Airborne Wind Electric Generator (AWEG) PLACIS Grand Challenge

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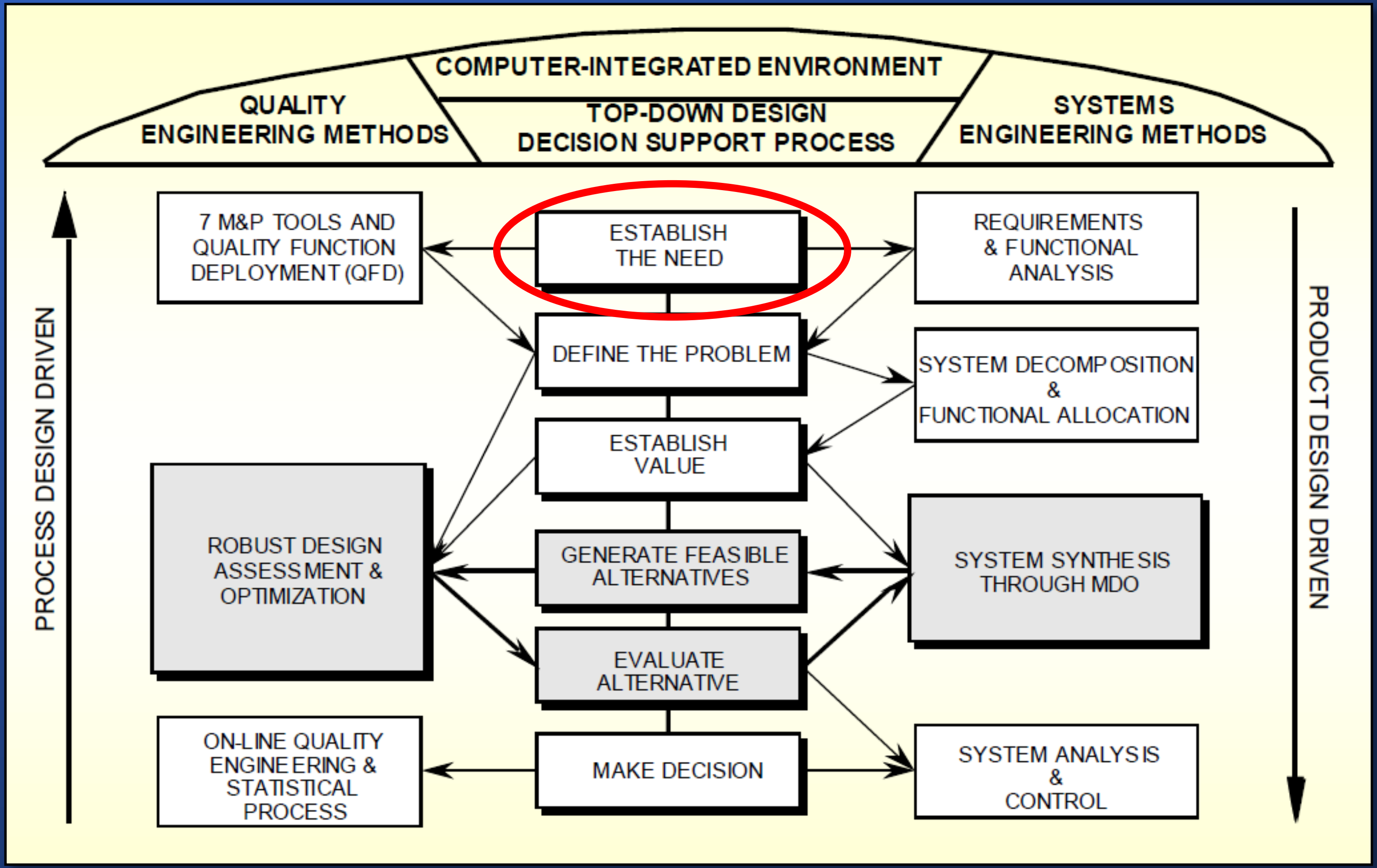
Step 1: Establish the Need



