# Evaluating a Set-Based Design Tradespace Exploration Process

Gregory Parnell

University of Arkansas

2019 CSER conference on systems engineering research


UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

CELDi
Center for Excellence in Logistics and Distribution

# Evaluating a Set-Based Design Tradespace Exploration Process

Eric Specking
**Gregory Parnell**
Edward Pohl
Randy Buchanan

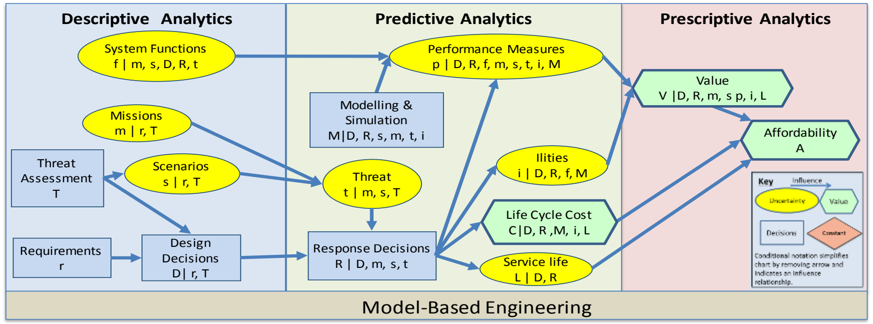
ERDC
Engineer Research and Development Center

Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design  Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

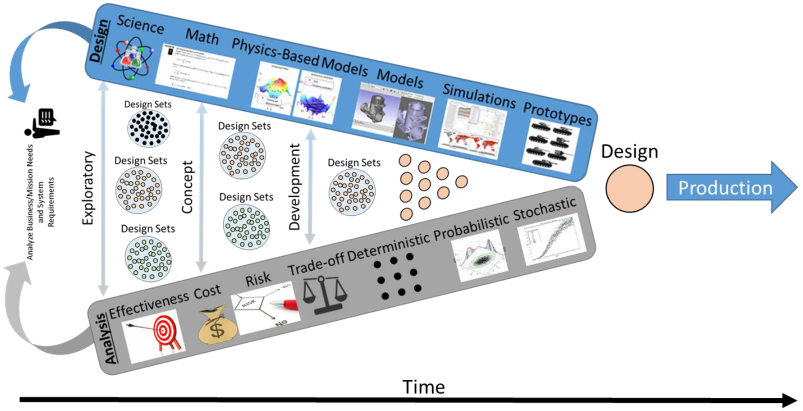
UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

# Bottom Line Up Front

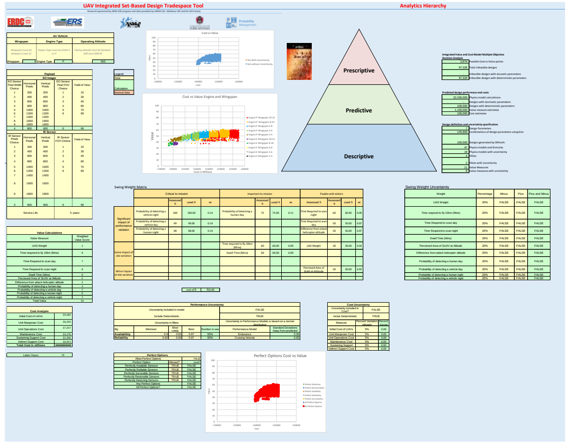
## Integrated Trade-off Analytics Framework



