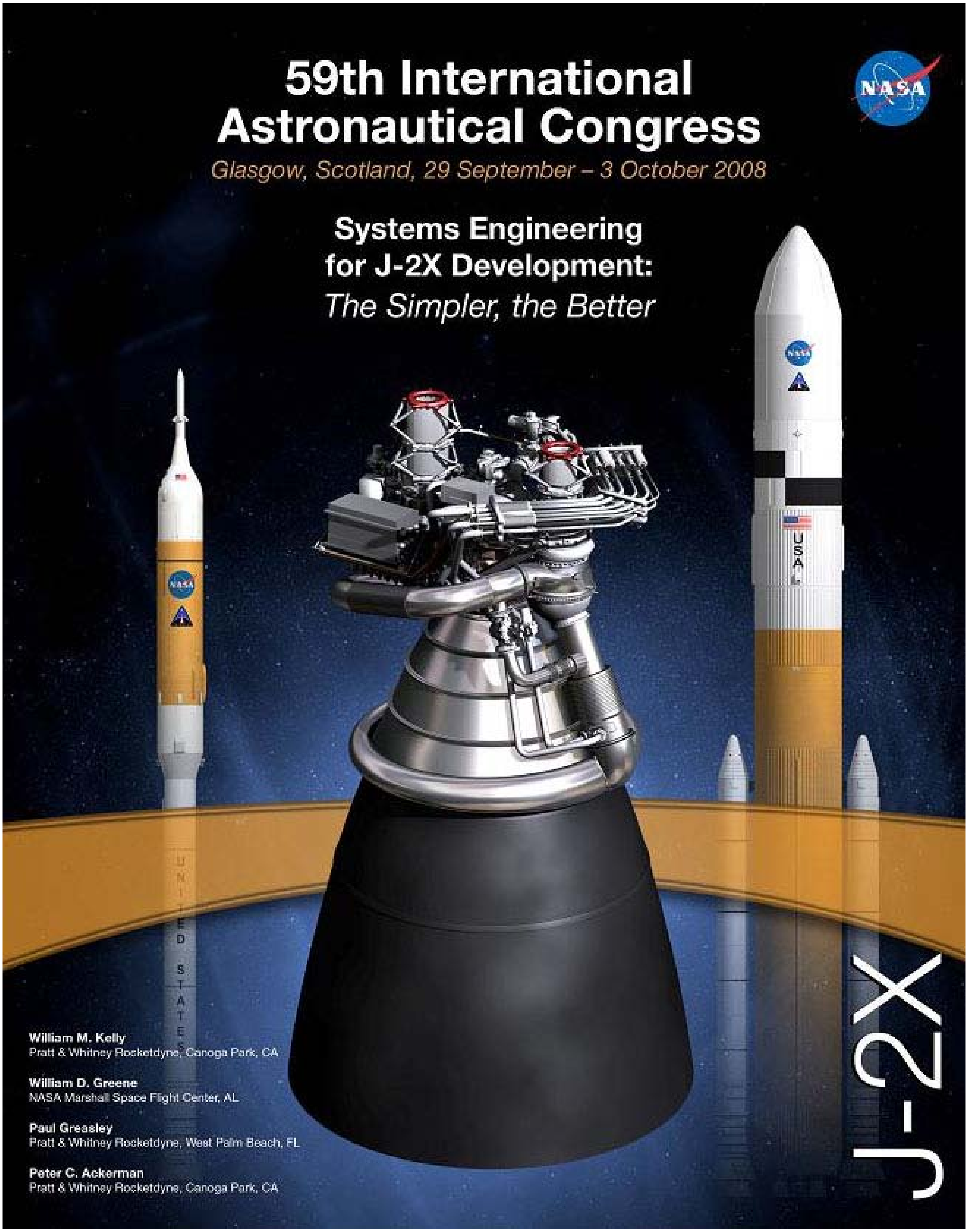

59th International
Astronautical Congress
Glasgow, Scotland, 29 September – 3 October 2008
Systems Engineering
for J-2X Development:
The Simpler, the Better
NASA
USA
UNITED STATES
J-2X
William M. Kelly
Pratt & Whitney Rocketdyne, Canoga Park, CA
William D. Greene
NASA Marshall Space Flight Center, AL
Paul Greasley
Pratt & Whitney Rocketdyne, West Palm Beach, FL
Peter C. Ackerman
Pratt & Whitney Rocketdyne, Canoga Park, CA

IAC – 08 – D1.6/D2.9

SYSTEM ENGINEERING ON THE USE FOR ARES I, V: THE SIMPLER, THE BETTER

William M Kelly
Pratt & Whitney Rocketdyne
USA
william.kelly@pwr.utc.com

William D. Greene
NASA MSFC
USA
william.d.greene@nasa.gov

Paul Greasley
Pratt & Whitney Rocketdyne
USA
paul.greasley@pwr.utc.com

Peter Ackerman
Pratt & Whitney Rocketdyne
USA
peter.ackerman@pwr.utc.com

ABSTRACT

The Ares I and Ares V Vehicles will utilize the J-2X rocket engine developed for NASA by the Pratt & Whitney Rocketdyne Company (PWR) as the upper stage engine (USE). The J-2X is an improved higher power version of the original J-2 engine used for Apollo. System Engineering (SE) facilitates direct and open discussions of issues and problems. This simple idea is often overlooked in large, complex engineering development programs. Definition and distribution of requirements from the engine level to the component level is controlled by Allocation Reports which breaks down numerical design objectives (weight, reliability, etc.) into quanta goals for each component area. Linked databases of design and verification requirements help eliminate redundancy and potential mistakes inherent in separated systems. Another tool, the Architecture Design Description (ADD), is used to control J-2X system architecture and effectively communicate configuration changes to those involved in the design process. But the proof of an effective process is in successful program accomplishment. SE is the methodology being used to meet the challenge of completing J-2X engine certification 2 years ahead of any engine program ever developed at PWR. This paper describes the simple, better SE tools and techniques used to achieve this success.

CONSTELLATION PROGRAM/ARES PROJECTS

As a result of President Bush's Vision for Space Exploration announced in January 2004 and subsequently made national policy by Congress, NASA embarked on the development of a new launch vehicle system to fulfill the U. S. national goals of replacing the Space Shuttle fleet and returning to the moon. These goals were shaped by the decision to retire the shuttle fleet by 2010, budgetary constraints, and the requirement to create a new fleet that was safer, more reliable, operationally more efficient than the shuttle fleet, and capable of supporting long range exploration goals. The present architecture for the Constellation Program is the result of extensive trades during the Exploration Systems Architecture Study and subsequent refinement by the Ares Project Office at Marshall Space Flight Center.

Figure 1 shows The Ares V Cargo Launch Vehicle (left) and Ares I Crew Launch Vehicle (CLV) in parallel flight (not a mission configuration) (NASA artist's concept). These will be the first new human-rated launch vehicles developed by NASA in more than three decades. Ares I will demonstrate its initial operating capability of flying up to six astronauts to the International Space Station (ISS) no later than 2015. Ares V is scheduled to be operational in the 2020 timeframe to support the lunar mission.

Figure 2 shows the location and use of the J-2X engine aboard the Ares-I CLV and Ares-V CaLV vehicles compared to the Saturn V with its multiple J-2 Engines.