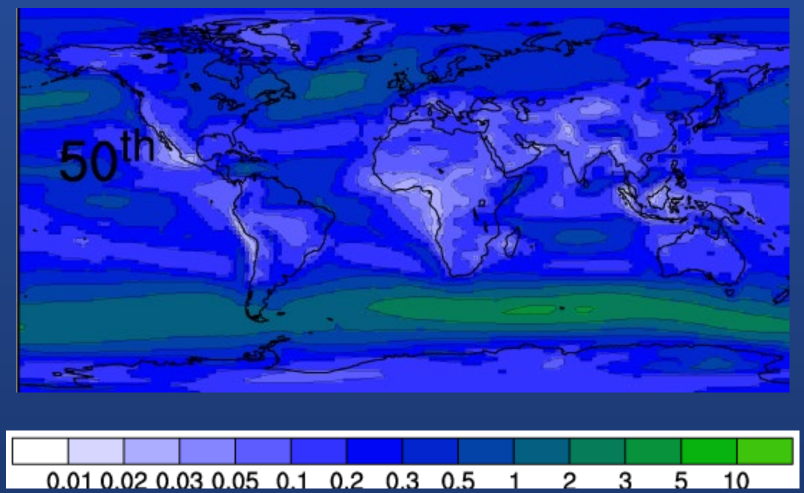
Background and Motivation

- Climate change is causing extreme weather patterns
- There is a need for “green” energy
- Wind Energy
  - Wind energy is a substantial source of renewable energy
  - Wind energy represents a potential entirely green source of energy
  - Available wind energy exceeds the energy supplied by the sun

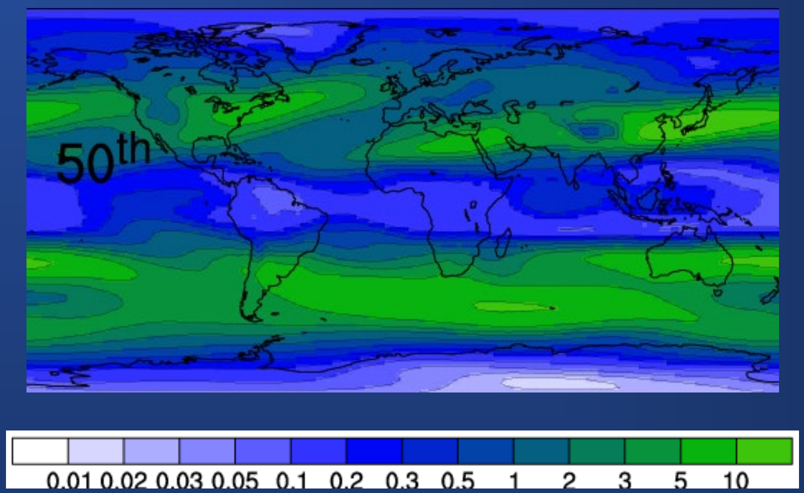
Background and Motivation

- "Wind power density at 10,000 m is on average over five times larger than that at 1,000 m" [1]
  - The use of high altitude provides more power than through ground-based systems
  - Also reduces the majority of location limitations