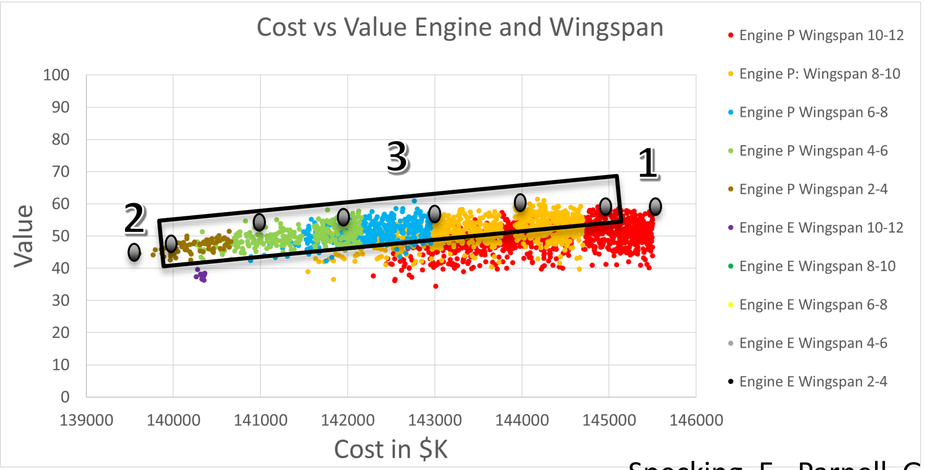

## Set-Based Design for Tradespace Exploration




## Demonstration Model

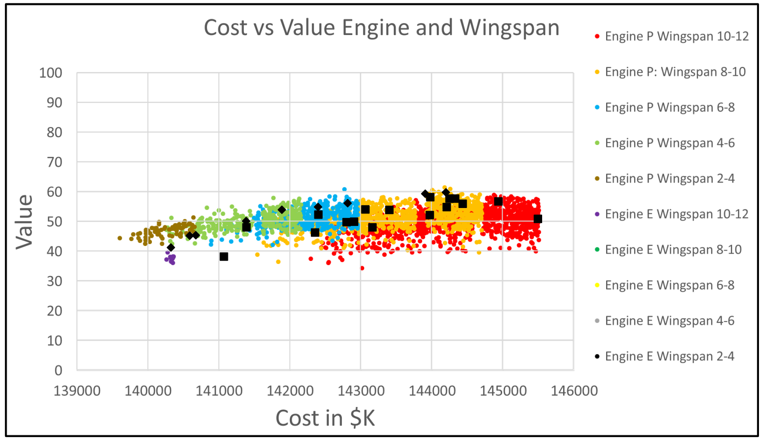


## SBD TSE Evaluation Method




TSE with SBD methodology found 189 design points that dominated points found by a genetic algorithm.

## Evaluation Results

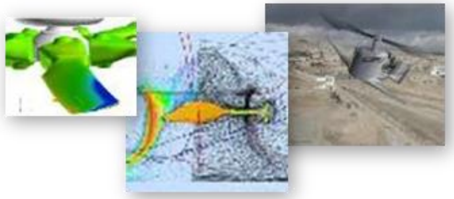



Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

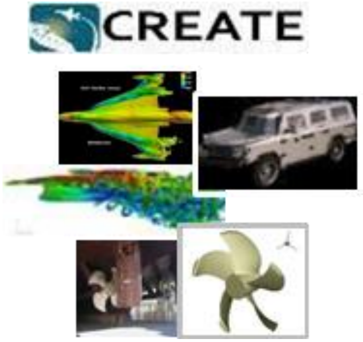
# Incorporating resilience options into DoD Analysis of Alternatives

**Best Practices**

**ERS Focus**



**Rapid Prototyping & Response**




**High Fidelity Engineering Models**

## Force Modernization

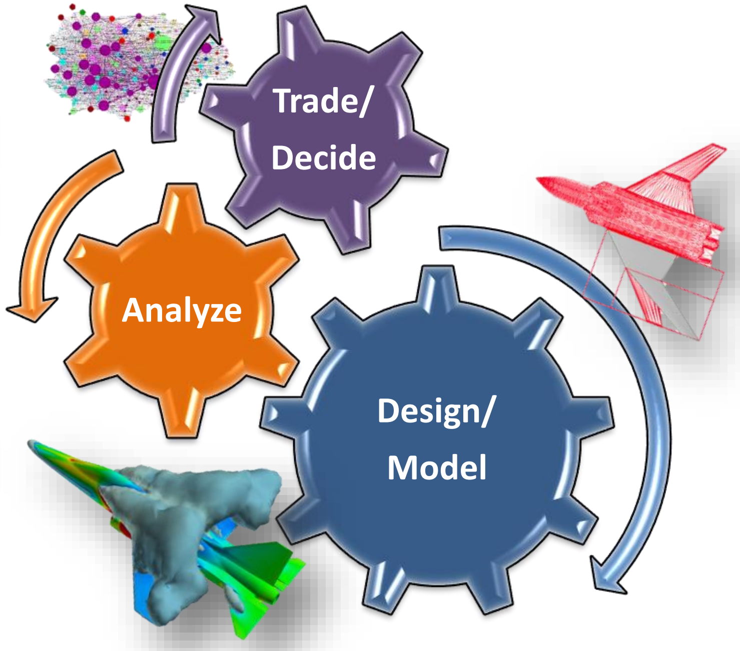
## Better Buying Power (BBP)

Adding ERS to best practices

- Perform affordability analysis
- Assessing Resilience Tradeoffs
- Quantify value trade space | Extend Service Lifetime | Extend Service Lifetime
- Quantify uncertainty
- Perform modeling and simulation
- Identify cost drivers | Identify relevant illities | Identify performance Measures
- Expand the design space and provide resilience options
- Identify missions, scenarios, threats and capability gaps

