Tailoring Systems Engineering Processes in a Conceptual Design Environment:

a case study at NASA's Marshall Spaceflight Center's Advanced Concepts Office

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Agenda

- Introduction
- Advanced Concepts Office (ACO)
- ACO Space Systems Team
- Exploratory Research Concept Development
- Collaborative Design Process
- Systems Analysis
- Systems Engineering in ACO
- Process Improvements
- Systems Integration
- Requirements
- Risk
- Advanced Concepts Evaluation of Risk Tool (ACERT)
- Conclusions

Introduction: Relevance to INCOSE

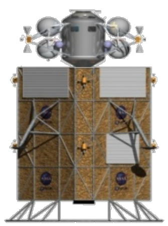
- Presentation is relevant to 2 INCOSE Life Cycle Phases
  - Exploratory Research
  - Concepts Development
- Presentation is relevant to 3 INCOSE Technical Processes
  - Integration
  - Stakeholder Requirements Definition
  - Requirements Analysis
- Presentation is relevant to 1 INCOSE Project Process
  - Risk Management

Advanced Concepts Office

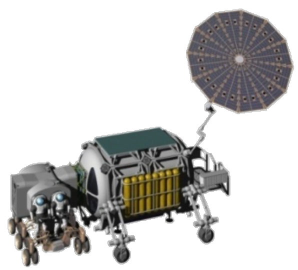
We Are An Office Specializing In Exploratory Research Concept Definition

RAVEN

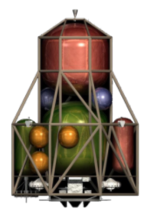
Altair



LTAS



Habitat / Crew Systems



CRYOSTAT

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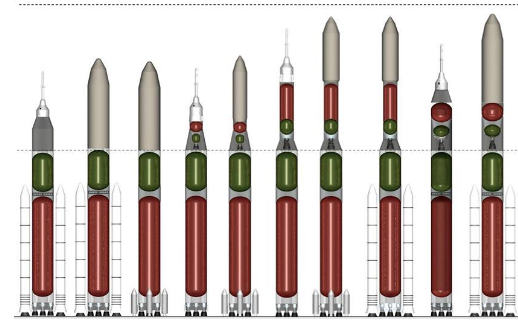
AXTAR



Space Systems

Earth-to-Orbit

ACO Space Systems Team

- **Architecture Design**
- **Concept Development**
- **Modeling and Simulation**
- **Analytical Studies**
  - Technology Assessments
  - Parametric and Sensitivity Analyses
- **Specific Areas of Expertise**
  - Mission Design and Analysis
  - Avionics
  - Power
  - Structures
  - Thermal
  - Propulsion
  - Payload Integration
  - CAD

ACO Space Systems Team

- Major Activities
  - Constellation
  - Review of U.S. Human Spaceflight Plans (Augustine Commission)
  - Heavy Lift Propulsion Technology (HLPT)
  - Human Exploration Framework Team (HEFT)
  - Office of the Chief Technologist (OCT): Cryogenic Propellant Storage and Transfer (CPST)
  - Human Spaceflight Architecture Team (HAT): Cryogenic Propulsion Stage (CPS) and Deep Space Habitat (DSH)

