

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Technical Report

**“A Study of Technical Engineering
Peer Reviews at NASA”**

November 20, 2003

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EXECUTIVE SUMMARY

This report describes the state of practices of design reviews at NASA and research into what can be done to improve peer review practices. There are many types of reviews at NASA: required and not, formalized and informal, programmatic and technical. Standing project formal reviews such as the Preliminary Design Review and Critical Design Review are a required part of every project and mission development. However, the technical, engineering peer reviews that support teams' work on such projects are informal, some times ad hoc, and inconsistent across the organization. The goal of this work is to identify best practices and lessons learned from NASA's experience, supported by academic research and methodologies to ultimately improve the process. This research has determined that the *organization, composition, scope, and approach* of the reviews impact their success. Failure Modes and Effects Analysis (FMEA) can identify key areas of concern before or in the reviews. Product definition tools like the Project Priority Matrix, engineering-focused Customer Value Chain Analysis (CVCA), and project or system-based Quality Function Deployment (QFD) help prioritize resources in reviews. The use of *information technology* and *structured design methodologies* can strengthen the engineering peer review process to help NASA work towards error-proofing the design process.

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1. INTRODUCTION

1.1. Background

Design reviews are a systematic way to manage the process of product development to ensure product design quality reflects and meets customer requirements within cost and time constraints. The Japanese Industrial standard JIS Z 8115-1981 defines design reviews as:

Judgment and improvement of an item at the design phase, reviewing the design in terms of function, reliability, and other characteristics, with cost and delivery as constraints and with the participation of specialists in design, inspection, and implementation.

There are two types of design reviews. Formal design reviews have standard policies and procedures. Each review is a key event in the process of product development and production planning. Informal design reviews are developed and conducted by individual reviewers. These reviews are used only as needed and their effectiveness can vary greatly.

In a survey by the Design Review Committee of the Union of Japanese Scientists and Engineers (JUSE), few reported any actions to correct misunderstandings of design reviews. Some of the most frequently cited concerns were time and scheduling constraints, lack of staff experience, inadequate preparation, and shortfalls in communication, cooperation, and commitment. (Ichida 1996)

1.2. Goal

This report describes the state of practices of design reviews at NASA and research into what can be done to improve review practices. There are many types of reviews at NASA: required and not, formalized and informal, programmatic and technical. Standing project formal reviews such as the Preliminary Design Review (PDR) and Critical Design Review (CDR) are a required part of every project and mission development. However, the technical engineering peer reviews that support teams' work on such projects are informal, ad hoc, and inconsistent across the organization. *The goal of this work is to capture the state of peer review practices currently at NASA and to go beyond that and identify best practices and lessons learned from NASA's experience, supported by academic research and methodologies to ultimately improve the process and work towards error-proofing the process.*

1.3. Method

Based out of NASA Ames Research Center in Moffett Field, CA, this design review research first referred to official NASA documentation and NASA mission webpages on formal design reviews as well as NASA interviews. Initial conversations with engineers and managers at NASA Jet Propulsion Laboratory in Pasadena, CA indicated that we should concentrate on the informal engineering peer reviews.

In addition to interviews at Ames Research Center, two visits were made to NASA Jet Propulsion Laboratory in Pasadena, CA on June 19-20, 2003 and July 15, 2003. These conversations initiated dialogue with several officials at JPL, Ames, Langley, and Goddard via phone, e-mail, and in person and are detailed in the appendix. Observations were also made from the Kepler Ground Segment (pre-SRR) peer review held at NASA Ames Research Center on June 26, 2003. Finally, there were opportunities for discussion at the "Space Mission Challenges in Information Technology" conference in Pasadena, CA on June 13-17, 2003; the "NPI Roundtable on Reliability and Validation" at Stanford University on June 24, 2003; and the "International Research Roundtable" at the Swiss Federal Institute of Technology in Lausanne (Ecole Polytechnique Federale de Lausanne) on September 11, 2003.

2. NASA REVIEW PROCESS

2.1. NASA Centers

The National Aeronautics and Space Administration (NASA) is an agency in the U.S. federal government with the mission of conducting research and developing operational programs in the areas of space exploration, artificial satellites, and rocketry. The agency came into existence on October 1, 1958, and there are currently 11 facilities in the agency [13]:

- **NASA Headquarters** - located in Washington, D.C., exercises management over the space flight centers, research centers, and other installations that constitute NASA.
- **Ames Research Center** - specializes in research geared towards creating new knowledge and new technologies that span the spectrum of NASA interests.
- **Dryden Flight Research Center** - innovates in aeronautics and space technology - the newest, fastest, the highest - as the lead for flight research.
- **Glenn Research Center** - develops and transfers critical technologies that address national priorities through research, technology development, and systems development for safe and reliable aeronautics, aerospace, and space applications.

- **Goddard Space Flight Center** – mission to expand knowledge on the Earth and its environment, the solar system, and the universe through observations from space.
- **Jet Propulsion Laboratory** - managed by the California Institute of Technology is NASA's lead center for robotic exploration of the Solar System and mission design.
- **Johnson Space Center** - continues to lead NASA's effort in Human Space Exploration, from the early Gemini, Apollo, and Sky Lab projects to today's Space Shuttle and International Space Station programs.
- **Kennedy Space Center** - America's "Gateway to the Universe," leading the world in preparing and launching missions around the Earth and beyond.
- **Langley Research Center** – continues to forge new frontiers in aviation and space research for aerospace, atmospheric sciences, and technology commercialization to improve the way the world lives.
- **Marshall Space Flight Center** - is world leader in the access to space and use of space for research and development to benefit humanity, bringing people to space and space to people.
- **Stennis Space Center** - responsible for NASA's rocket propulsion testing and for partnering with industry to develop and implement remote sensing technology.

This project was based in Ames Research Center but worked very closely with the Jet Propulsion Laboratory and supplemented by some conversations with individuals at Goddard and Langley.

2.2. NASA Life Cycle

For decades, the National Aeronautics and Space Administration has applied effective design principles with appropriate peer reviews and periodic systems design reviews to result in high reliability aerospace design . NASA has a well-defined life cycle which consists of the following areas, shown in Figure 1.

NASA - Defined Life Cycle						
Mission need determination	Mission needs and conceptual studies	Concept definition	Design and development	Fabrication, integration test and evaluation	Pre-operations	Operations and disposal

Figure 1: NASA'S DEFINED LIFE CYCLE

Like many organizations, NASA uses these phases as a means to organize decision points, illustrated in Table 1. Requirements definition begins in Phase A, with refinements and baseline occurring in Phase B. Lower level requirements are derived between Phases B and C, and major requirement definition is

completed for all levels by Phase C. Design reviews are at key transition points along this life cycle

Table 1: NASA LIFE CYCLE CHART SHOWING REQUIREMENTS AND REVIEWS

PHASE:	A Preliminary Analysis	B Definition	C Design	D Development	E Operations
Activities:	Conceptual studies Exploration of alternatives	Preliminary design Concept solution	Detail design System development	Final design & development Fabrication Test	Support Product improvement
Requirement Related Documents:	Program Plan Draft System Specification	Baseline System Specification	Segment Specs Element Specs	Maintain Specs ----->	Maintain Specs ----->
Reviews:		SRR PDR	CDR	SAR FRR	ORR

All NASA missions and spacecraft are subject to a technical design review process. The primary objective of this program is to enhance the probability of success by identifying potential or actual design problems in a timely manner. There are a number of system reviews which are performed throughout the lifecycle, including:

- System Concept Review (SCR)
- **System Requirements Review (SRR)**
- **Preliminary Design Review (PDR)**
- **Critical Design Review (CDR)**
- Mission Operations Review (MOR)
- Pre-Environmental Review (PER)
- Pre-Shipment Review (PSR)
- **Systems Acceptance Review (SAR)**
- Flight Operations Review (FOR)
- **Flight Readiness Review (FRR)**
- Launch Readiness Review (LRR)
- **Operational Readiness Review (ORR)**

The Technical Design Review Program consists of a subset of such system reviews, depending on whether it is a spacecraft or an instrument, or new or follow-up mission.

2.3. Types of Reviews

To help understand the organizational aspects of the design review system at NASA, we performed a **Customer Value Chain Analysis (CVCA)**. CVCA is a design tool taught in Stanford University's dfM course me317 (<http://me317.stanford.edu>) that helps an organization to understand the value proposition for each stakeholder. It lists the pertinent parties involved in the product including stakeholders, customers, partners, and regulators and identifies the relationship and flow of money, materials, resources, complaints, and information among the parties.

The CVCA in Figure 2 (the appendix contains breakdowns of the chain by category) shows the different stakeholders involved in typical projects from a design review perspective. NASA is a matrix organization which brings members from different functional line organizations together for projects. The different types of review teams that may impact a project are shown in the dotted circles. **Formal review boards** sit on system reviews such as the PDR and CDR. **Peer reviewers** are gathered from different organizations within NASA and even outside. As the CVCA shows, the funding for both these reviews comes from within the project and not from Headquarters or other NASA offices.

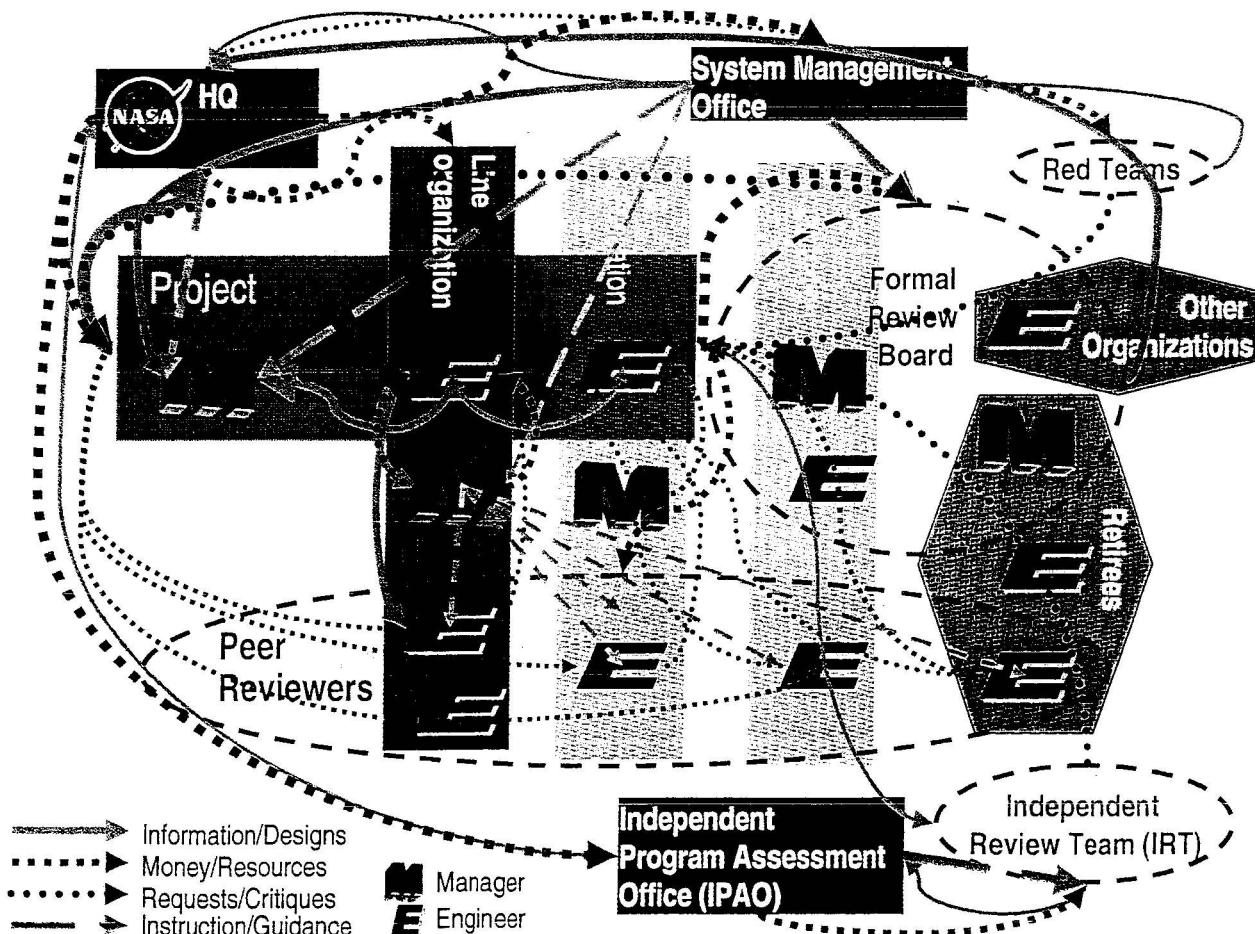


Figure 2: CUSTOMER VALUE CHAIN ANALYSIS (REFER TO APPENDIX)

In addition to the system reviews, there are also externally motivated project reviews. The “**Red Teams**” are comprised of senior management representatives that periodically review the process; they are charged with evaluating the approaches used to manage and mitigate risks during the lifecycle and report to the **System Management Office**. The Independent Program Assessment Office (IPAO) conducts independent evaluations of NASA programs and projects to ensure that the technical and programmatic commitments are being met. **Independent Review Teams (IRT)** consist of highly knowledgeable specialists both internal and external to NASA and conduct reviews as requirements mandate.

2.4. Formal Reviews

In the NASA life cycle, two key reviews are the PDR and CDR. Figure 3 shows a representation of the JPL life cycle including major reviews.