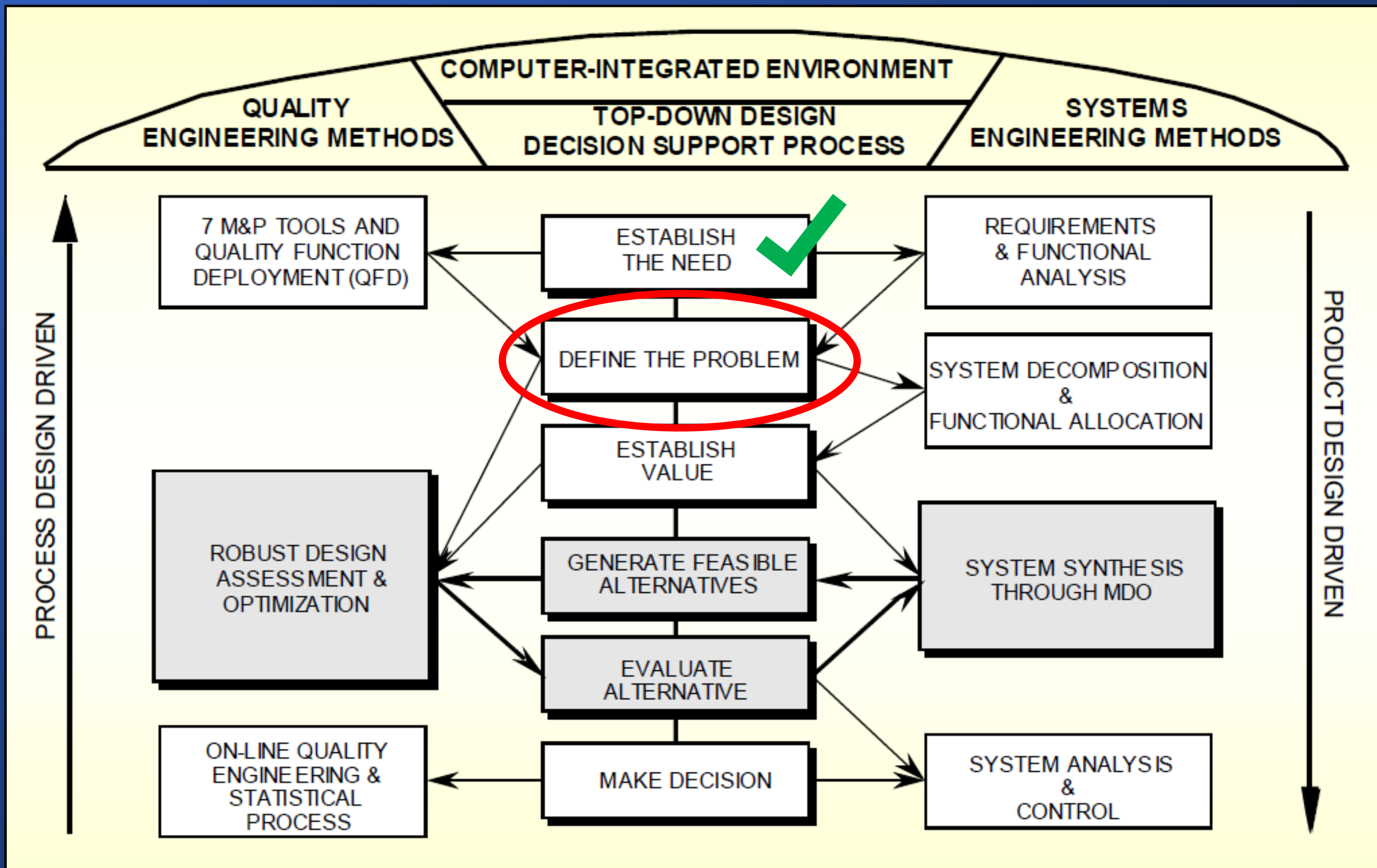
Altitude = 1,000m



Altitude = 10,000m

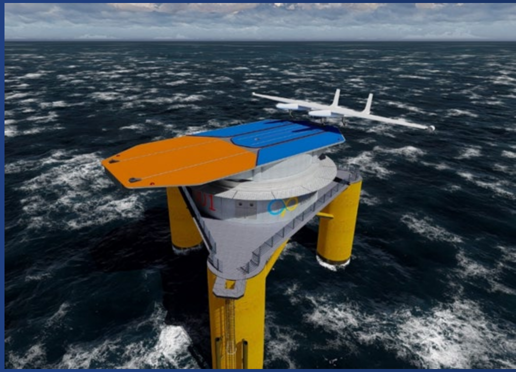


Step 2: Define the Problem



Background and Motivation

- Many concepts being researched by various companies/groups
  - Glider creates energy by pulling tether connected to ground based generator (Ampyx Power)
  - Sails used to pull tether connected to ground based generator (Sky Sails)
  - Tethered unmanned aircraft with onboard turbines (Makani Power, Joby Inc.)



Background and Motivation

- This study looks at Sky WindPower's concept of hovering Autogryo with generators placed on rotor
  - Rotors onboard both generate lift and generate power through excess wind energy
  - Tether is used to transmit power generated to the ground

- 4 rotor design
- Rotor Diameter: 10.7 m
- Operational Altitude: 4600m
- Mass: 520 kg
- Max. operational wind speed: 35 m/s

https://youtu.be/UxHgAPIPAGs

Operational Architecture

GPS Systems used for positioning

Stage 3: Peak Power
Peak altitude: 4600 m
Peak wind speed: 35 m/s
Autorotation speed: 11.5 m/s

