JPL Innovation Foundry

Space Mission Concept Development Using Concept Maturity Levels

(Paper 1665457)

Randii R. Wessen, Chester Borden, John Ziemer, Johnny Kwok

Jet Propulsion Laboratory,

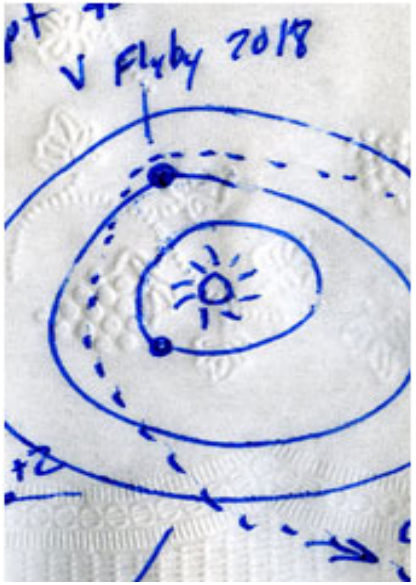
California institute of Technology

AIAA Space 2013 Conference

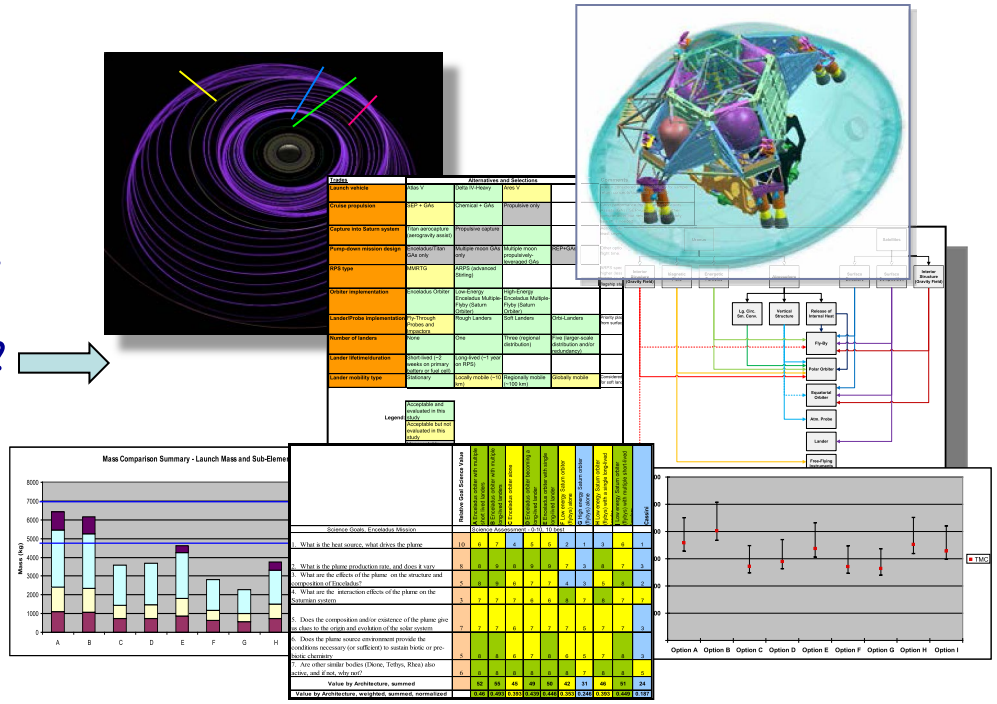
Absent: a Common Language for Concepts

JPL Innovation Foundry

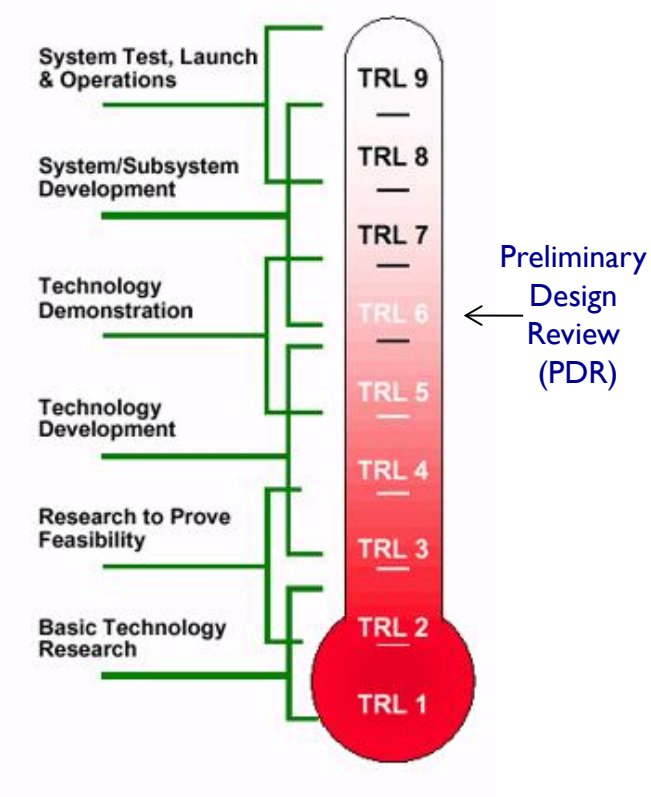
- How mature is your concept?