NASA Phases	FORMULATION		APPROVAL	IMPLEMENTATION			
JPL Life Cycle Phases	Pre-Phase A: Advanced Studies	Phase A: Mission & Systems Definition	Phase B: Preliminary Design	Phase C: Design & Build	Phase D: ATLO	Phase E: Operations	
Major JPL Reviews <i>Review Cluster Includes a Director's GPMC</i>	Concept Review ¹ STEP 1 TMC ^{2,3}	Preliminary Mission & Systems Review PMSR ^{1,4} STEP 2 TMC ²	Project PDR ⁵ PMSR ²	Project CDR	Assembly, Test & Launch Operation Readiness Review ARR	Operations & Mission Readiness Reviews ORR & MRR	Post Launch Assmnt Review PLAR Critical Events Readiness Review CERR ⁶
Major NASA Enterprise Reviews	Concept Proposal Review	Initial Confirmation ICR	Confirmation Review CR			Mission Briefing	
Major Events	Down Select for STEP 1	Commitment, Select for STEP 2	Contract			Launch	
(1) Program driven projects (2) AO driven projects (3) Not a GPMC review		(4) A PMSR is equivalent to what Code S refers to as a combined Mission Definition Review and SRR (5) For Earth Science Missions, a PDR may be combined with a Mission Design Review (6) CERRs are established at the discretion of Program Offices.					

Figure 3: JPL LIFE CYCLE INCLUDING MAJOR REVIEWS

The **Preliminary Design Review (PDR)** is the first major review of the detailed design and is normally held prior to the preparation of formal design drawings. PDR's are conducted to confirm that the approach for the system's design is ready to proceed into the detailed design phase. A PDR is held when the design is

advanced sufficiently to begin some testing and fabrication of design models. Detail designs are not expected at this time, but system engineering, resource allocations and design analyses are required to demonstrate compliance with requirements.

The **Critical Design Review (CDR)** is held near the completion of an engineering model, if applicable, or the end of the breadboard development stage. This should be prior to any design freeze and before any significant fabrication activity begins. The CDR should represent a complete and comprehensive presentation of the entire design. CDR's are conducted to demonstrate that the detailed design is complete and ready to proceed with coding, fabrication, assembly and integration efforts.

2.4.1. Guides

For formal reviews, there are a number of guides and documents to help projects through the review process. The JPL documentation **PD-ED-1215** [C] outlines the practice of conducting technical reviews. Figure 4 outlines the generic process for implementing project reviews from the review board's standpoint.

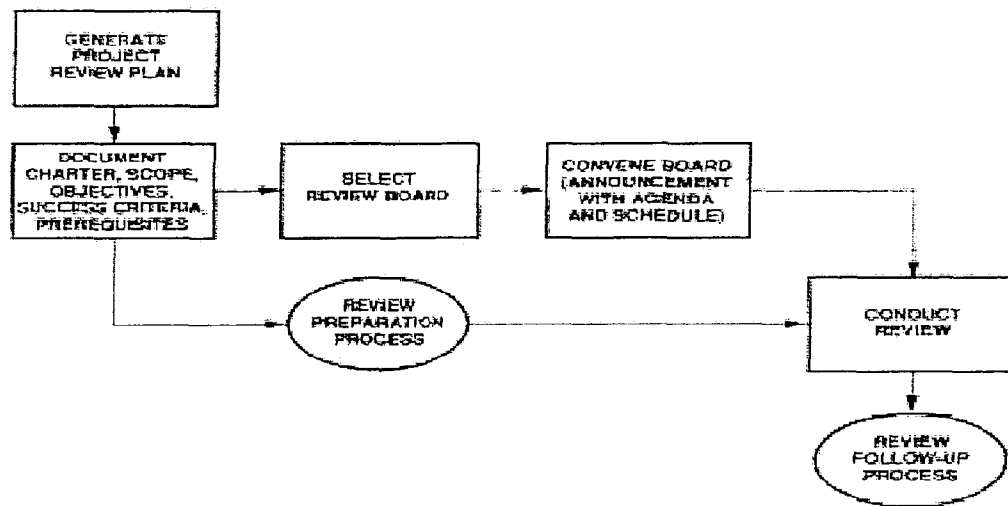


Figure 4: PROJECT REVIEW PROCESS OVERVIEW

Figure 5 illustrates the preparation for project reviews from the design presentation side.

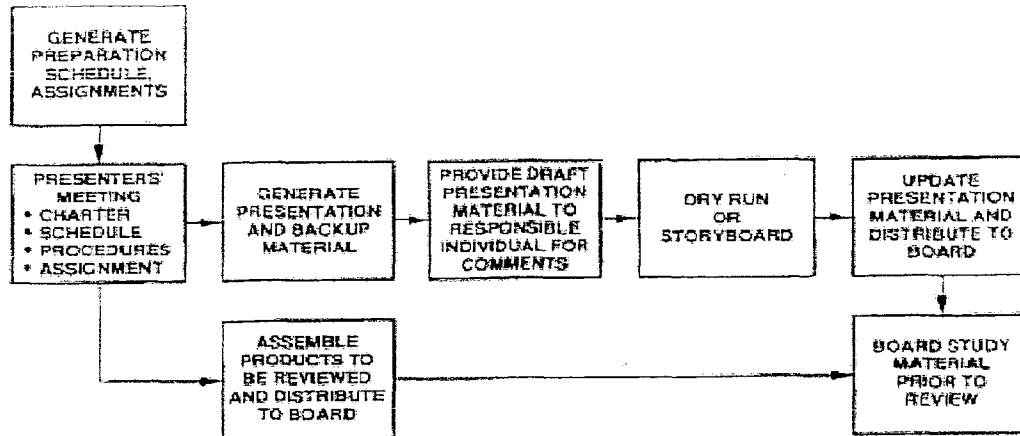


Figure 5: PROJECT REVIEW PROCESS: REVIEW PREPARATION

Some groups have design review forms with detailed activities. Below, Table 2 lists review forms used for the PDR and CDR for software verification and validation. These contents are to be verified and remarks are to be noted. [1]

Table 2: PDR AND CDR DESIGN REVIEW FORMS FOR SOFTWARE V&V

CONTENTS
The preliminary version of the Acceptance/Software Test Plan and verification matrix has been updated.
Software design consistent with the software requirements.
Deviations from the requirements documented and approved.
All assumptions documented.
Major design decisions been documented.
Design consistent with the major design decisions.
The design adequately addresses real-time requirements; performance issues (memory and timing); space capacity (CPU and memory; maintainability; understandability; loading and initialization; error handling and recovery; user interface issues; and software upgrades.
Process Spec for each process accurate and complete.
Dependencies on other functions, operating system kernel, hardware, etc., identified and documented.
Human factor considerations properly addressed in those functions that provide a user interface.
Design constraints, such as memory and timing budgets, specified where appropriate.
Requirements for error checking, error handling, and recovery specified where needed.
Interfaces consistent with module usage (missing interfaces or extra interfaces).
Interfaces specified to a sufficient level of detail that allows them to be verified.

CONTENTS
All action items from the PDR have been resolved.
Software structures and interfaces have been documented.
The SDD is consistent and traceable to the IDD.
Each of the elements in the IDD match the details in the SDD.
The input, processing, and output of each software unit via data and control flow have been supplied.
Performance requirements, including timing, storage, and similar constraints have been documented.
Performed independent design verification if applicable.
Software test plan and verification matrix are completed.
Any special security requirements have been met.
Facilities including support and system software, compiler(s), coding and test tools, utilities, libraries, databases, etc. are ready and available for use.
All related documentation (e.g., user's, operator's, maintenance, and diagnostic manuals) is up-to-date.
Discrete quality and adequacy checks have been performed.

Table 3 below demonstrates a standard review checklist which is used as an aid to review planning. The activities are to be performed in the order listed by the people indicated. This checklist is very high-level and does not describe how to handle technical aspects.

Table 3: STANDARD REVIEW CHECKLIST

Review Activity	Lead Person
Generate project review plan	Project manager
Establish and document charter	Convening authority
Establish and document scope, objectives, success criteria, and prerequisites	Responsible individual
Select review board	Convening authority, responsible individual
Announce schedule and agenda	Responsible individual
Prepare for review: <ul style="list-style-type: none"> • Schedule conference room • Arrange for audiovisual equipment and support, refreshments • Identify presentation team • Develop presentation guidelines • Hold presenters' meeting • Assemble material to be reviewed, and distribute material to board • Generate presentation and backup material • Dry run or story board presentation • Update, produce, and print presentation material, and distribute it to the board • Prepare slide and transparencies, and distribute them to the presenters 	Responsible individual
Study material prior to review	Board members
Conduct review	Board chair
Conduct post-review meeting: <ul style="list-style-type: none"> • Identify key findings and recommendations • Develop board consensus • Draft board report 	Board chair
Consolidate and filter recommendations for actions (RFAs)	Board chair, responsible individual
Accept RFAs as action items, advisories, or rejected items <ul style="list-style-type: none"> • Identify critical action items 	Responsible individual
Complete and issue final board report	Board chair
Submit metrics to the Office of Engineering and Mission Assurance	Responsible individual
Prepare and issue RFA disposition plan	Responsible individual
Approve disposition plan	Convening authority
Approve action item closures	Responsible individual
Review action item closures; provide feedback to responsible individual and convening authority	Board chair, selected board members

2.5. Review Examples

2.5.1. ASIC Program

In the ASIC program at NASA, the review process and other assessments are an important part of the program. The user and designer participate together in review early in the process. Review board members include individuals from design, product architecture, customer engineering, CAE/CAT, ASIC center personnel, resident ASIC experts, parts reliability, quality assurance, procurement, and ASIC vendors. General activities include verifying requirements, identifying problems, locating causes of problems, addressing concerns, making recommendations, and developing communication channels.

These include reviews for specifications and requirements, implementation (schematics), preliminary design, critical design, and chip sign-off (build-readiness/flight build). The specification review includes checks the completeness of specifications and the compatibility of existing design work and future applications. The implementation review looks at the specification implementation. The PDR reviews parts specification, verification of reports, test summary, package information, and schematics and directory structure. The CDR reviews part specification and includes a design verification check.

2.5.2. International Space Station Fluids and Combustion Facility

The Fluids and Combustion Facility (FCF) is a permanent, modular, multi-user facility to accommodate microgravity space experiments. Even with the cost of FCF development included, experimentation using FCF on the space station will cost only half of what it did on the space shuttles.

The Preliminary Design Review for the FCF took five days, including sessions on:

- **Day 1:** FCF System Preliminary Design Review
- **Day 2:** FCF Software, Common Subsystems, and System Summary; CIR Delta-PDR
- **Day 3:** FIR Preliminary Design Review
- **Day 4:** SAR Conceptual Design Review
- **Day 5:** FCF PDR Executive Session

The review teams included members from systems, structures, thermal, avionics, software, IOI, S&MA, combustion, fluids, management. The design review teams presented requirements, overviews, parts and features, and hardware lists. Other documents included flight drawing tree, FMEA, test plan, software requirements documents, reliability reports, compliance matrices, risk management plan, standards list, acceptance plan, and mechanical drawings and

schematics. Table 4 lists the documentation preparation plan for the FCF's PDR, including identifying the authors, responsables, and key dates.

Table 4: DOCUMENTATION PREPARATION PLAN FOR THE FCF PDR

Documents for review at PDR

Document	Author/Responsibility	Fidelity at PDR	Available for internal review	Internal Reviewers	Comments Due	PDR version available
Project Plan	Zurawski	ready for release	19-Oct-2000	Project Team	25-Oct-2000	27-Oct-2000
Risk Management Plan	Packard	released	N/A	N/A	N/A	15-Sep-2000
Configuration Management Plan	Berjak	ready for release	19-Oct-2000	Project Team	25-Oct-2000	27-Oct-2000
Product Assurance Plan	Patel	ready for release	19-Oct-2000	Project Team	25-Oct-2000	27-Oct-2000
Software Management Plan	Pomyk	preliminary				
EPCL Specification	Edwards	ready for release				
WFOA Specification	Edwards	released	12-Oct-2000	Rodgers	18-Oct-2000	25-Oct-2000
Other Government Documents (GFE docs, etc.)						
Risk Report (summary + individual risk sheets) (incl. only non-MRDOC risks)	Packard	current	9-Oct-2000	Rohan, Zurawski, Patel	16-Oct-2000	20-Oct-2000

Documents available for reference at FCF PDR

Document	Responsibility	PDR version available
SHED	Berjak	15-Sep-2000
Combustion SRDs*	Wesland	3-Oct-2000
FUDs SRDs*	MI	17-Oct-2000
Combustion Man-User SRDs*	CMater	10-Oct-2000
FLCQ Man-User SRDs	Gas	
Other Government Documents (GFE docs, etc.)		
EPCL ICD	Edwards	
EPCL Power Quality Spec	Rodgers	
Exhibit 1: SOW & Contract DDRI	Orban	10-Oct-2000

From this, the review board produced memorandums like checklists, minutes of attendees, summary of issues discussed, action items, as well as other recommendations and conclusions. Table 5 lists a design review checklist for the CIR Gas Chromatograph which includes the areas and items reviewed as well as comments.

