



NASA Lyndon B. Johnson Space Center

The 2003 Systems Engineering Benchmarking Study

A Summary for the AIAA

Jack Gavalas, Associate, Booz Allen Hamilton

November 10, 2005

Raytheon

Booz | Allen | Hamilton

Briefing Contents

- ▶ **Background**
- ▶ **Implementation Methodology**

Purpose of the Study

- ▶ A JSC Office of the Chief Engineer/Systems Management Office (OCE/SMO)-led team was chartered to
 - Assess the state of the Johnson Space Center Systems Engineering (JSC SE) practice
 - ▶ Develop a benchmarking process from various industry standards
 - ▶ Compare JSC SE best practice to that of other government-aerospace sector organizations
 - Establish and report on the state of the JSC center-wide and organization-specific SE practices to the Systems Engineering Working Group (SEWG) and JSC Chief Engineer

Ground Rules

- ▶ The basic need was to determine overall JSC SE capability **across the Center**
- ▶ The **limited time and resources** available for execution of the study indicated an approach based on sampling
- ▶ The data gathering and fact finding had to be conducted so that the **impact** and interaction with JSC personnel was **minimized**
- ▶ **Coordination** with the directorates and offices was to be handled **through the SEWG representatives**
- ▶ The study project-level **results were to be kept confidential** within the OCE and to be shared only with the specific project managers and the SEWG directorate representatives

Overall Approach – Study Parts A and B

Study Planning

- A – Review of SE standard(s), and preliminary review of JSC-external SE environment
- A – Introduction of study to JSC directorate, office, divisional, and SE leadership
- A – Understanding current JSC SE organization and activities
- A – Identifying possible projects for examination, then down-selecting to a “best-insight” final list for benchmarking
- A – Selecting the best benchmarking approach/tools plan, and preliminary selection of best report-out plan
- ◆ Obtaining approval to proceed with implementing the benchmarking approach/tools plan and the preliminary report-out plan