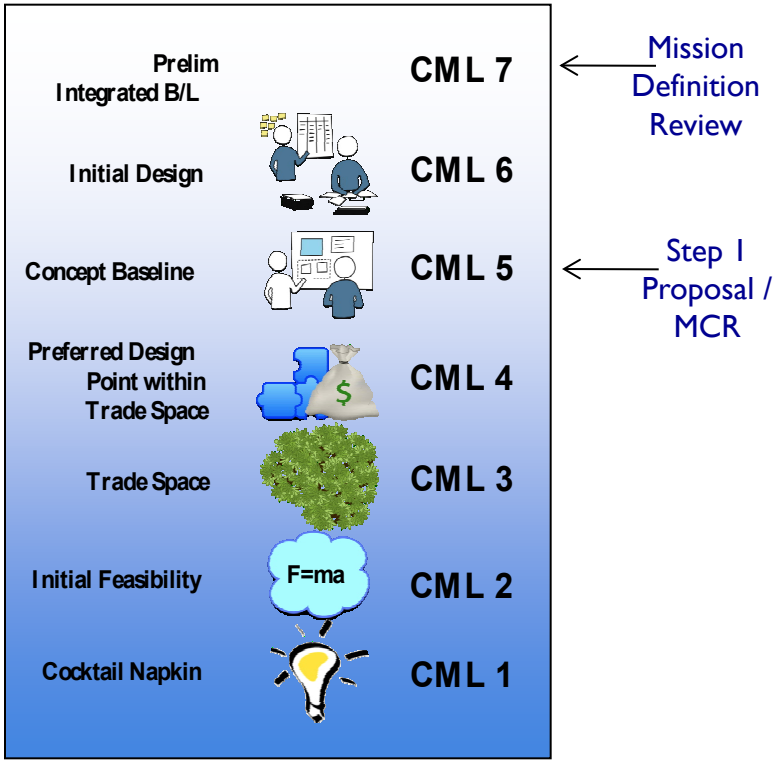


This or that?

