Concurrent Engineering at the JPL Innovation Foundry

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Concurrent Engineering evolves to meet evolving needs

- JPL is a primary NASA resource for helping the science community ideate, mature, and propose concepts for new missions
- Environmental context for the formulation lifecycle evolves continuously
- JPL continuously “system engineers” requirements and solutions for providing formulation support and winning new missions
- The JPL Innovation Foundry is an integrated formulation lifecycle enterprise
NASA science mission community faces a ratcheting challenge

Simultaneous, competitive formulation…

…of a large number

…of deeply engineered concepts

…for ambitious science objectives

…achieved using well-understood subsystems

…formulated on a strict diet
What All PIs and SDTs Need

• Darwinian evolution of a seed idea
  – Maturation into a toughened concept baseline
  – That can win, fly, and deliver

• Accurate forecasting despite incomplete data
  – Of the eventual state of truth regarding cost and risk
  – Of how others will model that state of truth when evaluating the concept
Every mission starts with a spark

Science

Mission Architecture

Technology

Engineering

A question

An invention

A mission concept
...then the concept is developed

or

One man’s concept is another’s doodle...
# 26 Elements of a Mission Concept

<table>
<thead>
<tr>
<th>Technical</th>
<th>Programmatic</th>
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<tbody>
<tr>
<td>• Science Objectives &amp; Requirements</td>
<td>• Acquisition and Surveillance</td>
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<td>• Mission Development</td>
<td>• Project Organization</td>
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<tr>
<td>• Spacecraft/Instrument System Design</td>
<td>• Schedules &amp; Margins</td>
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<td>• Ground System Design</td>
<td>• Cost Estimation &amp; Risks</td>
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<tr>
<td>• Technical Risk</td>
<td>• Project Scope</td>
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<tr>
<td>• Technology</td>
<td>• Documentation</td>
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<tr>
<td>• Inheritance</td>
<td>• NEPA Compliance</td>
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<tr>
<td>• Master Equipment Lists</td>
<td>• Subsystem Make-Buy</td>
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<tr>
<td>• Technical Margins</td>
<td>• Work Breakdown Structure</td>
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<tr>
<td>• Trade Studies</td>
<td>• Testbeds, Models &amp; Spares</td>
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<tr>
<td>• Modeling &amp; Simulation</td>
<td>• Export Compliance</td>
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<tr>
<td>• Launch Services</td>
<td>• Mission Assurance Management</td>
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<td>• Planetary Protection</td>
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<td>• Verification &amp; Validation</td>
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Concept Maturity Level (CML) Benchmarks *Before* NASA Gates

- **Cocktail Napkin**: Initial Feasibility
- **Trade Space**: Point Design
- **Baseline Concept**: Integrated Concept
- **Preliminary Implementation Baseline**: Integrated Baseline

**JPL Innovation Foundry**
Team X pioneered CE for CML 4

- Architectures
- Space Missions
- Flight Systems
- Instruments
Team X: Widely Emulated

• 1072 studies since creation in 1995
  Peak rate was 93 studies per year (2004)

• Drivers going forward

  Increasing concept diversity challenges design-model applicability

  Increasing need for customized, direct-use products (white papers, proposal sections, NRC reports)
Evolving Ideas *Before* CML 4

Next-gen CE at JPL

- Open trade space
- Frame key questions
- Analyze drivers
- Derive and assess "partials"

Trade space understood

- Specify value framework
- Assess potential tradeoffs
- Prioritize promising directions

A few design options synthesized

Baseline validated, ready to be advocated

Collaborative Engineering Support

Focused Team

- Specify value framework
- Assess potential tradeoffs
- Prioritize promising directions

- Open trade space
- Frame key questions
- Analyze drivers
- Derive and assess "partials"

Fundamental feasibility of one approach validated quantitatively

Salient kernel documented

CML 1

CML 2

CML 3

CML 4

CML 5

= Idea

= Concept analysis “seed”

= Point design

= Funding gate

JPL Innovation Foundry
# A-Team: New Type of CE for CML 1-3

<table>
<thead>
<tr>
<th>A-Team Type</th>
<th>Purpose</th>
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<tbody>
<tr>
<td>Generate Ideas</td>
<td>Produce and organize $10^2$ ideas from a single question or topic. Rank using figures of merit.</td>
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<tr>
<td>Assess Feasibility</td>
<td>Quantitative, tool-based examination of technical and programmatic feasibility</td>
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<tr>
<td>Explore Architecture Trade Space</td>
<td>Develop and use “concept analysis seeds” to expose gradients in the trade space</td>
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<tr>
<td>Science Traceability</td>
<td>Link science questions to goals, objectives, observables, measurements, and instruments</td>
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<tr>
<td>Technology Impact</td>
<td>Ideate potential applications, assess feasibility, quantify science-mission and architecture impacts</td>
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<tr>
<td>Strategic Opportunities</td>
<td>Quick-focus on one strategic question. Analyze potential ROI, develop forward plan.</td>
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In high demand: 39 studies in 1.5 years so far
A-Team allows study of high-leverage, open-ended ideas not ready for Team X

- Idea Generation
  - Mars Cave Dwelling
  - Small-Sats for Human Spaceflight

- Feasibility Assessment
  - Public Outreach for Insight
  - Planetary Science from Atmospheric Balloons

- Architecture Trade Space Exploration
  - Ultra High Energy Cosmic Ray Observatory
  - Low-Cost Landers

- Science Traceability
  - Sea Level Rise
  - Cube-Sats for Earth Science

- Technology Infusion
  - High Performance Space Computing
  - Mars Sample Return In-Space Propulsion

- Strategic
  - Follow-On Mission for EPOXI
  - Future Spacecraft and Science Missions