Table 5: DESIGN REVIEW CHECKLIST

Design Review Checklist - CIR Gas Chromatograph						
Area	Covered?	In Scope?	Reviewed?	Assessed Status- OK, INC, DEF, NA	Item Reviewed	Comments
Thermal/Fluids						
Requirements	P	Y	P	INComplete		No real discussion of the design flow rates for the various fluid lines.
Operation Philosophy						
Tie-ins to which ISS systems	Y	Y	P	OK		
Interfaces						
Design Limits						
Heat Generation Amounts	Y	Y	Y	OK	GC Electronics Box Gas Supply Manifolds	No thermal work on the gas supply manifolds.
Technique for removing heat	N	Y	NMD	INC	GC Electronics Box Gas Supply Manifolds	
Incoming Temperatures, air/fluids	Y	Y	Y	OK	Airflow	
Exit Temperatures, air/fluids	Y	Y	Y	OK	Airflow	
Touch temperature	Y	Y	Y	OK	Exterior Surface of GC Gas Manifold	
Pressure Drops	Y	Y	Y	INComplete	Airflow	Recent change in CIR cooling will impact the analysis.
Leakages						
Flowrates	Y	Y	P	INComplete		
Fluid Compatibility	Y	Y	Y	OK	GC Electronics Box, Gas Supply Manifolds	
Required Tolerances						
Airflow Restrictions	Y	Y	Y	OK		Recent change in CIR cooling will impact the analysis.
Failure Modes/Consequences	N	Y	NMD	INComplete	GC, Manifolds	There was no discussion of failure modes.
Preliminary Hazards Assessment	N	Y	NMD	INComplete	GC, Manifolds	No discussion of hazard reduction.
Requirements/Needs for Control System Interface						
T/F System Data Monitoring?						
Alarm Limits						
Maintainability/Serviceability	Y	Y	Y	OK	GC, Manifolds	Units are not serviceable on-orbit.
Self Shutdown capability						
Drawings	P	Y	Y		Flow Schematics	
Noise	N	Y	NMD	INComplete		
Test Data	NA	NA	NA	NA		
Calibration Issues						

2.5.3. Other Missions

New Horizons is the first mission to Pluto, its moon, Charon, and the Kuiper Belt of rocky, icy objects beyond. Its Preliminary Design Review lasted 3-days at Applied Physics Library in Laurel, MD. The 10-member review panel of spacecraft and system engineering experts from APL, NASA JPL, Goddard, and Southwest Research Institute examined New Horizons' mission plans and spacecraft design, with APL Space Department's chief engineer chairing.

The **Stratospheric Observatory for Infrared Astronomy (SOFIA)** is a joint effort between NASA and the German Aerospace Center, DLR. NASA's prime contractor was the Universities Space Research Association (USRA), which provides a mechanism through which universities, the government, and other organizations can further space science and technology. SOFIA's 4-day Critical Design Review took place in Waco, Texas, where USRA subcontractor Raytheon is modifying the aircraft to house the telescope. The event bridged design and manufacturing stages, where a successful review meant that the design is validated and will meet its requirements, is backed up with solid analysis and documentation, and has been proven to be safe. The industry team led by USRA

presented the complete system design developed to make sure that technical issues have been properly addressed. SOFIA's CDR completion granted USRA permission to begin manufacturing of hardware.

The critical design review for the **Mars Surveyor Orbiter Color Imager (MARCI)** and **Mars Surveyor Lander Descent Imager (MARDI)** took place on one day, lasting from 8:30am to 5pm. In it, the chairman of the review led the discussion, prepares the official report of the results, and is in charge of developing the system to operate future Mars missions. The lead engineer for the new cameras presented most of the technical details. Members of the review board were a JPL engineer in charge of science instruments for the Pathfinder, a SDSU astronomer who built and uses cameras on telescopes, and the designer of the Mars Observer and Mars Global Surveyor cameras.

The **Stardust** mission will gather samples of dust as it flies by a comet and return them to Earth. The PDR had an independent review board appointed by the space agency, and marked the end of the mission's concept definition phase (Phase B) and the start of design, development and fabrication (Phases C and D). The CDR confirmed that the design is complete and subsystems are on schedule for spacecraft integration.

The **Lunar Orbiter** missions were five missions that were launched with the purpose of mapping the lunar surface before the Apollo landings. Each landing was made successfully and, in total, they were able to photograph 99% of the moon. The PDR was conducted by Boeing and NASA. It checked any specific technical area or major subsystem before a final decision was made to freeze the design. The CDR concentrated on the components and subsystems to see if they passed as acceptable for fabrication and testing; if approved, changes were held to a minimum. Various other reviews took place during fabrication and a formal acceptance review was conducted at the completion point.

Cassini-Huygens was launched in 1997 to reach Saturn by 2004. The mission is composed of two elements. The Cassini orbiter, built and managed by JPL, will orbit Saturn and its moons for four years. The Huygens probe, built by the European Space Agency, will dive into the murky atmosphere of Titan and land on its surface. The reviews consisted of JPL and other NASA and independent reviewers, supported by the European Space Agency and the Italian space agency *Agenzia Spaziale Italiana*.

2.6. Lessons Learned

2.6.1. NASA Programs

The successes and failures of NASA missions have also provided lessons learned for the organization's design review practices, listed in Table 6.

Table 6: LESSONS LEARNED FROM SOME NASA MISSIONS

Mission	Event	Lesson Learned
Huygens	NASA personnel were denied access to the designs for the spacecraft by partners, making resolution of problems difficult or even impossible	Important to retain engineering rights to all designs, analyses, procedures, and test results
Skylab	Fell to earth in showering debris over uninhabited parts of Australia and the Indian Ocean.	Specific design reviews which are based upon an analysis of drawings can inadvertently overlook important features such as operational compatibilities
Mars Climate Orbiter	Navigation errors	Inadequate reviews missed use of different units, key personnel were missing from critical design reviews
Mars Polar Lander	Premature shutdown scenario. The spacecraft was not designed to send telemetry during descent.	Investigation was hampered by lack of data. The decision not to send telemetry during descent was severely criticized by review boards yet still not changed.

A number of studies have been done throughout NASA to improve the review process. The **ASIC program** [3] identified the following considerations:

- Plan for reviews at the *beginning* of a program.
- Don't underestimate the importance of *selecting appropriate board members*. Remember you will rely on their expertise to achieve first-pass silicon.
- Identify the participants for reviews early enough so that they may receive all necessary *review material in time* for their analyses.
- Work with the vendor's review methodology to *reconcile your organization's goals* for a particular review with those of the vendor.
- *Build the reviews into the contract* and the statement of work so that sufficient resources will be available from the vendor to properly support the reviews and action items generated from them.

A survey of software Validation & Verification processes and methods at NASA [1] identified the following recommendations:

- Organize modeling teams with *responsibility for entire sub-systems* to ensure internal coherence and communication.
- Evaluate testing coverage of autonomous software
- Develop tools to mitigate the *effect of late changes* to requirements.
- Develop *better model validation processes* and tools
- Use new *graphical tools* to provide visual inspection and modification of mission profiles, as well as constraint checking

Develop tools and *simplify the modeling languages* so spacecraft experts can encode models themselves and explain the models to test engineers more effectively.

- *Simplify the specification* of goals and automate consistency checking

2.6.2. Lessons Learned Information System

The Lessons Learned Information System (<http://llis.nasa.gov/llis/llis/llis.html>) is a reference database of different lessons from NASA projects. It is provided to NASA personnel and approved NASA contractors. Searching for “design review” in the system provided 154 different lessons, summarized in Table 7. Some of the lessons of interest pertain to process considerations and guides, but many only point out specific items that should be considered in future reviews of a similar system.

Table 7: LESSONS LEARNED ON “DESIGN REVIEW” IN LLIS

Type	LLIS Database Entry	Description
Coverage	0017, 0564, 0634, 0637, 0638, 0640, 0644, 0740, 0763, 0869, 0885, 0886, 0905, 0906, 0908, 0916, 0923, 0932, 0981, 0989, 1120, 1184, 1185, 1200	Specific items to review, such as certain analyses to perform in future reviews
Considerations	0271, 0286, 0387, 0393, 0440, 0584, 0588, 0862, 0917, 0974, 1063, 1089, 1180, 1196, 1278	More general considerations for reviews, such as when or what to include
Guides	0648, 0655 (PDR), 0656 (HR/CR), 0657 (CDR), 0667, 0668 (PSR), 0681, 0682, 0728, 0761, 0786, 0789 (SIR), 0929, 1211	Review method guides and guidelines
Tools	0371 (FMECA), 0599 (Taguchi), 0733 (PFR), 0738, 0791, 0825	Design tools to use during reviews and items to support reviews, like databases and forms
Organization	0495, 0533, 0534, 0619	Review authority and personnel inclusion
Benefits	0582, 1276	General reasons to do reviews

2.7. Issues

Initial surveys and interviews showed high confidence in the formal review process at NASA. The general consensus was that with the right people all problems should be caught in design reviews. Though there is high confidence in the individuals at NASA, there can be great variation in how design reviews are executed, depending on the combination of individuals involved. In addition, even though there are many guidelines there are some times inconsistencies in implementation. For some very small missions, a Single Design Review (SDR) is

done, combining the Preliminary and Critical Design Reviews. Engineers at Goddard who have been through this have said that it is a bad idea.

NASA has taken a closer look at how design reviews communicate information between reviewers and designers. Bill Parsons, space shuttle program manager, said he hopes to open the doors of communications between NASA's four spaceflight centers. NASA engineers debated the potential damage to Columbia right up until landing day but never notified NASA's top management. "Maybe we have not shown people how they need to get in the loop of the formal decision-making process," Parsons said. "We're going to go and characterize that for people and see how they may do that better." [8]

A major issue is with how designers view reviews. One project manager even said that reviews can be "dangerous" in that the project might assume that the review can catch everything for them. Some managers strongly believed that design reviews can and should catch any problem. Others feel that the design review is a weak process which is completely dependent on the individuals involved. And there are even others that feel the complexity of the systems has exceeded our abilities to grasp it.

In some interviews and conversations, discussion of design reviews begin with a statement along the lines that "99.9% of the value of reviews is preparing for them." This statement refers largely to the formal reviews which are a required part of the NASA life cycle. The informal peer reviews are viewed differently as part of the preparation process. Though important, these reviews lacked the consistency and formalism of the system reviews.

3. PEER REVIEWS

3.1. Background

Peer reviews were first introduced around 1690 and have served as a useful tool in evaluation in science and engineering. Though the process is not perfect, many believe it is far better than alternatives. (O'Reilly 2002) There are a number of models of summative evaluations. Eibeck (1996) lists the three prototypical models as:

1. Review
2. Checklists
3. Experimental/user observation

Trenner (1995) says the advantage of peer review comes when the designer is inexperienced or experienced developers are "too close" to their work to see it objectively. Difficulties can come in peer reviews when designers feel threatened

or demoralized, a reluctance to criticize, a pooling of ignorance, or the review doesn't show the severity of the problems identified. Peer reviews can also fall into the trap of being a cosmetic exercise with no commitment to making the changes suggested.

These peer reviews are key to success in the formal review. However, in initiating conversations with engineers and manager across NASA about "peer reviews," it was clear that the term meant different things to different people.

3.1.1. Official Definitions

Jet Propulsion Laboratory's Project Review document [G] defines peer reviews as:

A peer review is a working-level, in-depth review convened as needed to evaluate an analysis, concept, design, product, or process thoroughly. Peer reviews focus on early detection of flaws. They are also used to detect flaws in engineering products and processes prior to delivery from development organizations to test and operations organizations. Special in-depth reviews called pre-reviews are conducted before higher level design reviews.

Goddard's System Management Office [4] describes **Engineering Peer Reviews** (EPR's) as a resource for product design teams (PDT's) to "identify potential engineering design and implementation flaws, and increase the probability of success." These EPR's address:

- Requirements and Resource Adequacy
- Systems Management Processes
- Design Adequacy: Drawings, Schematics, Analyses, Parts and Materials
- Compliance with Policies, Procedures, Standards and Best Practices
- Implementation Adequacy
- Manufacturing Processes
- Verification Approach: Tests, Analyses, Simulation
- Verification Results: Data Adequacy, Observed Margins, Trends, Anomalies
- Claims of heritage from previous missions
- Lessons Learned (applied and learned)

3.1.2. Interview Scope

To facilitate discussions with NASA personnel, this research used a definition and scope of peer reviews for these discussions as informal, in-depth technical reviews, usually held before major reviews like PDR and CDR as pre-reviews. The number of people involved can include anywhere from a conference room

full to just one or two reviewers in an engineer's office. Even the definition of a "peer" varied somewhat. Peers are usually other people from a similar technical background, though some managers emphasized that peers should also be peers in term of organizational hierarchy, i.e. no managers or other "bosses."

3.2. Documentation

There are a number of guidelines, checklists, and documentation for system reviews like the CDR, but guides for peer reviews are quite limited. Often, peer reviews are simply mentioned as pre-reviews for the system reviews.

JPL D-11381 [F] simply recommends "a series of detailed peer reviews be conducted prior to the Preliminary Design Review (PDR) and, especially, the Critical Design Review (CDR)." The peer reviews should be informal but structured, including a checklist, and the team should summarize the review at the formal PDR or CDR.

The **NASA Mission Design Process** [B] recommends peer reviews to be conducted periodically through Phase A (Mission Analysis). The group should be composed of individuals chosen from outside the project. Review of analyses, drawings, and other design documentation versus viewgraphs is recommended. In Phase B (Definition/System Design), the technical part of the review should also examine associated cost and schedule data.

Perhaps the most extensive documentation on peer reviews comes in **D-10401** [G]. It calls for peer reviews to be "convened, as needed, as working-level reviews to evaluate detailed aspects of a product or process." Though it explicitly states that peer reviews are to be informal and not subject to the formal project review requirements, it suggests the following guidelines.

- *Peer reviewers should not be currently working in the project/major task element being reviewed.*
- *The plan for the use of peer reviews, and the plan for recording their results, should be included in the review plan. The number and subject areas for peer reviews should be generally scoped by the project manager or designee, in order to provide sufficient budget to implement them effectively.*
- *A record, consisting of the purpose and date(s) of all peer reviews conducted should be maintained by the project as part of the Product Delivery System records. Further, the records should include, for each review conducted, a list of reviewers, findings, recommendations, and action items accepted by the project.*
- *Peer reviews should thoroughly examine product or process issues. Peer reviews are also useful to detect and correct deficiencies in engineering*

- products and processes prior to delivery from development organizations to test and operations organizations.*
- *Peer reviews should be held during development of products or processes. They can be held at any time, but are particularly useful prior to higher-level design reviews. Peer reviews are limited to a single product or process to ensure a thorough, in-depth evaluation.*
 - *Peer reviews can be called by the project or by the cognizant line organization (Section Manager, Group Supervisor, etc.), when a concern exists. The concern could be effectiveness of the ongoing review and oversight of the effort in some area of development - either the design itself, or the design status. It also could be that a known or suspected problem in the design needs investigation.*

Even with these guidelines, it still emphasizes that reviews should be “kept simple and informal to minimize the cost and effort. Likewise, the supporting documentation for a peer review should be kept simple and informal.”

