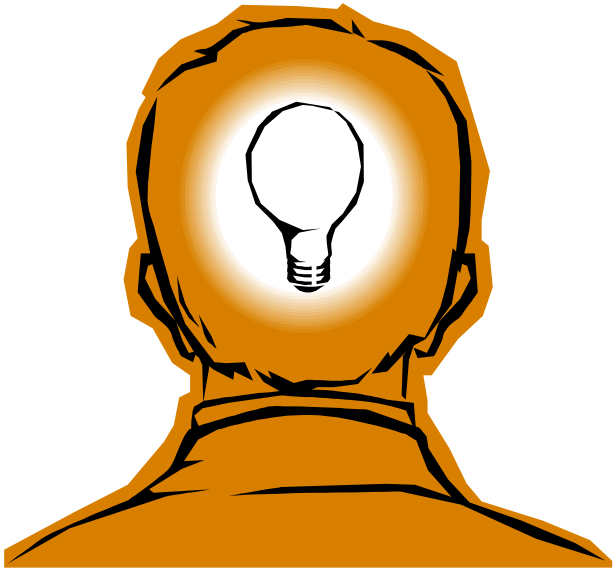
The Enterprise of Engineering



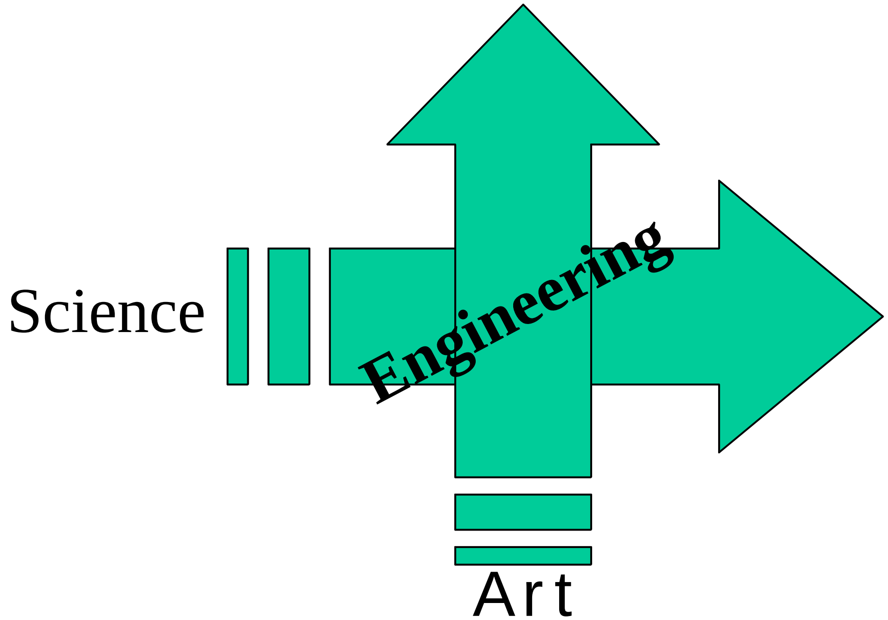
“Scientists discover what is,
engineers create what never was”

-- Theodore von Kárman

Engineering Design

Design **is a *process* whereby *abstract information* about the <u>need</u> for a product or process is converted into *concrete information* necessary to <u>realize</u> that product or process.**

Design, being at the crossroads of art and science, is the essential core of engineering.

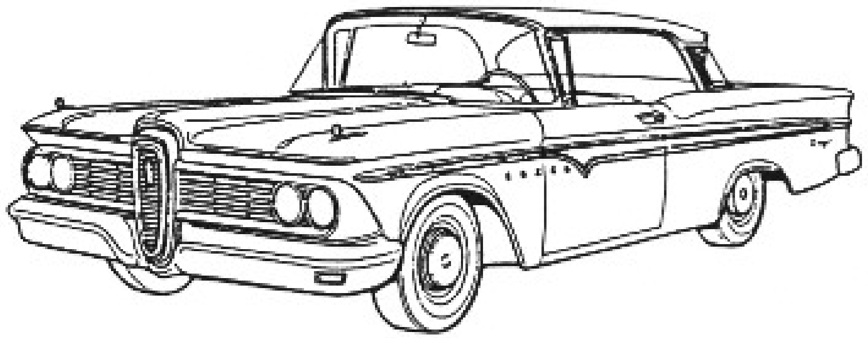


Engineering Design

The outcomes of the design process are <u>non-unique</u>.

One cannot expect to write a formula for a design problem nor arrive at a single correct answer.

There are “better” and “best” answers. There are “optimal” solutions but not “only” solutions.