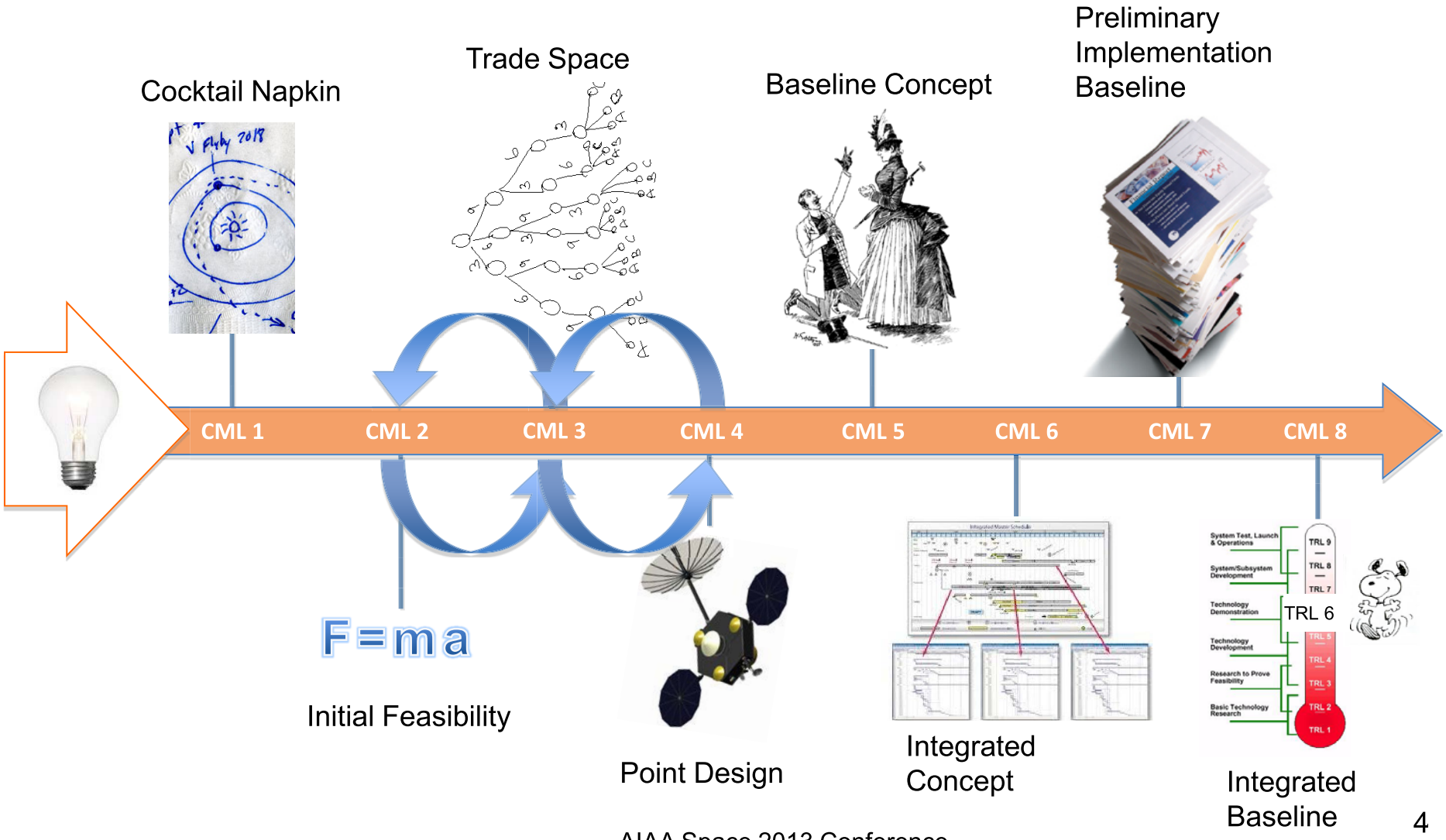


CML Scale is Based on the Structure of the TRL Scale





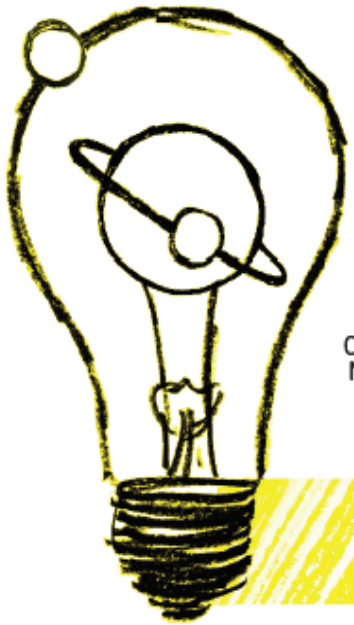
CMLs: A Powerful Communication Tool

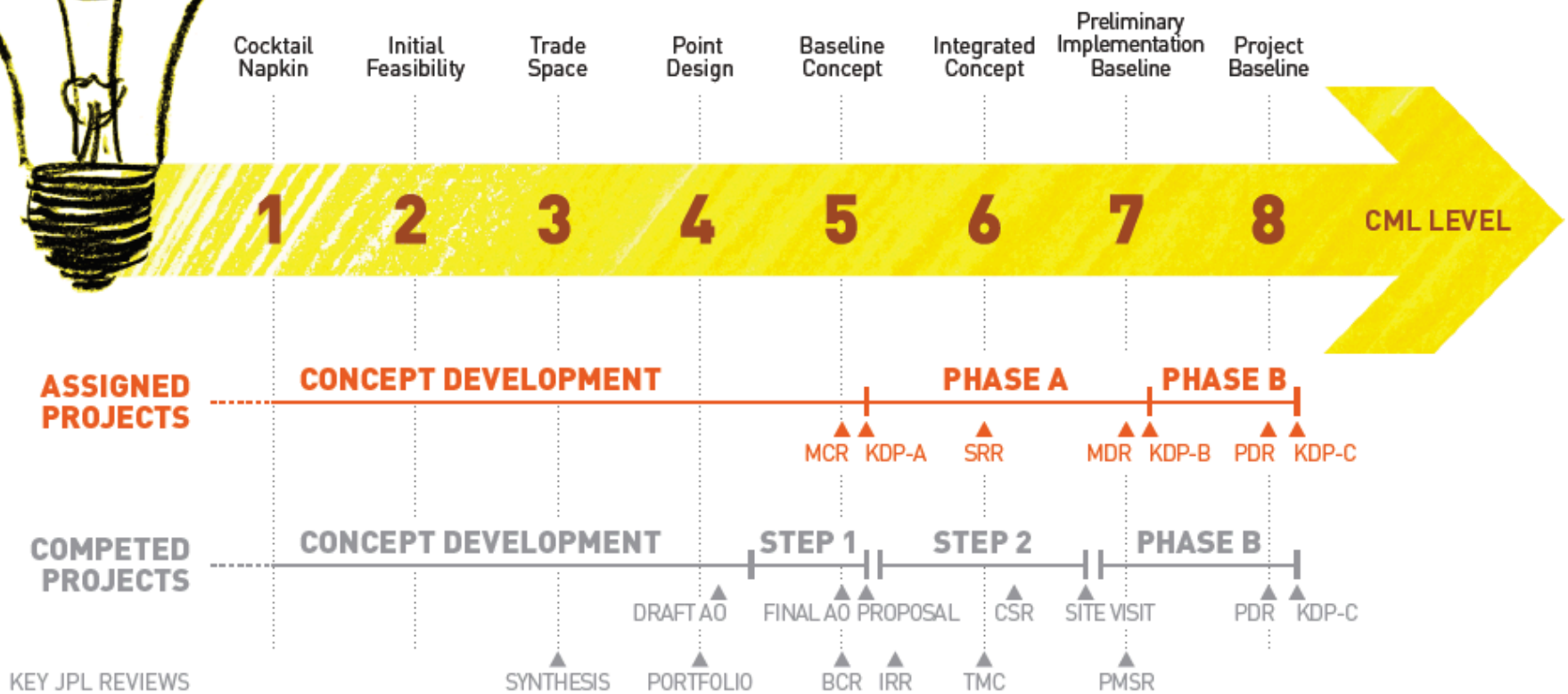


JPL Innovation Foundry

CONCEPT MATURITY LEVELS (CML)

for NASA Competed and Assigned Projects





JPL Innovation Foundry

Early CMLs Provide the Greatest Value to Mission Architects

- Mission concept development has limited guidance prior to Phase A
- As such, CML Matrix and checklists have their largest utility during CML 1 – 4
  - At the start of Pre-Phase A, there is no NASA guidance
  - At the end of Pre-Phase A (CML 5) guidance is provided by:
    - NASA's Announcement of Opportunity (Competed Projects)
    - NASA's Procedural Requirements 7120.5E (Assigned Projects)

JPL Innovation Foundry

CML Matrix is the Key for Measuring Maturity

- CML Matrix contains
  - 7 Columns (CML 1 – 7)
  - 24 Rows (attributes)
    - Science rows (2)
    - Technical rows (13)
    - Management rows (5)
    - Cost row (1)
    - “Other” rows (3)
- Rows organized by the way NASA holds technical reviews
  - Science Review
  - TMCO Review