3.3. Method

Peer reviews are usually held on the sub-system level, though reviews for specific components are held in support of the sub-systems as well. Ideally, peer reviews would be done on every subsystem and component in the greatest of detail with all the foremost experts, but that is not always possible. The project manager usually works with the sub-system section leaders to discuss how much time and resources should be invested in each sub-system review.

It is up to the program manager to decide who to include in reviews. Currently there is no organized system or list of reviewers in place for managers to refer to. The process is quite informal but intuitive in many ways. The sub-system leader will usually look for reviewers in his or her own line organization, so often will just choose his or her colleagues or ask the line manager for suggestions on reviewers. The main constraint is to choose people who are not working on the same project. For example, if the subsystem is in electronics, reviewers should be people who are in electronics, like former cognizant engineers. When experts are needed from other areas, often the best place to start is a manager of that section or line organization. The peer reviews are paid for by the project where the reviewers can bill their time to the project. Many times, however, the reviewers simply volunteer their time to help out their peers.

The peer review method varies from project manager to project manager. One project manager had a formalized method which for his “engineering peer meetings.” As pre-reviews, his rule of thumb is to conduct the peer reviews about a week or 10 days before the formal review. This gives enough time to react to suggestions and criticisms. To do a review too early, even as much as a month, likely means the review of something that is not the true status by the time the

formal review comes. However, the planning of these peer discussions must start to take place well in advance. It can take up to six months to get a good handle of a medium size mission. It takes a month to figure out good questions to ask, a month to collect questions about similar subsystems in the past, a month to find out who to talk to, two months to conduct the interviews, and another month to put the data into something that's reasonable and use probabilistic risk tools.

Some project managers are involved in the process by preparing templates of types of questions that reviewers should be concerned about, and are generated from historical and lessons learned sites. Most reviewers don't prepare anything before there reviews.

Langley Management System's **LMS-CP-5508** [E] outlines the procedure for Ad Hoc Technical Reviews in order to increase the probability of success of Langley's programs and projects through technical reviews, shown in Figure 6.

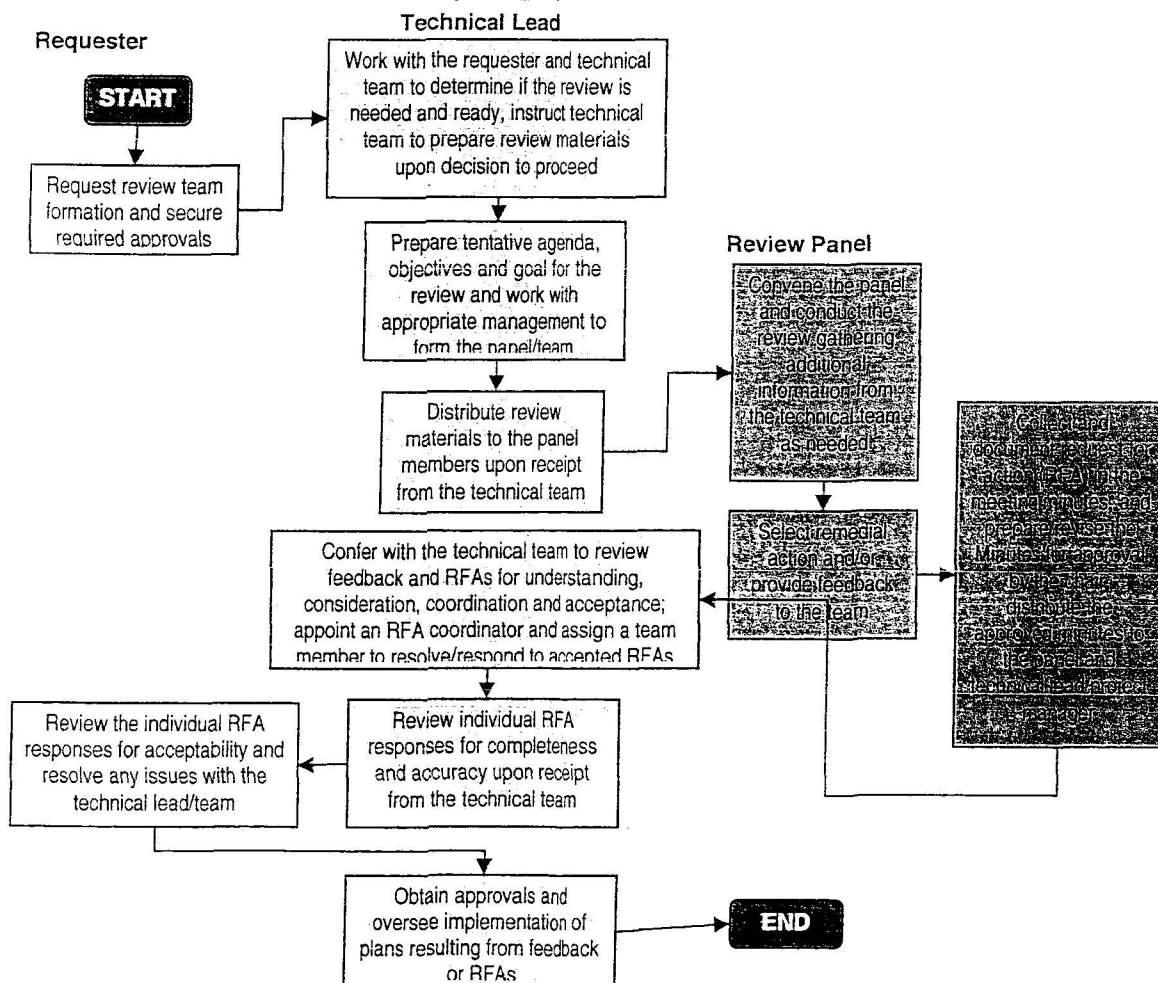


Figure 6: REPRESENTATION OF AD-HOC TECHNICAL REVIEWS AT LANGLEY

To get an idea of the typical size of these reviews, according to one branch chief, peer reviews are usually fairly short, on the order of around 2 hours, and participants are usually notified anywhere from one day to one week in advance. The project manager typically decides who can be of most benefit and invites them, usually holding the number to around 4-8 people. Branch management is typically invited but not required.

3.4. Issues

There is strong sentiment at NASA that peer reviews give the most benefit and cost the least amount of time and effort in the life cycle. Because these peer reviews are more or less “voluntary,” they can be done with more flexibility and cover the topics that are important to the designers not the reviewers. At the same time though, they lack consistency in implementation. A good project peer review is very dependent on strong leadership and involvement by the project manager.

While standing reviews like the PDR and CDR are highly structured and formalized, the technical peer reviews that are an important pre-review for these programmatic reviews are not. It is in these informal reviews that the engineers and managers must work out the details that can be missed in formal reviews. The key to success in these peer reviews though is a balance between discipline and freedom.

4. DESIGN REVIEW ANALYSIS

From the interviews with NASA engineers and managers and comparing them to research done in existing literature, NASA must further consider key five areas in working towards improving design reviews: the role of design reviews in the **organizational** structure, the **composition** of the design review boards, the **scope** of analysis for each peer review meeting, the personal **approach** taken by the team and reviewers, and the use of **information technology** and other tools to aid the reviews.

4.1. Organization

4.1.1. NASA lessons

At NASA JPL, the peer reviewers are usually full-time engineers and managers who donate some of their time to help review projects for their colleagues. However, at NASA Goddard, there actually is a full time review group which does the peer reviews. Some independent review boards are used at NASA,

though they are often there more to report on programmatic issues to Headquarters. At NASA Ames, there was extensive contracted use of independent reviews on their projects.

Most JPL personnel expressed a belief that reviewers should be full-time engineers and managers so that they don't lose their technical expertise and can stay current with the state-of-the-art at NASA. However, some expressed some interest in the idea of having a part-time review program where engineers could work as a "full-time reviewer," perhaps for a period of several months. This rotating review board could train the reviewers and allow them to review for several months then return to their original position, allowing them to stay "current."

At Ames, managers said they've learned that it was clear that it was necessary to budget for reviews, particularly the PDR and CDR. The requirements were levied in the contract. Independent and peer reviews weren't really budgeted for initially. Though some time is allocated for peer reviews, for the most part, money isn't allocated and when the budget becomes tight, it is not uncommon to cut peer reviews. Some managers even said the way to make the peer review system ideal is to make the personnel available to the project at no cost.

4.1.2. Literature review

Ichida et al. (1996) examined possible relationships between the design review board and the designers. They identified three models. The first has design reviews dominated by the design department. The advantages are that reviews can be introduced with minimal resistance and the designers can better prevent infringements upon their authority. The disadvantages are that the designers will more likely guard their own turf when determining action items, scheduling, and follow-up. Having a design review office advising the designers can result in more impartial action items and subjects to be addressed, but there can be difficulty in gaining sufficient understanding from both sides on the design and the philosophy of the design review. Finally, there can be a shared relationship where the design review board is elevated to a joint-decision making role within the design team. This gives the benefit of an impartial approach and suited towards phase-specific (like gate) management, however with even less sense of ownership, the designers would feel a loss of authority and easily overlook routine activities.

Though not design reviews in the strictest sense, many organizations use a type of stage-gate process to guide their product development. ABB is a multi-national organization with two product divisions (power and automation technologies) that also serve external channel partners, Financial Services, and Group Processes. Similar to NASA's Life-cycle model, ABB implemented a business decision model supported by the Gate Model, detailed in Table 8.

Table 8: THE ABB GATE MODEL

Gate	Title	Description
G0	<i>Start project</i>	Initiates the feasibility evaluation. The focus is on analysis of the requirements.
G1	<i>Start planning</i>	Defines the scope of the project. The requirements agreed here will control the planning.
G2	<i>Start execution</i>	Marks the agreement on requirements, concept, and project plan. The focus is on specification of functions and architecture.
G3	<i>Confirm execution</i>	Confirmation that target dates can be met and that the project executes according to the project description and plan. After this gate, the focus is on implementation.
G4	<i>Start introduction</i>	Release for acceptance testing. Focus is on validation on preparation for the market introduction and on production preparations.
G5	<i>Release product</i>	Handover of the results to the line organization. Indicates also that the project activities should be finished and focus is on finalizing any remaining issues.
G6	<i>Close project</i>	The project ends.
G7	<i>Retrospective investigation</i>	A follow-up of the project to check if the results are satisfactory and feedback experiences to the organization.

The model serves as a framework for various activities included in product development. Each organization runs their process through the Gate Model independently with a Gate Owner who has the authority to start/stop, fund, and staff the project, including the Gate Assessor. The Gate Owner is usually a manager responsible for the business that the project is focusing on. The Gate Assessor is an individual not directly involved in the project who is responsible to perform the assessment on behalf of the Gate Owner. The project leader aids the Gate Assessor in the assessments. Though there is no single organization which maintains and runs the Gate Model, ABB created a group-wide process organization to take ownership of the improvement activities and ensure consistent implementation of process standards across the company. [14]

At General Electric, the design review is integrated into the design process through interaction between individual contributors, key technical specialists, and the Chief Engineer's Office. By initiating informal meetings with Chief Consulting Engineers and the Chief Engineer throughout the design process, the designers can exchange data and discuss issues and ideas. Similar to NASA, these informal consultations are excellent preparation for formal design reviews and may consist of various meetings and discussions, including senior/staff engineers, peer engineers, technical specialists, or Chief Engineer's Office representatives. These design reviews are not tollgate reviews, program technical reviews, nor scorecard reviews.

There are other review models that can be followed. In the field of civil engineering in Germany, construction firms use full-time reviewers who are paid to review their projects with a share of the contract. In turn, however, these

reviewers assume half the liability of the project should anything go wrong. The U.S. government has had some programs where after contractors bid for a project, the runner-up contractor is hired as the reviewer for the winning contractor, as both are familiar with the technical details of the project. All contractors who bid for the job are made aware of this arrangement from the beginning.

4.1.3. Discussion

Though most interviewees did not have suggestions on major changes to the review process, when asked what they would do “infinite time and resources,” their answer was simply “get more reviewers.” Since the projects have to pay for their own reviews, it can dilute their effectiveness as there are a lot of competing interests within the project for the money. It is not uncommon for some sub-systems to not even do peer reviews. Even if the entire system is reviewed, there are no guarantees on its depth, consistency, or quality. It is not just getting a person, but getting enough quality time with them to comprehensively review the project. It is usually a privilege to even get two hours of some experts’ time to review drawings. Some times, two days are really needed to penetrate the design.

Even though formal reviews are mandated by NASA Headquarters while peer reviews are done on a voluntary basis for the projects’ own benefit, both are funded from the project and not the organization. For NASA to emphasize the importance of these reviews, it would make sense for them to guarantee funding perhaps from a separate source, at least on the formal reviews. There will be some changes in the NASA accounting structure, and it may be able to put reviews under a corporate charge in the future.

A review office can be useful to help project managers assemble and guide their review teams. Many showed interest in the idea of a rotating review program where engineers work as full-time reviewers for several months at a time. For most informal reviews, that probably is necessary. At the least, the review office can help provide training material to reviewers and managers, including providing tips on conducting successful reviews. A review office can provide more than just technical reviewers. Other ways the review office can benefit the review process is through full-time review historians, cost/risk analysts, and system administrators for review databases and lockers.