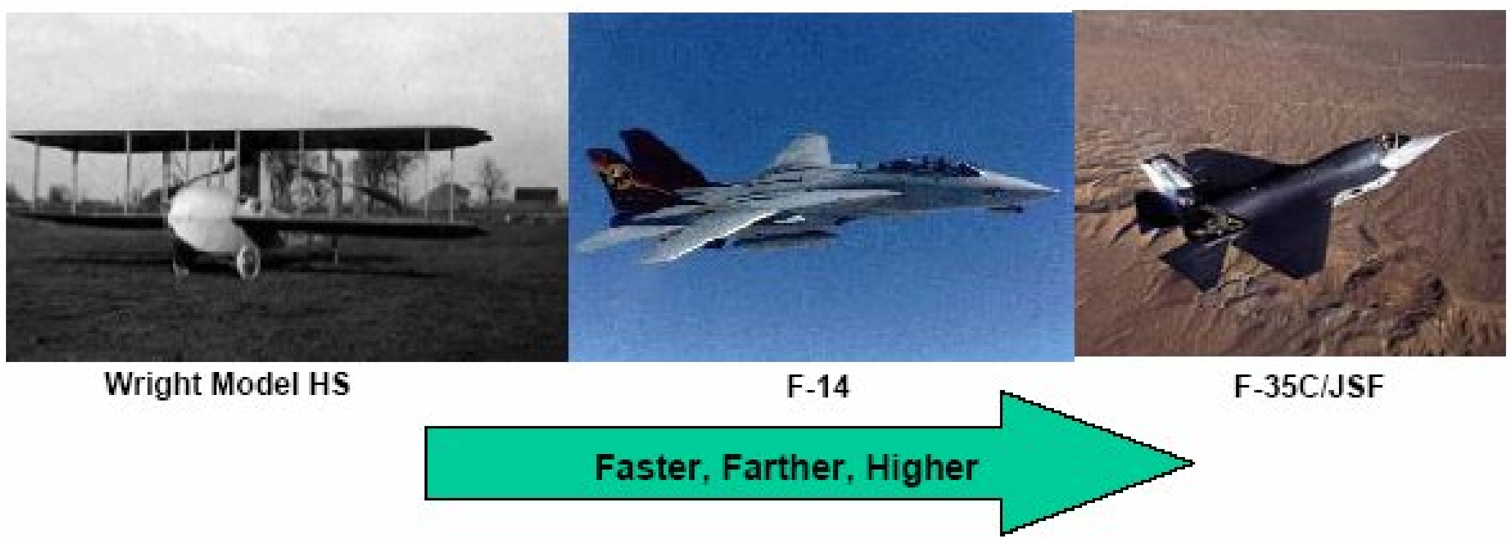
The Product Development Process

• The Changing Face of the Design Process

"Edisonian-Try & Try Again"
- Heavy on Experimentation
- Limited Theory
- Heavy on Rule of Thumb
- Limited Material Choice

"Analysis & Testing"
- Heavy Reliance on Testing
- Handbook Methods
- Early Computational Capability

"Physics-Based Simulation"
- Massive Simulation Capability
- Testing Shifted to Validation
- Integrated Product Teams
- "Lean" Concepts



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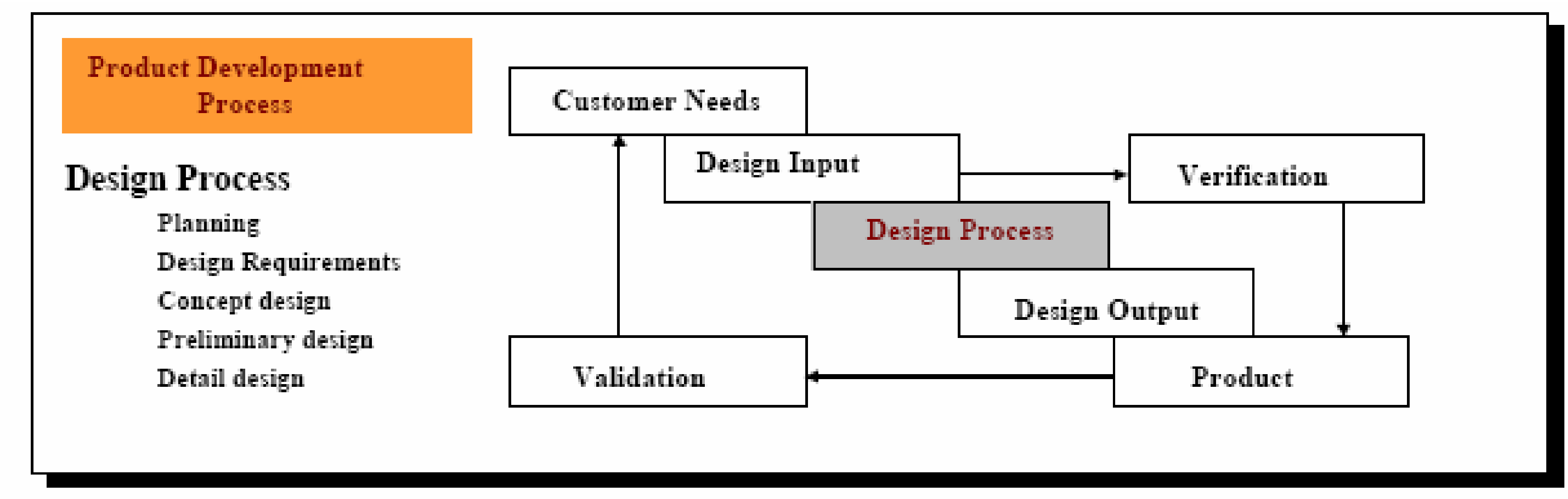
The Product Development Process