ACO Exploratory Research Concept Development

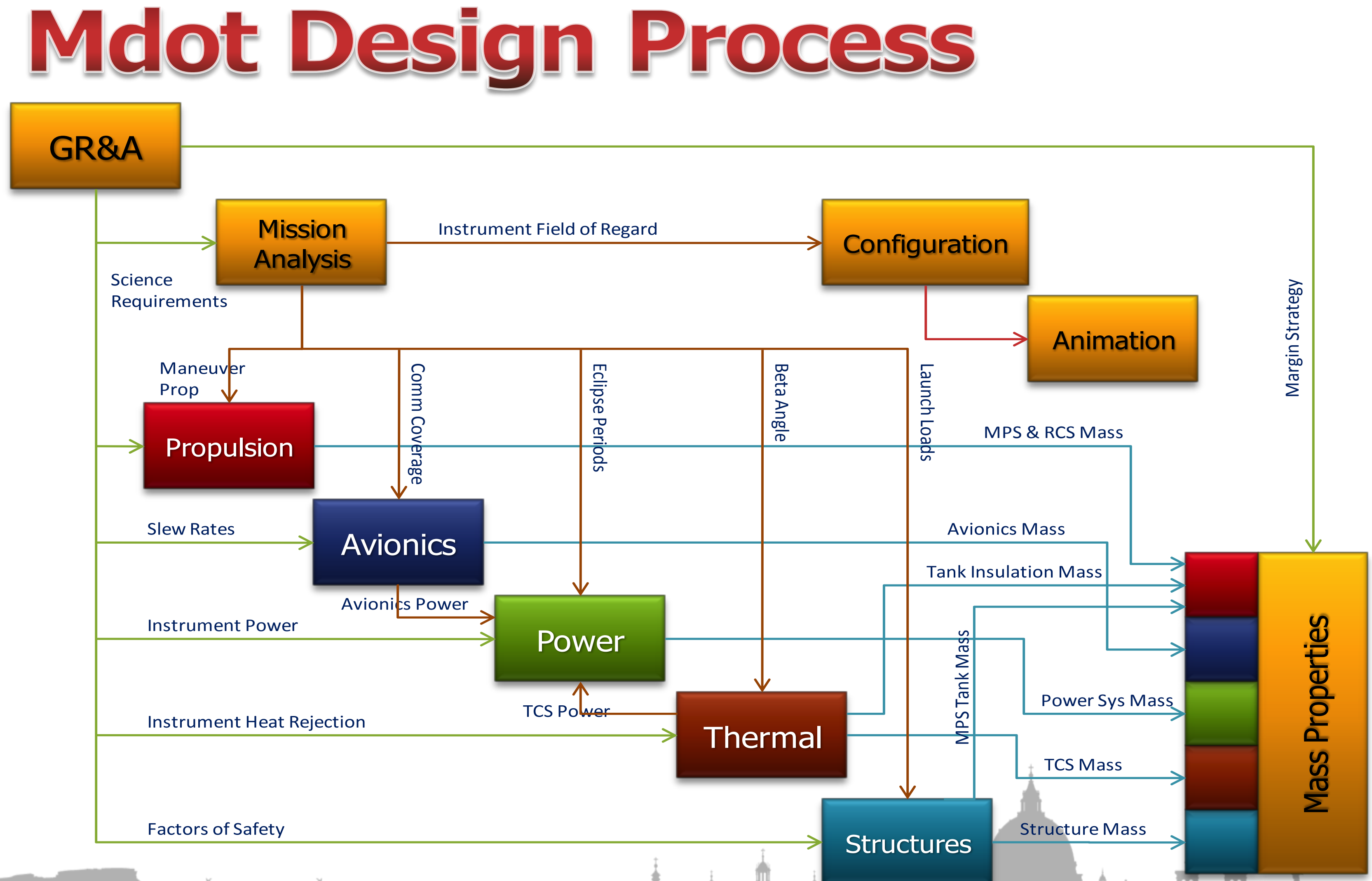
- **High level concept sizing and performance**
- **Quick turnaround with high relative degree of accuracy**
- **Supports concept level go-forward decisions**
- **Determines feasibility of specific concepts**
- **Evaluates individual concepts and scores them using figures of merit (FOM) derived jointly with the customer**
- **Determines which concepts are best suited to the mission by virtue of their FOM scores**
- **Decisions made in Exploratory Research**
  - Launch windows
  - Target orbits
  - Flight operations
  - Physical configuration
  - Subsystem implementation

ACO Exploratory Research Concept Development

- **Design of a concept at the subsystems level***
  - Avionics
  - Power
  - Propulsion
- **Uses components sized from models or selected from an existing hardware catalog***
  - Solar Cells
  - Rocket Motors
  - Star Trackers
- **Large breadth of concepts***
  - Launch Vehicles
  - Satellites
  - Nuclear Inter-Planetary Vehicles
  - Surface Systems
  - Space Habitats
  - Landers
  - Robotic Rovers
  - Space Telescopes
- Design at Subsystem Level – Broken down to Component Level
- Quick turn-around: performed in days to weeks

*Sub-bulleted listings are not all-inclusive.