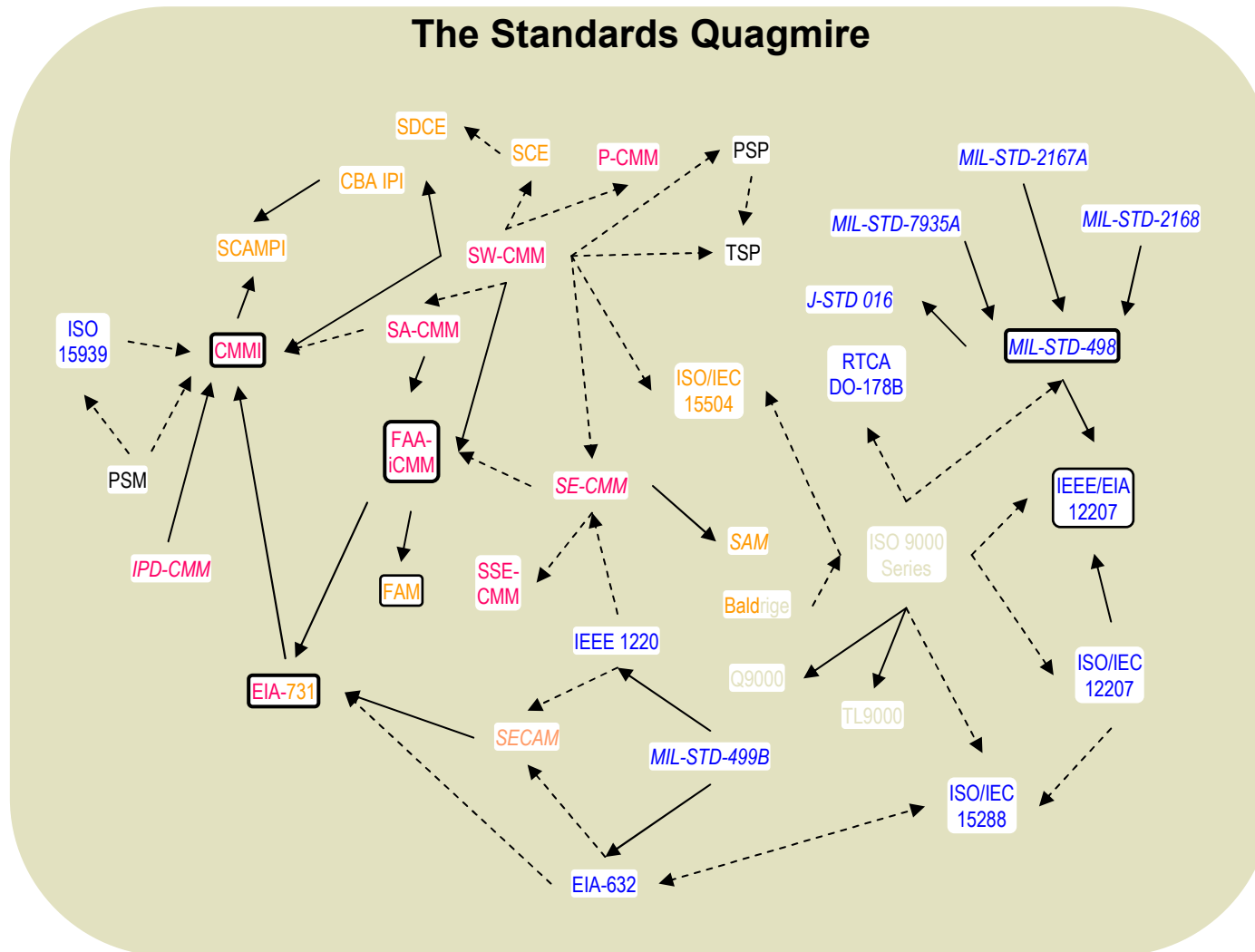
Study Execution

- B – Finalizing selected JSC projects, survey instruments, tools
- B – Requesting best-practice documents from JSC projects and info from external organizations
- B – Examining project file excerpts and conducting JSC project interviews
- B – Performing data analysis, State-of-Practice assessment(s), selecting final reporting-out plan
- B – Reporting out. Sharing specific directorate findings confidentially with the appropriate SEWG members

Survey of Previously Conducted Studies

- ▶ Interviewed JSC SEWG Chair with respect to agency efforts
- ▶ Polled JSC SEWG membership
- ▶ Performed literature survey and interviewed individuals in Government, academia, and industry
 - Richard Turner, D.Sc., DoD, Author “Implementation of Best Practices in U.S. DoD Software-Intensive Systems Acquisition,” January 2002, Faculty Member George Washington University
 - Jeffrey O. Grady, Consultant, Author of several books including “Systems Engineering Deployment,” Faculty Member University of California San Diego
 - Raytheon / Booz Allen Hamilton primary standards authors
 - ▶ Gary Wolf, Raytheon, Primary Author “Capability Maturity Model Integration”
 - ▶ John Evers, Raytheon, Primary Author EIA-731 “Systems Engineering Capability Model”
 - ▶ Charles Haist: Booz Allen, Contributor, MIL-STD-499

Which standard could be used to review the project sample?



At the time, EIA-632 was already being used as JSC's reference for establishing Center SE standards

EIA-632 Requirements for Engineering a System

Supply Process Requirements

1. Product Supply

Acquisition Process Requirements

2. Product Acquisition
3. Supplier Performance

Planning Process Requirements

4. Process Implementation Strategy
5. Technical Effort Definition
6. Schedule and Organization
7. Technical Plans
8. Work Directives

Assessment Process Requirements

9. Progress Against Plans and Schedules
10. Progress Against Requirements
11. Technical Reviews

Control Process Requirements

12. Outcomes Management
13. Information Dissemination

Requirements Definition Process Requirements

14. Acquirer Requirements
15. Other Stakeholder Requirements
16. System Technical Requirements

Solution Definition Process Requirements

17. Logical Solution Representation
18. Physical Solution Representation
19. Specified Requirements

Implementation Process Requirements

20. Implementation

Transition to Use Process Requirements

21. Transition to Use

Systems Analysis Process Requirements

22. Effectiveness Analysis
23. Tradeoff Analysis
24. Risk Analysis

Requirements Validation Process Requirements

25. Requirement Statements Validation
26. Acquirer Requirements Validation
27. Other Stakeholder Requirements Validation
28. System Technical Requirements Validation
29. Logical Solution Representations Validation

System Verification Process Requirements

30. Design Solution Verification
31. End Product Verification
32. Enabling Product Readiness

End Products Validation Process Requirements

33. End Products Validation

About EIA-632 . . .

- ▶ American National Standards Institute/Electronic Industries Alliance Standard Number 632, “Processes for Engineering a System” (ANSI/EIA-632)
 - Product of Government Electronics & Information Technology Association (GEIA) project SP3537, a joint activity of GEIA and INCOSE to prepare a national process standard for engineering a system
 - When published in 1998, it superceded EIA/IS 632, an interim standard created to replace MIL-STD-499B when it was canceled in 1994
 - **Treats all stages of engineering a system; deals with all aspects of the Engineering Life Cycle**
 - **Not limited to the physical development cycle, and does not focus solely on systems engineering management; covers Performance, Cost, Schedule, Safety, and their risks**
 - **Intended for both industry and government**
 - **Encourages tailoring to allow efficient application to any enterprise that performs an engineering function**

Other features that sold EIA-632

- ▶ Could provide a consistent approach for all projects
- ▶ Could provide a simple approach to a quantitative result
 - The various aspects of each of 33 requirements could be rolled up for a numerical score
- ▶ Could be mapped to the NPG draft on systems engineering (separate from the NASA SE Handbook, SP610S, June '95)
 - To express the results in terms of the developing institutional standard

Feedback from Software Engineering Institute supported the choice

Michael Phillips, then Capability Maturity Model® Integration (CMMI) Program Manager for the Software Engineering Institute (SEI) at Carnegie Mellon University, indicated that an assessment focusing on Systems Engineering capabilities would do well to base the assessment on EIA-632.

The sample of projects would have to reveal the Center-level status

- ▶ **Multiple projects in each role (customer, developer, integrator)**
 - Rationale:** First need to seek out projects representative of JSC capability to perform primary systems engineering roles and evaluate them accordingly

- ▶ **At least one project from each organization at the directorate level**
 - Rationale:** Roles appear to vary across organizations. Need to identify pockets of expertise and consistency across the Center.