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NASA Technology Readiness Levels

Basic Technology Research:

Level 1: Basic principles observed and reported

Research to Prove Feasibility:

Level 2: Technology concept and/or application formulated

Level 3: Analytical and experimental critical function and/or characteristic proof of concept

Technology Development:

Level 4: Component and/or breadboard validation in laboratory environment

Technology Demonstration:

Level 5: Component and/or breadboard validation in relevant environment

Level 6: System/subsystem model or prototype demonstration in a relevant environment (ground or space)

NASA Technology Readiness Levels

System/Subsystem Development:

Level 7: System prototype demonstration in a space environment

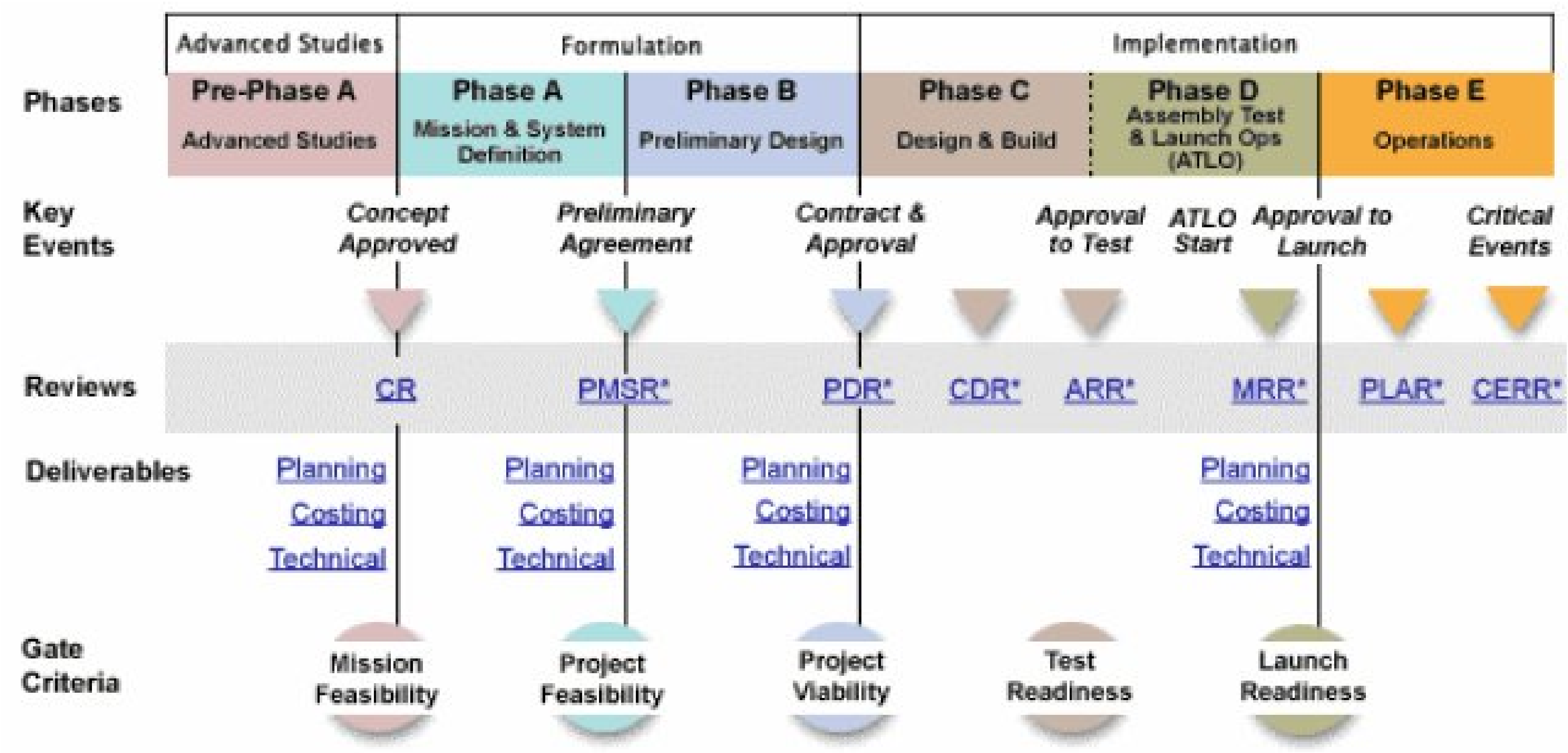
System Test, Launch and Operations:

Level 8: Actual system completed and "flight qualified" through test and demonstration (ground or space)

Level 9: Actual system "flight proven" through successful mission operations

The Product Development Process

- **The JPL Flight Project Life Cycle**



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The Product Development Process

• The Engineering Process Structure

Phase: Conceptual Design

Phase Gate: Conceptual Design Review

Design Product: Functional Baseline (system specification) and Design-to Package

Design Activities: requirements analysis; evaluation of feasible technology applications; selection of technical approach.