Collaborative Design Process



Systems Analysis

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Systems Analysis Applications

Mission Requirements

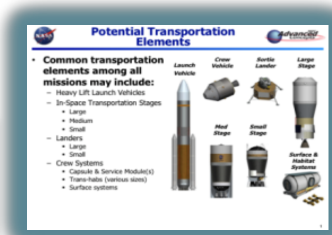
Functional Assessment

Initial Architecture/Element Definition

Architecture Trades/Assessments

Technology Assessment

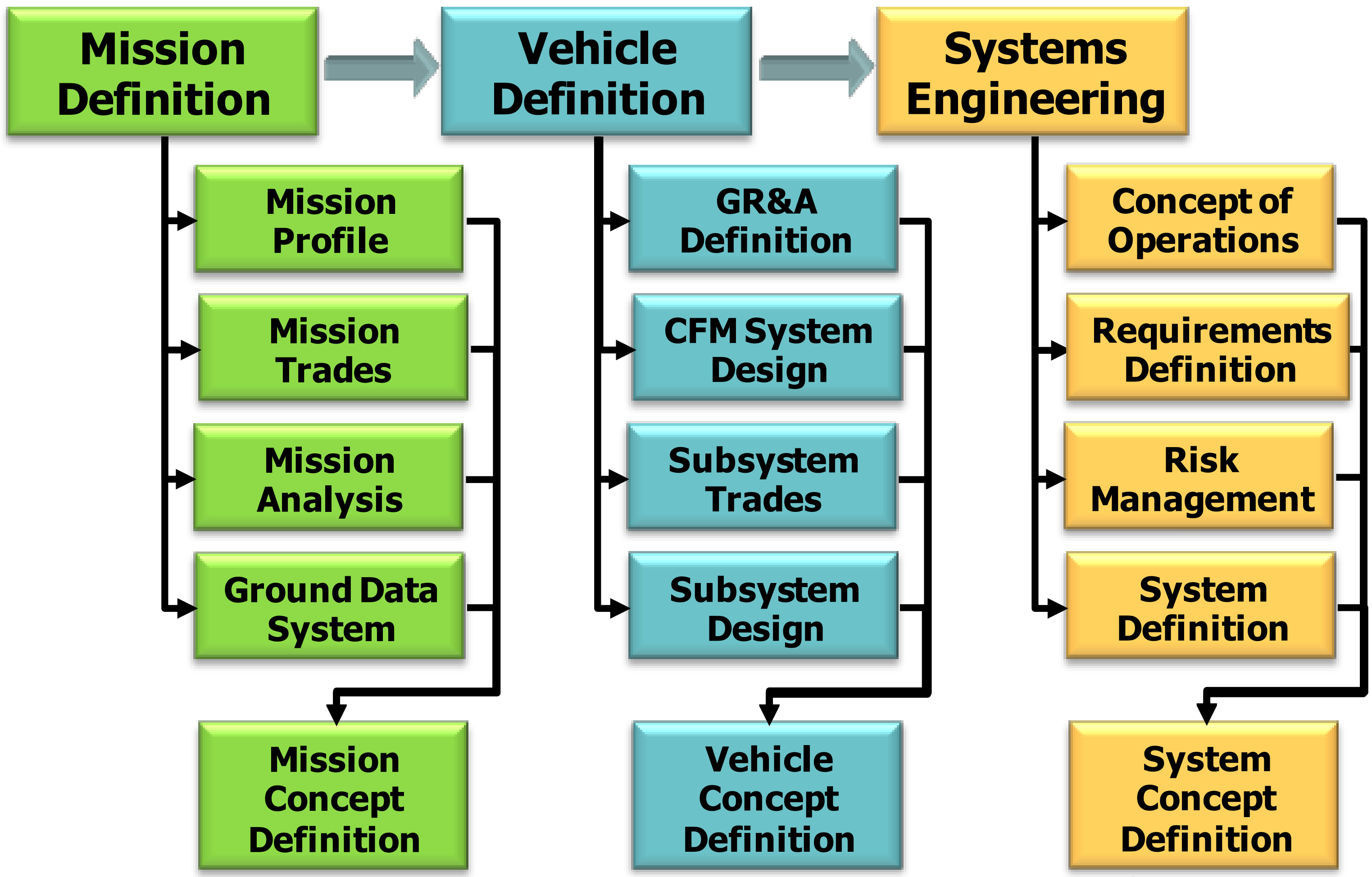
Technology Goals/Objectives



Systems Analysis

- Trajectory/Performance
- Subsystem Weights and Sizing
- Vehicle/Stage Weights and Sizing
- Structural/thermal loads/analysis
- Cost assessment
- Risk assessment
- Reliability assessment
- Ground/space operations
- Induced environments
- Natural environments