Fig. 1: Ares I, Ares V Vehicles in Flight

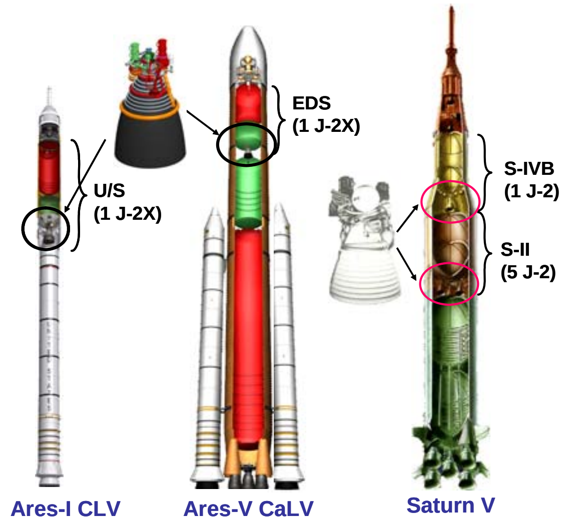


Fig. 2: J-2X and J-2 Aboard Vehicles

The reference lunar mission is still under development. There are scenarios where Ares I launches first and others where Ares V launches first. Regardless of the particular scenario, however, they all include the on-orbit docking of the Orion Crew Exploration Vehicle (CEV) carried by Ares I and the Earth Departure Stage carried by Ares V prior to heading to the moon.

The Ares V first stage propulsion system consists of a Core Stage powered by six commercial liquid hydrogen/liquid oxygen (LH2/LOX) RS-68 engines, flanked by two five-segment solid rocket boosters (SRBs). Atop the Core Stage is the Earth Departure Stage (EDS), powered by a single J-2X Upper Stage Engine and a payload shroud enclosing the lunar lander.

The Ares I first stage consists of a single five-segment SRB. Once that stage is expended during launch, the Upper Stage, powered, by a single J-2X, will ignite to take the Orion into orbit. The EDS/lunar lander will go into a stable checkout orbit. After Orion docks with the EDS/lander, the J-2X will ignite a second time to begin trans-lunar injection (TLI). The EDS would be discarded at the end of the TLI burn. The Orion and Lunar Lander perform the remainder of the mission, with Orion remaining in lunar orbit autonomously while the crew descends to the Moon in the lander. At the end of the surface stay, the crew returns to Orion in the lander ascent stage, which is then discarded. The crew returns to Earth in the Orion Crew Module for reentry and landing.

COMMUNICATION INFRASTRUCTURE

Ockham's razor is a principle attributed to the 14th-century English logician and Franciscan friar William of Ockham. The principle states that the explanation of any phenomenon should make as few assumptions as possible, eliminating those that make no difference in the observable predictions of the explanatory hypothesis or theory. This is often paraphrased as "All other things being equal, the simplest solution is the best." It is in this sense that Ockham's razor is usually understood and applied to SE principles.

In our high technology business world, such simple advice is often discarded in favor of highly detailed models and sophisticated electronic communication systems. To be sure, such systems are necessary to achieve accurate solutions to complex problems, to overcome the problems of physical distance and different time zones among working groups and to provide documentation securely on a very rapid schedule. However, J-2X personnel have also found the wisdom of William of Ockham's words by continuing to use the simplest of communication devices: talking to each other – to help assure complete understanding of program direction and issues. The program has established a culture of completely open communication with NASA. The NASA and PWR SE Teams embraced and encouraged this modus operandi with the usual major design reviews but supplemented by Technical interchange meetings (TIMs), teleconference tie-ins to Working Group meetings (Table 1 below), and other teleconference meetings with NASA on specific subjects.

J-2X SYSTEMS ENGINEERING

Regarding the J-2X NASA/Pratt & Whitney Rocketdyne (PWR) implementation of SE principles, it has been humorously said that the NASA side does not do anything. While that is a bit harsh, it is recognized that the Ares Project integrates the vehicle and PWR builds the J-2X engine. Further, the NASA J-2X Systems Engineering and Integration (SE&I) office is not responsible for coordinating or overseeing any hardware deliveries. It is not directly responsible for even the official documentation against which the J-2X will be built, verified, and with which the engine will be flown. On the other hand, without the NASA J-2X SE&I office not much would happen. So the statement that the NASA-side J-2X SE&I office does not do anything is really nothing more than an admonishment to keep things as SIMPLE as possible.

Within the realm of SE, separate from the activities of vehicle and stage integration, the NASA J-2X SE&I office coordinates "the in's and the out's," meaning that it acts as the conduit for critical information back and forth between the Ares Project and the PWR J-2X development effort. This communication takes many forms, but the following disciplines form the core: Requirements

Management, Risk Management, and Technical Review Management.

Requirements management in this context involves the structured communication of contract requirements and program needs to the point of application, the developer of the hardware. The NASA J-2X SE&I office handles this at the system level through the maintenance of the J-2X Element Requirements Document (J-2X ERD). This requirements document acts as the intermediate point between the needs of the vehicle, both the Ares I and the Ares V as expressed in two systems requirements documents, and the engine system specification developed, delivered, and maintained by PWR and to which the J-2X is built. The J-2X ERD expresses the performance, functional, and physical characteristics that the J-2X shall have to meet Constellation objectives. It also provides 'how-to' direction in the form of design and construction standards from NASA and other organizations. Figure 3 shows the flow down of requirements from the highest levels through the J-2X ERD and how this feeds the engine system specification developed by PWR.

At the next organizational level down, in order to facilitate the critical insight role that NASA plays in the J-2X development effort, the NASA J-2X SE&I office develops and maintains a J-2X Component Requirements Document (J-2X CRD). This is not a collection of all the requirements to which the various engine subsystems and components must be built. Also, it is not the function of the NASA J-2X SE&I office to specifically define how the constituents of the engine are built to meet the mandated system-level requirements. Rather, the J-2X CRD contains direction for the key subsystem and component derived requirements as expressed by

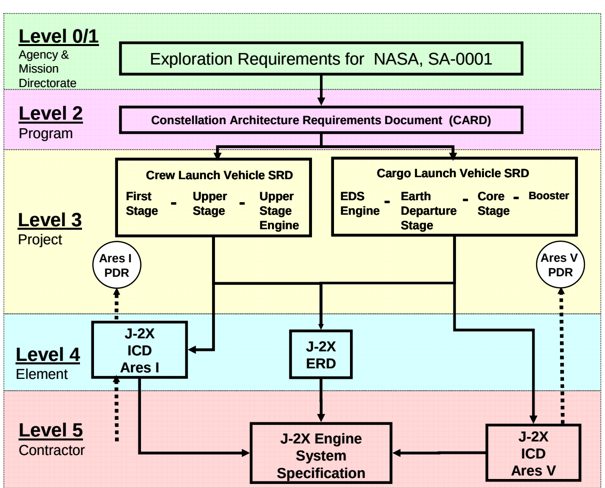


Fig. 3. J-2X Technical Requirements Flowdown

the combined NASA/PWR technical community. These requirements are those for which formal tracking and verification are necessary to accomplish effective insight to the development of the engine. In other words, the J-2X CRD is a communication tool between technical disciplines and designers that is enabled by the NASA J-2X SE&I office.

Another key communication tool takes the form of tracking programmatic and technical risks. PWR is ultimately responsible for risk management of the J-2X development effort at the detailed part level, but NASA acts as the programmatic interface between those risks managed and mitigated internally and those expressed to the Ares Project and the Constellation Program. Whereas requirements flow downwards, risks flow upwards. It is the function of program management to determine how far risks are raised organizationally, how resources are allocated to mitigate the risks, and at what level decisions must be made along these lines to achieve risk resolution. The NASA J-2X SE&I office provides the linkage between the PWR risk database and communication through the NASA risk database so as to make this management possible.

Nothing so far has been said about the classic structure of SE, the V consisting of requirements allocation on one side and development, verification, and validation on the other. Yet, this is how the J-2X development effort is being conducted. The NASA J-2X SE&I office facilitates this structure not only through the communication tools discussed above, but also through a series of milestone reviews consistent with NASA agency policy. The NASA J-2X SE&I office translates NASA policy along these lines into a series of plans for milestone reviews. Thus far, the J-2X development effort has progressed through the System Requirements Review (SRR), the System Definition Review (SDR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). Yet to be accomplished, but with identified target dates on the calendar, are the Production Readiness Review (PRR) and the Design Certification Review (DCR). For each of these reviews, a plan is generated describing the review process, the review goals, and the criteria by which the development activity will be judged a success or against which greater emphasis must be applied to help assure success in the future.