Phase: Preliminary Design

Phase Gate: Preliminary Design Review

Design Product: Allocated Baseline (development, process, product and material specifications)

Design Activities: requirements allocation; trade-off studies; synthesis; preliminary design.

Phase: Detail Design

Phase Gate: Critical Design Review

Design Product: Product Baseline (process, product and material specifications) and Build-to Package

Design Activities: Subsystem design; development of engineering models; verification of manufacturing and production processes.

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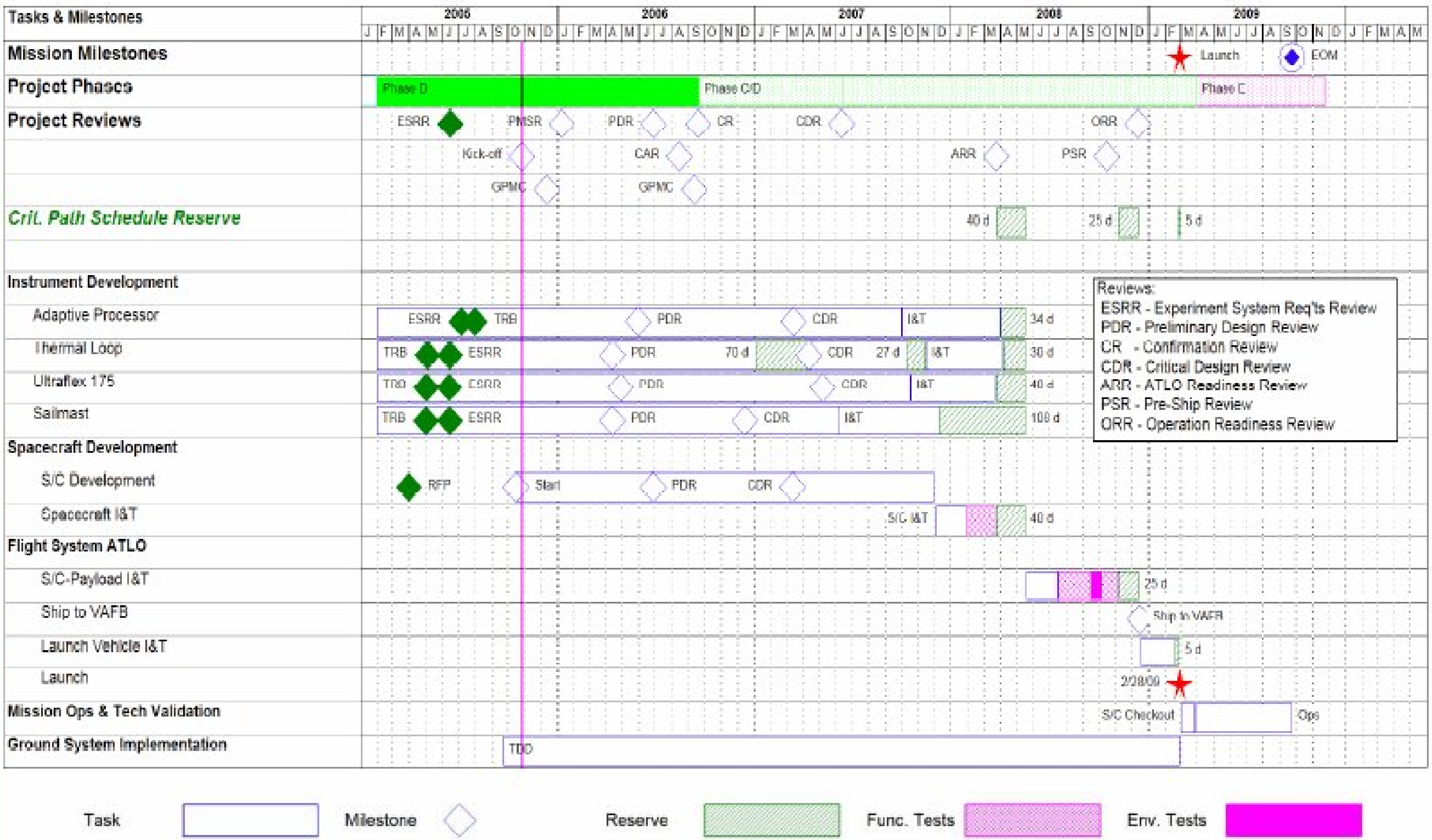
The Product Development Process