## Requirements Generation
## Fully Explore & Identify KPPs

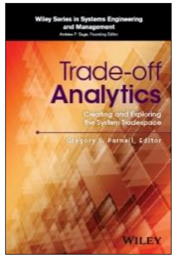

**Analysis of Alternative**
**(Alternatives Reduction)**



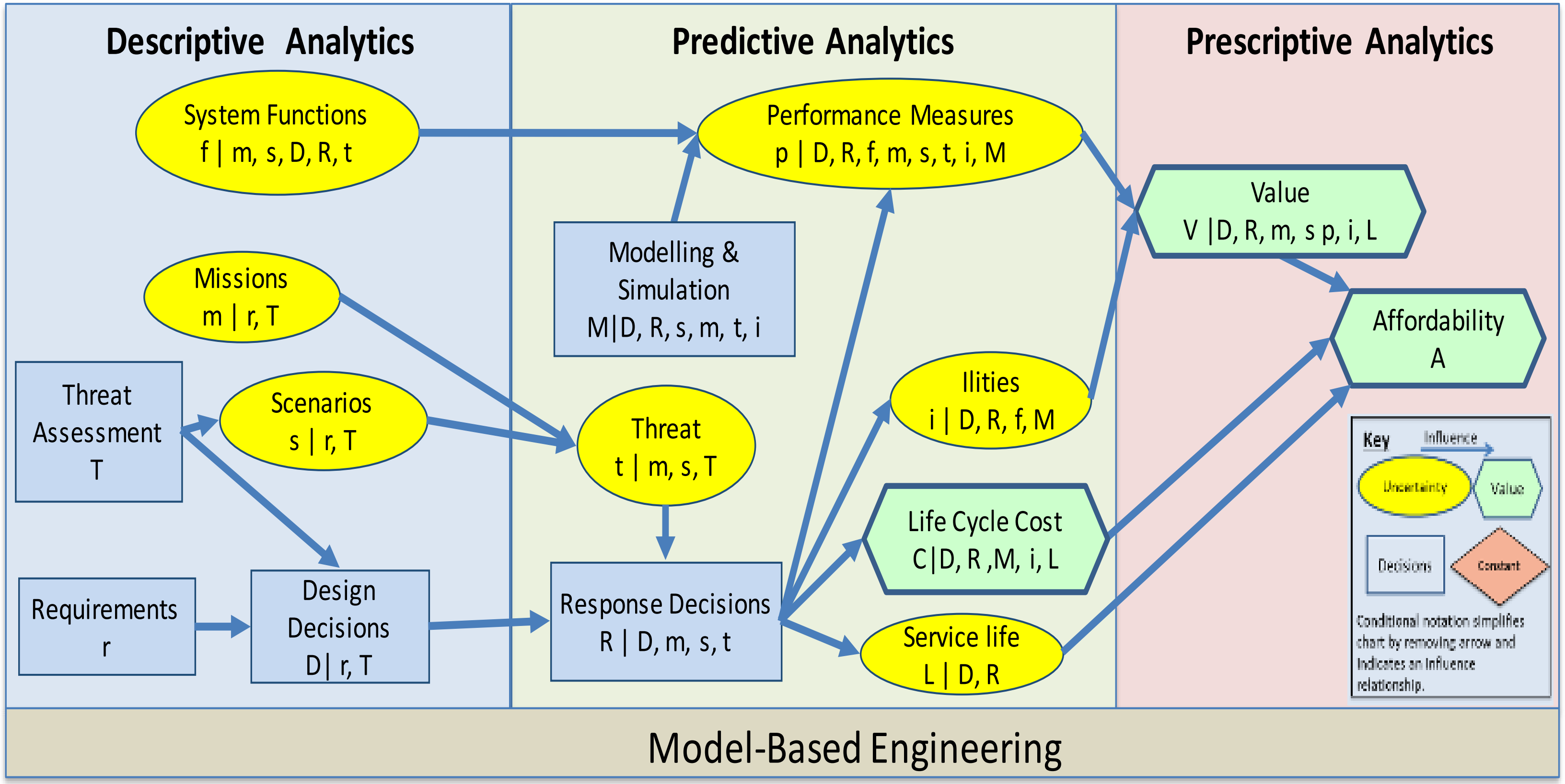

Based on Small, Colin; Parnell, Greg; Pohl, Ed; Goerger, Simon; Cottam, Bobby; Specking, Eric; Wade, Zephan. (2016). Engineering Resilience for Complex Systems. 15th *Annual Conference on Systems Engineering Research Conference Proceedings.*

UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

# Developed Integrated Trade-Off Analytics Framework




- Retained the sound mathematical foundation
  - Multiple Objective Decision Analysis for value
  - Life Cycle Cost
  - Value and Cost Risk
- Retained SIPmath
- Expanded integrated framework to focus on ERS
- Focused on Set-Based Design to create and explore the tradespace

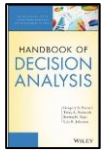



The integrated model uses MBE to simultaneously assess the value, cost, and risk of the tradespace to identify affordable, efficient decisions.