So while it is true that the NASA J-2X SE&I office on the NASA side does not do anything in terms of delivering hardware, it plays an essential programmatic roll. Through the development and maintenance of a purposeful number of key documents; the J-2X ERD, the J-2X CRDs, and the series of milestone review plans, the NASA J-2X SE&I office provides the driving force and structure for the development effort. Through the communication and coordination of key risks between the PWR and NASA databases, the NASA J-2X SE&I office facilitates ongoing program management success. Figure 4 shows the functional organization of the PWR SE team and indicates the penetration points for those key elements of the NASA SE effort which drive the SE effort. Abbreviations on Figure 4 include Reliability, Maintainability, System Safety (RMSS), System Engineering and Integration Team (SEIT), and Non-Destructive Test (NDT).

TOOLS AND TECHNIQUES FOR J-2X SE REGULAR TELECONS/PROGRAM LEVEL MEETINGS

Each of the PWR Integrated Products Teams (IPT) of the J-2X program holds regular (weekly, etc.) teleconferences with their counterpart organizations in NASA. The purpose of these teleconferences is to exchange information about the course of events between the last teleconference and the current one. The program has never found a good reason not to have a teleconference. They are occasionally rescheduled because of the unavailability of key personnel but there is always a good reason to communicate regularly. The typical subject matter includes requirements changes, verification planning, vehicle interface issue discussions, upcoming events, and long range commitments which require regular attention to maintain schedule.

Table 1 identifies just 3 of more than 15 regular meetings held to maintain a high quality level of communication between PWR and NASA. The table identifies the technical coordination working meetings, their purpose, frequency, organizer, and attendees. PWR IPT leaders are responsible for organizing intra-IPT meetings at their discretion. Abbreviations on Table 1 include System Engineering Working Group (SEWG), Engine Development Working Group (EDWG) and Engine Integration Working Group (EIWG), Program Manager, Deputy Program Manager (PM/DPM), Engineering Review Board (ERB), Integrated Product Team (IPT), and Concept of Operations (ConOps).

It's as SIMPLE as that – talk to each other regularly.

NEXPRISE (INFORMATION PARAPHRASED FROM NEXPRISE SECURITY WHITEPAPER, JUNE 2007, AVAILABLE ON NEXPRISE WEB)

The J-2X program is using NexPriseTM as a secure inter-site communication tool. The NexPriseTM Web Space platform is a 100% Web-based solution designed to facilitate improved communication, change management and project execution with remote and project execution with remote partners, suppliers, customers and

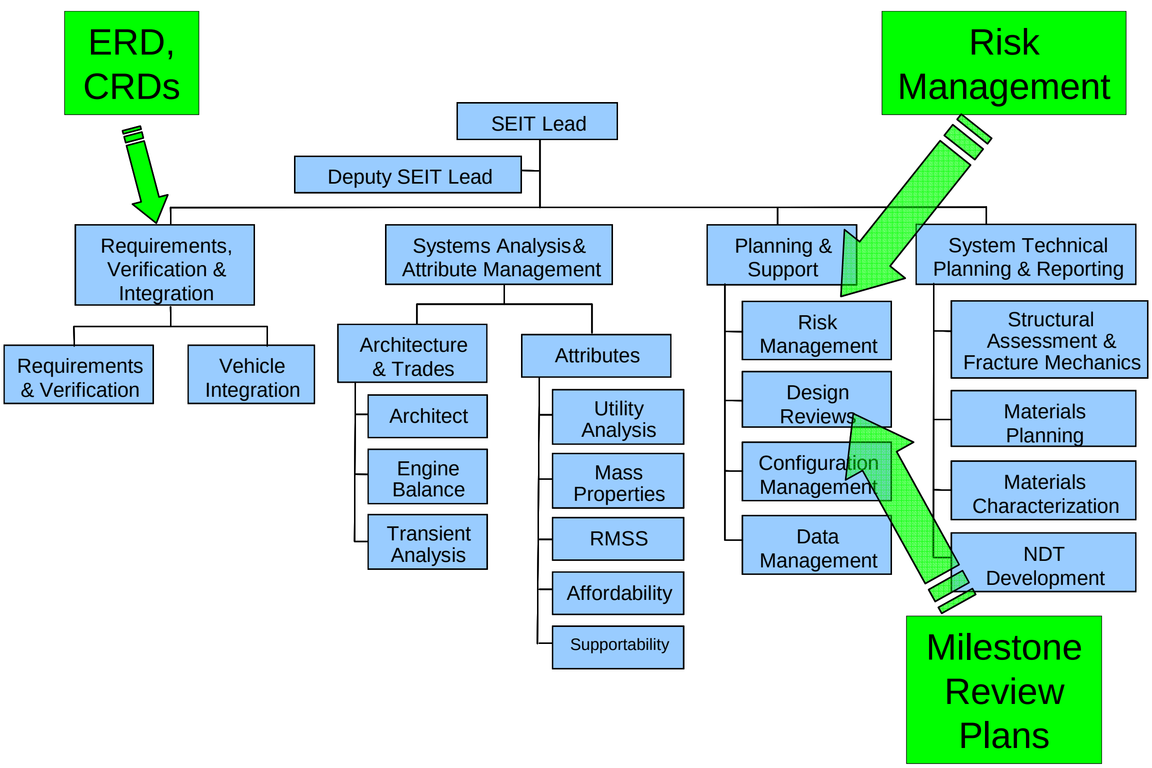


Fig. 4: PWR J-2X SE Functional Organization

Table 1: Technical Coordination Working Meetings

Meeting Title	Lead Team	Attendees	Objectives/Purpose/Charter	Decision Making Authority	Frequency
SEWG	Office of Chief Engr	PWR SEIT & IPT Leads & PM/DPM; NASA Chief Engr, SEIT Lead, & Prog Office; Architects; Integrators & Specialty Personnel as required	Operated as an ERB. Coordination, integration, and review of significant technical and design efforts, including: – engine & sub-system architecture/design configuration definition & management; – trades & specific issue resolutions & impacts; – engine-wide analyses, plans, allocations, & assessments; – general engine requirements, policies, and guidance.	A decision making body for technical items & issues	Weekly
EDWG	SEIT	Lead dev person or designated dev rep from each IPT	EDWG is held in order to discuss system functional integration, trade studies, and architecture development issues between component teams that need to be worked in a forum less formal than SEWG but more formal than email or one-on-one discussions. Also status/review of ConOps, test planning, facility planning, & assy planning. (In the future, become a forum for test & flight ops integration.)	A working meeting to develop recommendations for SEWG.	Weekly
EIWG	Eng Integ	Lead designer or designated design rep from each design IPT	Coordination forum for physical layout and integration of the engine system. Also to work physical interface trades with vehicle.	A working meeting to develop recommendations for SEWG.	Weekly

employees. Designed for security, rigid implementation, and ease of use, the NexPriseTM solution offers a SIMPLE, proven, B2B extranet platform specifically designed to facilitate secure collaboration over the public Internet while utilizing existing master data sources: the simpler, the better. Figure 5 shows a sample NexPriseTM J-2X screen which uploaded the SEWG agenda for the May 15, 2008 meeting.

ARCHITECTURE DESIGN DESCRIPTION

PWR utilized a simple spreadsheet entitled the Architectural Design Description (Table 2) to maintain control over rapidly changing architectural features of the J-2X in the pre-CDR phase of the program. The SIMPLE use of a spreadsheet to track architectural design changes provided design control during a period of rapidly changing design characteristics. Changes were monitored at the weekly SEWG meeting with NASA while trade studies were conducted to select the most desirable options. After the CDR a more traditional Configuration Control Board approach was implemented to control engine architecture.