National Aeronautics and
Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Space Technology 8

Top Level Schedule



The Product Development Process

• Project Risk Assessment

Phase 2 and Phase 3 Risks
(PRELIMINARY)

L = Likelihood (1 - 5)
S = Severity (1 - 5)
P = Product L x S (1 - 25)

#	RISK	L	S	P	CONSEQUENCE
1	Membrane modes cannot be well excited in air	5	3	**15**	Many modes cannot be measured in Phs 2
2	Increased LaRC overhead rates reduce available procurement dollars	3	4	**12**	Some test equipment cannot be purchased
3	Delays in purchasing JMU sun simulator	3	4	**12**	Delays in completing planned tests
4	ISP funds for Phase 3 not arriving at LaRC on time	3	4	**12**	Phase 3 schedule slip
5	Al Burner (LaRC) is unavailable to complete all single-camera studies	2	5	**10**	Important photogrammetry work not done
6	Unaffordable cost for using LaRC's Leica laser radar system	5	2	**10**	Use V-STARS for truth data instead
7	Testing thermography techniques on small (1-2 m) membranes only	5	2	**10**	Suitability at larger sail size unknown
8	Polytec scanning laser vibrometer unavailable	3	3	**9**	Alternative needed for vibration truth data
9	Delay in delivery of Texas A&M camera system	3	3	**9**	Delays in evaluating 2nd camera system
10	Too little research in Phase 2	3	3	**9**	Insufficient understanding of problem
11	Too much research in Phase 2	3	3	**9**	Missed deadline
12	Air currents in lab cause small, unwanted sail motion	2	4	**8**	Effects may be indistinguishable from measurement error
13	Amount of wrinkling in lab sail structure different than in space	4	2	**8**	Significance needs to be evaluated
14	Lab illumination conditions different from in-space conditions	5	1	**5**	Significance needs to be evaluated
15	V-STARS camera severely damaged (e.g., dropped)	1	5	**5**	Unplanned repair cost probably ~$50k
16	Delay in delivery of IO Industries camera system	1	5	**5**	Delays completing photogrammetry work
17	Hardware failures in IO Industries camera system	1	5	**5**	Delays completing photogrammetry work

