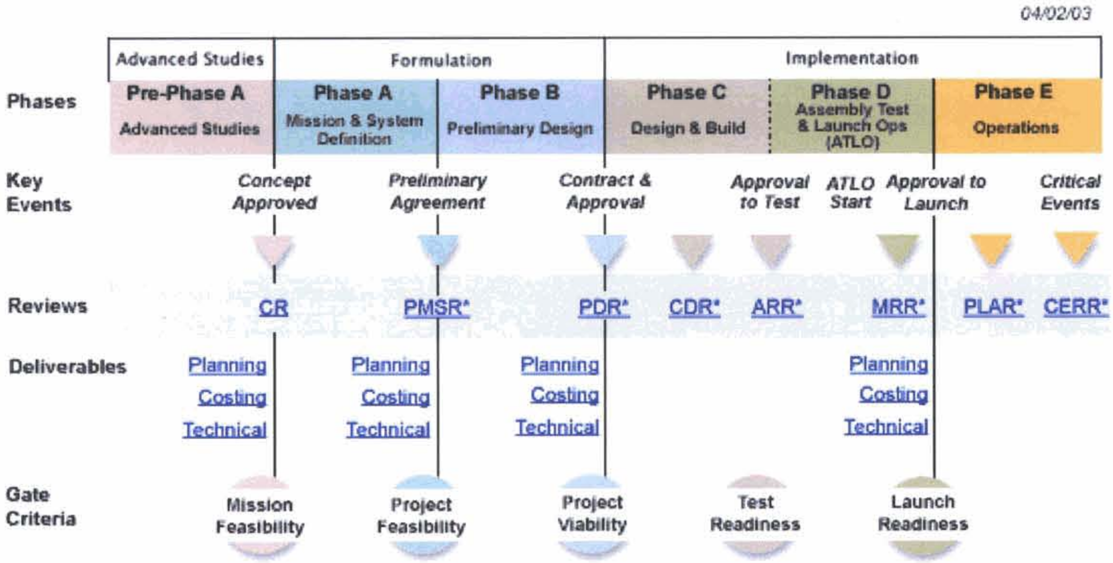

Figure 3. JPL Flight Project Life Cycle

The Life Cycle definition also included specification of the project plans, documents and products with the maturity of these products increasing with later phases. Specification of Gate Products instills rigor into the project development process by requiring a specified level of maturity at major project milestones and phase transitions. For example, the Formulation Phase exit Gate Product requirements are established to ensure a depth of planning and design consistent with the fidelity of the cost commitment to be given to the sponsor. A Project Risk Management Plan is one Gate Product that must be Preliminary upon entering Phase B Preliminary Design and at Final prior to entering Phase C Detail Design.

IV. DNP Process Development and Process Structure

DNP Process Owners were appointed from Line Management with relevant experience and responsibility for that work. They are supported in their technical work by Process Engineers. A Process Development Team (PDT) with other relevant line and technical managers provides assistance and broader advocacy. Processes and procedures are the responsibility of the line organization (Engineering and Science Directorate).

The PDT developed a summary Process Description and an ICOR (Input Constraints Outputs Resources) Diagram to describe the process. All process requirements were collected and flowed down to each PDT. See Fig. 4. External sources included NPG 7120.b (NASA), ITAR Regulations, Corrective Action Notices and ISO requirements. Internal requirements include Design Principles and Flight Project Practices and each process must be consistent with the Flight Project Life Cycle.