SAFETY ANALYSIS

Crew and vehicle safety are major design considerations for the J-2X Program. The analysis required to evaluate the safety/reliability of the Ares vehicle systems is a highly developed process supported by large staffs both at NASA and PWR. The interconnected nature of familiar techniques such as Failure Modes and Effects Analysis (FMEA), Critical Items List (CIL), and Hazards Analysis demand a highly integrated approach in order to assure a meaningful analysis in such a complex system as a rocket engine. PWR has created a tool which uses computer technology to integrate the various techniques mentioned above.

The Integrated Operability Toolbox (IOT) establishes a unified platform to associate and share operability analyses and data for product definitions and system implementation. Related information is readily available for Integrated Product Teams (IPTs) to support real-time

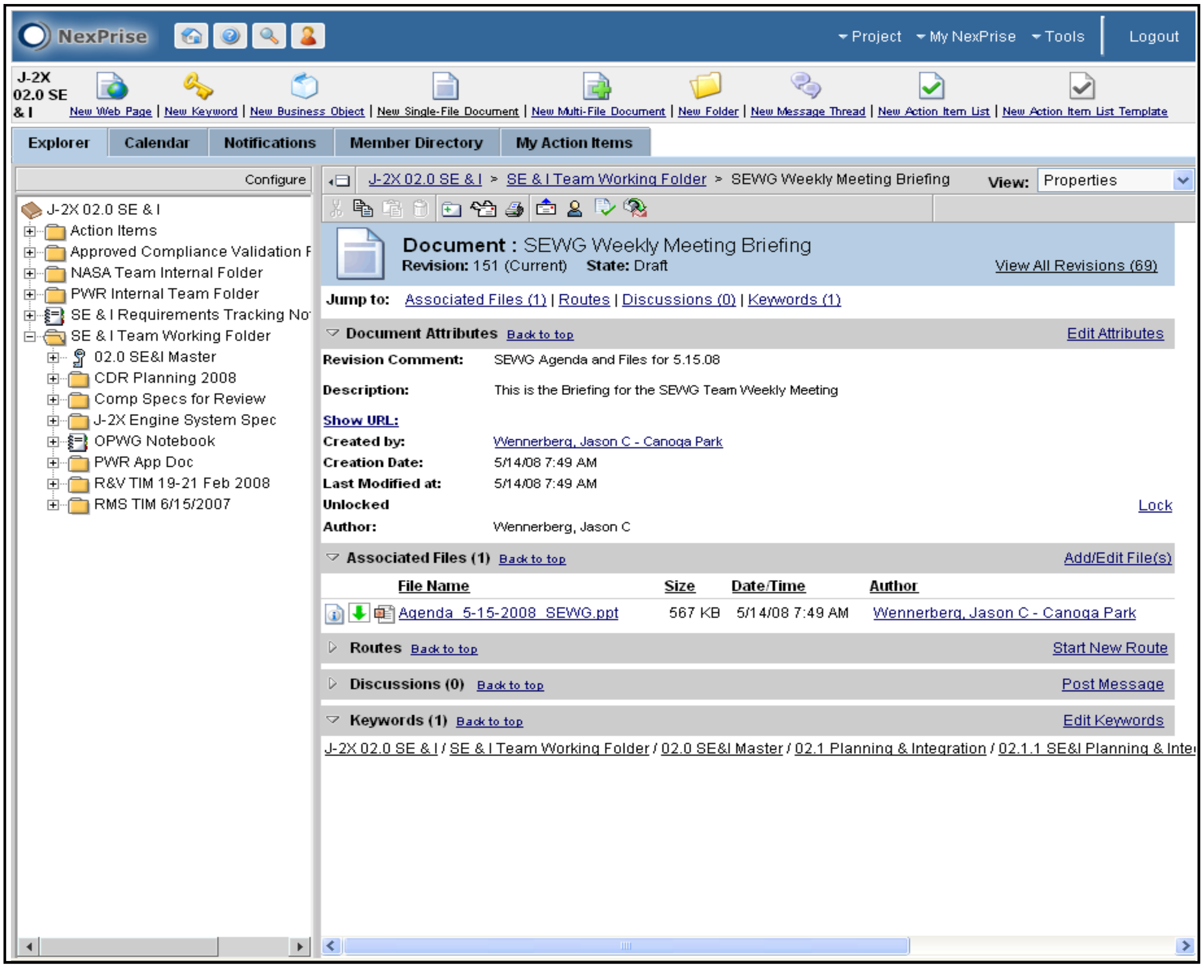


Fig. 5: Sample J-2X NexPriseTM Screen

Table 2: Architectural Description Document – Outline Form

Rev	Document Revision Date	Tab	Action	Description	Old Value	New Value	Rationale	Date Agreed to in SEWG	Significant Impact to Cost or Schedule?	Conflicts with Sys. Spec?	Notes
2.5.2	12/13/2006	GG	Changed					12/7/2006			
		GG	Changed					12/7/2006			
		Subsystem View	Added					12/7/2006			
		Hot Gas System	Added					12/8/2006			
2.5.3	1/11/2007	Subsystem View	Added					12/20/2006			
		Sys Int	Added					12/20/2006			
		Electric Control	Added					1/3/2007			
		Propellant Valves	Changed					1/3/2007			
		Propellant Valves	Changed					1/3/2007			
		Sys Int	Changed					1/3/2007			
		Veh Int	Changed					1/3/2007			

decisions during design, assembly, development and sustained test and flight operations. The IOT data can also be referenced while developing new products.

This tool integrates the operability infrastructure of several groups: Safety, Reliability, Maintainability and Testing (SRMT), Product Support, Design Engineering and Configuration Management. Linking the information obtained and stored by each functional group improves the design of the product life cycle, reduces cost and increases the system's operational availability.

The IOT is designed to link related operability analyses and data, namely information pertaining to Model Based Design, Design for Operability, Requirements Management, Risk Management, Operability Database, the Control & Health Management System (HMS), and the future Test/Flight Log Database. By centralizing and standardizing the access location for this related information, retrieval of the information required to make time-critical decisions is facilitated throughout the life of the product. Within the IOT, there are four main modules, the Failure Modes and Effects Analysis (FMEA), the Hazard Analysis, the Instrumentation Module, and the Supportability Tools module. Each module is tailored to the potential needs of disparate programs. The navigation between and within modules is accomplished through a main menu tool bar containing the four main modules.

With the goal of process consistency in mind, the IOT is designed to consolidate the access point for diverse operability data. The IOT utilizes the integrated FMEA/HAR (Hazards Analysis Report) database as a basis to support the product life cycle. Product and process integration is achieved through direct links to the Product Support Toolbox, HMS architecture and a unified Reliability Maintainability and Testability (RMT) and Systems Safety (SS) data base. Design definition efforts are directly supported for current and future programs because knowledge capture continues for the entire product life cycle. Figure 6 is an example of the FMEA Version List screen from the IOT.

RISK MANAGEMENT (PARAPHRASED FROM THE J-2X RISK MANAGEMENT PLAN)

The objective of risk management is to apply a systematic process for identifying, assessing, handling, mitigating, and tracking risks that arise during a development program. As used here, the term 'risk' is defined as an undesirable situation or circumstance that has a realistic likelihood of occurring and that results in an unfavorable consequence if it does occur. Risks are characterized as being technical, schedule, or cost related, depending on the consequence of the risk if it occurs. Any risk not classified as either a cost or schedule risk is considered to be a technical risk. Safety risks are considered technical risks. Risk management occurs continuously throughout the program life cycle and consists of a six-step process: (1) Identify, (2) Analyze, (3) Plan, (4) Track, (5) Control, and (6) Communicate and Document. Risk management is performed at all levels of the program hierarchy. Integrated Product Teams (IPT) or other teams are best able to identify potential risk items at the lowest level within the system where handling those risks can frequently be accomplished with the least impact to the total system.

A 5-by-5 risk assessment matrix provides a graphical representation of risk status. Risks are mapped on the matrix according to a likelihood and consequence assessment. Likelihood is measured on the vertical axis, and consequence is measured on the horizontal axis. Both axes consist of five levels of assessment for a total of 25 likelihood-consequence combinations on the matrix. Green, yellow, and red colored regions on the matrix indicate areas of low, medium, and high risk, respectively. Figure 7 shows a typical 5-by-5 risk assessment matrix.