1 = Lowest, 5 = Highest

The Product Development Process

- **Conceptual Design**

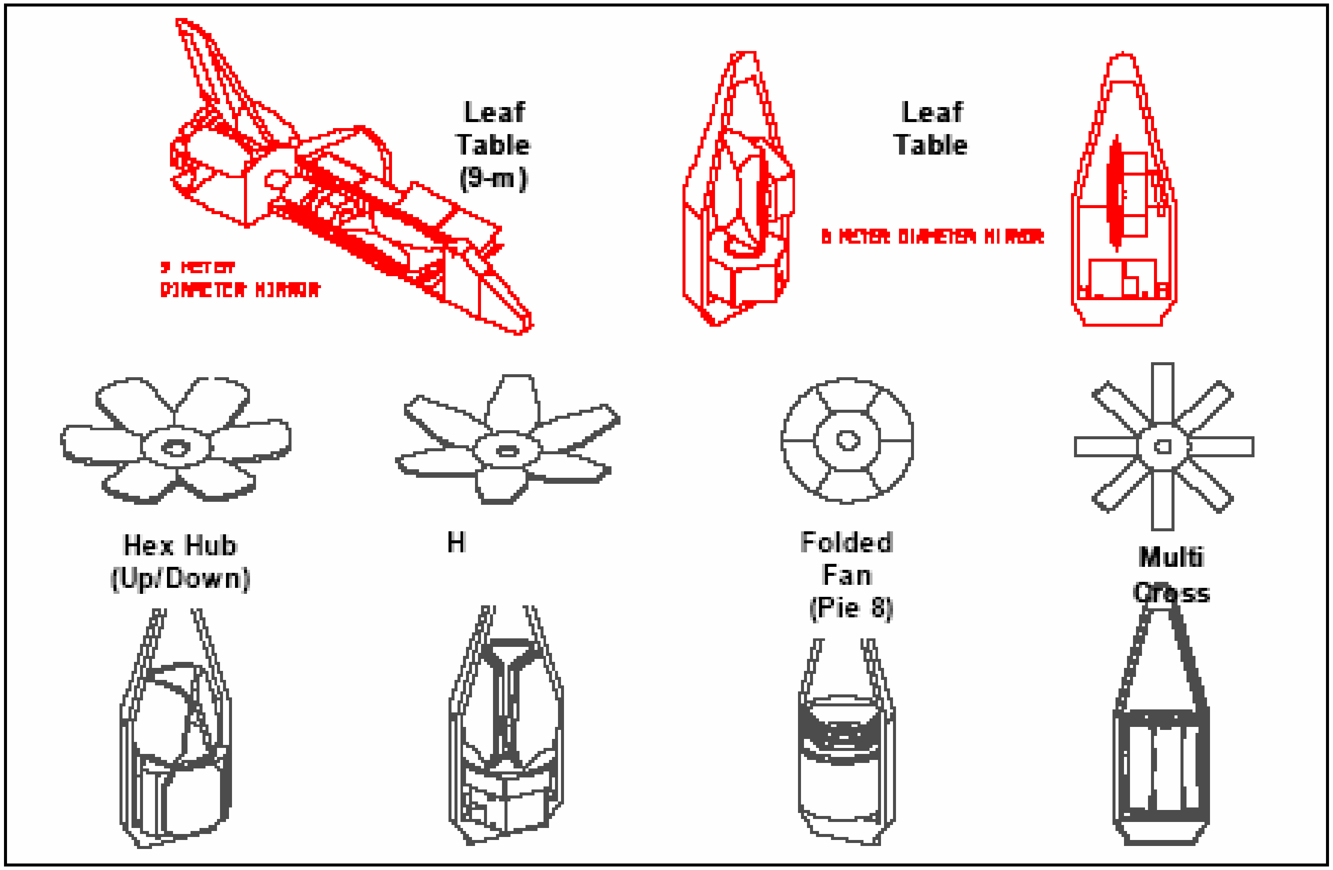


Figure 10. Deployable optics design concepts (2 of 4)

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The Product Development Process

- **Trade Study and Down Selection**

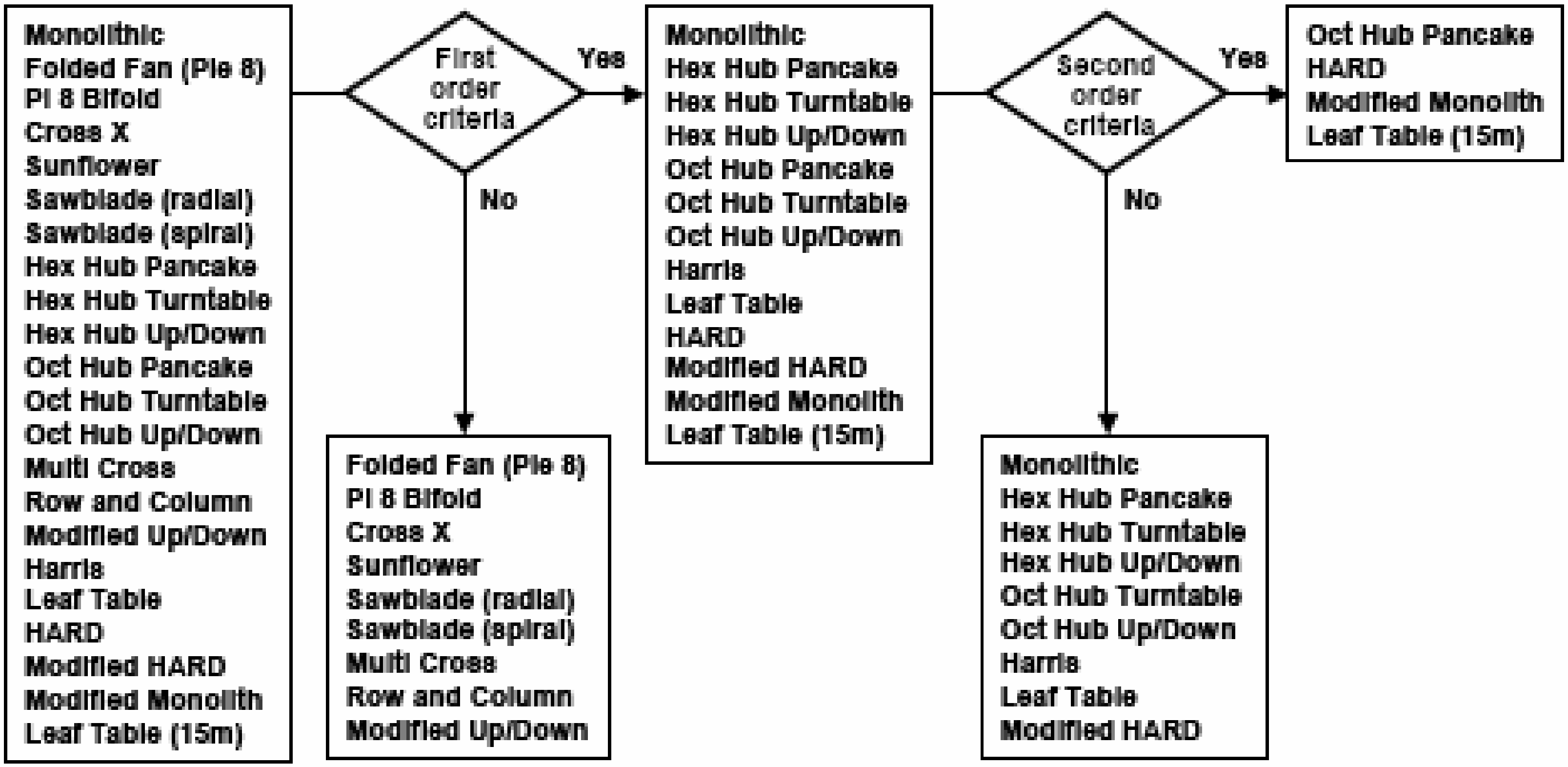

Figure 13. Trade study methodology

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The Product Development Process