Systems Engineering in ACO



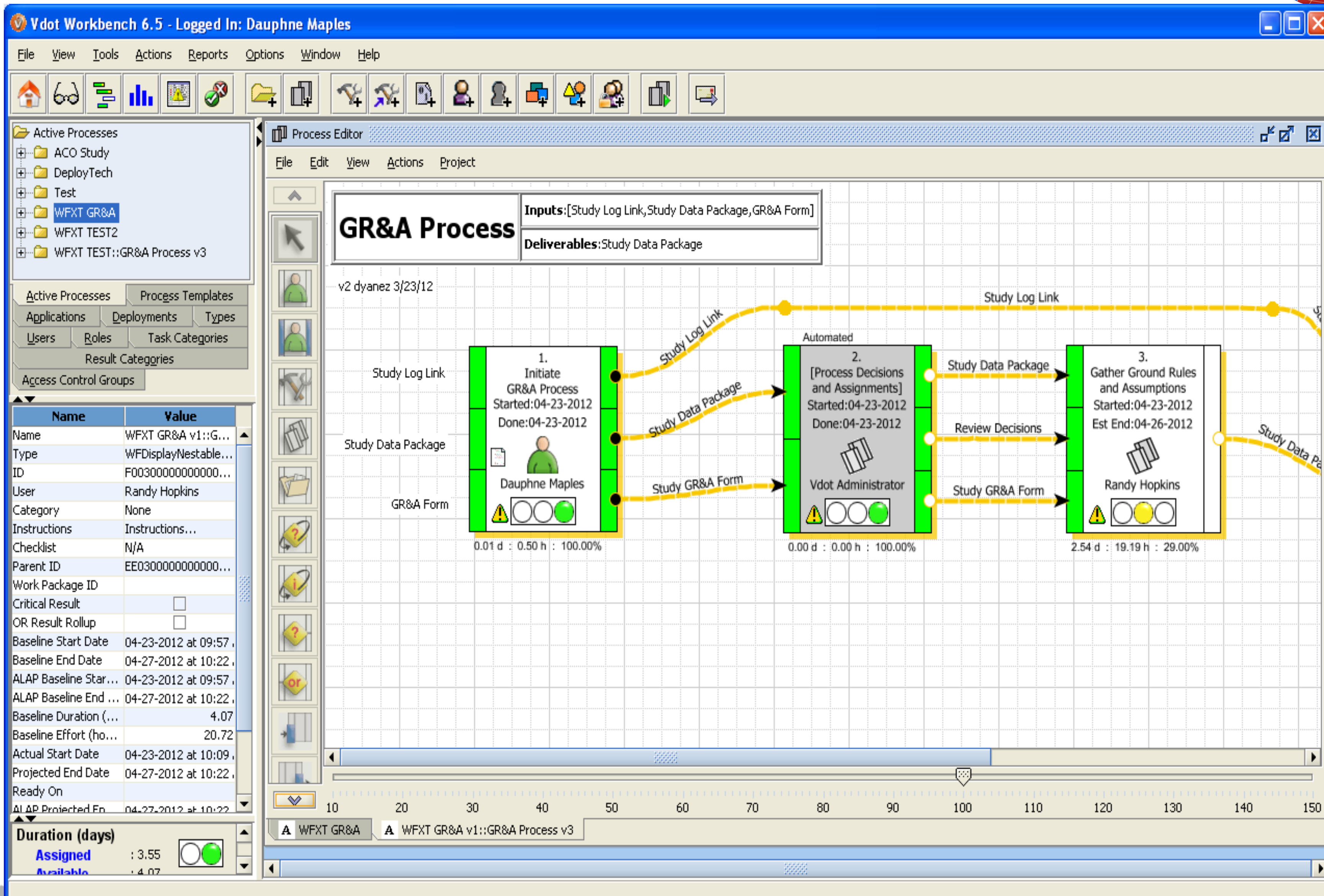
Process Improvements

- Generate and implement clearly defined, consistent products
  - Establish consistent templates for standard products
    - Study Planning
    - Subsystem Documentation
    - Ground Rules & Assumptions
    - Mass Properties Report
- Identify, document and execute Design Team processes
  - Clearly define and document the design process sequence, including inputs and outputs between subsystems
  - Clearly define roles and responsibilities of team members
  - Identify and implement tool updates or improvements
  - Implement the Vdot collaborative engineering tool for process control and tracking
- Establish team metrics by which performance can be measured
  - Determine what metrics are important and how to evaluate them
  - Establish a standard time period for evaluation
- Identify areas for continuous improvement
  - Once initial measures are complete, what other areas or next steps need work