JPL | JPL SPACE | JPL RULES | EBIS | JPL HOME | CALTECH | NASA

PRE-PROJECT PRINCIPLES AND PRACTICES

Home | P4 | P4 Search | CML Check Lists | CML Matrix

cml matrix : recommended cmls

Lifecycle Phase		Pre-Phase A					Phase A	
		Advance Studies			Concept Development		Early Formulation	
CML		1	2	3	4	5	6	7
Name		Cocktail Napkin	Initial Feasibility	Trade Space	Point Design	Baseline Concept	Integrated Concept	Preliminary Implementation Baseline
Lifecycle Gate		-	-	-	Concept Gate (Draft AO Out / Mission Study Report)	Baseline Commitment Gate/ MCR	Step 2 Submittal	PMSR/MDR
Science								
Attribute	P4 Section							
Science Objectives & System Requirements	5.3	Science objectives described in one sentence	Objectives described to levels that allow comparison with previous investigations and NASA science community documents	Objectives linked to investigations and measurements; Science return as a function of cost, risk and programmatics quantified	Produce draft Science Traceability Matrix; Initial Level 1 requirements considered; Specifying one Baseline and one Threshold Science investigation; Key Performance Parameters listed	Science Traceability Matrix (or equivalent) produced; Preliminary PLRA produced (assigned projects)	Proposed Level 1 requirements documented Level 2 & 3 driving requirements listed; Full and minimum success criteria defined; Baseline PLRA submitted @ SRR (assigned projects)	Update PLRA if necessary; Preliminary Level 2 & 3 requirements listed
Science Data System	5.4	-	Identify science data drivers	Science data rates and volume included in trade space analysis	Science data system sizing	Science data processing architecture, release and archive approach defined	Science data management approach (includes Level 0, 1, 2 data products) defined	Same as for CML 6
Technical								
Attribute	P4 Section							
Mission Development	6.1	One sentence description of unique mission & system characteristics	Key mission concept parameters and performance requirements quantified; Rudimentary calculations & comparisons to mission analogues performed; Gross characterization of space environment	Alternative set of mission architectures evaluated against science objectives, cost & risk; Quantitatively bounded hazards of space environment	Driving requirements, initial high-level scenarios, timelines and operational modes documented; Propellant load and delta-V budget determined; Power, telecom, data processing approach defined; Descopes & backup options identified as needed	Concept is complete, viable & stable; Mission phases documented to level for illustrating how science objectives will be met; Mission traceability matrix created; Resource utilization consistent with scenarios and ops modes; A mission categorization and risk classification determined	Expand description of mission phases to illustrate critical s/c/ ground functions; Delta-V & maneuver strategy (for s/c projects), communications approach & ground station needs determined	Key driving mission scenarios, timelines and modes documented in detail
Spacecraft System Design	6.2	-	Key flight elements, design parameters & performance requirements listed; High-level comparison to similar flight systems documented	Unique features that distinguish one flight system architecture from another evaluated; Perform sensitivity studies to bound performance within trade space performed	System architecture with mechanical configuration drawings, block diagrams & descope options compiled	Subsystem designs to enable external evaluation & costing documented; System contingencies & margins established	Major architectural trades complete and incorporated; All key LV, s/c, and payload I/F qualitatively defined	System & subsystem designs and external I/F defined; Plans for closing open design issues finalized; Plans for maturing technology, long-lead items, and prototyping engineering developments in place
Instrument System Design	6.3	-	One sentence description of potential measurement technique(s); Perform high-level comparison to similar measurement technique(s)	Key instrument performance requirements, measurement techniques and instruments selected against science/mission objectives, cost & risk; Sensitivity studies to bound performance within trade space performed	Instrument design with mechanical configuration drawings, block diagrams & descope options compiled (Earth Science & Astrophysics concepts), Instrument performance requirements traced to level 1 requirements	Instrument designs sufficient to enable external evaluation & costing developed (competed projects); Initial Instrument accommodations noted; Plans for maturing technology, long-lead items, and prototyping engineering developments in place; Science data Quantity, Quality, Continuity & Latency (QQCL) requirements, instrument contingencies & margins established	Major payload trades complete and incorporated; Final instrument designs & accommodations specified	Instrument design, accommodation, open issues & external I/F defined
Ground System/Mission Operations System Design	6.4	-	Mission ops approaches defined	Mission ops drivers and sensitivities assessed; Major flight/ground trades identified; New ground system capabilities identified	MOS/GDS architecture based on ops scenarios described	Major MOS responsibilities, block diagrams, facilities & I/Fs with science community defined; MOS based on operations complexity sized Approach for acquiring & returning critical events data documented	MOS diagrams with proposed inheritance compiled; Major flight/ground trades complete; Operational roles, responsibilities & data flow elaborated	MOS implementation w/ mission unique items defined; Plans for upgrading facilities, software & hardware complete

Science (2)

Technical (4 of 13)