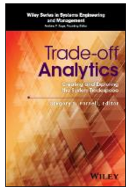
Modified from MacCalman, Alexander D., Gregory S. Parnell and Sam Savage. "An Integrated Model for Trade-off Analysis." Parnell, Gregory S. Trade-off Analytics: Creating and Exploring the System Tradespace. Wiley, 2016

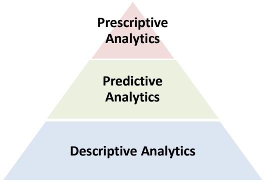
Small, C., Parnell, G., Pohl, E., Goerger, S., Cottam, C., Specking, E., Wade, Z., (2018) Engineering Resilience for Complex Systems. In: Madni A., Boehm B., Ghanem R., Erwin D., Wheaton M. (eds) Disciplinary Convergence in Systems Engineering Research. Springer, Cham, pp. 3-15

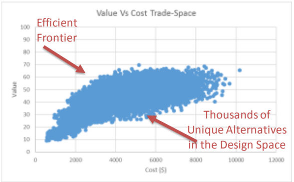
# Key Trade-off Analytics Ideas

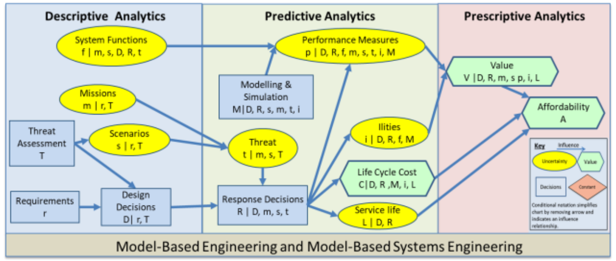


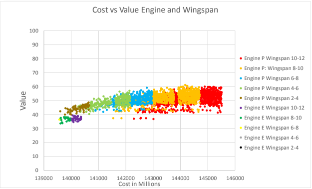

- Use decision analysis to define value of the capability to the stakeholders
- Perform trade-off analytics (cost vs. value) using descriptive, predictive, and prescriptive analytics
- Develop integrated model that use Model-Based Engineering to assess the value, cost, and risk of designs
- Perform AoA tasks simultaneously in near real-time using Excel
- Use Set-Based Design to identify and explore the tradespace (SIPmath*)
- Incorporate analysis of uncertainty (SIPmath*) in near real-time
- Transparently describe the complexity of the trade-off analytics