- ▶ **Try for a variety of subtypes (Flight Systems/GFE; Flight Ops Systems/Robotics; etc.)**
 - Rationale:** Seeking a range of projects that represents depth of the organization and not just pockets of expertise or lack thereof

- ▶ **Classification preference: Development, Operations, Closeout, and Sustaining**
 - Rationale:** Projects in development represent the most current SE practice. But, in order to gain insight into the entire range of expertise, may need to look at development history and experience of projects in operations. Closeout projects may expose lessons learned and gaps.

- ▶ **Highest complexity available is preferred**
 - Rationale:** Projects where complexity is greatest exercise the SE capability of an organization the most.

The existence and state of certain project artifacts would indicate project SE practices

Documents

- ▶ Agreements between Customer and Project
- ▶ Agreements between Project and Suppliers
- ▶ Source and technical documents
- ▶ Program Management Plan
- ▶ Risk Management Plan
- ▶ Metrics Management Plan
- ▶ Systems Engineering Management Plan
- ▶ Technical Review Plan
- ▶ Verification/Validation Plans
- ▶ Configuration Management Plan
- ▶ Change Management Plan
- ▶ Interface Management Plan
- ▶ Data and Document Management Plan
- ▶ Specialty Engineering Management Plan

Products

- ▶ Stakeholder and derived requirements
- ▶ Product and process metrics
- ▶ Technical performance measures
- ▶ Event-based/calendar-based schedules
- ▶ Task lists/work packages
- ▶ Staffing/skill requirements
- ▶ Logical solution representations
- ▶ Physical solution representations
- ▶ Tradeoff analyses
- ▶ Milestone and Peer review data
- ▶ Integration results
- ▶ Verification and validation results
- ▶ End product transition results
- ▶ Project library

The scoring approach had to be streamlined but equitable

- ▶ Each EIA-632 requirement was weighted equally
- ▶ Only those requirements applicable to the project with regard to life-cycle phase were considered
- ▶ A degree of compliance for each applicable requirement was assigned based on responses to checklist questions
- ▶ The four aspects of compliance were:
 - Whether an established process existed
 - The appropriateness of the established process
 - The degree to which the work was performed satisfactorily
 - The degree to which work was performed in accordance with the established processes
- ▶ The sum of compliance numbers for the applicable requirements was divided by the total number of applicable requirements

Approach Rationale Summary

▶ EIA-632 versus CMMI versus NPG as best practice baseline

- **Rationale:** JSC is developing SE guidelines based on EIA-632. Using EIA-632 aligns fact finding and analysis with JSC direction and provides the Center, directorates, and projects a relative context for evaluating current capabilities and compliance with this standard. NPG is still in draft. CMMI too advanced for this stage.

▶ Project versus Organizational Level Focus of basic examination

- **Rationale:** A Project focus is necessary to begin to establish a broad-based, general understanding of SE capabilities, because the projects are where elemental SE is practiced. Those capabilities can then be collectively analyzed and averaged to establish a Center-wide baseline.

▶ Breadth versus Depth Analysis

- **Rationale:** The objective is to establish Center SE capabilities, not the absolute capability of any particular projects. The more projects studied across as many organizations as possible, the more accurate will be the understanding of SE capabilities across the Center.

▶ Survey versus Questionnaire versus Audit

- **Rationale:** Controlling answers to written questionnaires in order to get at desired status is difficult, and detailed audits are too time-consuming. A checklist-based survey administered through in-person interviews provides requirements coverage, eases impact on projects, and provides some assurances regarding validity of responses.

▶ Project Team versus Individual Interviews

- **Rationale:** Both approaches have pros and cons. Effective fact finding can be achieved either way and misleading information could be received either way. Since project interference needs to be minimized, project team interviews are the more efficient, if not quite as effective.

From the foregoing preparations, an internal study process was developed

- ▶ Using EIA-632 and other information explaining previous SE benchmarking efforts, develop a list of practices necessary to the execution of JSC SE tasks into a project SE checklist to guide individual project review
- ▶ Coordinate with directorate or office delegates to the SEWG to select one or more sample projects that were representative of the state of SE practice in that organization
- ▶ Request from each sample project a standard set of kinds of documentation from which the study team could discover the state of the selected practices for that project; fill out as much of the survey as this research answers
- ▶ Conduct interviews with contact personnel on a non-interference basis to clarify points not informed by the project document study; accept answers at face value without further verification, and finish the survey
- ▶ From the survey results, determine states of practice of JSC organizations at the directorate and Center levels

Methodology for External Survey

▶ Approach

- Conducted survey of literature to leverage existing data related to Systems Engineering best practices
 - ▶ Polled other NASA Centers, Academia, SEI, INCOSE and DoD
- Selected NASA Centers plus Department of Defense organizations with comparable responsibilities
- Followed process outlined in Turner’s 2002 study of “Best Practice Adoption by Defense Acquisition Programs” (emphasizing those areas pertaining to System Engineering)
- Used “expert elicitation” approach utilized in DoD survey (center-level perception of SEWG chairs)
- Correlated JSC Internal benchmarking results with external best practices survey.