<u>Assessment Criteria</u>

Likelihood and consequence assessment criteria have been defined for evaluating risks. Each set of criteria has five levels of increasing likelihood and consequence severity. The likelihood assessment criteria consist of multiple sets of measures based on defined categories of risk consisting of general, design, integration, management, process, production, requirements, safety, software, supplier, supportability, technology, and others as appropriate. Similarly, the consequence assessment criteria consist of a set of measures for each risk consequence: technical, schedule, and cost. Technical includes anything that is not cost or schedule related such as design, management, production, safety, and others as appropriate. All red and yellow risks require a risk response such as avoid, transfer, assume, or mitigate. Risk response for green risks is optional and dependent on the nature of the risk.

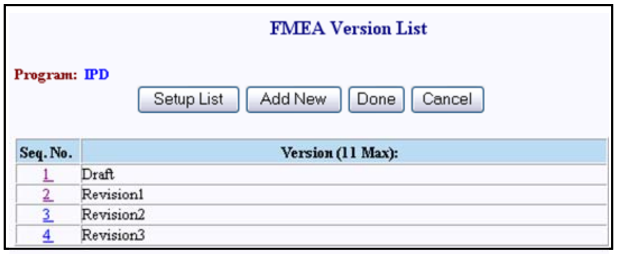


Fig. 6: Sample IOT Screen

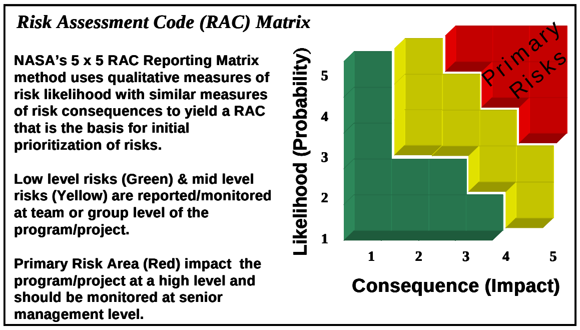


Fig. 7: Risk Assessment Matrix

Risk Management Database Software Tool — Risk Control

To facilitate the implementation of the risk management process, the J-2X program uses a web-based program risk management database software tool known as RisControl. The tool facilitates the identification, assessment, planning, controlling, communicating, documenting, and reporting of risks. Tailored for the J-2X team structure and the assessment criteria, RisControl may be accessed by all program personnel. A regularly published risk status report features a 5-by-5 matrix showing the actual and scheduled risk reduction in likelihood and consequence assessment levels as a result of completing some risk events. Figure 8 is a sample 5x5 matrix. Other reports feature time-phased mitigation plans.

CONFIGURATION MANAGEMENT (PARAPHRASED FROM THE J-2X CONFIGURATION MANAGEMENT PLAN)

The objective of Configuration Management (CM) is to implement an organized, efficient, and accurate process for managing the configuration of hardware, software, and related data products. CM encompasses the total product life cycle and results in accurate, consistently managed, and verified as-designed, as-planned, as-built and as-maintained product configurations, and program data. This includes: configuration identification and defining Configuration Items (CI); the control of changes to established baselines; configuration verification; maintaining of configuration status accounting records and reports; and participation in CM related reviews and audits.

The tool PWR uses for configuration management on J-2X is named the Enterprise Process and Data Management system, EPDM. It is a computer data based tool which gives multiple users simultaneous access to documents and drawings to enable review, release, version control, and electronic archiving functions. EPDM is used to manage product and process related information throughout the entire product life cycle. The system allows information sharing regardless of user location, data location, or hardware platform. End users can access the system through a secure, password protected web interface to review and approve or search for documents and view them on-line or print copies of them.

EPDM is a SIMPLE and powerful program resource that enables cost effective communication and data accessibility. It provides a system that facilitates the creation, collaboration, review, approval, distribution and vaulting of J-2X documentation. By using a web-based system, any authorized user within the enterprise can access the documentation from their work site, greatly improving the accessibility of the data. It gives the end users access to formally released data, as well as work in process. Tailoring the system to J-2X processes, such as the Build-To Package process, has improved collaboration, both in-house and with suppliers, and reduced cycle time in comparison to manual paper systems. A Build-To Package (BTP) is an integrated, electronic package that contains the complete product definition, and the traditional "what to build" and "how to build it" information for a particular part or assembly. What distinguishes the BTP process from traditional methods of product definition is not the documentation itself but the manner in which it is created and managed. It is created with parallel processes as a shared responsibility of a multifunctional Integrated Product Team (IPT). A pre-release vault, called the Team Vault, was created to facilitate collaboration within the team prior to formal release. In addition to the Drawing and

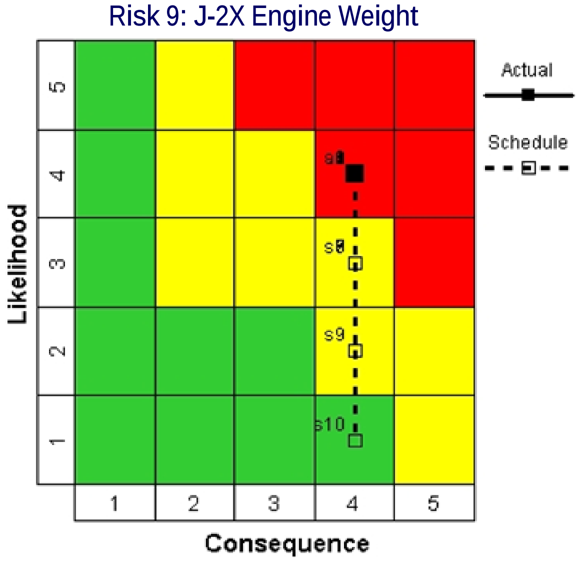


Fig. 8: Individual Risk Status Report Chart

other model derivative files, Supplier, Quality and Manufacturing requirements have been added to the composition of the BTP, along with links to applicable documents, including Specifications, resulting in a single source for data required to manufacture or purchase the part or assembly. The BTP is released and configuration managed as a single, integrated entity. An automated interface flows the Bill of Material from EPDM to the manufacturing control system further improving communication between design engineers and manufacturing and eliminating redundant data entry. Implementation of the EPDM BTP process has resulted in significant reduction in cycle time for the entire drawing release, requisition release, and purchase order placement life cycle. Figure 9 is a sample screen from just one of EPDM's functional areas.

THINGS WE LEFT OUT

It would have taken a lot more space in this paper to adequately describe the entire range of SE tools and technique utilized on the J-2X program. Some of those we skipped are mentioned in this paragraph in an attempt at abbreviated completeness.

At its best SE is integrated into every part of the J-2X program in such a way that its influence brings simple solutions and processes to complex development issues. The principle of employing uniform processes across a complex and dynamically changing program is an example of clear communication processes. A good example of this is the SE practice of establishing a set of comprehensive "technical performance measurements" at the beginning of the program that define key characteristics of the engine system. Propulsion system goals such as predicted Specific Impulse (Isp), engine weight, reliability targets, and production cost are carefully monitored and tracked on a monthly basis.

Another SE tool is the use of analytical modeling of engine system and component performance. Using advanced modeling techniques such as computational fluid dynamics (CFD) to develop component designs reduces risk of achieving performance goals at component, subsystem, and engine system levels. The J-2X program also makes use of computerized material

Fig. 9: EPDM Document Search Function Screen

property databases to assist in component design. Available information is supplemented with a growing body of material knowledge that is being generated as part of the program. Risks associated with critical flaw size and probability of detection are included and become part of the technical design process.

The simple process of using more experienced employees to mentor younger or less experienced employees is a vital part of the SE process. Investing the time and effort to help others not only brings efficiency to the J-2X development process but is an effective means of sharing and spreading SE principles throughout the organization.