Systems Integration

- Customer purchased Vdot in late 2011 as part of the process improvement effort
- Started training on the tool in early 2012
- Began using Vdot for the GR&A on the Wide Field X-ray Telescope Study in April
- Next step is to use the tool for the Mass Properties reports
- Ultimately, all data transfers will be performed and captured in Vdot
- Benefits of using Vdot
  - Traceability
  - Planning
  - Discipline
  - Prioritizing
  - Visibility
  - Communication
  - Transparency

Vdot



Vdot Workbench 6.5 - Logged In: Dauphne Maples
File View Tools Actions Reports Options Window Help
Active Processes
ACO Study
DeployTech
Test
WFXT GR&A
WFXT TEST2
WFXT TEST::GR&A Process v3
Active Processes
Process Templates
Applications
Deployments
Types
Users
Roles
Task Categories
Result Categories
Access Control Groups
Name
Value
Name WFXT GR&A v1::G...
Type WFDisplayNestable...
ID F003000000000000...
User Randy Hopkins
Category None
Instructions Instructions...
Checklist N/A
Parent ID EE0300000000000...
Work Package ID
Critical Result
OR Result Rollup
Baseline Start Date 04-23-2012 at 09:57
Baseline End Date 04-27-2012 at 10:22
ALAP Baseline Star... 04-23-2012 at 09:57
ALAP Baseline End ... 04-27-2012 at 10:22
Baseline Duration (... 4.07
Baseline Effort (ho... 20.72
Actual Start Date 04-23-2012 at 10:09
Projected End Date 04-27-2012 at 10:22
Ready On
Duration (days)
Assigned : 3.55
Process Editor
File Edit View Actions Project
GR&A Process
Inputs:[Study Log Link,Study Data Package,GR&A Form]
Deliverables:Study Data Package
v2 dyanez 3/23/12
Study Log Link
Study Data Package
GR&A Form
1. Initiate GR&A Process Started:04-23-2012 Done:04-23-2012
Dauphne Maples
0.01 d : 0.50 h : 100.00%
Study Log Link
Study Data Package
Study GR&A Form
Automated
2. [Process Decisions and Assignments] Started:04-23-2012 Done:04-23-2012
Vdot Administrator
0.00 d : 0.00 h : 100.00%
Study Data Package
Review Decisions
Study GR&A Form
3. Gather Ground Rules and Assumptions Started:04-23-2012 Est End:04-26-2012
Randy Hopkins
2.54 d : 19.19 h : 29.00%
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
WFXT GR&A
WFXT GR&A v1::GR&A Process v3