▶ Output

- Survey data represented Valued Systems Engineering Practice perceptions based on expert opinions of SEWG chairs at selected NASA Centers (JSC, GSFC, MSFC, LaRC).
 - ▶ A valued SE practice was one which would likely be effective if adopted
 - ▶ A valued SE practice could be perceived as effective whether or not a particular reviewer’s NASA center had fully embraced that practice

External View Participant Selection Criteria

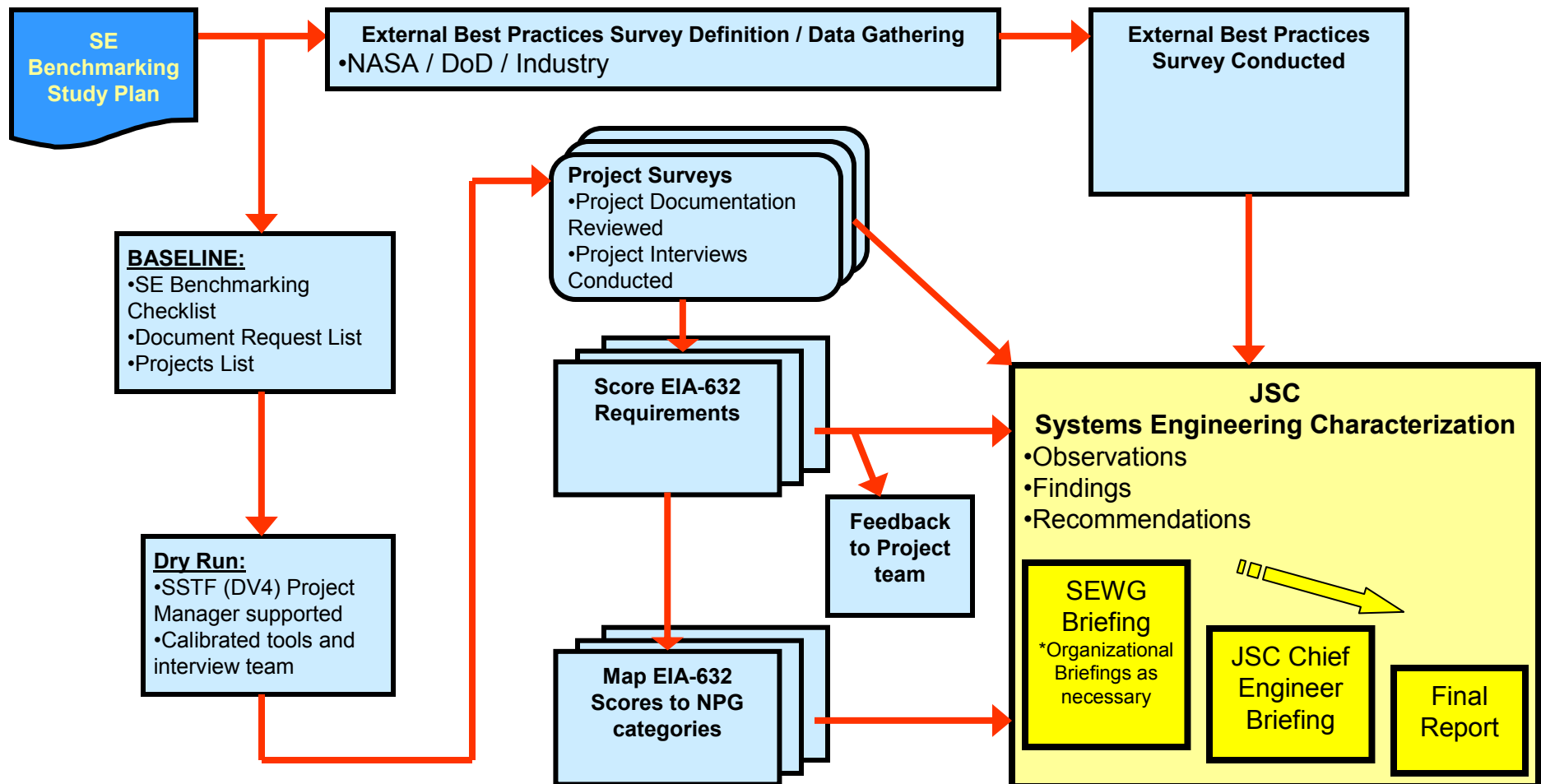
▶ NASA Centers

- Select NASA Centers with strong Systems Engineering mandate and preferably those with a similar mission (related to space flight initiatives). Candidates: GSFC, MSFC, JPL, Langley (alternate)

▶ Other

- Select U.S. Government organizations with similar role and mission to JSC.
 - ▶ NASA Human Exploration & Development of Space (HEDS) Enterprise
 - ▶ unmanned space flight
 - ▶ atmospheric flight
 - ▶ complex systems development, integration and operation
- Candidates:
 - ▶ U.S. Navy (Naval Air Systems Cmd, Naval Sea Systems Cmd, Naval Undersea Warfare Ctr)
 - ▶ U.S. Air Force (Electronic Systems Center)
 - ▶ U.S. Army (Tank-Automotive & Armaments Cmd, Tank-Automotive Research, Development & Engineering Ctr, Communications-Electronics Cmd)

Recap: Implementing the study in Phase B . . .