Stage 2: Ascent
Power generated during ascent

Stage 4: Descent
Power generated during descent

Electrical Ground Facility

Stage 1: Takeoff

Stage 5: Landing

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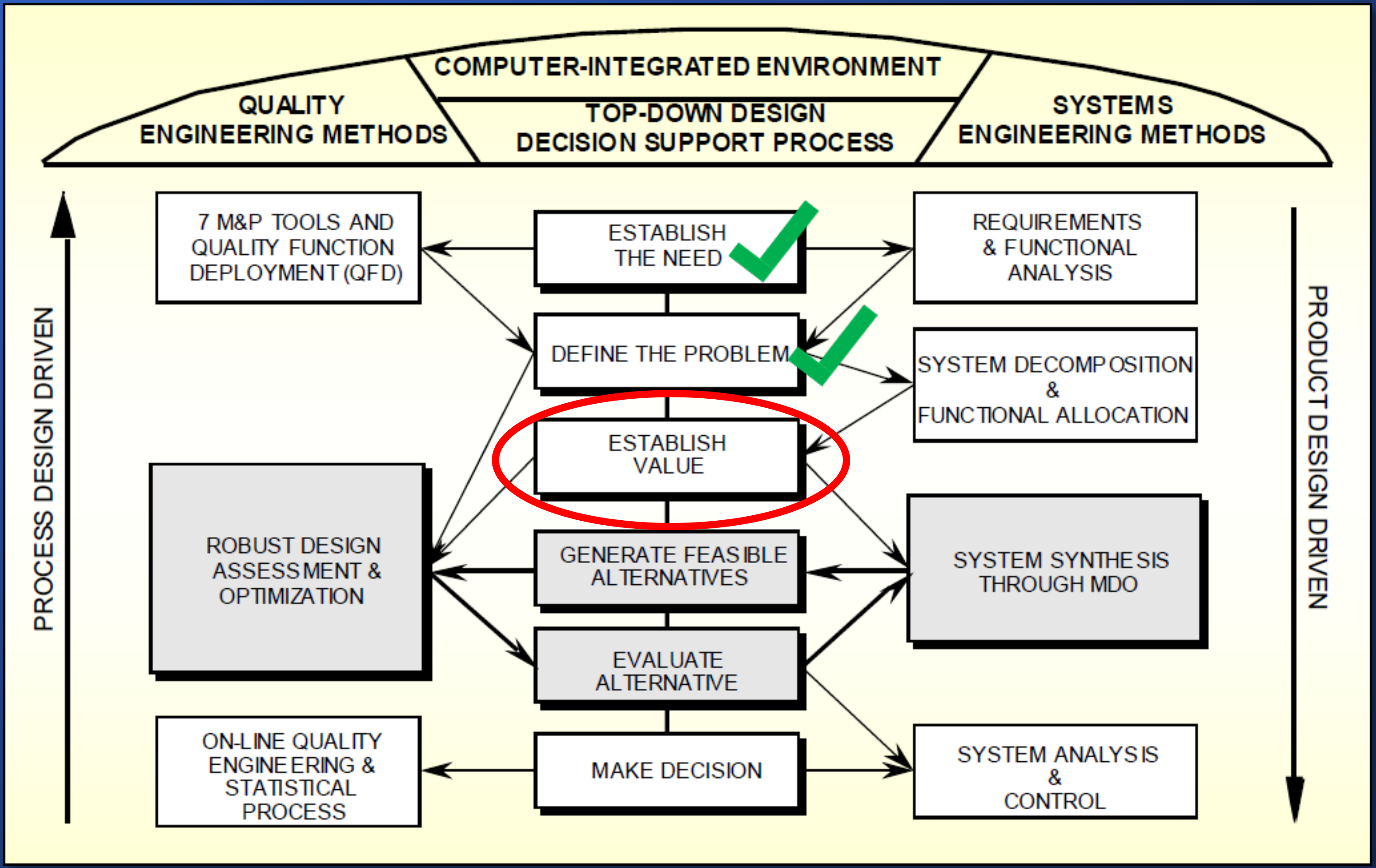
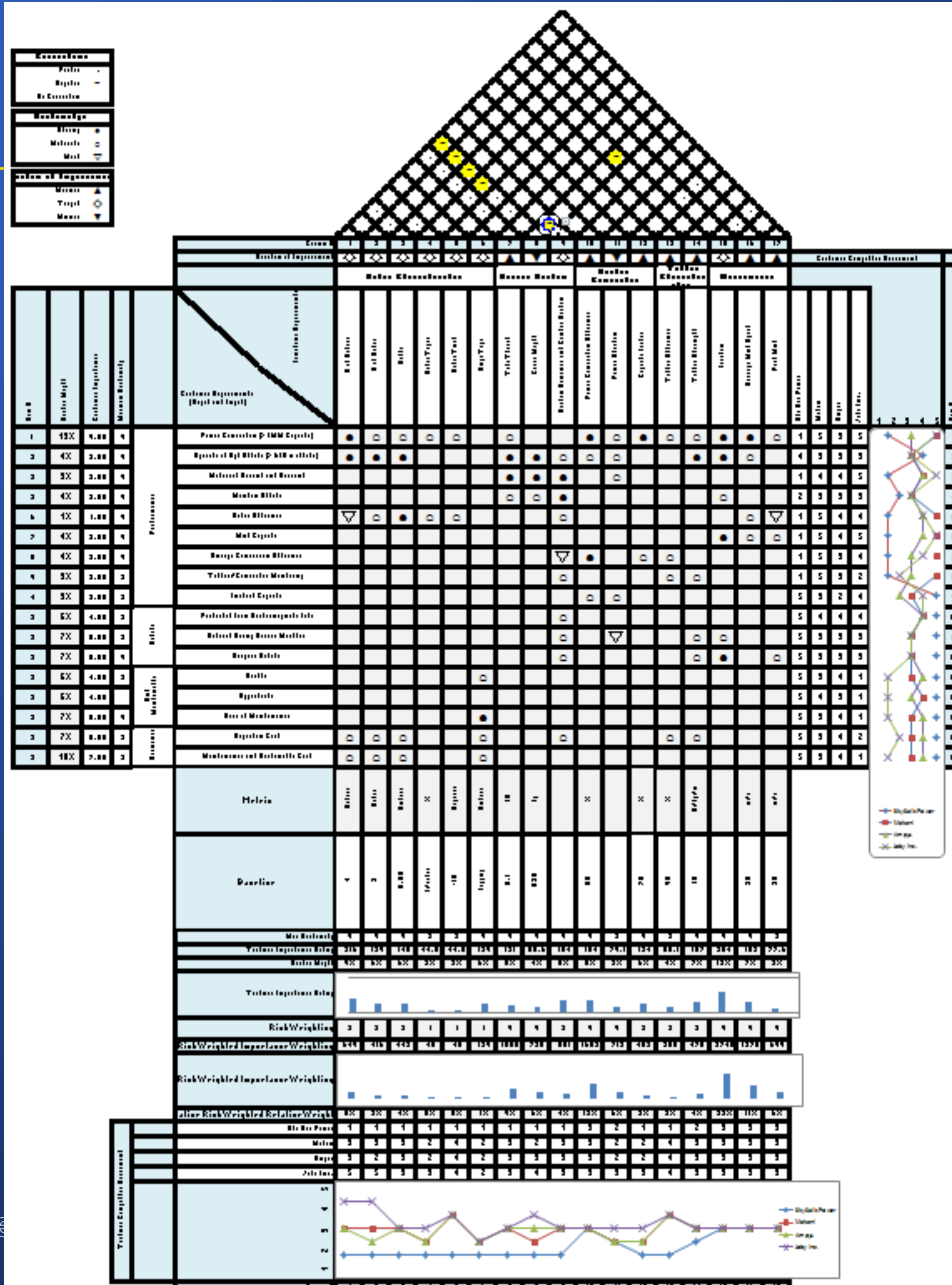
Step 3: Establish Value