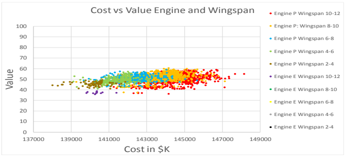


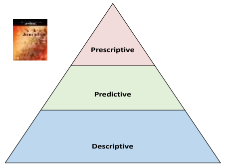



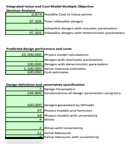



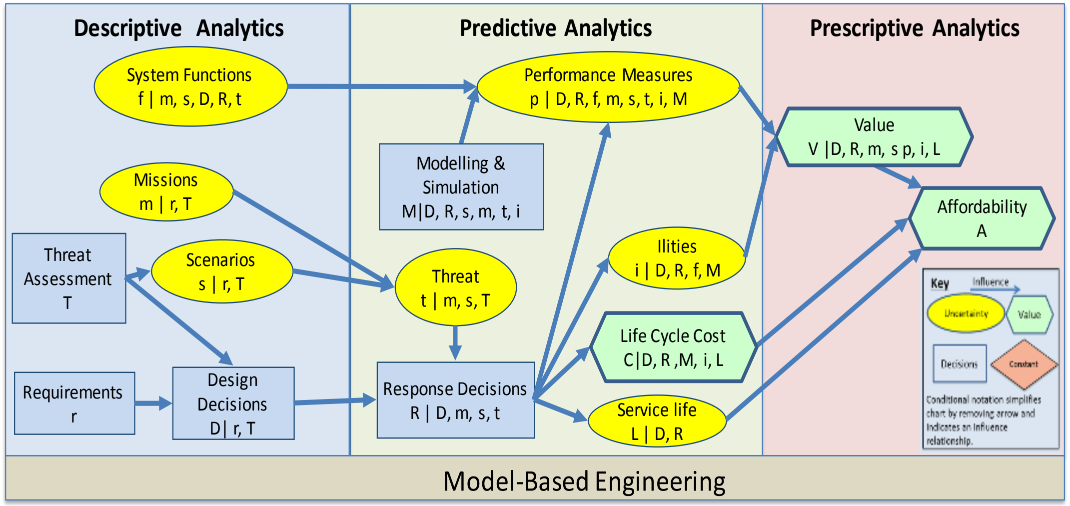
* www.probabilitymanagement.org/

UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

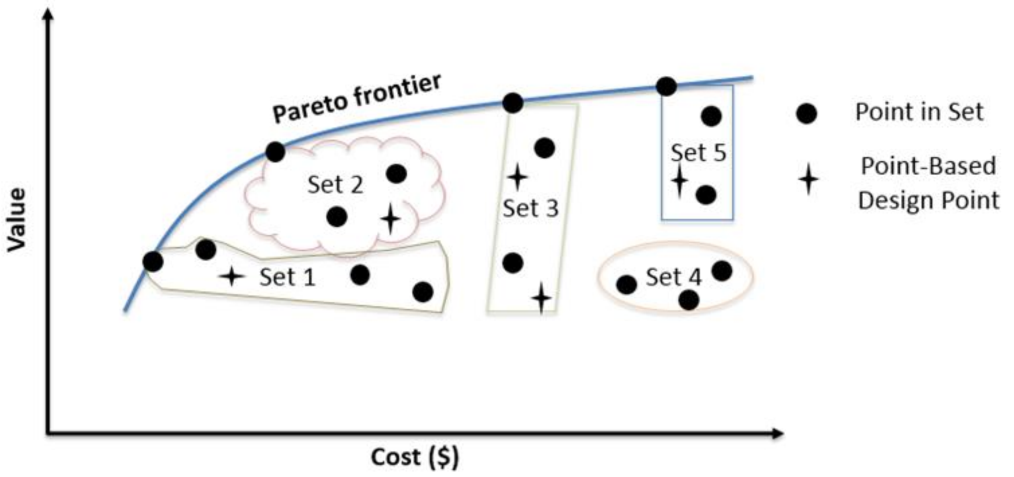
# An Integrated Process with SBD

ERS ENGINEERED RESILIENT SYSTEMS
DEPARTMENT OF DEFENSE

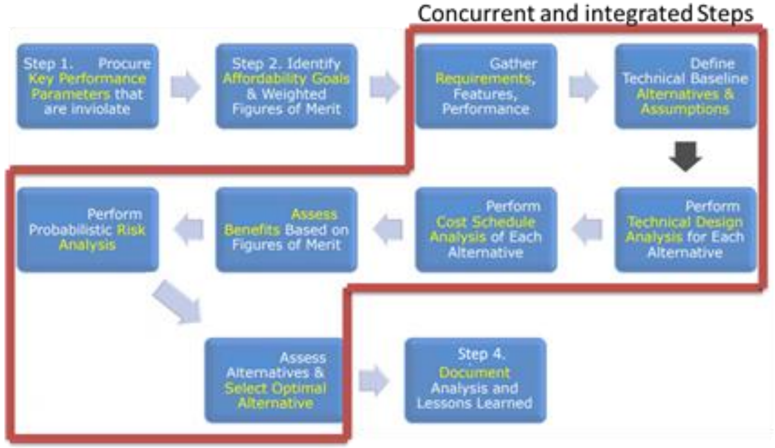
## Integrated Framework



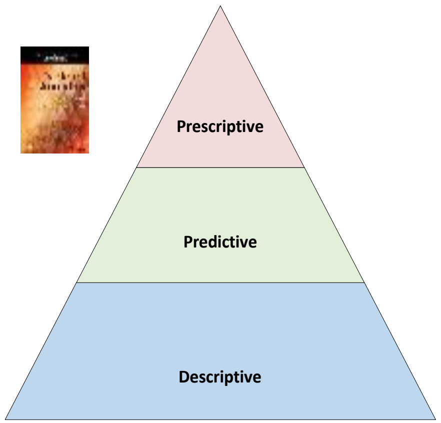

## Set-Based Design




## Simultaneous Modeling




## Trade-off Analytics Hierarchy




**Integrated Value and Cost Model Multiple Objective Decision Analysis**

| | |
|---|---|
| 2,674 | Feasible Cost vs Value points |
| 97,326 | Total infeasible designs |
| - | Infeasible designs with stocastic parameters |
| 97,325 | Infeasible designs with deterministic parameters |