Reference Information

SE Benchmarking Study Team Members

Team Member	Organization	Role / Background
Dwight Auzenne	JSC SMO	NASA Study Lead
Ralph Anderson	JSC SMO	Alternate NASA Study Lead
Hal Smith	Raytheon	Contractor Study Lead System Architect
Jerry McCullough	Booz Allen Hamilton	Retired JSC Systems Engineer
Larry Patrick	Raytheon	Assessment Methodologist
Mike Hazen	Raytheon	Systems Engineering Manager
Jack Gavalas	Booz Allen Hamilton	Systems Engineer

Governing & Reference Documents

The study would follow the documents that direct and guide the JSC Systems Engineering Working Group (SEWG)

► Governing documents

- Systems Engineering Process and Requirements, NPG 71xx.x [Draft]
- American National Standards Institute/Electronic Industries Alliance Standard Number 632, “Processes for Engineering a System” (ANSI/EIA-632)
- Johnson Space Center Policy Directive (JPD)
- Johnson Space Center Policy Guide (JPG)

► Reference documents

- The Capability Maturity Model for Integrated Product Development, Version 3.1 (CMMI)
- The Systems Engineering Capability Assessment Model of the International Council on Systems Engineering (INCOSE SECAM)
- Raytheon’s Integrated Product Development System (IPDS)

Draft Questions – I. Technical Management

PLANNING PROCESS QUESTIONS

1. Process Implementation Strategy Questions

- 1A Are users, customers, and other stakeholders identified?
- 1B Have applicable source and technical documents been identified and acquired?
- 1C Have enabling products associated with production, test, deployment/installation, and logistics processes been identified?
- 1D Have life cycle phases, expected work product outputs, applicable management reviews, and life cycle phase completion criteria been identified?
- 1E Have technical processes and project integration issues been identified and defined?
- 1F Have progress assessment metrics and reporting requirements been identified and defined? That is, how do you measure progress?
- 1G Has a process implementation strategy been prepared, documented, and made available?

2. Technical Effort Definition Questions

- 2A Have project requirements been identified?
- 2B Has a project information database been established allowing capture of project data? Is it available to the team?
- 2C Has a risk management strategy been defined?
- 2D Have product and process metrics been defined?
- 2E Have cost objectives been established?
- 2F Have technical performance measures been identified?
- 2G Have applicable tasks been identified?
- 2H Have appropriate methods and tools, required facilities and equipment, and necessary training been identified?
- 2I Have applicable or potential technology constraints been identified and approaches for overcoming each constraint been developed?

3. Schedule and Organization Questions

- 3A Has an event-oriented schedule based on key events, related tasks, and relevant completion criteria been developed?
- 3B Has a calendar-based schedule showing the dates of expected task and event completion been developed?
- 3C Have resources required to complete the scheduled tasks been identified?
- 3D Have the staffing and discipline needs to complete the scheduled tasks, training needs, and risks been defined?
- 3E Has the team and organizational structure required to complete the scheduled tasks within resource constraints been defined?

4. Technical Plans Questions

- 4A Has an engineering plan been developed?
- 4B Has a risk management plan been developed?
- 4C Has a technical review plan been developed?
- 4D Have verification plans been developed?
- 4E Have validation plans been developed?
- 4F Were other applicable plans developed? For example: certification, technology insertion, safety, security, human factors engineering, and maintenance reliability.

5. Work Directives Questions

- 5A Have individual project work packages been developed that describe the work to be done, resource sources, schedules, budget, and reporting requirements?
- 5B Have work authorizations for the project team been generated and distributed?



Draft Questions – I. Technical Management (cont)

ASSESSMENT PROCESS QUESTIONS

6. Progress Against Plans and Schedules Questions

- 6A Have events, tasks, and process metrics for monitoring progress against plans and scheduled been identified?
- 6B Are identified process metrics data and results from completion of planned and scheduled tasks and events collected and analyzed?
- 6C Are process metrics data compared against plans and schedules to determine technical areas requiring attention?
- 6D Are required changes to correct variances, make changes to plan and schedule, and redirect work determined and implemented?

7. Progress Against Requirements Questions

- 7A Have product metrics and their expected values been identified?
- 7B Are product metrics data collected and analyzed?
- 7C Are rationale for decisions and assumptions made with respect to collected data recorded in a project information database?
- 7D Are results compared against requirements to determine degree of technical requirement satisfaction, progress toward maturity of the product, and variations and variances from requirements?
- 7E Are required changes identified, and approved revisions to specifications and configuration baselines implemented?

8. Technical Review Questions

- 8A Have technical review objectives and requirements been identified?
- 8B Is progress toward satisfying technical review entry requirements determined?
- 8C Are technical review boards, agendas, and speakers established? Are board members qualified and unbiased?
- 8D Are the appropriate materials prepared, such as read-ahead technical review packages and presentation packages?
- 8E Are emerging issues identified and resolved prior to reviews?
- 8F Are technical reviews conducted according to technical review plans, and action items identified and documented?
- 8G Are closeout reviews held after minutes have been prepared, approved, and distributed; action items have been resolved; and the review signed off by the chairperson?

Draft Questions – I. Technical Management (cont)

CONTROL PROCESS QUESTIONS

9. Outcomes Management Questions

- 9A Are outcomes captured? Examples: descriptions of methods and tools used, decisions and assumptions, lessons learned, and other data that allow for tracking requirements.
- 9B Is configuration management performed in accordance with the configuration management plan?
- 9C Is change management performed in accordance with the change management plan?
- 9D Is interface management performed in accordance with the interface management plan?
- 9E Is risk management performed in accordance with the risk management plan?
- 9F Is data and document management performed in accordance with the data and document management plan?
- 9G Is data captured and managed in a project information database for proper retentions, security, and availability?
- 9H Are stakeholder requirements, system technical requirements, logical solution representations, physical solution representations, derived technical requirements, specified requirements, approved changes, and validation results managed and tracked?