QFD



Overall Evaluation Criteria (OEC)

$$OEC = \frac{\alpha\left(\frac{Rotor}{Rotor_{Baseline}}\right) + \beta\left(\frac{Overall}{Overall_{Baseline}}\right) + \gamma\left(\frac{Generator}{Generator_{Baseline}}\right) + \delta\left(\frac{Tether}{Tether_{Baseline}}\right) + \varepsilon\left(\frac{Miscellaneous}{Miscellaneous_{Baseline}}\right)}{\frac{Life\ Cycle\ Cost}{Life\ Cycle\ Cost_{Baseline}}}$$

$$\alpha = \sum_{i=1}^{N} weight_{Rotor\ i} = 0.32$$

$$\gamma = \sum_{i=1}^{N} weight_{Generator\ i} = 0.17$$

$$\varepsilon = \sum_{i=1}^{N} weight_{Misc_i} = 0.23$$

$$\beta = \sum_{i=1}^{N} weight_{Overall\ i} = 0.17$$

$$\delta = \sum_{i=1}^{N} weight_{Tether_i} = 0.11$$

Functional Requirements	Element	Weight	Baseline	Target	Variance	Units
Rotor Characteristics (α)	# of Rotors	0.31	4	4	0.00	
	# of Blades		2	4	2.00	
	Solidity		0.05	0.10	0.05	
Overall System (β)	Total Thrust	0.17	5.10	5.50	0.40	kN
	Gross Weight		520	500	-20.00	kg
Electric Generator (γ)	Power Generation Efficiency	0.17	0.5	0.56	0.06	Betz limit = 0.59
	Capacity Factor		0.7	0.8	0.10	
Tether characteristics (δ)	Tether Efficiency	0.11	0.9	0.95	0.05	
	Tether Strength		10	15	5.00	MYuri (N/kg/m)
Miscellaneous (ε)	Average Wind Speed	0.23	20	25	5.00	m/s
	Peak Wind		30	35	5.00	m/s
Functional Requirements Value	**2.79**					
Cost	Life Cycle	1	$820,000.00	$800,000.00	-20000.00	dollars
Cost Value	**0.98**					
OEC	**2.86**					