JPL Innovation Foundry

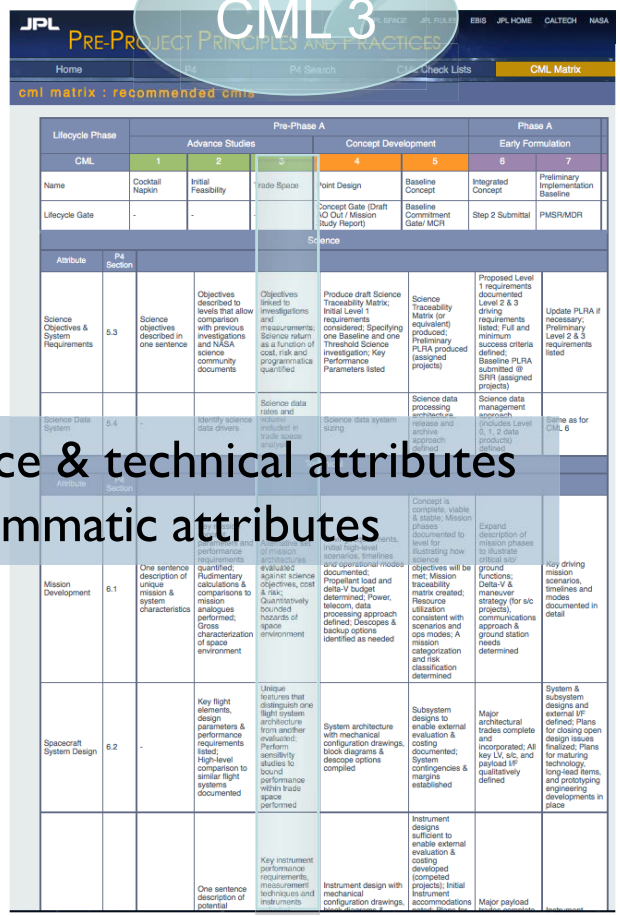
The Science Rows of the CML Matrix

Lifecycle Phase		Pre-Phase A					Phase A	
		Advance Studies			Concept Development		Early Formulation	
CML		1	2	3	4	5	6	7
Name		Cocktail Napkin	Initial Feasibility	Trade Space	Point Design	Baseline Concept	Integrated Concept	Preliminary Implementation Baseline
Lifecycle Gate		-	-	-	Concept Gate (Draft AO Out / Mission Study Report)	Baseline Commitment Gate/ MCR	Step 2 Submittal	PMSR/MDR
Science								
Attribute	P4 Section							
Science Objectives & System Requirements	5.3	Science objectives described in one sentence	Objectives described to levels that allow comparison with previous investigations and NASA science community documents	Objectives linked to investigations and measurements; Science return as a function of cost, risk and programmatics quantified	Produce draft Science Traceability Matrix; Initial Level 1 requirements considered; Specifying one Baseline and one Threshold Science investigation; Key Performance Parameters listed	Science Traceability Matrix (or equivalent) produced; Preliminary PLRA produced (assigned projects)	Proposed Level 1 requirements documented Level 2 & 3 driving requirements listed; Full and minimum success criteria defined; Baseline PLRA submitted @ SRR (assigned projects)	Update PLRA if necessary; Preliminary Level 2 & 3 requirements listed
Science Data System	5.4	-	Identify science data drivers	Science data rates and volume included in trade space analysis	Science data system sizing	Science data processing architecture, release and archive approach defined	Science data management approach (includes Level 0, 1, 2 data products) defined	Same as for CML 6