10. Information Dissemination Questions

- 10A Is progress status provided to relevant stakeholders, i.e., management, team members, suppliers, etc.?
- 10B Is planning information provided to relevant stakeholders?
- 10C Are approved and controlled requirements disseminated to relevant stakeholders?
- 10D Is information for and from reviews provided to relevant stakeholders?
- 10E Are design data and schema made available to relevant stakeholders?
- 10F Are lessons learned made available to relevant stakeholders?
- 10G Are variances reported to relevant stakeholders?
- 10H Are data deliverables disseminated to relevant stakeholders?
- 10I Are approved changes disseminated to relevant stakeholders?
- 10J Are directives disseminated to relevant stakeholders?

Draft Questions – II. Acquisition and Supply

SUPPLY PROCESS QUESTIONS

11. Product Supply Questions

- 11A Was the capability of the project to meet program requirements assessed?
- 11B Was an agreement negotiated?
- 11C Was the agreement captured and recorded?
- 11D Was a project established and processes activated to implement the agreement?
- 11E Are (were) products delivered in accordance with the agreement?

ACQUISITION PROCESS QUESTIONS

12. Product Acquisition Questions

- 12A Were documents prepared for the acquisition of products from suppliers? Example: acquisition requests, offers, directives.
- 12B Were supplier responses evaluated?
- 12C Were offers made to selected suppliers?
- 12D Were agreements negotiated and established with the selected suppliers?
- 12E Were the agreements captured and recorded?
- 12F Have delivered products been accepted?

13. Supplier Performance Questions

- 13A Are relationships between suppliers and the project defined?
- 13B Are procedures established for the participation of supplier and project team members in each other efforts?
- 13C Are supplier performances monitored against key product metrics?
- 13D Are changes to supplier requirements made by suppliers controlled?
- 13E Are project requirements or operational concepts flowed down to suppliers?
- 13F Are supplier performances against assigned requirements assessed?
- 13G Are supplier products validated prior to integration with other project products?

Draft Questions – III. System Design

REQUIREMENTS DEFINITION PROCESS QUESTIONS

14. Program Requirements Questions

- 14A Are customer's system requirements identified, collected, and prioritized?
- 14B Is the set of collected customer requirements complete, consistent, and valid?
- 14C Are validated customer requirements recorded in a project information database?

15. Other Stakeholder Requirements Questions

- 15A Are other stakeholders' end product requirements identified and collected? Examples: project plans, team assignments and organizations, tools availability, required metrics, management decisions, enterprise technologies.
- 15B Have other stakeholders' enabling product requirements been identified and collected?
- 15C Have other stakeholders' external constraints been identified and collected?
- 15D Is the set of other stakeholders' requirements complete, consistent, and valid?
- 15E Are validated other stakeholder requirements recorded in a project information database?

16. System Technical Requirements Questions

- 16A Have required inputs, outputs, states, modes, and configurations, as appropriate to each system product, been established?
- 16B Have operational requirements been defined?
- 16C Have performance requirements been defined?
- 16D Have customer and other stakeholder requirements been analyzed to define human factor effects and concerns, establish capacities and timing, define technology and product design constraints, define enabling product requirements, identify conflicts, and determine criteria for tradeoff analyses to resolve conflicts?
- 16E Have requirements that have questionable utility or unacceptable risk of not being satisfied been identified and resolved?
- 16F Have identified conflicts between the sets of customer requirements and other stakeholder requirements been resolved?
- 16G Has a set of associated assumptions and technical requirements statements for the system been prepared and validated?
- 16H Is the set of systems technical requirements complete, consistent, and valid?
- 16I Has the resulting set of system technical requirements been recorded in a project information database?

Draft Questions – III. System Design (cont)

SOLUTION DEFINITION PROCESS QUESTIONS

17. Logical Solution Representation Questions

- 17A Have one or more appropriate approaches been selected and implemented to provide an abstract definition of the solution to the system technical requirements? Examples: functional analysis, object-oriented analysis, structured analysis, information modeling.
- 17B Have sets of logical solution representations been established? That is: doing tradeoff analyses; identifying and defining interfaces, states and modes, timelines, and data and control flows; analyzing behaviors; and analyzing failure modes and defining failure effects.
- 17C Were system technical requirements assigned to elements of the logical solution representations? That is, sub-functions, groups of sub-functions, objects, and data structures.
- 17D Have derived technical requirements statements resulting from A and B above been identified and defined?
- 17E Are logical solution representations complete, consistent, and valid?
- 17F Have the logical solution representations and derived technical requirements been recorded in a project information database?

18. Physical Solution Representations Questions

- 18A Have logical solution representations, derived technical requirements, and any unassigned system technical requirements been analyzed to determine which ones provide requirements for enabling products; can be done best manually or by facilities, materials, data, services, or techniques; and can be done best by hardware, software, or firmware products?
- 18B Have representations, derived technical requirements, and unassigned system technical requirements been assigned to appropriate physical entities?
- 18C Have alternative physical solution representations be generated and evaluated?
- 18D Have derived technical requirement statements results from above tasks been identified, defined, and stated acceptably?
- 18E Has a preferred physical solution representation been selected for further characterization into a design solution from the evaluation of each physical solution representation results?
- 18F Is the selected physical solution representation consistent with the assigned logical solution representations, derived technical requirements, and any unassigned system technical requirements?
- 18G Have the selected physical solution representation, the derived technical requirements statements, and the selection rationale and assumptions been recorded in a project information database?