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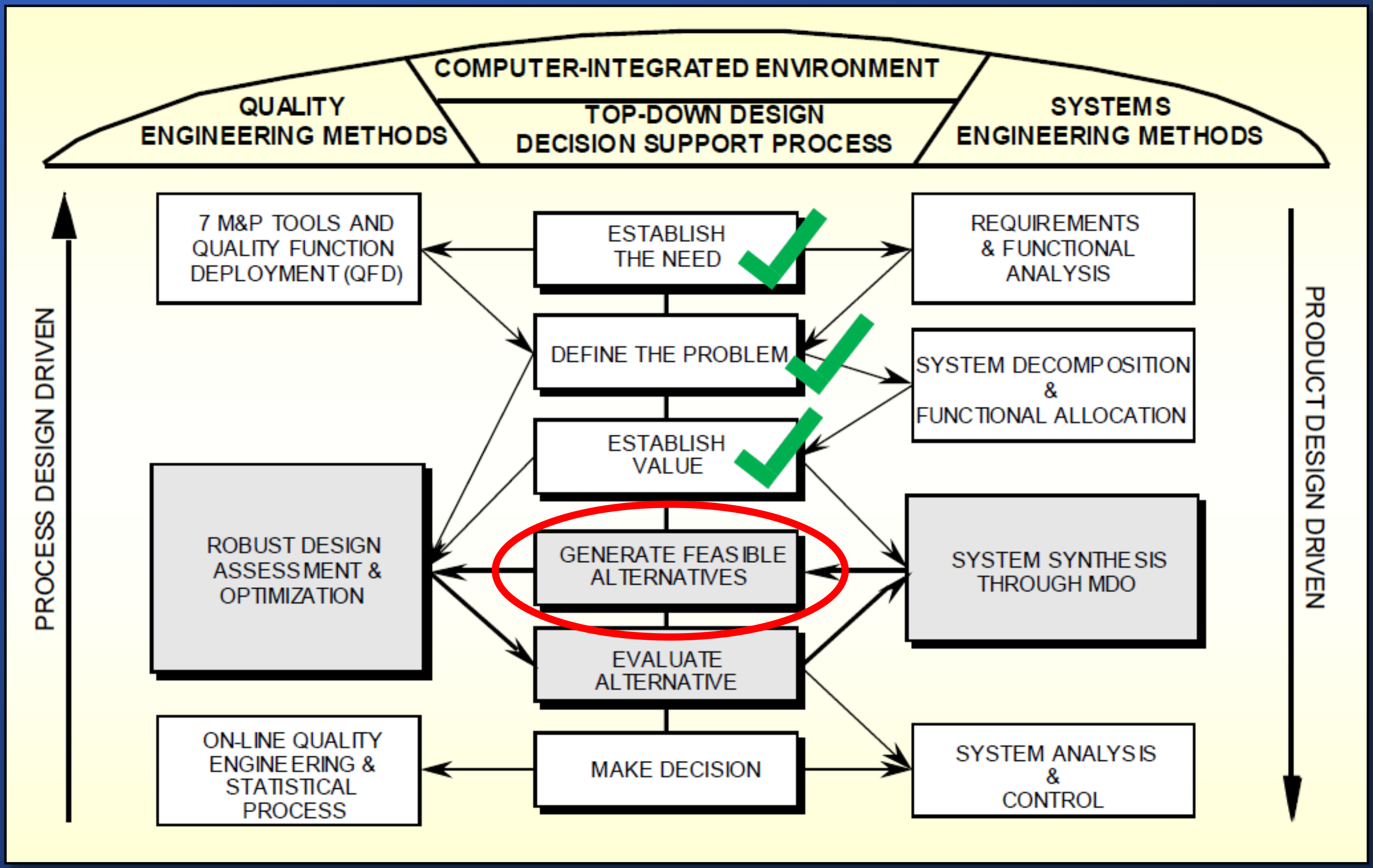
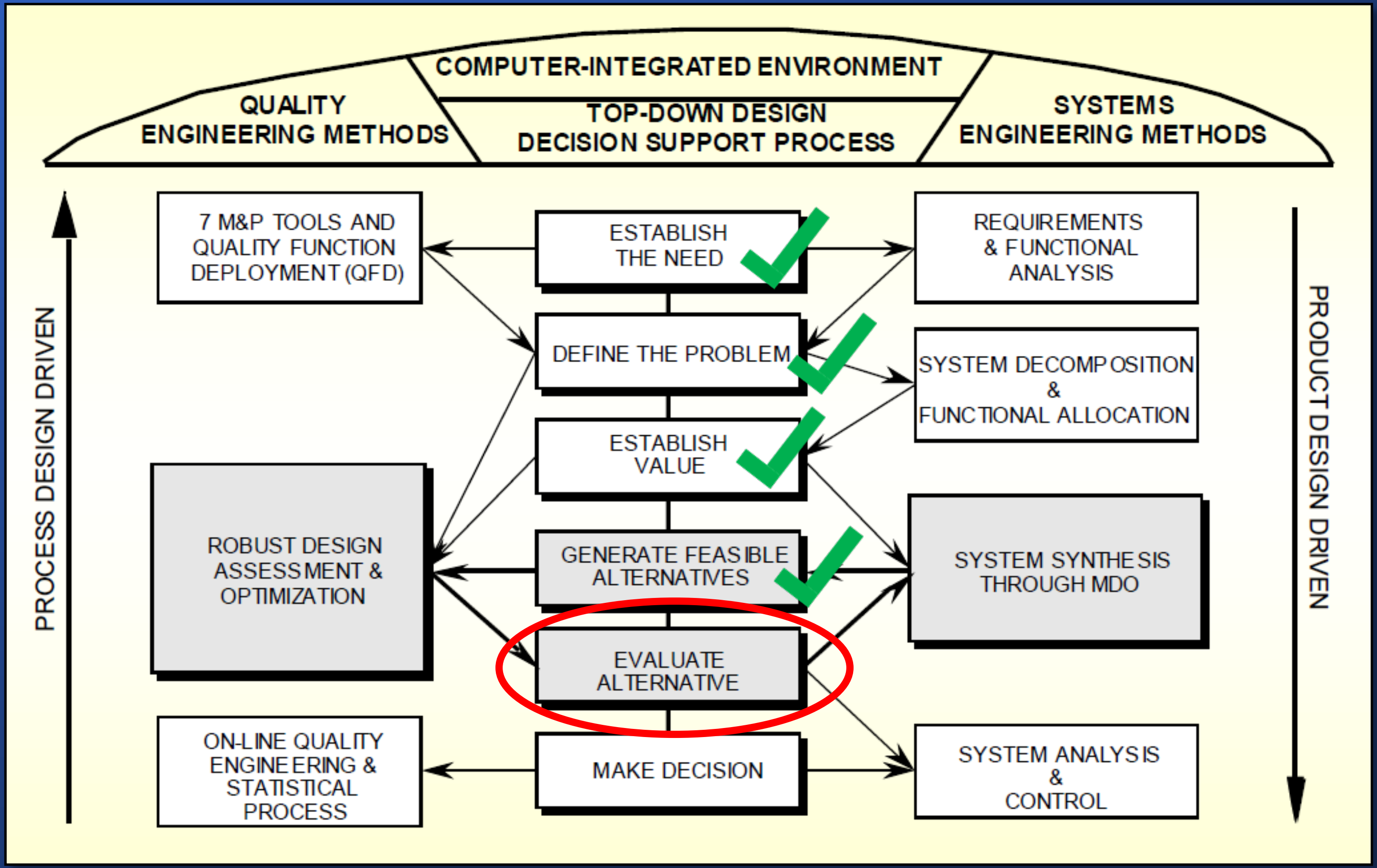
Step 4: Generate Feasible Alternatives