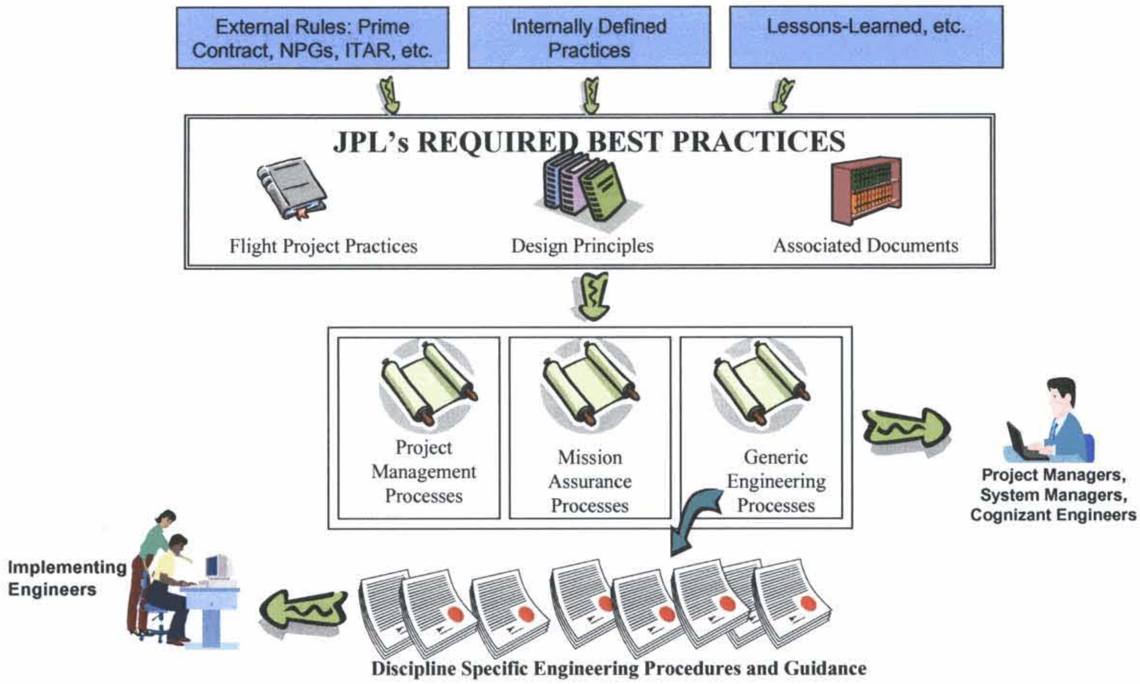

Figure 4. Flow of Requirements to Processes

Flight Project Practices specify what Projects are to do and are a vehicle for communicating the JPL way of doing business, both internally and to sponsors. For example:

> "Each Project defines the required level of flight system fault tolerance and the use of redundancy and cross strapping prior to the PDR, in order to properly scope and cost the Project"

The Design Principles specify essential attributes of the designs and define a risk level acceptable to management. They establish a common standard by which project risks can be assessed. For example:

> "No credible single failure of any electrical, mechanical, or electromechanical element shall result in loss of the minimum mission"

These requirements are integrated into the processes themselves. By following the processes, users can be confident that they are satisfying all such requirements. The requirements are captured and managed for maintaining currency and traceability.

Modifications to the procedures are reviewed by the PDT and technical area specialists prior to enactment.

Deviations and/or exceptions to flight project practices and design principles are not precluded, but require appropriate rationale to justify the risk exposure associated with the proposed alternative. Exception to some design principles is not uncommon, for example single fault tolerance, floating power bus, and technical and programmatic margins. Projects address compliance with the procedures at formal reviews in the Project Life Cycle.

A process is a collection of activities which transform a set of given inputs into a desired output. Frequently the term "process" is used to refer to the collection of procedures that control the activities of a process.

DNP Engineering procedures for mission and system elements were organized by Product scope: Project, System, Subsystem, Assembly, and Component. See Fig. 5.

Project engineering activities are covered by Engineer the Project. System engineering activities are covered by Engineer the Flight System, Engineer Mission Operation and Integrate and Test Mission Systems. Subsystems are covered by Design Product Systems, Engineer Mission Design and Navigation Systems, Develop Hardware Products and Integrate and Test Products.

Project level processes are executed by a Project Manager and staff. System level processes are executed by the Flight and Ground System Managers and staff. Subsystem level processes are executed by Project Element Managers.