19. Specified Requirements Questions

- 19A Has the design solution been fully characterized through drawings, documents, architectures, etc.?
- 19B Is the design solution consistent with its requirements?
- 19C Have requirements for the system, system end products, and subsystems of each end product been specified?
- 19D Has the design solution work products including the specified requirements been recorded in a project information database with all tradeoff analyses results, design rationale, assumptions, and key decisions?
- 19E Have projects been established to develop or procure enabling products?

Draft Questions – IV. Product Realization

IMPLEMENTATION PROCESS QUESTIONS

20. Implementation Questions

- 20A Have supplier products been received?
- 20B Have acquired products been validated against their requirements?
- 20C Have the validated products been integrated into the respective test article or end product?
- 20D Has each test article or end product been verified against its specified requirements?
- 20E Have the enabling products been ready and available to perform their intended support functions required by the system's end products?
- 20F Have the verified end products been validated against their customer requirements prior to delivery, if required by the agreement?

TRANSITION TO USE PROCESS QUESTIONS

21. Transition to Use Questions

- 21A Have appropriate enabling products necessary to carry out relevant transition to use requirements been acquired and put in place?
- 21B Have end products been prepared for shipping and storage?
- 21C Are end products awaiting shipping stored in accordance with the agreement and shipped or transported to the customer at the intended usage sites?
- 21D Are sites where end products will be stored, installed, used, maintained, or serviced prepared as required by the agreement?
- 21E Are end products installed at the appropriate sites as required by the agreement?
- 21F Is commissioning to bring delivered or installed end products to operational readiness performed with appropriate acceptance and certification test completed as required by the agreement?
- 21G If required by the agreement, is a parallel operation (ghosting) of the new and the legacy end products provided so that service is continuous during the transition period?
- 21H Is training for users, maintenance, and other personnel provided in accordance with the agreement?
- 21I Is in-service support provided in accordance with the agreement?

Draft Questions – V. Technical Evaluation

SYSTEMS ANALYSIS PROCESS QUESTIONS

22. Effectiveness Analysis Questions

- 22A Are effectiveness analyses planned?
- 22B Is each alternative analyzed for system and cost effectiveness based on factors such as accuracy, availability, capacity, maintainability, reliability, responsiveness, operability, safety, security, spares requirements, survivability, transportability, and vulnerability?
- 22C Is each alternative analyzed for total ownership cost to the project and to the customer?
- 22D Is the environmental impact of each alternative analyzed? Example: environmental regulations.
- 22E Is each alternative for each required operational profile analyzed to provide confirmation that the alternative satisfies appropriate requirements?
- 22F Are effectiveness analysis outcomes recorded in a project information database including assumptions, details of the analysis, findings, lessons learned, models used, rationale for decisions made, and other pertinent information that affects the interpretation of the effectiveness analysis results?

23. Tradeoff Analysis Questions

- 23A Are tradeoff analyses planned?
- 23B Are tradeoff analyses performed according to plans?
- 23C Are outcomes of tradeoff analyses recorded in a project information database including assumptions, details of the analyses, lessons learned, models used, rationale for decisions made, recommendations and effects, and other pertinent information affecting the interpretations of the decisions made?

24. Risk Analysis Questions

- 24A Are technical risks and resulting project risks identified?
- 24B Are risks characterized by causes, possible effects or consequences, likelihood of occurrence, options for dealing with risks, how long an option is available, and coupling with other risks?
- 24C Are risks that would likely cause harm, have the greatest effect on the system, and would require attention in the near term prioritized?
- 24D Are ways evaluated to avert risks and determine the cost, schedule, and performance effects on the project? Are unmitigated risks approved and managed?
- 24E Is a plan or approach for averting each significant risk defined and implemented?
- 24F Are risk analysis outcomes recorded in a project information database and communicated or used as appropriate?

Draft Questions – V. Technical Evaluation (cont)

REQUIREMENTS VALIDATION PROCESS QUESTIONS

25. Requirements Statement Validation Questions

- 25A Has each technical requirements statement been analyzed to ensure ability to preserve competitiveness, clarity, correctness, feasibility, focus, singularity, testability, and verifiability?
 25B Have technical requirement statements been analyzed in pairs and as a set to ensure absence of redundancy, connectivity, and removal of conflicts?

26. Program Requirements Validation Questions

- 26A Have methods been selected and procedures defined for validating that the set of defined customer requirements is consistent with the level of system structure, project life cycle phase, and validation plan, as appropriate?
 26B Has the downward traceability of stated, documented, or otherwise determined customer needs and expectations to the set of defined customer requirements been determined?
 26C Has the upward traceability been established?
 26D Have variances, voids, and conflicts been identified and resolved?
 26E Have validation results been recorded in a project information database?

27. Other Stakeholder Requirements Validation Questions

- 27A Have methods been selected and procedures defined for validating that the set of other stakeholder requirements is consistent with the level of system structure, project life cycle phase, and validation plan, as appropriate?
 27B Has the downward traceability of stated, documented, or otherwise determined other stakeholder needs and expectations to the set of defined customer requirements been determined?
 27C Has the upward traceability been established?
 27D Have variances, voids, and conflicts been identified and resolved?
 27E Have validation results been recorded in a project information database?