Requirements

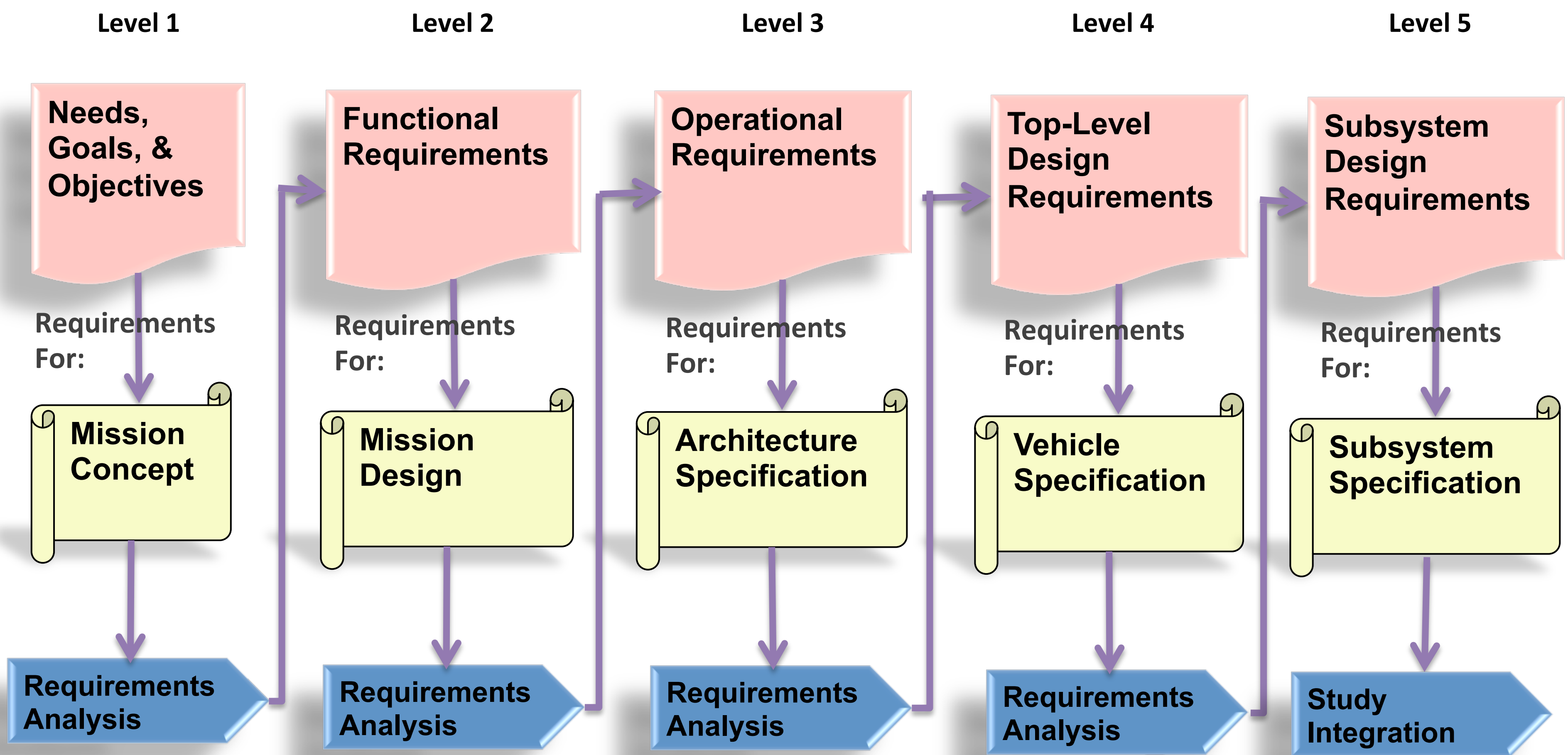
- Requirements Focus Team established as part of the overall process improvements being implemented
- Plan to manage requirements in Excel due to the small number of requirements per study
- Requirements data will be provided to external customers in a format used by their organization
  - Excel for science study customers and Principal Investigators
  - Word with formatting similar to an MRD or SRD for SLS Project office customers or Engineering Directorate customers supporting SLS or another project office
- Subsystem disciplines currently include their requirements in study presentation charts
  - This may or may not change as a result of the Requirements Focus Team

Requirements

Requirements are successively derived in five distinct levels in ACO

- Level 1 – Needs, Goals, and Objectives (NGOs)
  - Top-level objectives for the overall project as envisioned by the initiators together with any constraints that the initiators or the agency demand
- Level 2 – Functional Requirements
  - The required functions that a mission must perform in order to achieve the goals, objectives and constraints, including locations, durations, time windows, etc.
- Level 3 – Operational Requirements
  - Mission-specific operational requirements for each of a number of architecture elements needed to fulfill the mission functions
- Level 4 – Top-Level Design Requirements
  - For each vehicle in the architecture, the set of system performance requirements to realize each of the operational requirements
- Level 5 – Subsystem Design Requirements
  - For each vehicle subsystem, the specific requirements to achieve each of the top-level design requirements

Requirements Process



Risk Analysis in Exploratory Research Design

- Many NASA Announcements of Opportunity specifically demand Risk Assessment as a part of proposal response
- In addition, Risk Assessment is often requested by internal customers

Reluctance to use Risk Analysis in Exploratory Research

- Unnecessary
  - Seen as contrary to a ‘Can Do’ attitude
  - Negative views of Risk Analysis obscure benefits
- Time Consuming, Expensive
  - Past risk identification methods often required significant effort
  - Feeling at NASA that Risk Analysis is a cost to be avoided until after ATP when down-selected concept is detailed
- Low Fidelity of Risk Likelihood, Impact
  - Prevalence of poor risk evaluation methods has led to common belief that risk estimates cannot be made with any accuracy before design is complete
  - Confusion of *Risk* with *Reliability* leads to conclusion that only very high fidelity risk estimates are useful

What To Do?