The review office could also maintain a list of reviewers for project managers to refer to. Though there was some discussion of rating reviewers and the usefulness of that, many felt the politics associated with it would outweigh the benefits. However, a completely objective list with only the reviewers’ names, contact information, and “resume” of their current position and background, as well as portfolio of projects that they have reviewed could be helpful. If this list could be cross-linked with project information, managers could look for certain similar projects to find qualified reviewers.

4.2. Composition

4.2.1. NASA lessons

Most NASA engineers and managers said they had no hard and fast rules on composition of their peer review boards other than to find the qualified people with the requisite skill set and experience. Usually these are the people they know from previous reviews or identified from talking to the managers in the appropriate line organizations.

Some engineers and even project managers did believe that it is important to have only peers, not only in the sense of technical expertise, but also peers in term of organizational hierarchy present at peer reviews. By having no bosses or anybody who would “review the individual,” rather than just the project, it allows the engineers to be more open about challenges and problems they are facing. This allows the review to be conducted in a more informal manner.

There have been differing views on the number of reviewers that should be present at a peer review. One school of thought is that the more reviewers, the better, as there are more “sets of eyes” to spot problems. However, one project manager felt very strongly that smaller sets of reviewers are better as they allow more personal interaction. In addition, a smaller peer review can be held in an engineer’s office where he or she has full access to any materials needed and allows them, for example, to look over a piece of paper and make marks directly on it together. This project manager said in his experience, the best “peer meetings” are with 1-on-2 or 2-on-2 reviews, with 2 reviewers to one or two team members. In addition, he has the reviewers talk with him informally afterwards to discuss next steps. If there are 3 or more reviewers, then not only does it limit the dialogue, but it is necessary to make copies of the papers and makes the presentation process more formal. With only a few people, the team can just look over the same sheet of paper and have a more intimate dialogue.

4.2.2. Literature review

Research has found some general, though some times conflicting, rules of thumbs which can be considered. On the inclusion of supervisors, one view is that the review is highly influenced by the project supervisor whose responsibilities and knowledge of the project can more easily bring others to his or her point of view. According to this train of thought, the supervisor’s participation is therefore obviously needed. However, Freedman and Weinberg (1990) state very flatly that “Nobody should be present at a review whose role might create a conflict of interest.” Because team leaders can not be objective when leading a review of their work, they should never lead reviews of their own team’s work.

Regarding the ideal size of reviewing teams, D'astous, Robillard, et al (2001) found that it is subject to debate. Weller (1994) found that four reviewers are twice as efficient as three. Buck (1981) found no difference in the efficiency in two, three, and four reviewers. Porter and Johnson (1997) determined size doesn't influence anomaly detection rate.

4.2.3. Discussion

The key in design review board composition is to have a group with the requisite skill set and right personality match to make the process run smoothly. More is not necessarily better. Both engineers and managers expressed the belief that having supervisors at peer reviews tended to hinder the process. However, not having managers physically present at the reviews doesn't mean that they should not be involved. The project managers and section leaders must take an active role in choosing the review board members, ensuring that the review will cover the technical aspects in a manner they find appropriate, perhaps generating a list of suggested topics to cover.

The manner in which reviews should be constructed depends on the people involved. Some people do require tougher criticism than others. It depends on the project manager to assemble a review team that can work well with the project team. No matter the style of the reviewer, it is important to emphasize the point of reviews is to identify opportunities for improvement. Managers should choose the members who will cover the issues they want. Formalism in the process can help keep things professional.

Also, because these reviews are informal doesn't mean there are no rules or documentation. The idea is to give the engineers and reviewers more freedom in covering the issues they want in a manner they are comfortable with. It is still necessary to report to the rest of the group the status of their piece of the system so that others can be informed of issues that may impact them.

4.3. Scope

4.3.1. NASA lessons

Since projects have limited resources and competing interests, projects often cannot cover the breadth of all topics in sufficient depth. Tradeoffs must continually be made by projects as design reviews are one part of each project which must compete for attention in terms of both time and funds. It is not uncommon for some sub-systems to not even do peer reviews.

There are a number of documents which guide reviews. Langley's **LMS-CP-5505** [D] has all of the criteria and metrics associated with what is reviewed and what is needed to be successful based on which type of review is being held, i.e. PDR, CDR, etc. These same criteria and metrics are used for the particular major review.

Even when peer reviews are done on all subsystems, they are not always done in a consistent fashion. Reviews are often too shallow technically. A number of factors must be considered when deciding whether a subsystem needs more resources and reviewers. Some of the criteria used to decide what is peer reviewed include:

1. *Complexity of the subsystem*
2. *Technological Readiness Level of the subsystem*
3. *Criticality of the subsystem to overall performance of the total system*
4. *Breadth of the technical area over the entire project such as software*
5. *Lack of sufficient information on the subsystem at a previous review (i.e. at a PDR, the subsystem was not to that level of maturity)*
6. *Past history of trouble in that area or subsystem.*

The subsystems or areas to be reviewed are chosen through a negotiated agreement between the Review Chairperson and the Project Manager.

4.3.2. Literature review

Dorner (1996) has researched and identified the logic of failure in complex situations. Humans have many inadequacies in dealing with complex systems. Complexity, dynamics, intransparency, and incomplete understanding of systems are all factors in recognizing and avoiding errors. Humans tend to badly mishandle temporal developments. They tend to extrapolate linearly and cannot handle exponential changes. The "slowness" of human thought often obliges shortcuts and prompts use of scarce resources as efficiently as possible. But instead of clarifying the complex relationships, humans often select one variable as central and economize around that.

The scope of the review is important from both the reviewer and reviewee side. For the design team presenting, it is important that they provide a full picture of the situation. According to Leveson (2000), cognitive psychologists have determined that people tend to ignore information during problem solving when it is not represented. An incomplete representation actually impaired performance because they assume it as comprehensive and truthful. An incomplete problem representation can actually lead to worse performance than having no representation at all. One possible explanation for these results is that some problem solvers did worse because they were unaware of important omitted information. However, both novices and experts failed to use information left out

of the diagrams which they were presented, even though the experts could be expected to be aware of this information.

There currently is a dearth of proactive design tools to guide reviewers. The main aids available are questionnaire and checklists. However, it is difficult to create general and re-usable guides such as these. Eibeck (1996) studied different models for evaluations and found from feedback that detailed questionnaires were not successful tools for peer reviews. Review is highly subjective and can give significant information to the design team. A checklist can only address issues on a superficial level.

Trenner (1995) says another difficulty of peer review comes in that there is often no system to quantify and compare the severity of the problems identified. Weyuker (1999) developed a questionnaire that computes a risk metric based on fifty-four of the most commonly occurring and severe problems in project management, requirements, and performance. There was a total of 440 points possible if every one of the problems were present, where a score less than 75 is a low risk and a score greater than 300 is a high risk.

4.3.3. Discussion

There are a number of structured methods to identify priority areas to cover in the peer review. It is necessary to do these tradeoff analyses because even if the design and review team says they will cover “everything,” chances are there will either be a few areas skipped or skimmed over. Often times, engineers are afraid that the planning of them takes too much time or that they inhibit innovation. However, as Barkan (1993) rebutted, planning not only results in significant reduction in development time and also leads to better quality. Using the right methods encourages innovation because they reduce the risk of failure, minimize oversights, and focus innovation on what counts.

Project Level

System Review QFD allows the project manager to analyze the elements of a system when trade-offs are necessary in making plans for peer reviews. The vision behind this QFD is to identify important areas to review in a system by quantifying their impact on the requirements for the project or mission. Doing so ensures the efforts spent during the project work towards that goal. By performing the System Review QFD before the engineering peer reviews, this tool can help prioritize and plan the sub-system reviews.

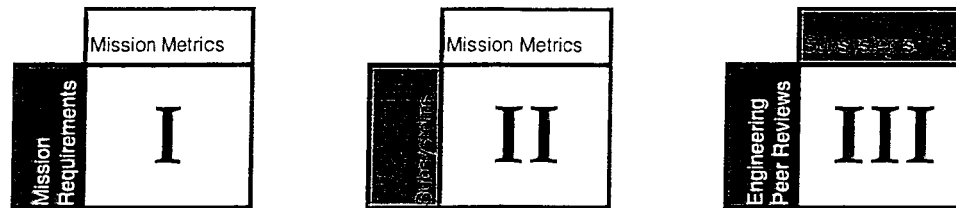


Figure 7: SYSTEM REVIEW QFD

System Review QFD is a variation of the traditional Quality Function Deployment. However, in the modified House I, the Project or **Mission Requirements** and Risks are mapped against Project or **Mission Metrics**. In House II, the **Metrics** are mapped against the different sub-systems sub-teams for the group. By weighting the requirements and correlating the metrics and sub-systems using standard QFD weightings, rough allocations of the project time can be estimated in a transparent and documented manner. This allows the project manager to better plan and dedicate resources according to these weights for the project reviews to ensure that the key risks are covered. Depending on the size of the systems or sub-systems, this same process can be used within a given sub-system to identify how the review should allocate coverage within one sub-system's peer review.

There are also tools which can be used on the sub-system level to help analyze the each sub-system, including FMEA. In contrast to the System Review QFD, these tools can be applied separately at each engineering review meeting. If applied, they can help the individuals involved at each meeting identify specific technical areas to discuss.

Subsystem Level

Because it is already used at many organizations, including at NASA, FMEA is perhaps the simplest and easiest method to identify problem areas in system. **Failure Modes and Effects Analysis (FMEA)** is a design tool that identifies, prioritizes, and alleviates potential problems in a given product, system, or process. Along with structured methods like **Quality Function Deployment (QFD)**, FMEA is a risk management tool that provides decision guidelines to aid the team of designers to achieve a design that provides the most in terms of cost and quality. FMEA begins with the identification of the functions or requirements of the system and ways that they can fail to be satisfied. From that, the analysis identifies potential causes. Table headings are shown in Table 9

Table 9: HEADINGS FOR A TYPICAL FMEA ANALYSIS

Function or Requirement	Potential Failure Modes	Potential Causes of Failure	Occurrence	Local Effects	End Effects on Product, User, Other Systems	Severity	Detection Method/ Current Controls	Detection	R P N	Actions Recommended to Reduce RPN	Responsibility and Target Completion Date
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For each failure mode and cause, the probability that they can occur must be identified and scored on a scale from 0-10. After the local and end effects are identified, the severity of each end effect must be scored on a similar scale. Finally, the detection rating scored refers to the likeliness of catching the failure modes before they happen. The product of these three terms is known as the **Risk Priority Number (RPN)** which gives a relative magnitude for each failure mode. The higher magnitude RPN's should be a higher priority within the peer reviews, and the review team can discuss actions to reduce the RPN.

If teams perform an FMEA analysis before each peer review, the peer reviewers can more quickly see problem areas already identified by the teams and either supplement the analysis with additional failure modes or investigate and discuss the high RPN items with the teams to devise corrective actions. The FMEA provides not only a systematic and consistent tool which forces the teams do to their homework before these reviews, but it also helps the peer reviewers understand the project and problems better.

For analysis of the engineering tasks of each sub-system team, a process analysis such as **design process FMEA** (Chao 2003) can be applied. The goal of design process FMEA (dpFMEA) is to identify and apply rough weights to potential design errors as part of an error-proofing effort. Simplicity and speed are the goal of this analysis. A small group should analyze a design process in several hours rather than several days. Design process FMEA fully allows and expects changes to adapt to different processes. The design group performing the dpFMEA analysis should do the analysis using a spreadsheet environment to electronically record progress. In addition, this allows resorting of data to facilitate analysis.

For each task, one should look through each category of the design errors. Start with each category and set of questions, and generate a list of errors, if applicable. If there is an error of the given type for a task, complete it on the FMEA table in the second column. For each error that is brainstormed, the immediate effects of the error should also be listed in Table 10. This approach looks at design errors from several key categories of error factors. (Chao 2003).

Table 10: DESIGN ERROR CLASSIFICATION SYSTEM CATEGORIES

Category	Description
Knowledge	<i>Inexperience or misunderstanding of the system</i>
Analysis	<i>Inaccurate assessment of the system</i>
Communication	<i>Mistransfer or misinterpretation of information</i>
Execution	<i>Improper or inaccurate implementation</i>
Change	<i>Unanticipated variation or modification</i>
Organization	<i>System or managerial deficiencies</i>

Quantifying the errors identified in either FMEA analysis identifies the areas of highest risk are often where the greatest opportunities are to be found. The issue is that it is difficult to quantify these different errors or risks. Expected cost is a good and easy to understand measure, but it often takes a full-time person much time to get good estimates on a dollar amount and probability for the different errors or risks. Tools in industrial engineering to estimate rework cost as well as surveys on reputation cost exist, but an engineer still cannot easily comprehend the eventual end effects of latent errors early in the life-cycle, much less measure them. One error can have multiple consequences of varying degrees of magnitude.

An alternative is to use the importance values calculated through Quality Function Deployment, based on importance to the customer requirements. This QFD method can be used to quantify the errors identified in either the traditional of design process FMEA analyses. The application of **Design Error QFD**, illustrated in Figure 8, relates customer requirements and risks to the design tasks as an alternate method of defining severity. (Chao 2003)

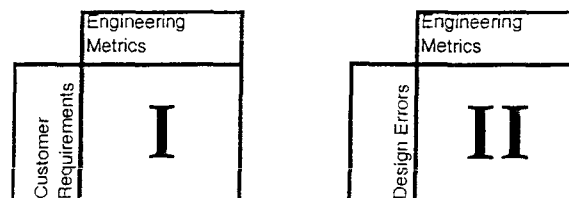


Figure 8: USING QFD TO RANK DESIGN ERRORS OR RISKS

Rather than mapping engineering metrics to parts in House II, the design errors are correlated to the customer requirements through engineering metrics. This quantifies the errors according to the customer values, which is important in determining quality of the design. These QFD values give priorities for errors to consider from an error-proofing perspective.