**Predicted design performace and costs**

| | |
|---|---|
| 22,200,000 | Physics model calculations |
| - | Designs with stochastic parameters |
| 100,000 | Designs with deterministic parameters |
| 1,100,000 | Value measure estimates |
| 100,000 | Cost estimates |

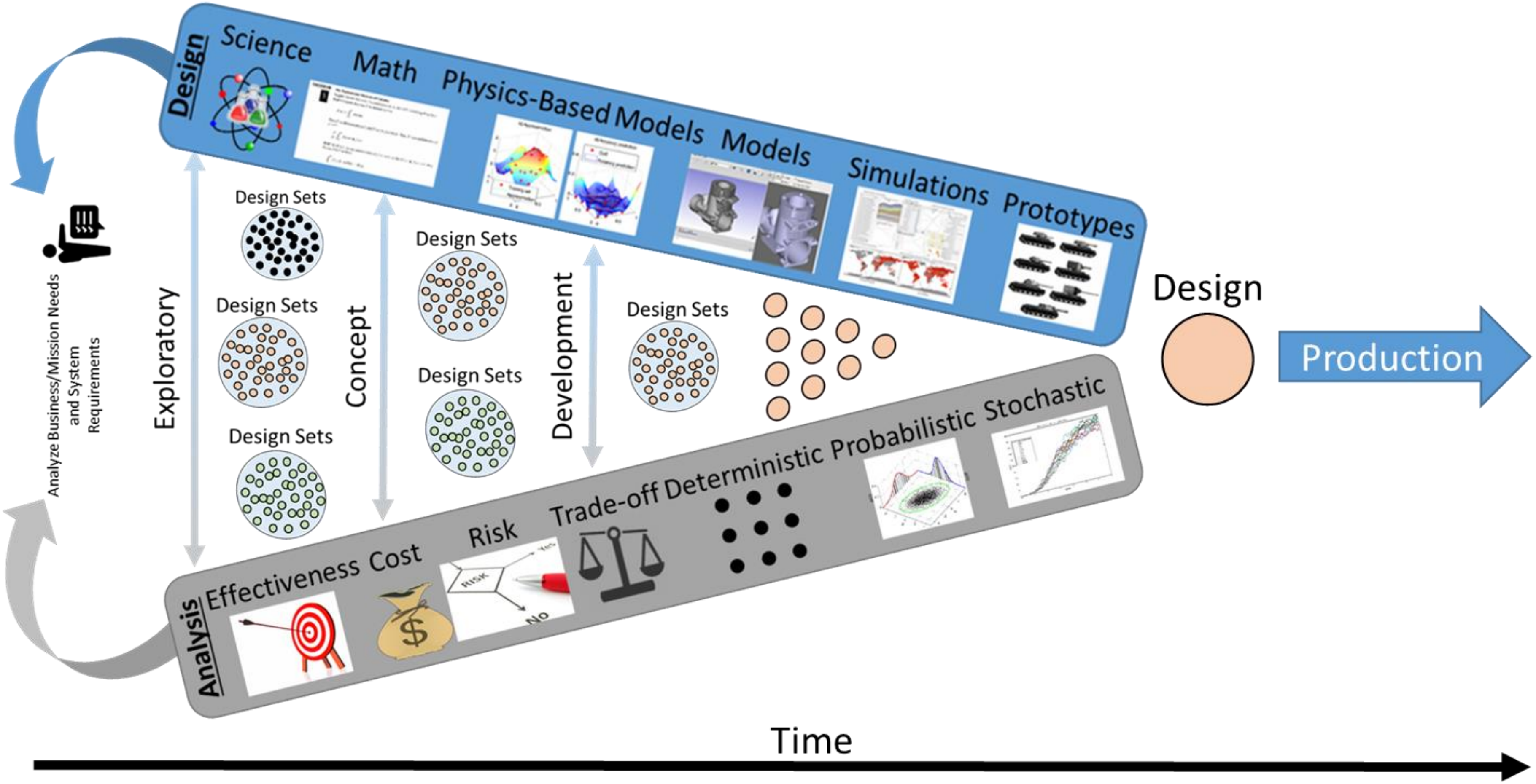
**Design definition and uncertainty specification**

| | |
|---|---|
| 7 | Design Parameters |
| 145,800 | Combinations of design parameters using bins |
| 100,000 | Designs generated by SIPmath |
| 47 | Physics models and formulas |
| 19 | Physics models with uncertainty |
| 4 | Illities |
| 2 | Illities with Uncertainty |
| 11 | Value Measures |
| 8 | Value measures with uncertainty |