28. System Technical Requirements Validation Questions

- 28A Have methods been selected and procedures defined for validating that the set of defined system technical requirements is consistent with the level of system structure, project life cycle phase, and validation plan, as appropriate?
 28B Has the downward traceability of the validated sets of stakeholder requirements to the set of defined system technical requirements been determined?
 28C Has the upward traceability been established?
 28D Have assumptions regarding consistency of the system technical requirements with the system being engineered been determined?
 28E Have system technical requirements that have been defined as essential for the design effort for which there is no parent requirement been analyzed to ensure that they are consistent with the system being engineered and other system technical requirements?
 28F Have variances, voids, and conflicts been identified and resolved?
 28G Are system technical requirements revalidated whenever a requirement change is made that affects customer requirements, other stakeholder requirements, or system technical requirements?
 28H Are validation results including lessons learned recorded in a project information database?

29. Logical Solution Representations Validation Questions

- 29A Have methods and procedures been selected and defined for validating the defined sets of logical solution representations and derived technical requirements?
 29B Has the downward traceability of the validated set of system technical requirements to each set of logical solution representations and derived technical requirements been determined?
 29C Has the upward traceability been established?
 29D Have assumptions made while defining the sets of logical solution representations and derived technical representations been analyzed to ensure that they are consistent with the system technical requirements and the system being engineered?
 29E Have variances, voids, and conflicts been identified and resolved?
 29F Are the sets of logical solution representations revalidated whenever a requirement change is made that affects customer requirements, other stakeholder requirements, system technical requirements, or sets of defined logical solution representations and derived technical requirements?
 29G Are validation results including lessons learned recorded in a project information database?



Draft Questions – V. Technical Evaluation (cont)

SYSTEM VERIFICATION PROCESS QUESTIONS

30. Design Solution Verification Questions

- 30A Has the design solution verification been planned in accordance with the verification plan, the agreement, and the applicable project life cycle phase, and level in the system structure?
- 30B Has planned design solution verification been performed using selected methods and procedures within the established verification environment?
- 30C Is re-verification performed when test outcome variations and anomalies exist?
- 30D Are verification results recorded in a project information database to include corrective actions taken; lessons learned; outcomes achieved; tradeoff, effectiveness, and risk analyses completed with resulting key decisions; test activities completed; variances; and the verified design solution?

31. End Product Verification Questions

- 31A Has end product verification been planned in accordance with the verification plan, the agreement, and the applicable project life cycle phase, and level in the system structure?
- 31B Has planned end product verification been performed using selected methods and procedures within the established verification environment?
- 31C Is re-verification performed when test outcome variations and anomalies exist?
- 31D Are verification results recorded in a project information database to include corrective actions taken; lessons learned; outcomes achieved; tradeoff, effectiveness, and risk analyses completed with resulting key decisions; test activities completed; variances; and the verified end product?

32. Enabling Product Readiness Questions

- 32A Has enabling product readiness determination and associated process proofing been planned in accordance with the appropriate plan, maturity of the related end products, agreement, applicable project life cycle phase, and level in the system structure?
- 32B Has planned enabling product readiness determination and associated process proofing been performed using selected methods and procedures within the established environment?
- 32C Has readiness determination re-accomplishment been performed according to redesigned plans, test method, or procedure when variances were determined to be caused by poor readiness or proofing conduct or by inadequate environmental preparation?
- 32D Are readiness determination and process proofing results recorded in a project information database to include corrective actions taken; lessons learned; outcomes achieved; tradeoff, effectiveness, and risk analyses completed with resulting key decisions; test activities completed; variances; and the verified enabling products and proofing of associated process?

Draft Questions – V. Technical Evaluation (cont)

END PRODUCTS VALIDATION PROCESS QUESTIONS

33. End Products Validation Questions

33A Has the type of end product validation required and exit criteria been determined including the customer requirements applicable to the system end products being validated?

33B Has the test article, or aggregation of end products, for the validation been acquired as appropriate to the project life cycle phase and level of the system structure?

33C Has the end product validation been conducted in accordance with the validation plan, as required in the agreement?

33D Are end products revalidated with improved or corrected procedures and equipment when variances were caused by poor test conduct or conditions?

33E Are validation outcomes, procedures, assumptions, lessons learned, and other pertinent information recorded in a project information database?

External Study: Systems Engineering Best Practices Survey Approach

- ▶ Literature survey revealed highly regarded doctoral dissertation that included assessment of over 100 candidate best practices from the government–aerospace sector perspective
 - R.G. Turner’s “Implementation of Best Practices in U.S. DoD Software-Intensive System Acquisitions,” George Washington University, 31 January 2002
 - Revealed 32 key best practices.

- ▶ After consulting with leaders in the Systems Engineering community (NASA, INCOSE, SEI, DoD, academia), study team decided to utilize above survey instrument to gather comparable NASA perceptions on the 32 key best practices, then compare NASA data to 2002 survey data.

- ▶ Survey data represent Valued Systems Engineering Practice perceptions based on expert opinions of SEWG chairs at selected NASA Centers (JSC, GSFC, MSFC, LaRC).
 - A valued SE practice is one which would likely be effective if adopted
 - A valued SE practice may be perceived to be effective whether or not a particular reviewer’s NASA center has fully embraced that practice