• Trade Study and Down Selection

Concept	Segment Dimen (m)	Seg No./ Shape No.	Mech No./ Quantity	Initial Deploy Accuracy	Stowed Volume Eff	Panel Thickness	Stow Stability	Testability At 1 g
Monolithic	8	1	0	N/A	Low	No Affect	High	Self Supporting
Folded Fan (Pie 8)	3.4	8/2	14/52	5	Low	Reduced Area	Low	Gravity Off load
Pie 8 Bifold	1.8	16/3	16/88	3	Low	Impractical	Low	Gravity Off load
Cross X	3.5	13/4	14/70	2	Low	Reduced Area	Low	Gravity Off load
Sunf low er	3.5	18/4	17/104	3	Low	Reduced Area	Medium	Self Supporting
Saw blade(radial)	3.5	16/1	5/59	4	Low	Reduced Area	Low	Self Supporting
Saw blade(spiral)	3.5	22/1	5/63	4	Low	Impractical	Medium	So Supporting
Hex Hub (pancake)	3.5	7/2	11/96	6	High	No Affect	High	Self Supporting
Hex Hub (turntable)	3.5	7/2	8/42	6	Low	Reduced Area	Medium	Self Supporting
Flex Hub (up/dow n)	[illegible]	7/2	5/40	6	Low	Reduced Area	Medium,	Self Supporting
Oct Hub (pancake)	3.5	9/2	11/128	4	High	No Affect	High	Self Supporting
Oct Hub (turntable)	3.5	9/2	8/55	4	Low	Reduced Area	Medium	Self Supporting
Oct Hub (up/dow n)	3.5	9/2	5/52	4	Low	Reduced Area	Medium	Self Supporting
Multicross (daisy)	4.5	7/2	5/50	6	Low	No Affect	Medium	Self Supporting
Row and Column	3.5	8/4	19/47	5	Low	Reduced Area	Low	Gravity Off load
Modified Up/Dow n	3	9/3	11/56	4	Low	Reduced Area	Low	Gravity Off load
Harris	3.5	7/2	8/44	7	Low	Reduced Area	Low	Gravity Off load
Leaf Table	8	3/3	4/12	9	Low	No Affect	Low	Self Supporting
HARD	3.5	7/2	4/39	8	High	No Affect	High	Gravity Offload
Modified HARD	3.5	7/2	4/42	8	High	No Affect	High	Self Supporting
Modified Monolith	4.95	13/2	6/72	8	Medium	Reduced Area	Medium	Gravity Off load
Leaf Table (15 meter)	15	3/2	4/12	9	Low	No Affect	Low	Self Supporting

Shaded Concepts Eliminated

Segment Dimension - Largest single piece dimension (defines polish facility size)
Segment Number - Number of mirror pieces
Shape Number - Number of mirror shapes (mirrored Image is separate tooling).
Mech No./Quantity - Total mechanisms by non reoccurring cost (ex. 1 door hinge design) / Total reoccurring units (ex. 2 hinges)
Stowed Volume - Mirror volume / Diameter x Height
Panel Thickness - Impact of the 177.8mm thick panel segments (may exclude a design or reduce the area due to Interference
Stowage Stability - Load path assessment for launch loads
Testability at 1g - Does deployment testing require elaborate gravity offloading with weights and pulleys) or can it support itself

Figure 14. First order criteria down-selection data

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The Product Development Process