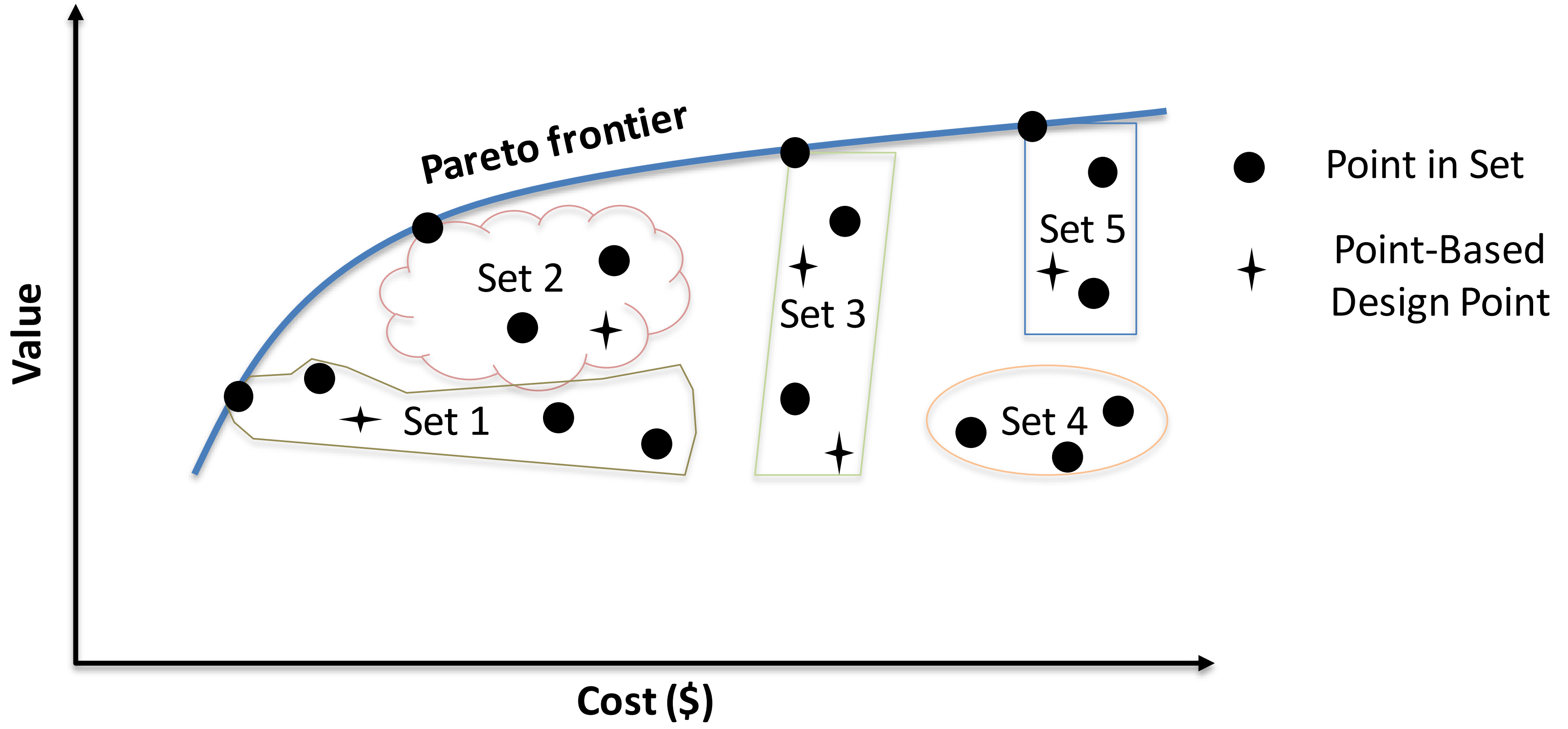
An integrated framework with Model-Based Engineering provides an efficient and responsive analysis process.

UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

# SBD Conceptual Framework



# Set-Based Design Motivation




- In set based design, design decisions are split into Set Drivers and Set Modifiers
- The sets in Set-Based design are determined by the set drivers.