Morphological Matrix

	Characteristic	Alternatives					Total
Physical Configuration	Number of Rotors	3	4	5			3
	Number of Blades	2	3	4	5		4
	Rotor Taper	Yes	No				2
	Rotor Twist	Linear	Non-Linear	None			3
	Rotor Solidity	Low	Moderate	High			3
	Hinge Type	Teeter	Flapping	Lead/Lag	Fully Articulated		4
	Tether Material	Metal	Composite				2
Control	Fully Autonomous	Yes	No				2
	Retractable for Severe Weather	Yes	No				2
	Pitch Control	Collective	Collective & Cyclic				2
Power Generation	Power Generation Method	Tether Pull	Autogyro	Circular Flight			3
	Power Generation Location	Airborne	Ground Station				2
Mission Profile	Operating Altitude	500 ft	1000 ft	2000 ft	3000 ft	15000 ft	5
	Operating Location	Land	Sea	Either			3
					Total Alternatives		**1,244,160**

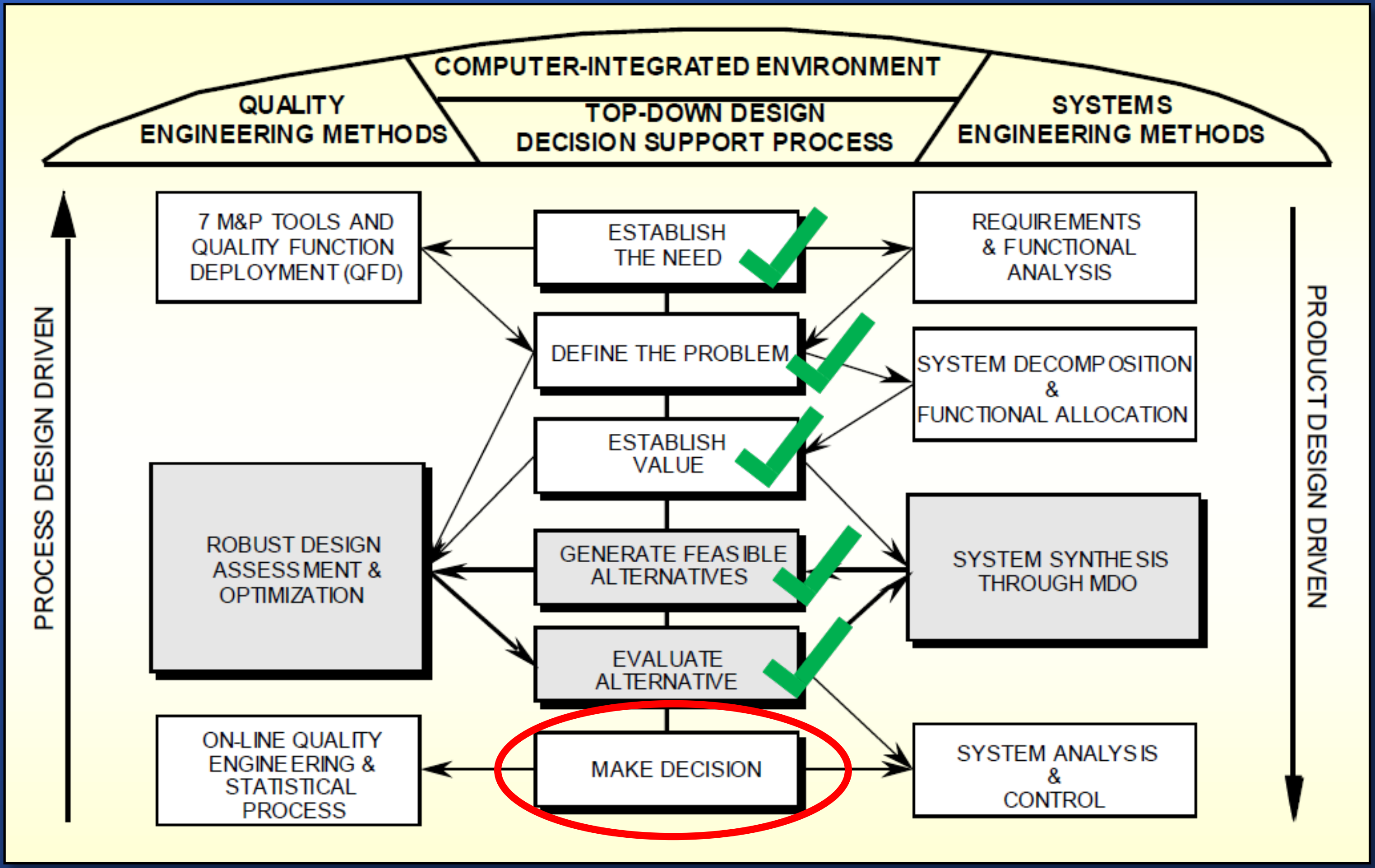
Step 5: Evaluate Alternatives



Pugh Matrix

	Alternative 1 (Blade Count Increase, No Taper, Hinge, Tether Material, Altitude)	Alternative 2 (Twist, Altitude)	Alternative 3 (Rotor Count, Blade Count, Hinge, Tether Material, Power Generation)	Baseline
Power Generation	+	+	+	Datum
Power Generating Efficiency	-	+	-	
Power Utilization	S	S	S	
Capacity Factor	-	+	-	
Total Thrust	+	S	+	
Gross Weight	-	-	-	
System Dynamics and Control System	S	S	-	
Tether Efficiency	+	S	+	
Tether Strength	-	S	-	
Average Wind Speed	+	+	S	
Peak Wind	+	+	S	
Reliability	-	S	-	
Acquistion Cost	-	-	-	
Maintenance and Sustainabiltiy Cost	-	-	-	
Σ+	5	5	3	
Σ-	7	3	8	
ΣS	2	6	3	
Sum	**-2**	**2**	**-5**	

Step 6: Make Decision



TOPSIS Decision

	Power Generation	Power Generation Efficiency	Power Utilization	Capacity Factor	Total Thrust	Gross Weight	System Dynamics and Control System	Tether Efficiency	Tether Strength	Average Wind Speed	Peak Wind	Reliability	Acquisition Cost	Maintenance and Sustainability Cost
Positive Ideal Soln	0.4508	0.7625	0.5774	0.7625	0.5232	0.8452	0.6509	0.4508	0.7625	0.6312	0.6312	0.8452	0.8452	0.8452
Negative Ideal Soln	0.6312	0.4575	0.5774	0.4575	0.6727	0.1690	0.3906	0.6312	0.4575	0.4508	0.4508	0.1690	0.1690	0.1690

		Separation from Positive Ideal	Separation from Negative Ideal	Closeness to Ideal Soln
Alternatives	A/C1	0.0776	0.0794	0.5059
	A/C2	0.0258	0.1496	0.8531
	A/C3	0.1496	0.0258	0.1469

	Characteristic	Alternative 2
Physical Configuration	Number of Rotors	4
	Number of Blades	2
	Rotor Taper	Yes
	Rotor Twist	Non-Linear
	Rotor Solidity	Low
	Hinge Type	Flapping
	Tether Material	Metal
Control	Fully Autonomous	Yes
	Retractable for Severe Weather	Yes
	Pitch Control	Collective
Power Generation	Power Generation Method	Autogyro
	Power Generation Location	Airborne
Mission Profile	Operating Altitude	15000 ft
	Operating Location	Land