SUMMARY

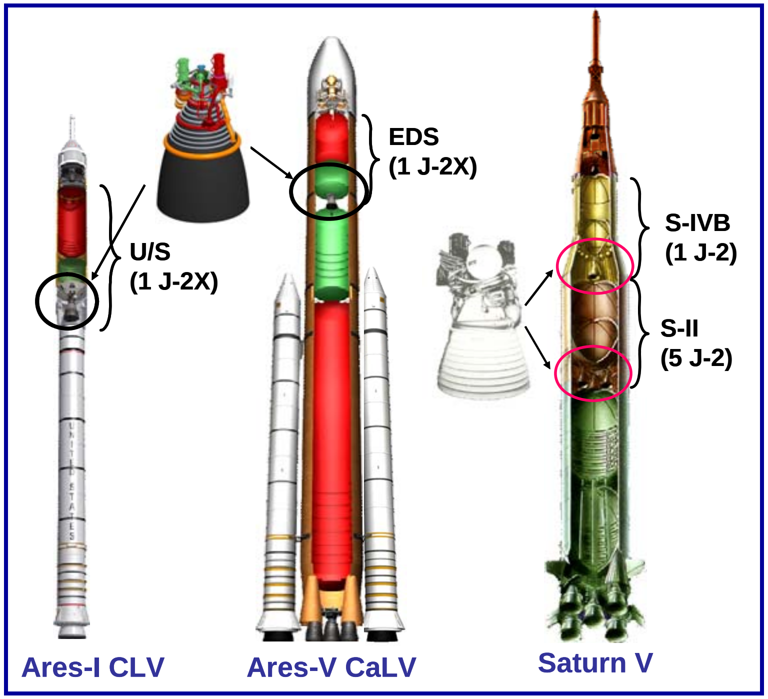
The J-2X engine development program continues to support the Ares Program goals of returning astronauts to the moon and moving out to explore the solar system. The implementation of SE principles with good communication practices is integral to the success of this effort and central to the strategy of unifying all elements of the program. The simplest communication tool of regular conversations among NASA, contractors, and sub-contractors is fully utilized to ensure not just the transfer and flow down of requirements but the proper understanding of those requirements and the potential subtle nuances which may turn into problems. Regular teleconferences, technical interchange meetings, working groups using electronic communication tools and face to face contact among real people is the simplest and yet most effective tool for ensuring the success of the SE effort on J-2X. Electronic data handling tools (NexPriseTM, EPDM, IOT, etc.) ensure consistency of information and controlled change of requirements. The simple act of recording and monitoring the architectural change decisions in the Architecture Description Document maintains vigilance over multiple changes and encourages the engineering community to continually evaluate the impact of the range of changes from a broader systems perspective. The complex J-2X Hazards Analysis effort is simplified by the use of the IOT which ensures the proper interrelationship among the design details, FMEA information, and the CIL. But the proof of SE is in successful program accomplishment. SE is the methodology being used to meet the challenge of completing J-2X engine certification 2 years ahead of any engine program ever developed at PWR. This approach has delivered according to expectations thus far. All major design reviews have been successfully conducted satisfying overall project and program objectives using SE as the basis for accomplishment. It would seem that William of Ockham was on to something.

Systems Engineering for J-2X Development: The Simpler, the Better

Bill Kelly (PWR - Canoga Park, CA)
Bil Greene (NASA - MSFC)
Paul Greasley (PWR - West Palm Beach, FL)
Pete Ackerman (PWR - Canoga Park, CA)

J-2X SE: The Simpler, the Better
Upper Stage Propulsion For the ARES Vehicles

- Based on J-2 historical success
- SE principles simplify development
- Better SE tools and techniques

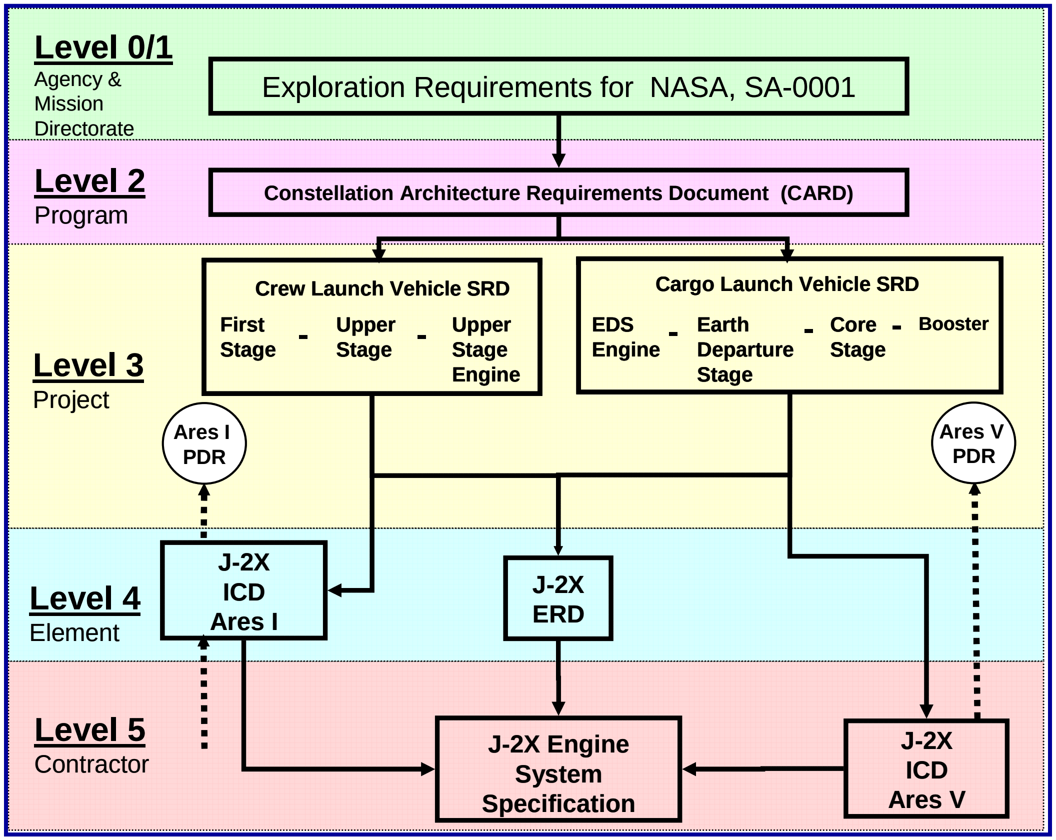


Ares-I Crew Launch Vehicle (CLV) and Ares-V Cargo Launch Vehicle (CaLV)