- Define Exploratory Research Risk Analysis and Management Requirements
  - Must be quick and easy to implement
  - Must be adaptable to a wide variety of concepts
  - Must be capable of producing a Risk Plan useful for further studies (continuous risk management)
- Tailor Risk Analysis to the specific needs of Exploratory Research work
  - Start by viewing risk in the context of the decisions that we make in Exploratory Research studies. The appropriate risks are always found in the specific uncertainties that affect those decisions
  - Identify as many risks as possible by inspecting those decisions.
  - Estimate the Risk Probability and Impact using historical data along with expert judgment.
  - Estimates must be sufficient to inform Exploratory Research decisions but will not have the fidelity available at later phases of development.
- Use automated tools to reduce cost and improve standardization

Advanced Concepts Evaluating Risk Tool (ACERT)

- The ESTS Group within ACO took the initiative to develop a risk tool tailored to Exploratory Research
- Tool was validated by ESTS risk experts from EV
- ACERT was verified by using the tool on two studies using other risk identification methods and comparing the results
- A conference paper, *"Risk Evaluation in the Exploratory Research Conceptual Design of Spacecraft"* was presented at the AIAA Space 2010
- Funding and resource limitations have prevented the development of formal documentation and tool maintenance
- Forward Work Needed
  - Addition of rules to identify more operations risks
  - Creation of more detailed risk statement templates
  - Tool Maintenance
  - Documentation

ACERT

- Taxonomy/source – based risk identification tool
  - Taxonomy-based risk identification searches the risk space by the source of uncertainty
- Value-based risk assessment assigns a comparable value to each risk
  - Computes risk probability based on empirical data, expert judgment
  - Computes impact value based on value (cost in $) of risk event occurrence

$$\textit{Risk Value} = \textit{Probability} \times \textit{Impact}$$

- Excel workbook-based interface
- Allows input of mission, operations, and design concept information, including the concept WBS
- Excel macro launches a rule-based (backward-chaining) system
  - Asks each discipline expert a series of questions about the mission or concept design
  - The answers are used to identify risks
- Risk suggestions may be edited in Excel and scored with VBA custom formula functions
- Tool may be customized by editing risk identification rules, risk statement templates, and other configuration information

ACERT

- ACERT has been used successfully in several recent studies
  - Advanced X-Ray Timing Array (AXTAR)
  - Nth Degree Photovoltaic Printing Technology development effort
  - Cryogenic Propellant Storage and Transfer (CPST)
    - *CPST Risk Identification*
      - 16 Total Distinct Risks
      - ACERT Found 10
      - GRC Found 6
      - 1 of the Risks found by Both Leads and ACERT
  - Human Spaceflight Architecture Team Cryogenic Propulsion Stage (CPS)
    - *CPS Risk Identification*
      - 27 Total Distinct Risks
      - ACERT Found 21
      - 8 Other Risks were found by GRC
      - 2 of the 27 were found by both methods
- ACO is exposing groups at MSFC and other NASA Centers to ACERT
- ACERT has been well-received at most NASA Centers

Benefits of Risk Analysis in Exploratory Research Design

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- Useful Figure of Merit in evaluating Concept Design Decisions (e.g. choice of Rocket Motor)
- Figure of Merit in choosing 'Go-Forward' concept in trade studies
- Informs the planning of the crucial Phase A study
- Guides Project Management in allocating resources to solve potential problems early

Conclusion

- Systems Engineering is about the implementation of processes that assure that the customer's NGOs are met throughout the engineering product lifecycle
- ACO is currently engaged in an effort to implement those processes
- The Exploratory Research engineering environment represents the very beginning of that product life-cycle, and presents a number of unique challenges that affect systems engineering implementation
- Current experience suggests that by tailoring traditional systems engineering processes to the specific demands of the unique environment, ACO is able to realize the full benefits of systems engineering and provide a product that better prepares the customer for Phase A and beyond
  - Integration: Vdot
  - Requirements: Group requirements according to the ACO study flow
  - Risk: Use semi-automated tools to implement taxonomy-based risk identification and value-based risk assessment processes that require less time and effort