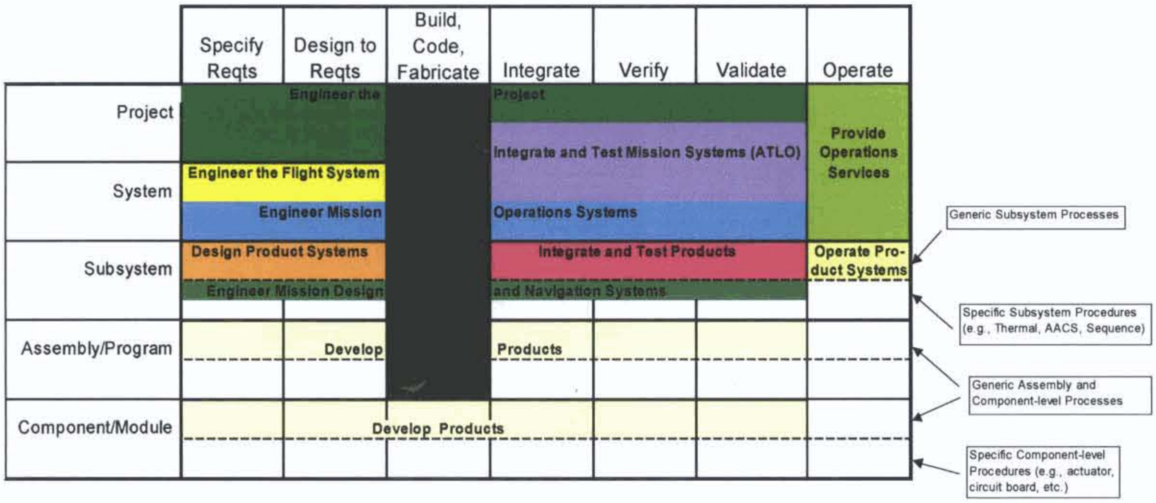

Figure 5. Engineering Process Structure

The procedures are in Actor/Action format and define "how" the process is to be accomplished consistent with external requirements. See Fig. 6. Procedures are stepwise descriptions of the workflow activities required to accomplish the process consistent with best practice. In general all steps in a procedure are mandatory unless otherwise specified. (Step 6.5 in Fig. 5 is an example of an optional step.) The procedure is the only process view the user needs.

Actor	Action
Cognizant Engineer	6.1 Update work agreements with project and line management, as required. Negotiate resources necessary for long-lead item acquisition. Refer to JPL Project Life Cycle. Ensure that work plans are responsive to generation of the Gate Transition Products included in the Step 6.6 Review. Use these procedures: • Documenting Work Agreements • Scheduling
Cognizant Engineer	6.2 Update input requirements. Develop and analyze hardware requirements.
Cognizant Engineer	6.3 Update the plans for acquisition of long lead-time items as appropriate. Consult the Flight Hardware Logistics Guideline for applicable hardware.
Cognizant Engineer	6.4 Develop a preliminary design. a. Incorporate: Design, Verification/Validation and Operations Principles for Flight Systems, Mission Assurance Principles, and Flight Project Practices. b. Conduct preliminary design engineering analysis until the design meets the requirements. c. Negotiate allocations for managed resources, e.g. mass, power, bandwidth. d. Produce design documents, interface agreements and drawings, and place under configuration control per project plans. e. Use these procedures: • Structural and Dynamic Analysis, Loads/Environments and Test • Thermal System Engineering and Design • (Remainder of list deleted for clarity
Cognizant Engineer	6.5 Make and test a simulation or breadboard model. *(Optional when significant heritage exists.)*
Cognizant	6.6 Review the product design to ensure compliance with the Gate Transition

Actor	Action
Engineer	Products. Use the Project Reviews Guideline.
Cognizant Engineer	6.7 If the review is failed, revisit Steps 6.4 through 6.6 as needed.

Figure 6. Preliminary Design Steps from a Typical Hardware Development Procedure

These design procedures capture references to other procedures, such as preparing Work Agreements in Step 6.1 and the Design Principles in Step 6.4 of Fig. 6. The work in a Project Life Cycle Phase is seen as concurrent and iterative, although this can not be well represented in the tabular format. Notice the steps are recognizable activities but don't establish standard practices for every one. A review is to be conducted in Step 6.6 and an institutional method for reviews is to be used, but the Lab has not developed a standard for how to design engineering systems in Step 6.4.

V. Conclusion

With many years of hard work, JPL has constructed a coherent and thorough process structure that captures how best practices are to be used so that institutional requirements are met. A few subsystem-level procedures remain to be finalized, but most procedures are in place, training has begun and a maintenance mode is being established.

The process structure flows nicely from three top level mission processes to engineering processes to group-level product development procedures. Architectural decisions, such as establishing the Flight Project Lifecycle and the Design Principles, have been very effective at establishing a common environment for lower level procedures. The decision to add Process Owner to the duties of Line Managers has resulted in the procedures reflecting the way the front line organizations work. This is critical to achieving acceptance and compliance at the working level.

Acknowledgments

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.