- Safer
- More reliable
- Operationally more efficient

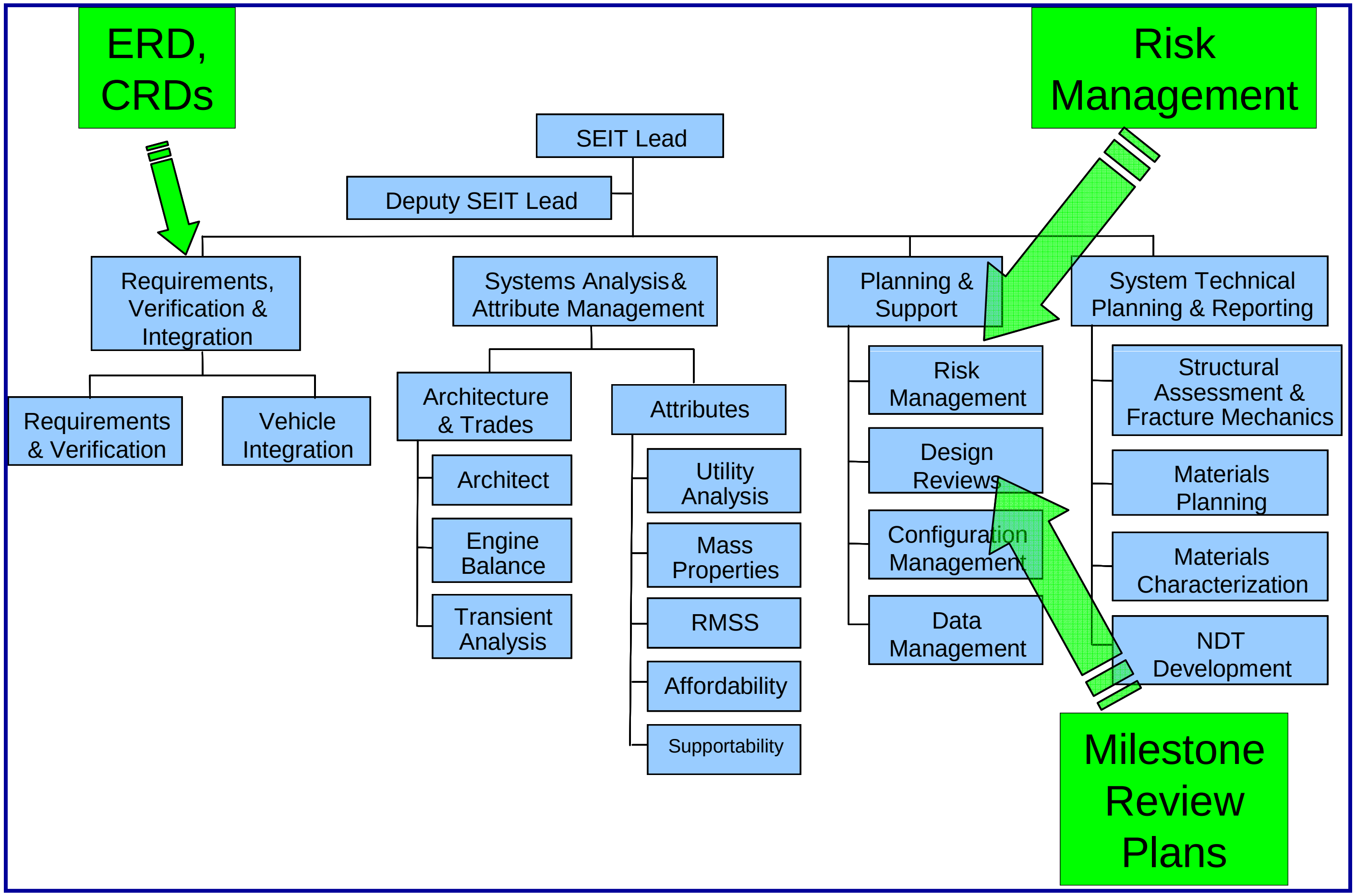
J-2X SE: The Simpler, the Better
A Simple Communication Plan

- Technical requirements flowdown
- Structured program requirements
- Tiered flowdown provides traceability between levels
- J-2X Element Requirements Documents provides basic engine design parameters
- J-2X Engine System Specification decomposes ERD into engine level details



J-2X SE: The Simpler, the Better
Element Requirements Provided to PWR SE Team

- Simple relationship between PWR and NASA SE efforts
- PWR SE Organization Parallels NASA



J-2X SE: The Simpler, the Better
Working Meetings Mean Talking To Each Other

- Simple and effective way to achieve high quality communication
- 15 regular meetings between PWR and NASA
- Opportunity for technical experts to discuss mutual interests

Meeting Title	Lead Team	Attendees	Objectives/Purpose/Charter	Decision Making Authority	Frequency
SEWG	Office of Chief Engr	PWR SEIT & IPT Leads & PM/DPM; NASA Chief Engr, SEIT Lead, & Prog Office; Architects; Integrators	Operated as an ERB. Coordination, integration, and review of significant technical and design efforts	A decision making body for technical items & issues	Weekly
EDWG	SEIT	Lead dev person or designated dev rep from each IPT	EDWG is held in order to discuss system functional integration, trade studies, and architecture development issues	A working meeting to develop recommendations for SEWG.	Weekly
EIWG	Eng Integ	Lead designer or designated design rep from each design IPT	Coordination forum for physical layout and integration of the engine system. Also to work physical interface trades with vehicle.	A working meeting to develop recommendations for SEWG.	Weekly

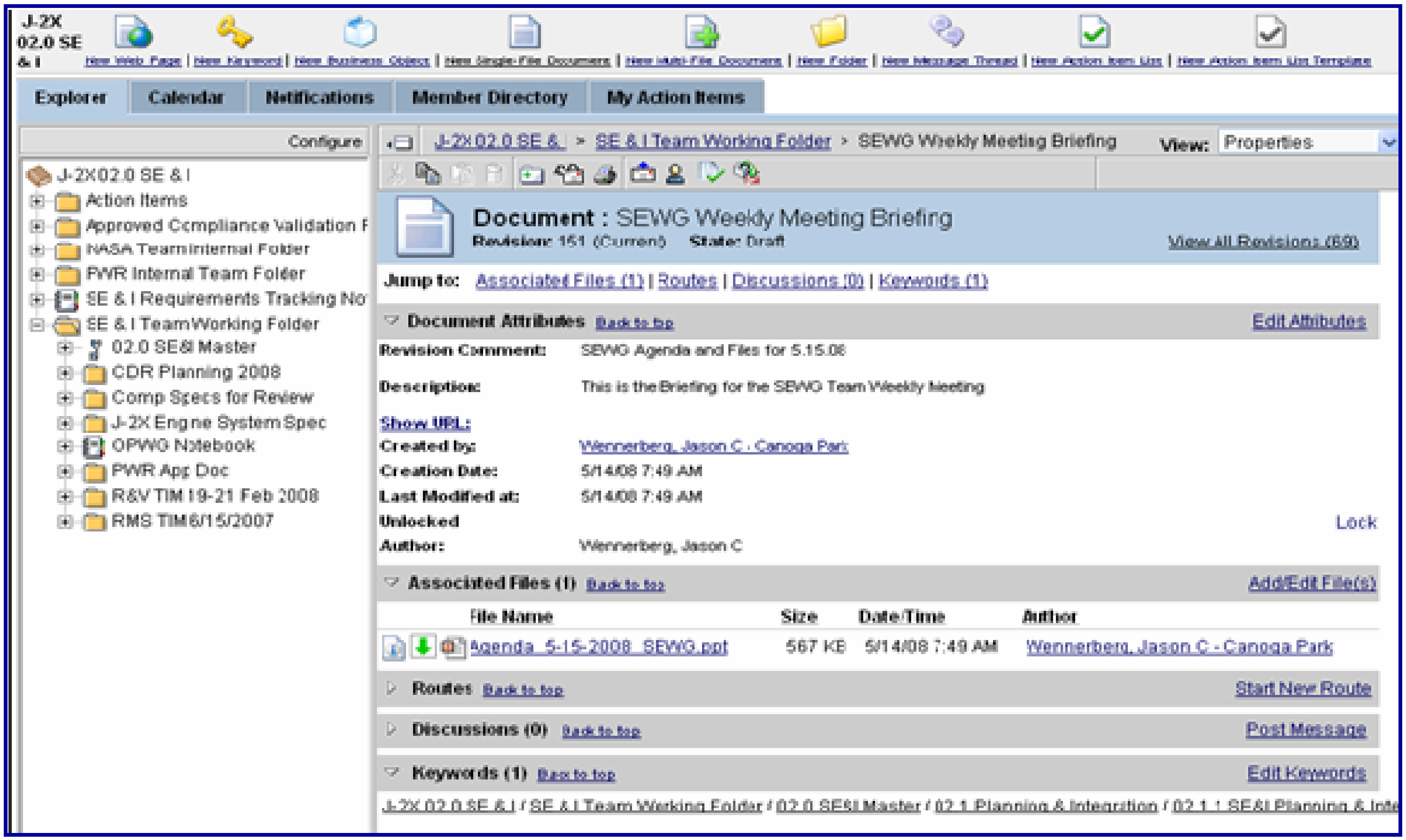
J-2X SE: The Simpler, the Better
ADD Provides Control With Demanding Schedule