4.4. Approach

4.4.1. NASA lessons

The nature of the human interactions that connect reviewers and reviewees can influence the results of the review as much as the technical understanding of both sides. Some design reviews are extremely adversarial and are even compared to prosecutors cross-examining the defendants in a legal setting. Others emphasize consensus building in a positive manner, so much so that people call them “group hug” reviews. Both approaches have their positives and negatives. The group approach tends to have broader and more even coverage of all the review topics. The more adversarial approach tends to get very detailed coverage, but only of one or two areas, usually the areas where the reviewer is most comfortable or familiar in. The project manager must be aware of these factors in the selection of the review board.

One project manager has done much work on the psychology of risk and reminds reviewers to make corrections for personalities. If a person is optimistic in nature, his cost estimate will be optimistic as well. If the person is late to meetings, his schedule estimate will likely be underestimated. If the person has never worked on a badly overrun project, the next one likely will be.

Another question is what the nature of the reviews should be. At Goddard Space Flight Center, the Management of Government Safety and Mission Assurance defines a spectrum of activities, from oversight to insight, to determine the adequacy of a product or process. Oversight typically entails onsite, in-line involvement with the supplier's processes and generally includes detailed monitoring of the process itself. In contrast, insight typically entails monitoring a minimum set of product or process data to provide an adequate understanding of the product or process. In general, the tendency as NASA is to lean more towards oversight if the risk is high and more toward insight if the risks are low. The strategy can change as the program progresses and more risk information identifies where changes are necessary or beneficial to reflect either an increase or decrease in risk. Within an area there may be varying levels of insight and oversight applied to portions of the surveillance.

4.4.2. Literature review

In light of recent events such as the difficulty with the Mars missions and most notably the Columbia disaster, NASA as an organization has taken a deep look into changing the atmosphere around reporting problems. Former flight manager and a member of Columbia's mission management team says it is important to note that “I wouldn't look at this case as being all of NASA was wrong except one guy who had the answer. There has to be a more fundamental structural problem with how the communication broke down here.” Former astronaut Sally Ride has commented on the design review process saying that “This is a very personality-dependent thing, and these large meetings can be intimidating.” [7]

NASA chief Sean O'Keefe has promised dramatic change towards creating an atmosphere in which "we're all encouraged to raise our hand and say something's not right or something doesn't look straight." He has proposed changes such as going to a NASA web site to file anything anyone sees as being wrong, making it easy for anybody to participate and voice their concerns anonymously if they want. NASA is already well-known for its safety-reporting hotline and printed forms. [7]

Dorner (1996) researched characteristics of good and bad problem solvers. Good problem solvers favor expressions that take circumstances and exceptions into account, stress main points but don't ignore subordinate ones, and suggest possibilities. They tend to use more qualified expressions like: *now and then, in general, sometimes, ordinarily, often, specifically, perhaps, may, can, and be in a position to*. Bad problem solvers tended to use unqualified expressions like: *every time, absolutely, completely, nothing, only, must, and have to*.

Freedman and Weinberg (1990) suggested several rules of thumbs with running reviews. They recommend 2-10% of labor allocation should go to technical reviews. Reviews should try to run for about 2 hours. Starting at 10:00AM tends to be a good time to have reviews. Late in the afternoon reviews are likely to produce rushed and superficial reviews as people continually look to the clock, hoping to get home early.

4.4.3. Discussion

The approach of the design review board obviously is greatly correlated with its composition. The formality of the design review can influence this behavior. Even the seating arrangements have psychological impact in peer reviews. By putting the review in a round table format and not having people stand-up and present the material, it prevents the exchange from being too formal or adversarial with a prosecutor's mentality. Not having direct superiors or any sort of personnel evaluators is important for this reason. The peers involved should be concerned only with the problem at hand and not with impressing anyone. Certainly it is difficult to create guidelines on how to construct a review team based on personality types. Nonetheless, it is something that should be considered in constructing the teams just as technical ability is.

Another key is for the reviewees to not fear tough review panels. They should not worry about "passing" the peer reviews and rather welcome the most insightful, experienced bruisees. As the ST-6 program manager said "Bruises now prevent bleeding wounds later." The reviewees should listen to the criticism and not worry about defending the project. Reviewers' suggestions of potential problems are items that the team must be aware of.

Though reviews should be informal and the team should be comfortable being open in discussing their concerns, there are still rules needed to ensure consistency. These reviews should still be in formal in the sense of ensuring the attendance of the invited reviewers and documentation of requests. If the proceedings are too informal and reviewers come and go early or late, the entire process will be much less efficient.

Another view of insight and oversight is not as a continuum but as two distinct approaches that are both necessary to better mitigate error. Insight is not only necessary when risk is low. Insight into the process and system are both necessary before oversight can be implemented. Design Process FMEA is a good way to understand the risks inherent in the process. In the review process, the formal system reviews aim to oversee the project, primarily from a programmatic standpoint. Peer review should precede and complement those reviews and be used to gain insight on technical risks.

4.5. Information technology

4.5.1. NASA lessons

Information technology is an important part of NASA's push towards making their space and technology missions "faster, better, and cheaper". Different projects require different review practices. Larger projects are by definition required to have a certain rigor and will have the resources like information systems with configuration control and integrated project management. Smaller projects tend to use more informal tools such as e-mails and applications like Microsoft Project or Outlook for project management.

Most projects keep track of their own project information, but there are very few centralized information repositories which are accessible by parallel or future projects. This likely results in much repeated work. There are a number of systems available including DocuShare and Livelink in use at NASA.

DocuShare is a collaborative workgroup solution to allow project personnel to share their documents with each other and with their industry partners and affiliates around the world. NASA has 23 DocuShare servers and a total of 1,700 users, including project managers, engineers, administrative staff, and scientists. **Livelink** is a highly scalable collaborative application that delivers Web-based file sharing for users in remote locations. This allows users to access and share files with users outside of NASA through the use of an Internet connection.

There are a number of other knowledge systems, reference databases, and software tools in use or in development at NASA. The **Lessons Learned Information System** (<http://llis.nasa.gov/llis/llis/llis.html>) is a database of different lessons from NASA projects. The Engineering for Complex Systems group at NASA Ames is developing a Mishap and Anomaly information system.

There are also software tools like **DDP** (Defect Detection and Prevention) being developed at NASA JPL to help identify risks. The major issue with these systems is that not all engineers are aware of them or how to use them. It is important for project managers to inform their teams about the availability and benefits of such resources. Training material with demonstrative examples that help with such tools are also a good way for engineers to learn their benefits themselves.

4.5.2. Literature review

Information technology can play a key role in error mitigation for design. (Chao 2003) Computer technologies allow simulations of nearly any complex situation of interest. The flexibility of computer scenarios allows examination of experimental processes that were previously observable only in isolated cases. Industry and academia have explored numerous information technology tools towards error-proofing. Automation played a major role in improving quality on the assembly line. Similarly, automating a development process is necessary as part of the transition towards an increasingly electronic environment. In addition to modernizing the process to improve contact and communication between reviewers and reviewees, technology supports what people already know (Friedman 1997).

Liu et al. (2001) discussed numerous ways web-based peer review systems can function, including as:

1. An information distribution channel and management center for assignment submission and peer review
2. A media for peer interaction and knowledge construction
3. A storage center for knowledge construction procedures

Gehring (2000) also found that sharing reviews on a webpage is not sufficient to stimulate give-and-take between reviewers and reviewees. The reviewees do not “poll” the page periodically to see when new comments are submitted. A push system where both reviewers and reviewees are notified, like via e-mail, is necessary to update both sides.

4.5.3. Discussion

Information is essential part of the design process and the importance of information technology is increasing because of the increasing use of computers in design and communication. Computers can aid error-prevention by automating processes to prevent errors or aiding analyses through stand-alone software or even Excel templates and forms.

At a minimum, every review project should have a “locker” to store their files so that it is sharable within the group and with reviewers. There are a number of systems available to choose from. Ideally, one with configuration management capabilities should be used and would make the implementation of this simple and straightforward. The locker should be divided up into the different subsystems, just as the team and the peer reviews are, and also directories for system issues and one for background materials. The reviewers should be given read permission of all the files. The system ideally should have project management capabilities which can not only schedule the reviews but link the reviewers with relevant files. The system also needs to “push” e-mail to the impacted parties when changes are made to the documents.

As mentioned previously, as important as storing the review content is to store the names and contact information of the different project and review personnel. By listing and linking this information objectively, future projects and reviewers can find resources to guide their work and learn from the accumulated knowledge of the entire organization.

Due to the increasing complexity of the systems in these projects, it is becoming increasingly difficult to understand them. Computer tools can play a big role in visualizing and demonstrating concepts. The use of these tools should be brought into the review process as much as possible and allow the reviewers to be more “hands-on” in understanding the systems, rather than just showing static pictures in a presentation viewgraph.

5. CONCLUSIONS

5.1. Implementation

Because engineering peer reviews are usually technical pre-reviews of specific subsystems in preparation for the formal system reviews, most system related issues are addressed after the peer reviews. Considering this, and the fact that the system level reviews often must spend a half day or more of the scheduled formal review’s time reviewing the background of the mission or spacecraft in preparation for the “actual review,” one solution is to do this background and early system level analysis before both the informal and formal reviews. This encourages advance preparation for the technical review. Weinberg and Freedman (1990) found that at least 80% of review failures can be traced to lack of advance preparation.

The goal of strengthening the process is not to force methodism. In complex and dynamic situations, the most reasonable strategy is to plan a rough outline and delegate to subordinates. These subordinates need considerable independence but also a thorough understanding of the overall plan. If these subordinates don’t

work together within the context of an overall plan, the unpredictability of the independent agents will simply add to the complexity of the overall problem. (Dorner 1996)

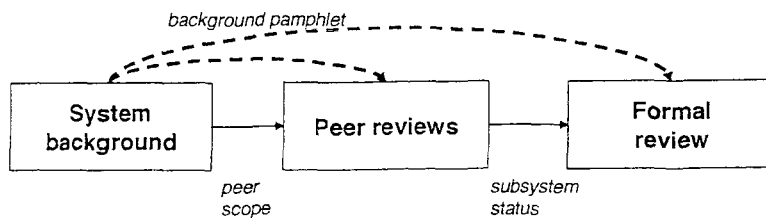


Figure 9: SYSTEM REVIEW TIMELINE

At this **system background meeting**, the design team can present the mission background to the formal review board and other peer reviewers. At the same time, initial discussion of the mission requirements and scope of the subsystems should be discussed to plan out the number of and depth of the various subsystem peer reviews. Identification of key contacts can facilitate initial communications. This meeting should be short, ideally half a day or so.

Definition of what is expected from the review process should also be done at the system background meeting. **Customer Value Chain Analysis** can be done to list the relationship and the identities of the different engineering teams and reviewers. The steps of the analysis are to list the pertinent parties involved in the project and to identify the relationship and flow of information (like designs, requirements, or specifications), resources (like money), and requests (like criticisms, complaints, requests for actions, regulatory influences, votes). The graph should be analyzed to see what the value proposition of each party is to understand how they will impact the process.

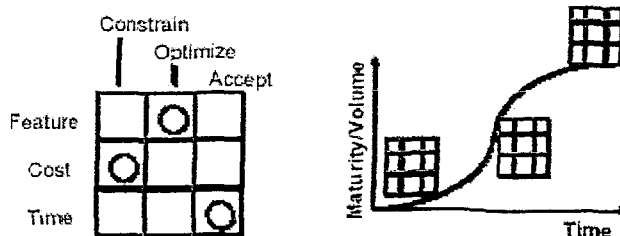


Figure 10: PROJECT PRIORITY MATRIX: OFTEN DEPENDS ON PRODUCT MATURITY

The identification of the project priorities can also help plan the process. The construction of a project priority matrix begins by identifying the constrained factor. This can come from a hard limit on time-to-launch or time-to-market, a

hard budget or cost target, or a minimum set of new functions and features. Next, the target to be optimized should be identified. For example, does the team want quicker time to market, to minimize cost, or to maximize the function/feature set. The remaining item has to be accepted and whatever level achieved has to be lived with. The discussion can be preliminary and allow for the initial building of the **System Review QFD** without completing the entire QFD to help plan out the later peer reviews and formal reviews. The design team should also select a representative to identify issues where the reviewers had questions regarding the background of the project.

At the end of the system background meeting, the design team should put together a pamphlet which summarizes the project background and key parameters, updating it as necessary, until the formal reviews. This pamphlet can be used by the review board members during the meeting to refresh their memory on the background of the project without spending the time to go through it all once again for the entire group.

5.2. Complexities of distributed projects

This report has concentrated on items for project managers to consider in directing their review process. However, many distributed and more complex projects at NASA and other organizations have several levels of hierarchy and different customer value chains. At the levels of the chief engineers and project sponsorship, it is difficult for the managers to be as hands-on with the design staff especially when they are distributed organizationally and geographically. Often times, they will have many different systems to manage, and involve the use of several sub-contractors from outside the organization.