• Preliminary Design

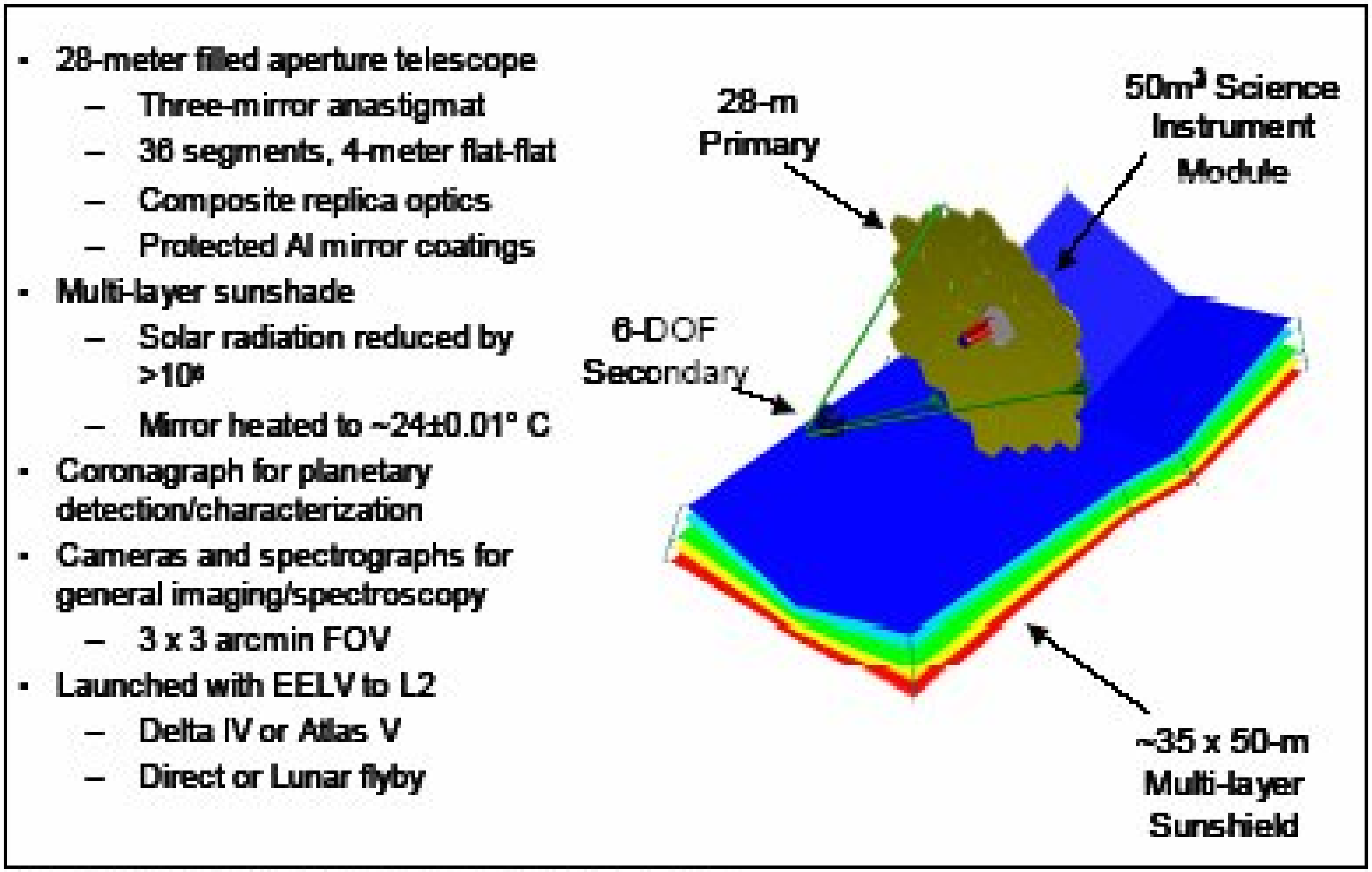

Figure 18. (Very) Large aperture telescope design concept

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The Product Development Process

• Trade Study and Down Selection

Decision Matrix: Weighted Averages

Criteria	Design:		1	2	3	4	5	6	7	8
	Wt.	Norm.	Wt. Avg	Wt. Avg	Wt. Avg	Wt. Avg	Wt. Avg	Wt. Avg	Wt. Avg	Wt. Avg
Appearance	2	0.043	0.087	0.087	0.120	0.109	0.109	0.098	0.087	0.065
Adaptability	4	0.087	0.217	0.196	0.196	0.239	0.174	0.217	0.196	0.174
Durability	5	0.109	0.245	0.272	0.272	0.245	0.217	0.272	0.190	0.190
Aerodynamics	3	0.065	0.114	0.130	0.130	0.114	0.163	0.114	0.114	0.114
Loading Height	5	0.109	0.272	0.326	0.217	0.272	0.136	0.299	0.163	0.190
Loading Reach	5	0.109	0.299	0.326	0.190	0.299	0.163	0.299	0.190	0.190
Wheelchair Clearance	5	0.109	0.299	0.245	0.326	0.272	0.272	0.299	0.299	0.245
Operation/Control	5	0.109	0.245	0.217	0.190	0.245	0.190	0.272	0.245	0.272
Overall Clearance	3	0.065	0.163	0.147	0.196	0.147	0.130	0.130	0.147	0.130
Weight	3	0.065	0.130	0.130	0.130	0.163	0.163	0.163	0.163	0.130
Load Capacity	4	0.087	0.174	0.239	0.217	0.174	0.174	0.196	0.130	0.239
Cost	2	0.043	0.098	0.087	0.120	0.098	0.098	0.098	0.109	0.087
Total/Average =	46	1.000	7.808	8.007	7.681	7.917	6.630	8.188	6.775	6.757