- Engine Architecture Design Description (ADD)
- Simple spreadsheet to track configuration and changes
- Changes monitored during weekly PWR / NASA meetings
- Changes made by Configuration Control Board after CDR

Rev	Document Revision Date	Tab	Action	Description	Old Value	New Value	Rationale	Date Agreed to in SEWG	Significant Impact to Cost or Schedule?	Conflicts with Sys. Spec?	Notes
2.5.2	12/13/2006	GG	Changed					12/7/2006			
		GG	Changed					12/7/2006			
		Subsystem View	Added					12/7/2006			
2.5.3	1/11/2007	Subsystem View	Added					12/20/2006			
		Sys Int	Added					12/20/2006			
		Electric Control	Added					01/03/2007			

J-2X SE: The Simpler, the Better
NEXPRISE Provides Secure Communication

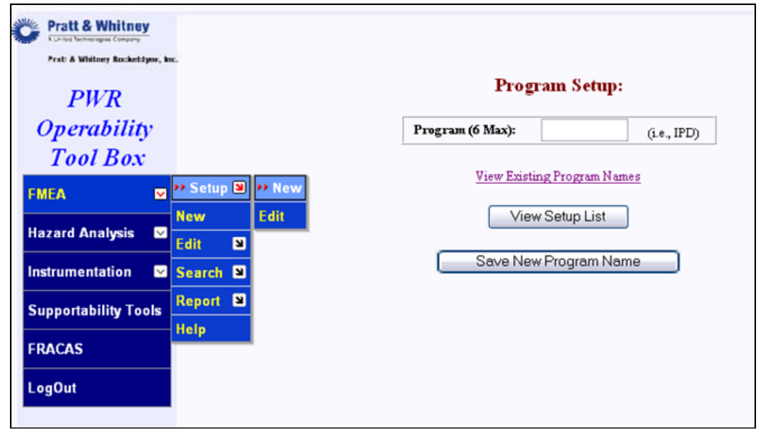
- Electronic communication via secure Internet tool
- Simple and safe means to share vital information
- Electronic communication tools enhance clarity and speed

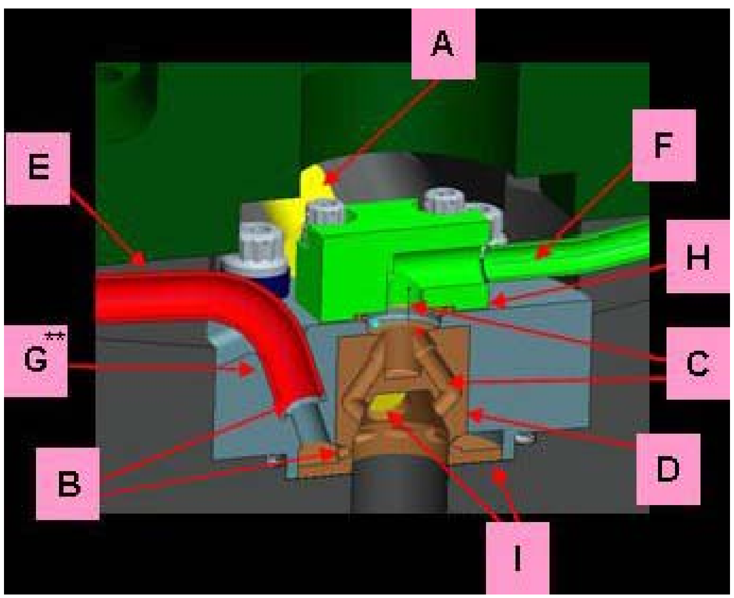


J-2X SE: The Simpler, the Better
IOT Simplifies and Integrates Engine Safety

Integrated Operability Toolbox (IOT)

- Unified platform to associate and share operability analyses and data
- Integrates efforts of various groups - Safety, Reliability, Maintainability and Testing, Product Support, Design Engineering, Configuration Management

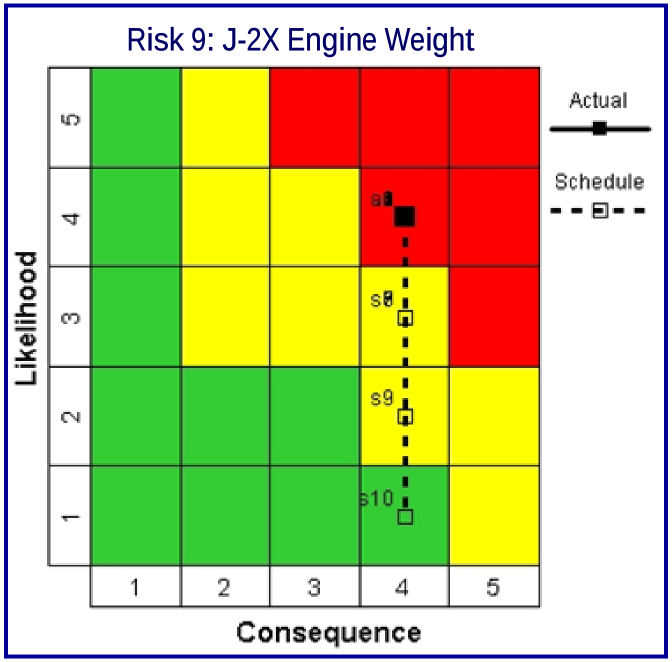




Failure modes can be linked to Bill of Material assembly

- Simple coordination of activities
- Reliable tool for design work

J-2X SE: The Simpler, the Better
RisControl Simplifies Risk Management



Risk Assessment Matrix

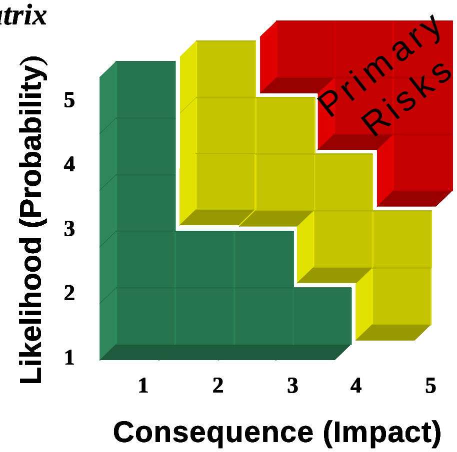
- Graphical representation of risk status
- Electronic database used to monitor risk items
- Simple communication tool between PWR and NASA

Risk Assessment Code (RAC) Matrix

NASA's 5 x 5 RAC Reporting Matrix method uses qualitative measures of risk likelihood with similar measures of risk consequences to yield a RAC that is the basis for initial prioritization of risks.

Low level risks (Green) & mid level risks (Yellow) are reported/monitored at team or group level of the program/project.

Primary Risk Area (Red) impact the program/project at a high level and should be monitored at senior management level.



Individual Risk Status Report Chart

- Likelihood and consequence
- Colors indicate severity
- Effective tool for tracking risk mitigation plans

J-2X SE: The Simpler, the Better
EPDM Simplifies Configuration Management

Enterprise Process Data Management (EPDM)

- Electronic tool that gives multiple users simultaneous access to documents and drawings
- Used to enable review, release, control, and electronic archiving
- Simple and powerful tool that enables cost effective communication and data accessibility

J-2X SE: The Simpler, the Better
Things We Left Out

- Creative use of advanced technology tools
- Technical performance measurements tracking
- Analytical modeling of engine and component performance
- Training and mentoring of new employees

J-2X Engine Model

J-2X SE: The Simpler, the Better
Summary

- "All Things Being Equal, The Simplest Solution Is The Best" – William of Ockham
- "Talking To Each Other"
- Simple but effective communication in meetings and telecons
- Simple monitoring tools (ADD, etc.) keep focus on the details
- Safety tools integrate technical efforts of many engineers
- Success via simple and better SE practices