NASA and the DLR, German Aerospace Center, are working together to create a Stratospheric Observatory For Infrared Astronomy (**SOFIA**). A Boeing 747SP aircraft modified by L-3 Communications Integrated Systems to accommodate a 2.5 meter reflecting telescope, SOFIA will be the largest airborne observatory in the world, and will make observations that are impossible for even the largest and highest of ground-based telescopes. It will be based at NASA's Ames Research Center at Moffett Federal Airfield near Mountain View, California, and is expected to begin flying in the year 2004. [5]

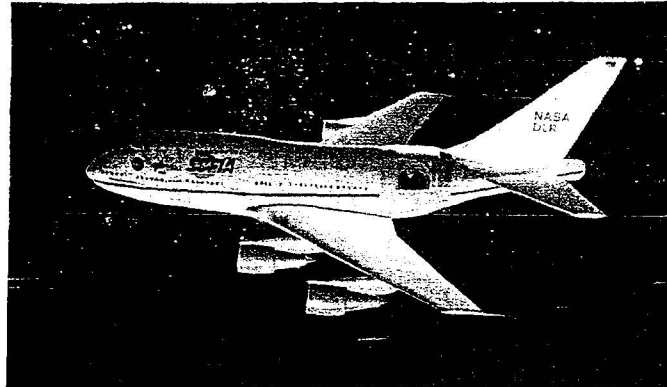


Figure 11: SOFIA – ARTIST’S CONCEPTION

NASA does not interface directly with some of these organizations as USRA subcontracts the majority of the work. A team of industry experts led by the Universities Space Research Association is developing and operating the observatory for. As Figure 12 shows, there are a number of organizations involved in this project, and NASA does not have direct control or oversight of *many of them*. In addition, SOFIA has several components including science instruments, where the principal investigators are at various universities. DLR must work with German organizations like Kayser-Threde and MAN.

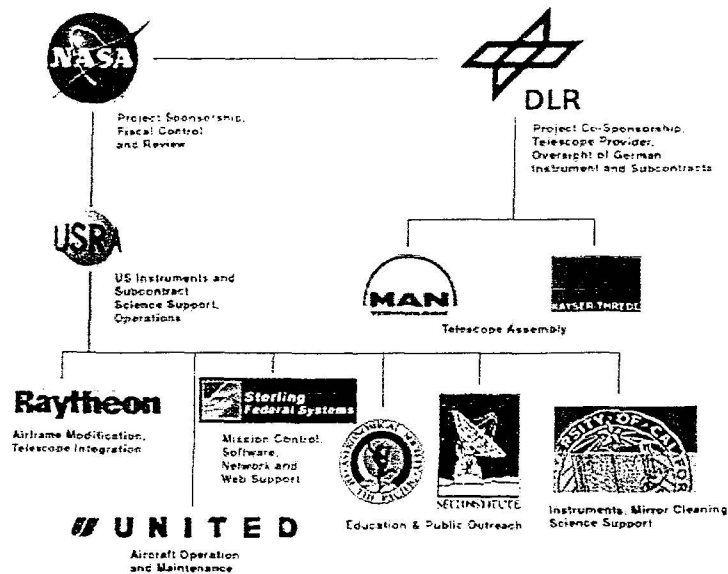


Figure 12: ORGANIZATIONS INVOLVED IN THE SOFIA PROJECT

The organizational structure here is nearly as complicated as the technology involved. Though NASA has an oversight role, it does not directly manage the

projects. They act as a customer and can call up major reviews. It is up to the contractors to monitor their own process. Not even USRA is involved deeply on the peer review process. There are some informal meetings, but otherwise not much insight for “external” customers. It is a matter of personality for these organizations as to whether NASA is even invited to some of these reviews because NASA is seen as a customer.

Even on the most macroscopic level, each of these organizations has very different cultures. Academic, industrial, and government agencies have varying practices. Even the project teams within one organization can have very different practices whether the team is mechanical, electrical, software, or etc. Aircraft and aerodynamics groups, though seemingly related, have very different cultures.

At a certain point, it is necessary for NASA to push for some process requirements in the review process. Though system reviews like the PDR and CDR are a start, due to the fact that these reviews address more programmatic issues and are much shallower on technical aspects, it is necessary for NASA to formalize the technical analysis, and thereby, the peer review process, to some degree.

With its position very high up on this organizational structure, NASA is able to play a key role in interfaces. For the most part, people working on their portion of this system don't need to worry about the overall structure and where they fit into the system. When different organizations need to work together, **Interface Control Documents (ICD's)** help identify system concerns. SOFIA had over 30 identified documents to negotiate interfaces between the major pieces of the telescope and the infrastructure. Power, cooling, heat loads, pressure, interface, and motions were just a number of the functional areas involved.

The groups work together in **Interface Control Working Group Meetings** to iron out the design concept on both sides. This process is highly iterative and some times a bit rushed as both sides want the other side to finish their part so that they themselves can work to those specifications. NASA facilitated these meetings even though it was a non-contractual relationship, but it is still driven by each side's desire to proceed along their development. To some degree, it is not in these contractors interest to better define these relationships. Lack of definition can often be used an excuse when there is a failure to meet schedule. As these working group meetings are essentially peer reviews, NASA does have the capability to get involved in this lower level review process.

Another direction NASA can go is by requiring contractors, and their subcontractors, to work within some organizational guidelines in these peer reviews as part of the contract. At some aircraft engine companies, for example, when certain contractors have had major failure events or other quality issues, they are required to go through **error-proofing awareness training (EPAT's)**. In response to problems, the aircraft engine company will send a team which will

educate the contractor in error-proofing methods and then work with the contractor to implement error-proofing methods into their process. Failure to do so will affect the relationship of the company with the contractor. Though it is easier to leverage such methods in response to failure events, this is still a reactive process and means that a failure did go through. Ideally, this type of training should be done upfront. Also, it does not necessarily need to have a scope of this magnitude. Many organizations including the Manufacturing Modeling Laboratory at Stanford University have developed this type of material. (<http://mml.stanford.edu>)

5.3. Summary

There is no question that the formal review process at NASA is strong. However, because of the scope of these projects and the limited time and resources of those reviews, they must often concentrate largely on programmatic issues and can only cover technical issues in a fairly shallow manner. It is the role of the engineering peer reviews to identify the specific issues that can impact a project. Unfortunately, peer reviews lack consistency in implementation and depend very strongly on the strength of the project and section leaders.

Currently different projects can have very different review practices and requirements. Larger projects have some advantages in terms of having more experienced people, as well as mentors available for the inexperienced. Smaller projects do not have this luxury – the projects are often the training grounds for new engineers. In addition, larger projects are by definition required to have a certain rigor in areas like configuration control. As a result, there is also less flexibility in larger projects. Because the large projects have more resources and priority, the quality and number of both the engineers and reviewers are also usually higher on larger projects. Because the formal reviews are also more rigorous, these projects can benefit from peer reviews as a good preparation work and a pre-review.

The design review process is a weak process which depends on the individuals involved, both manager and engineer, reviewer and reviewee. Still, many at NASA do not recommend more requirements and formalism necessarily as a way to improve the process. Because design processes can vary so greatly in terms of not only size and scope, but also domain and technology, it is not feasible or practical to create a universal checklist for all reviews. There is an inherent tradeoff between the specificity of items in the list with the burden of performing such a review. The key to improving the design review process is to treat it as an activity of insight and not just oversight. Structured design methods can play a key role in this understanding. These tools are not static and require insight. In addition, they help document and share the groups' thoughts and concerns. Failure Modes and Effects Analysis can identify key areas of concern before or in the reviews. Product definition tools like the Project Priority Matrix, Customer

Value Chain Analysis, and Quality Function Deployment help prioritize resources in reviews.

The organization, composition, scope, and attitude of reviews all play a role in their success. Information technology can also aid design reviews. In the end, NASA must acknowledge what design reviews can not catch and the human limitations of their engineers. One project manager said that the basic reasons for bad cost estimates and risk plans are inherent to human nature due to blind initial optimism, overestimating the completeness of knowledge, underestimating the peril of unknown, and the belief that the worst just cannot happen.

For most organizations, design reviews are the only line of defense against errors in the design process. Even if they are applied universally, they are still an imperfect gauge susceptible to human errors and will always allow some problems through. Nonetheless, they will always be an essential part of any organization's efforts to error-proofing the development process. The key to using design review as a part of the design error-proofing toolkit is to recognize their inherent weaknesses. Design reviews are a dangerous tool. They can give the users a false sense of security.

Unlike other error-proofing solutions, design reviews constitute a system that is, for the most part, already in place at most organizations. Improving the process does not require large capital investments in technology or even a change in the process necessarily. Design reviews can be impacted immediately. The key is to make these reviews as robust and thorough as possible. That can only be done with good pre-work, gathering both strong reviewers and reviewees and being committed to reviewing consistently.

It is also important to regard design reviews as the first line of defense against errors and failures. In one representation of the different levels of error-proofing against design errors (Chao 2003), design reviews would fit at best as level 3 in robustness (refer to Table 11). There are still further steps that can be done to prevent and mitigate errors from occurring.

Table 11: ROBUSTNESS LEVEL OF ERROR-PROOFS

Level	Type	Description
5	<i>Prevention</i>	Eliminate the possibility of performing an erring action
4	<i>Detection</i>	Detect the error immediately after being made
3	<i>Inspection</i>	Source inspection of completed parts
2	<i>Improvement</i>	Improvement to simplify the process
1	<i>Aid</i>	Tool or methodology to aid design/engineering

Improvements of an organization's developments can be done at different levels. It is not uncommon for some organizations to deny problems and rationalize them without fixing them by saying they are a "one of a kind" occurrence. With resources like lessons learned database, many of NASA's improvements are on the problem level and very reactive and specific. Ideally, an organization should aim to fix the process and the system.

One way to improve the peer review process is to target project managers and create a guide on how to conduct reviews, beginning with a background on the psychology of reviews. That can be followed with a training class, probably no longer than 2 hours. The first half-hour session can be on the current state of design reviews, a second on peer review techniques, and a third would be a retroactive example. A general guide like these would likely be accepted at both the upper management and project management levels.

Many hesitate to have the organization place additional requirements on the engineers and managers as there are a number of regulations and requirements already in place. Certainly the biggest fears are the threat of more bureaucracy and requirements that don't help people get their work done. Obviously, the organization, the project, and the individual some times have differing priorities, but the overall goal of all involved should be the same. Each side will need to make some adaptations for all involved to succeed.

The key to using design reviews effectively is to understand where human limitations in dealing with complexity of systems impact the ability to review. Confidence in the process is different than blind faith in it. By having a strong and consistent process, both the process and the system reviewed can be understood. An organization can be both less dependent and use more effectively the review process if it better understands its limitations.

ACKNOWLEDGEMENTS

I sincerely appreciate the cooperation of the following: Nick Thomas, Dave Swenson, Jim Rose, Art Chmielewski, Steve Cornford, Steve Prusha, and Tom Fouser of NASA JPL and Chris Wiltsee, Nans Kunz, and Ramsey Melugin of NASA Ames for taking the time to speak with us in person and answer all the questions we had. Thanks also to Tom Glavich, Jim Graf, Jim Marr, Doug Bernard, Howard Eisen, John Cox, Mike Gilbert, Ron Johnson, Steven Scott for their time and comments as well. Thanks to Kosuke Ishii, David Bell, and Peter Putz for their thoughts on this research on design reviews. Thanks to Irem Tumer and Chet Borden for their patient organization and oversight of the interviews, and their insightful comments about the whole project.

REFERENCES

- Barkan, P. and Hinckley, M. 1993. "Benefits and Limitations of Structured Design Methodologies." *ASME Manufacturing Review*. Sep. 2003: 211-220.
- Chao, L., and Ishii, K. 2003. "Design Process Error-Proofing: Failure Modes and Effects Analysis of the Design Process," *Proceedings of the ASME DETC: DFM*, Chicago, IL. Sep. 2003.
- Chao, L., and Ishii, K. 2003. "Design Process Error-Proofing: Development of Automated Error-Proofing Information Systems." *Proceedings of the ASME Design Engineering Technical Conference: DAC*, Chicago, IL. Sep. 2003.
- Chao, L., Beiter, K., and Ishii, K., 2001, "Design Process Error-Proofing: International Industry Survey and Research Roadmap," *Proceedings of the ASME DETC: DFM*, Pittsburgh, PA.
- D'Astous, P., Robillard, P.N., Detienne, F., and Visser, W. 2001. "Quantitative Measurements of the Influence of Participant Roles during Peer Review Meetings." *Empirical Software Engineering*. 6: 143-159.
- Dorner, D. 1996. *The Logic of Failure*. Perseus Books. Cambridge, MA.
- Eibeck, P. 1996. "Criteria for Peer-Review of Engineering Courseware on the NEEDS Database." *IEEE Transactions on Education*. Vol. 39, No. 3, Aug. 1996.
- Eschenbach, E.A. 2001. "Improving technical writing via web-based peer review of final reports." *Frontiers in Education Conference*, 31st Annual, Volume 2, 10-13 Oct. 2001: F3A -1-5 vol.2.
- Freedman, D.P. and Weinberg, G.M. 1996. *Handbook of Walkthroughs, Inspections, and Technical Reviews*. Third Edition. Dorset House Publishing, New York.
- Friedman, J.R. 1997. "An experiment in processing electronic documents." *Professional Communication Conference. IPCC '97 Proceedings. 'Crossroads in Communication.'* 1997 *IEEE International*, 22-25 Oct. 1997: 193 -201
- Gehringer, E.F. 2000. "Strategies and mechanisms for electronic peer review." *Frontiers in Education Conference (FIE 2000)*. 30th Annual, Volume 1, 18-21 Oct. 2000: F1B/2 -F1B/7.
- Ichida, T., ed. 1996. *Product Design Review*. Productivity Press. Portland, Oregon.
- Leveson, N.G. 2000. "Intent Specifications: An Approach to Building Human-Centered Specifications." *IEEE Transactions on Software Engineering*. Vol.26. No.1, Jan. 2000.