JPL Innovation Foundry

Checklist Derived from CML Matrix to Measure Concept Maturity

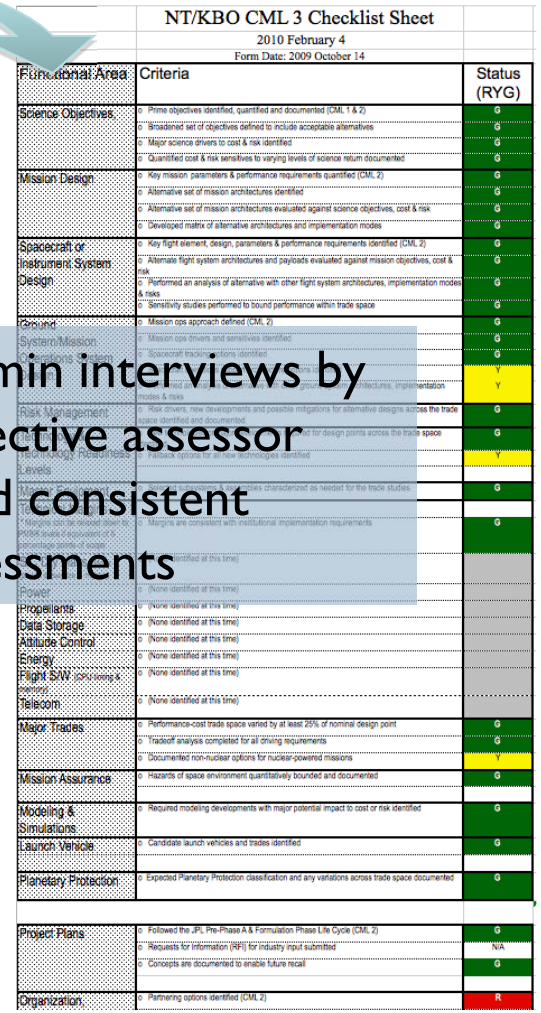
CML 3



CML Matrix

15 science & technical attributes
9 programmatic attributes

CML 3 Assessments



NT/KBO CML 3 Checklist Sheet
2010 February 4
Form Date: 2009 October 14

Functional Area	Criteria	Status (RYG)
Science Objectives	Prime objectives identified, quantified and documented (CML 1 & 2)	G
	Broadened set of objectives defined to include acceptable alternatives	G
	Major science drivers to cost & risk identified	G
	Quantified cost & risk sensitivies to varying levels of science return documented	G
Mission Design	Key mission parameters & performance requirements quantified (CML 2)	G
	Alternative set of mission architectures identified	G
	Alternative set of mission architectures evaluated against science objectives, cost & risk	G
	Developed matrix of alternative architectures and implementation modes	G
Spacecraft or Instrument System Design	Key flight element, design, parameters & performance requirements identified (CML 2)	G
	Alternate flight system architectures and payloads evaluated against mission objectives, cost & risk	G
	Performed an analysis of alternative with other flight system architectures, implementation modes & risks	G
	Sensitivity studies performed to bound performance within trade space	G
Ground System/Mission Operations System	Mission ops approach defined (CML 2)	G
	Mission ops drivers and sensitives identified	G
	Spacecraft tracking options identified	G
	[illegible] architectures, implementation modes & risks	Y
Risk Management	Risk drivers, new developments and possible mitigations for alternative designs across the trade space identified and documented	G
	[illegible] for design points across the trade space	G
	[illegible]	Y
Levels	[illegible]	G
	[illegible] characterized as needed for the trade studies	
	Margins are consistent with institutional implementation requirements	G
Power	(None identified at this time)	
Propellants	(None identified at this time)	
Data Storage	(None identified at this time)	
Attitude Control	(None identified at this time)	
Energy	(None identified at this time)	
Flight S/W (CPU loading & memory)	(None identified at this time)	
Telecom	(None identified at this time)	
Major Trades	Performance-cost trade space varied by at least 25% of nominal design point	G
	Tradeoff analysis completed for all driving requirements	G
	Documented non-nuclear options for nuclear-powered missions	Y
Mission Assurance	Hazards of space environment quantitatively bounded and documented	G
Modeling & Simulations	Required modeling developments with major potential impact to cost or risk identified	G
Launch Vehicle	Candidate launch vehicles and trades identified	G
Planetary Protection	Expected Planetary Protection classification and any variations across trade space documented	G
Project Plans	Followed the JPL Pre-Phase A & Formulation Phase Life Cycle (CML 2)	G
	Requests for Information (RFI) for industry input submitted	N/A
	Concepts are documented to enable future recall	G
Organization	Partnering options identified (CML 2)	R

Check List

30-min interviews by objective assessor yield consistent assessments

JPL Innovation Foundry

Strengths and Weakness of CML Checklists

- Strengths:
  - Provides a systematic approach for measuring a mission concept's maturity in Pre-Phase A
  - Provides study team guidance about where to allocate their limited resources for the biggest benefit
  - Assessment is quick and repeatable
- Weaknesses:
  - Does not measure the quality of the items produced, just their level of completeness
  - No attempt to weight relative value of one attribute over another
  - Study teams are too optimistic as self-assessors