- Liu, E.Z.F., Lin, S.S.J., Chiu, C.H., and Yuan, S.M. 2001. "Web-based peer review: the learner as both adapter and reviewer." *IEEE Transactions on Education*. Volume 44, Issue 3, Aug. 2001: 246 -251.
- O'Reilly, J. 2002. "Risk, adventure and the tyranny of peer review." *Engineering Science and Education Journal*. Dec. 2002: 251-253.
- Trenner, L. 1995. "Prototyping for usability: the benefits of peer group review." *IEEE Colloquium on Integrating HCI in the Lifecycle*, London, UK. 11 Apr. 1995.
- Wertz, J.R., and Larson, W.J. 1999. *Space Mission Analysis and Design*, Third Edition. Microcosm Press, El Segundo, California.
- Weyuker, E.J. 1999. "Predicting project risk from architecture reviews." *Software Metrics Symposium, Proceedings. Sixth International*, 4-6 Nov. 1999: 82 -90

NASA DOCUMENTS

- [A] Chmielewski, Art B. 2003. "Psychology of Risk Management: The ST6 Experience." *New Millennium Program, ST6*.
- [B] Huber, Thomas E., ed. 1992. "The NASA Mission Design Process." *NASA Engineering Management Council*. 22 Dec. 1992.
- [C] Jet Propulsion Laboratory. 1996. "Common Review Methods for Engineering Products." *Preferred Reliability Practices*. (Practice No. PD-ED-1215.4). Feb. 1996.
- [D] Langley Management System. "Flight Project and Experiments Review Planning and Implementation." *LMS-CP-5505*.
- [E] Langley Management System. *LMS-CP-5508*.
- [F] Quinn, James. 1994. "Flight P/FR's and the Design Review Process." *JPL D-11381*. Jan. 1994.
- [G] Rose, James. 2003. "Project Reviews (D-10401), Rev. B." *JPL Rules!* DocID 35163. 23 Apr. 2003.

INTERNET REFERENCES

- [1] Software V&V
<http://ase.arc.nasa.gov/vvvhm/reports/FinalNASAReport1.htm>
- [2] Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contracts
http://nodis3.gsfc.nasa.gov/library/displayDir.cfm?Internal_ID=N_PG_8735_0002_&page_name=Chp2
- [3] ASIC Program
<http://nppp.jpl.nasa.gov/asic/Sect.1.5.html#A0>
- [4] System Management Office – Goddard Space Flight Center
http://smo.gsfc.nasa.gov/project_management/pm_checklists/Eng_Peer_Review_Guidelines_and_Checklist.html
- [5] SOFIA
<http://sofia.arc.nasa.gov/Sofia/sofia.html>
- [6] CNN.com, “Investigator worried NASA culture won’t change.”
<http://www.cnn.com/2003/TECH/space/08/01/sprj.colu.shuttle.investigation.ap/index.html>
- [7] CNN.com, “NASA promises to break culture of silence”
<http://www.cnn.com/2003/TECH/space/07/27/sprj.colu.nasa.culture.ap/index.html>
- [8] CNN.com, “NASA shakes up shuttle management.”
<http://www.cnn.com/2003/TECH/space/07/03/nasa.shakeup.ap/index.html>
- [9] Encyclopedia.com, “National Aeronautics and Space Administration”,
<http://www.encyclopedia.com/html/n/natlalero.asp>
- [10] Xerox DocuShare
<https://partners-lib.jpl.nasa.gov/partners-lib/en-us/Help/whatis/customer.htm>
- [11] NASA Glenn Knowledge Management Working Group
<http://www.grc.nasa.gov/WWW/kmwg/solutions.html>
- [12] International Space Station Fluids and Combustion Facility PDR
<http://fcf.grc.nasa.gov/pdr/>

[13] NASA Sites

<http://www.nasa.gov/about/sites/index.html>

[14] ABB Software Process Improvement

[http://www.abb.com/global/seitp/seitp145.nsf/fa8413e5fae4c5a4c12568b7002be8bd/265e6b1f98d9fbc0c1256ad10035a33d/\\$FILE/10-15%20M713.pdf](http://www.abb.com/global/seitp/seitp145.nsf/fa8413e5fae4c5a4c12568b7002be8bd/265e6b1f98d9fbc0c1256ad10035a33d/$FILE/10-15%20M713.pdf)

[15] Stanford University ME317 Design for Manufacturability

<http://me317.stanford.edu>

[16] Manufacturing Modeling Laboratory

<http://mml.stanford.edu>

APPENDIX

Resources

Resources related to this research can be found on under “ECS/MAIS/Review Methods.”

<https://docushare.aen.nasa.gov/docushare/>

Meeting Schedule

Visits/Interviews:

- *Jet Propulsion Laboratory (June 19-20, 2003)*
Jim Rose, Dave Swenson, Nick Thomas

- *Jet Propulsion Laboratory (July 15, 2003)*
Art Chmielewski, Steve Prusha, Steve Cornford, Tom Fouser

- *Ames Research Center (July 30, 2003)*
Chris Wiltsee, Nans Kunz, Ramsey Melugin

- *Jet Propulsion Laboratory (October 16, 2003)*
Steve Prusha, Steve Cornford

Reviews/Conferences:

- *Kepler Ground Segment Peer Review (June 26, 2003)*
NASA Ames Research Center
Moffett Field, CA, USA
 - <http://www.kepler.arc.nasa.gov>

- *Space Mission Challenges in Information Technology (July 13-17, 2003)*
Pasadena Convention Center
Pasadena, CA, USA
 - <http://smc-it.jpl.nasa.gov/>

- *NPI Roundtable: Reliability Validation and Time to Market (July 24, 2003)*
Stanford University
Stanford, CA, USA
 - <http://mml.stanford.edu/>

- *International Research Roundtable: Design for Life-cycle Quality across the Supply Chain (September 11, 2003)*
Swiss Federal Institute of Technology at Lausanne
Lausanne, Switzerland
 - <http://www.epfl.ch>

Customer Value Chain Analysis

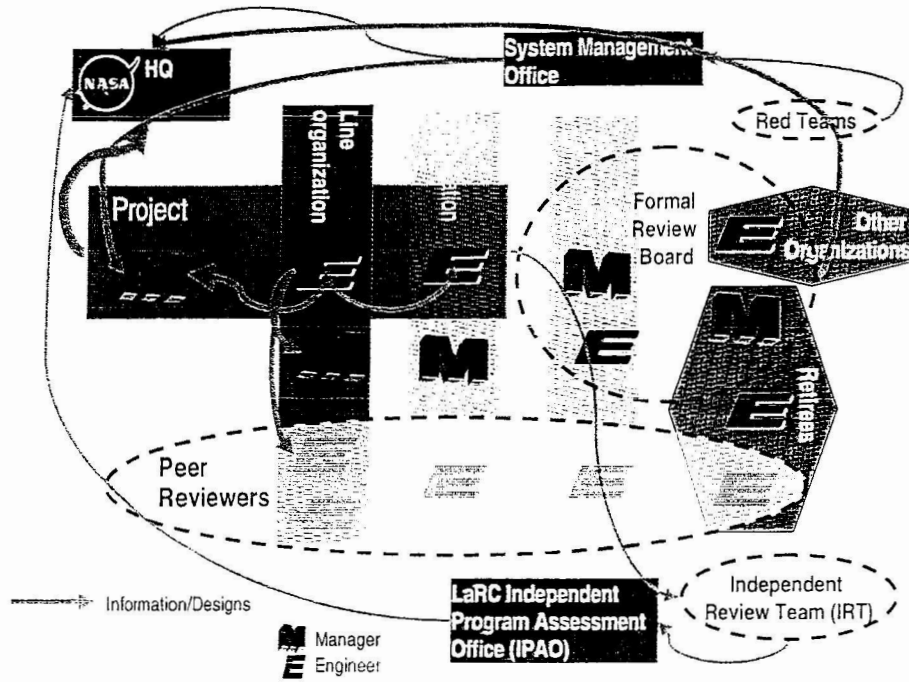


Figure 13: CVCA ON THE TRANSFER OF INFORMATION

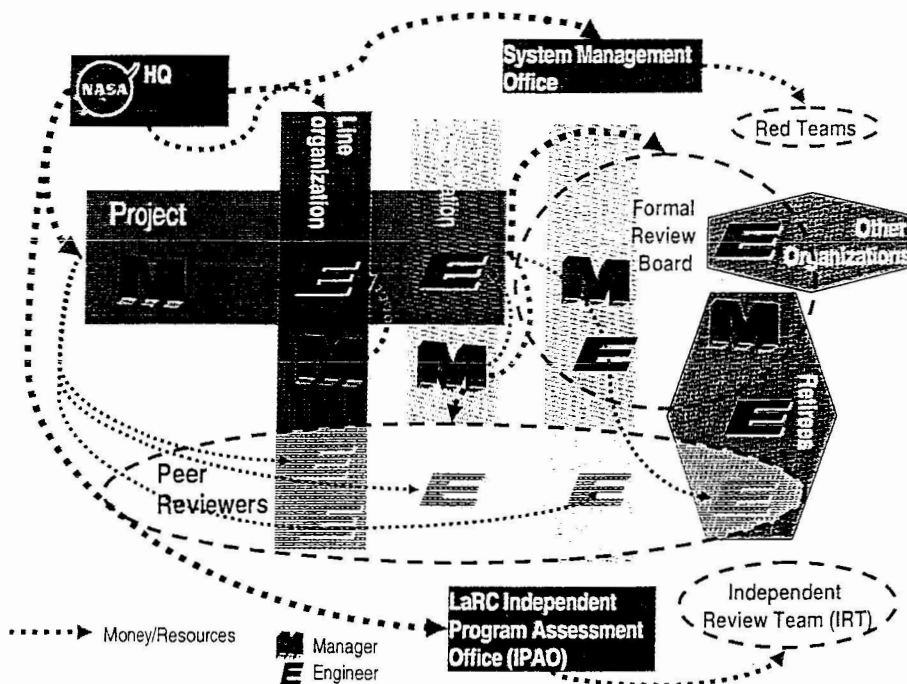


Figure 14: CVCA ON THE TRANSFER OF MONEY AND RESOURCES

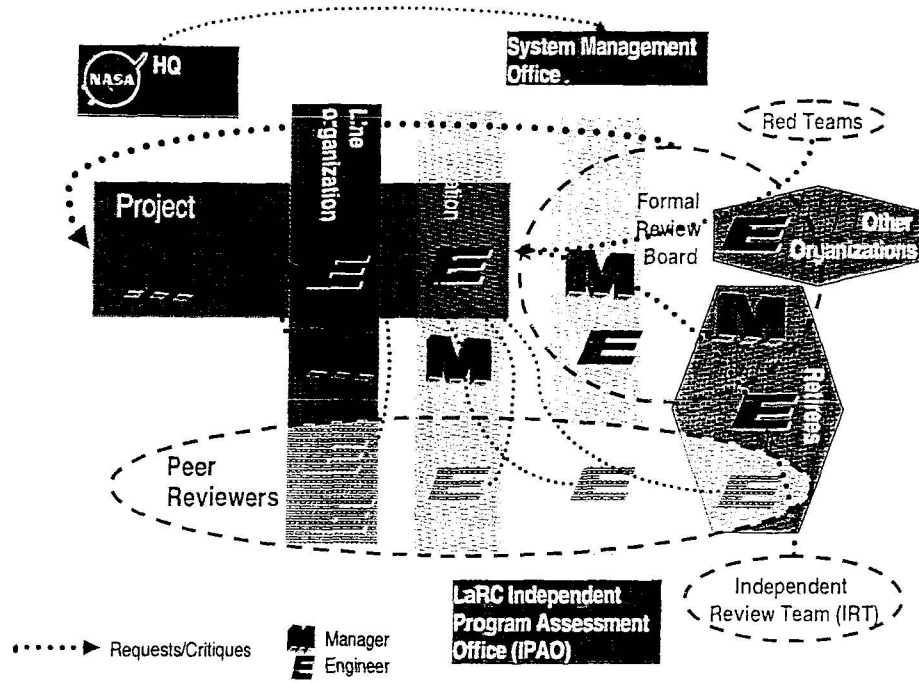


Figure 15: CVCA ON THE TRANSFER OF REQUESTS AND CRITICISMS

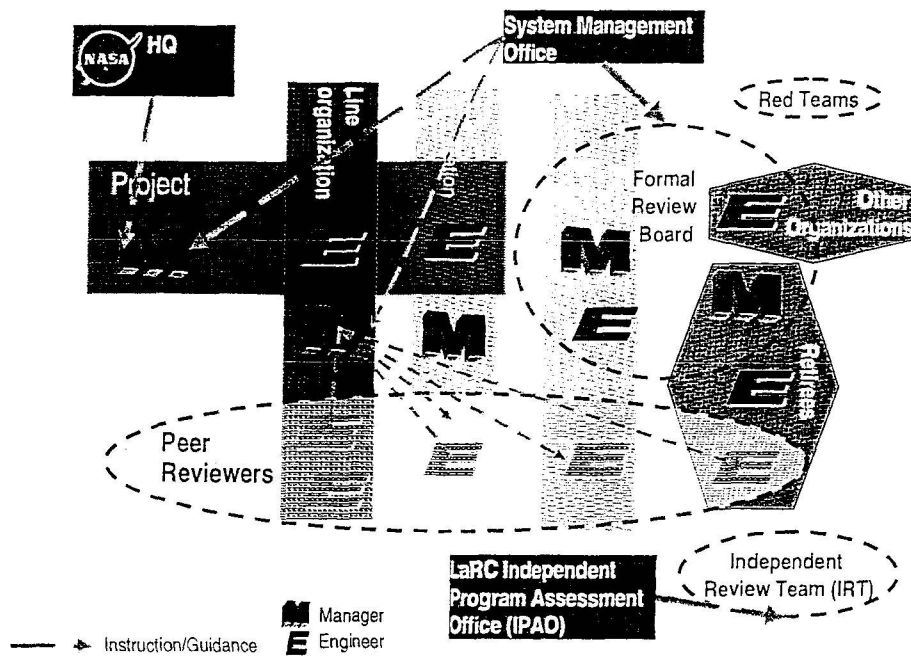


Figure 16: CVCA ON THE TRANSFER OF GUIDANCE AND INSTRUCTIONS