CML Assessment Process is Continuously Being Evaluated

JPL Innovation Foundry

Functional Area	Criteria	Proposal 1	Proposal 2	Proposal 3	Proposal 4	Proposal 5
Science Objectives, Driving Requirements & Descope Options	o Prime objectives identified, quantified and documented (CML 1 & 2)	G	G	G	G	G
	o Broadened set of objectives defined to include acceptable alternatives	G	G	G	Y	Y
	o Major science drivers to cost & risk identified	G	G	G	G	G
	o Quantified cost & risk sensitives to varying levels of science return documented	G	G	Y	G	Y
Mission Design	o Key mission parameters & performance requirements quantified (CML 2)	G	G	G	G	G
	o Alternative set of mission architectures identified	G	G	G	G	G
	o Alternative set of mission architectures evaluated against science objectives, cost & risk	G	G	G	G	G
	o Developed matrix of alternative architectures and implementation modes	Y	G	Y	Y	Y
Spacecraft or Instrument System Design	o Key flight element, design, parameters & performance requirements identified (CML 2)	G	G	G	G	G
	o Alternate flight system architectures and payloads evaluated against mission objectives, cost & risk	Y	G	Y	G	Y
	o Performed an analysis of alternative with other flight system architectures, implementation modes & risks	Y	G	Y	G	Y
	o Sensitivity studies performed to bound performance within trade space	Y	G	G	G	Y
Ground System/Mission Operations System Design	o Mission ops approach defined (CML 2)	G	G	Y	G	Y
	o Mission ops drivers and sensitivies identified	G	G	Y	G	Y
	o Spacecraft tracking options identified	G	G	G	G	G
	o Spacecraft operations support architecture options identified	Y	G	G	G	R
	o Performed an analysis of alternative with other ground system architectures, implementation modes & risks	Y	G	G	G	R
Technical Risk Assessment & Mitigation	o Risk drivers, new developments and possible mitigations for alternative designs across the trade space identified and documented.	Y	G	Y	G	G
Technology & Technology Readiness Levels	o New technologies or major developments required for design points across the trade space identified	G	G	G	G	G
	o Fallback options for all new technologies identified	N/A	G	G	G	G
Master Equipment Lists	o Selected subsystems & assemblies characterized as needed for the trade studies	G	G	G	G	Y
Technical Margins * Margins can be relaxed down to PMSR levels if equivalent of 5 percentage points of scope contingency can be identified.	o Margins are consistent with institutional implementation requirements	Y	G	G	G	G
Major Trades	o Performance-cost trade space varied by at least 25% of nominal design point	R	G	G	Y	G
	o "Trade off" analysis completed for all driving requirements	Y	G	G	Y	Y
	o Documented non-nuclear options for nuclear-powered missions	N/A	N/A	N/A	G	N/A
Mission Assurance	o Hazards of space environment quantitatively bounded and documented	G	G	G	G	Y
Modeling & Simulations	o Required modeling developments with major potential impact to cost or risk identified	G	G	R	G	G
Launch Vehicle	o Candidate launch vehicles and tracks identified	G	G	G	G	G
Planetary Protection	o Expected Planetary Protection classification and any variations across trade space documented	N/A	G	N/A	N/A	G
Project Plans	o Followed the JPL Pre-Phase A & Formulation Phase Life Cycle (CML 2)	G	G	G	G	G
	o Requests for Information (RFI) for industry input submitted	G	N/A	G	G	G
	o Concepts are documented to enable future recall	G	G	G	G	Y
Organization, Partnering & Staffing	o Partnering options identified (CML 2)	G	G	Y	G	G
	o Concept assumes that JPL retains project management, system engineering, mission design, navigation, mission assurance and E&PO roles and responsibilities consistent with historical practices	G	G	Y	G	G
	o Final agreement on the implementation mode made by PI and JPL Director (AO only)	G	G	Y	G	G
	o Acquisition has been contracted because study requires significant industry participation	G	Y	G	Y	G
	o Capture Lead and PI identified (AO only)	G	G	G	G	G
	o Program Office approved PI and key proposal team staff (AO only)	G	G	G	G	G
	o Implementation organizational options identified	G	G	Y	G	G
	o Acting PS appointed if concept not initiated by a scientist (Assigned only) (Study Team Staffing)					
Schedules	o Rough launch year and mission duration documented (CML 2)	G	G	G	G	G
	o Variations and risks to development schedule identified	Y	G	Y	G	Y
	o Variations and risks to mission duration identified	G	G	G	G	G
Inheritance	o Inheritance options, benefits and risks identified	Y	G	Y	G	R
Cost	o Cost estimates generated using Division 5X costing models (CML 2)	G	G	G	G	G
	o Cost sensitivities across trade space performed as a function of major drivers	G	G	G	Y	Y
Cost Risk Assessment & Reserves	o Cost Risk Subfactors form evaluated across trade space	Y	Y	Y	Y	R
	o Cost "reserve" allocated by major WBS item (e.g. subsystems, functions or deliverables being tracked)	G	G	Y	Y	R

- Comparing results provides the ability to "tune" the checklists
  - If a particular attribute is all "red" and "yellow," 1) study teams need training in that area or 2) attribute should be moved one CML later
  - Results are compared with results from an all-day JPL review prior to the start of Step 1

JPL Innovation Foundry

How CMLs are Used at JPL to Advance Concept Design Maturity

- JPL's A-Team (CML 1 – 3)
  - Idea generation, feasibility assessment, architecture trade space evaluation, science traceability, technology infusion, and strategic evaluation
- JPL's Team X (CML 4)
  - Initiated in 1995 and pioneered the collaborative engineering capability within NASA
  - Conducted over 1000 studies
  - Collaborative design sessions to generate a specific mission design, spacecraft design, mission cost range and associated risks
- JPL's Proposal Effort (CML 5 – 6)

JPL Innovation Foundry

Future Plans

- CMLs are not the entire answer to measuring concept maturity
- Other factors that can impact concept maturity are:
  - Complexity
  - Design Maturity
  - Technology Readiness
- JPL has begun work on identifying factors that are known in Pre-Phase A that can measure a concept's complexity
  - Initial results indicate that a concept's complexity level can be used to predict future cost growth

JPL Innovation Foundry

Conclusion

- CMLs are catching on at:
  - JPL
  - NASA Planetary Science Directorate
    - (based on application during Planetary Science Decadal Survey)
- Many uses
  - communication tool
  - evaluating and sorting concepts
  - identifying areas that need strengthening
  - input to estimating cost uncertainty
- Will improve concept robustness prior to moving into Project Formulation
  - Most compelling science identified for a given cost class
  - Detailed trade space exploration has been performed
  - Mission concepts are complete (no omissions)