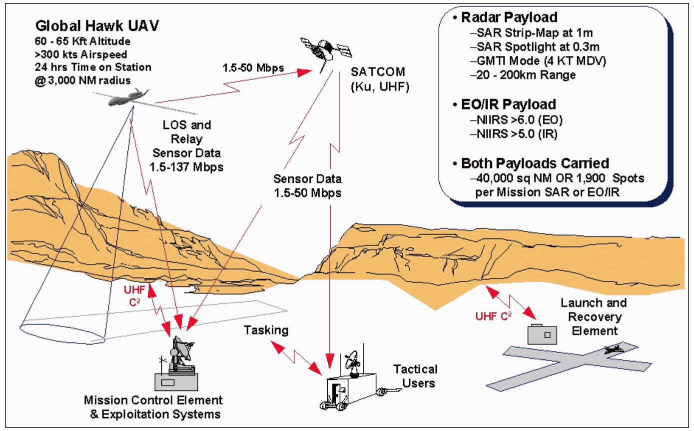
Set-based design allows for further exploration of the design space over point-based design.

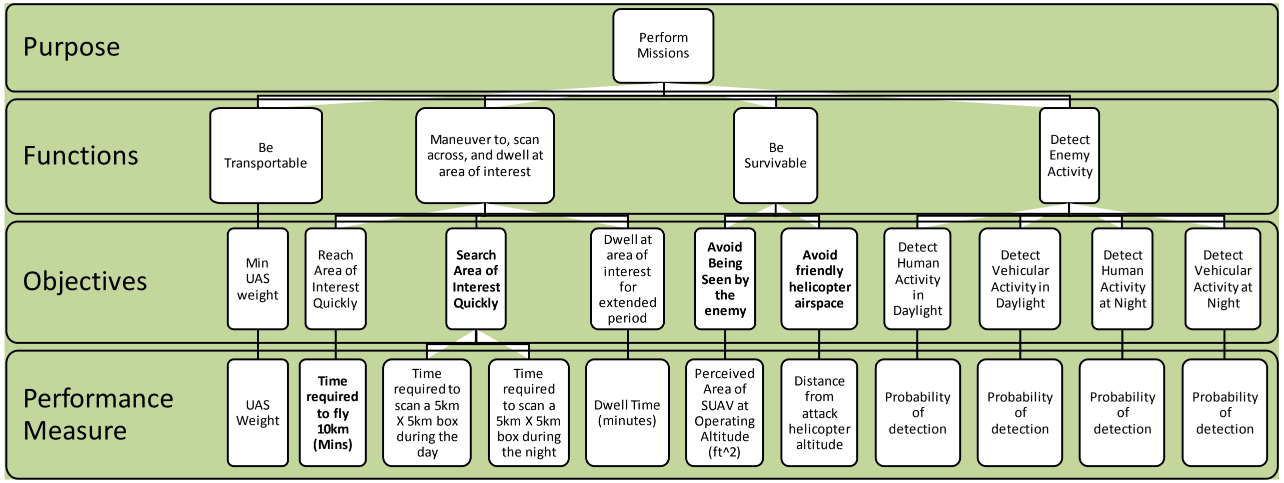
Wade, Z., Parnell, G., Goerger, S., Pohl, E., Specking, E. “Designing Engineered Resilient Systems Using Set-Based Design” 16th Annual Conference on Systems Engineering Research, Charlottesville, Virginia, May 8-9, 2018

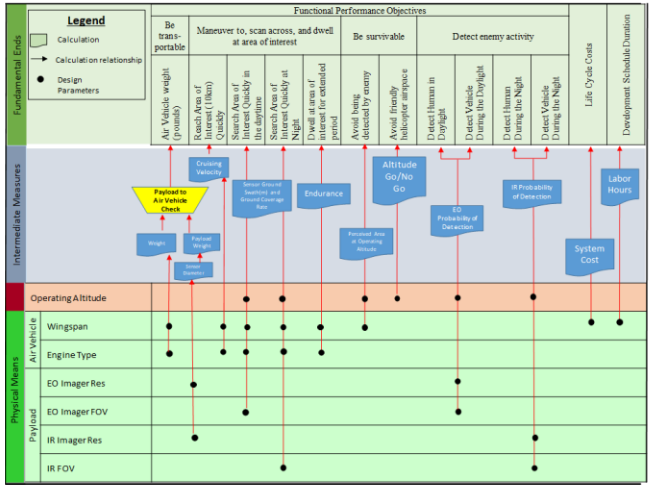
UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

# ERS UAV Demonstration Data

- Using a UAV Case Study, this research has applied the Trade-off Analytics Framework and set based design to the case study.
- In the initial case study, 7 design decision were propagated through physics-based models to performance measures and cost.



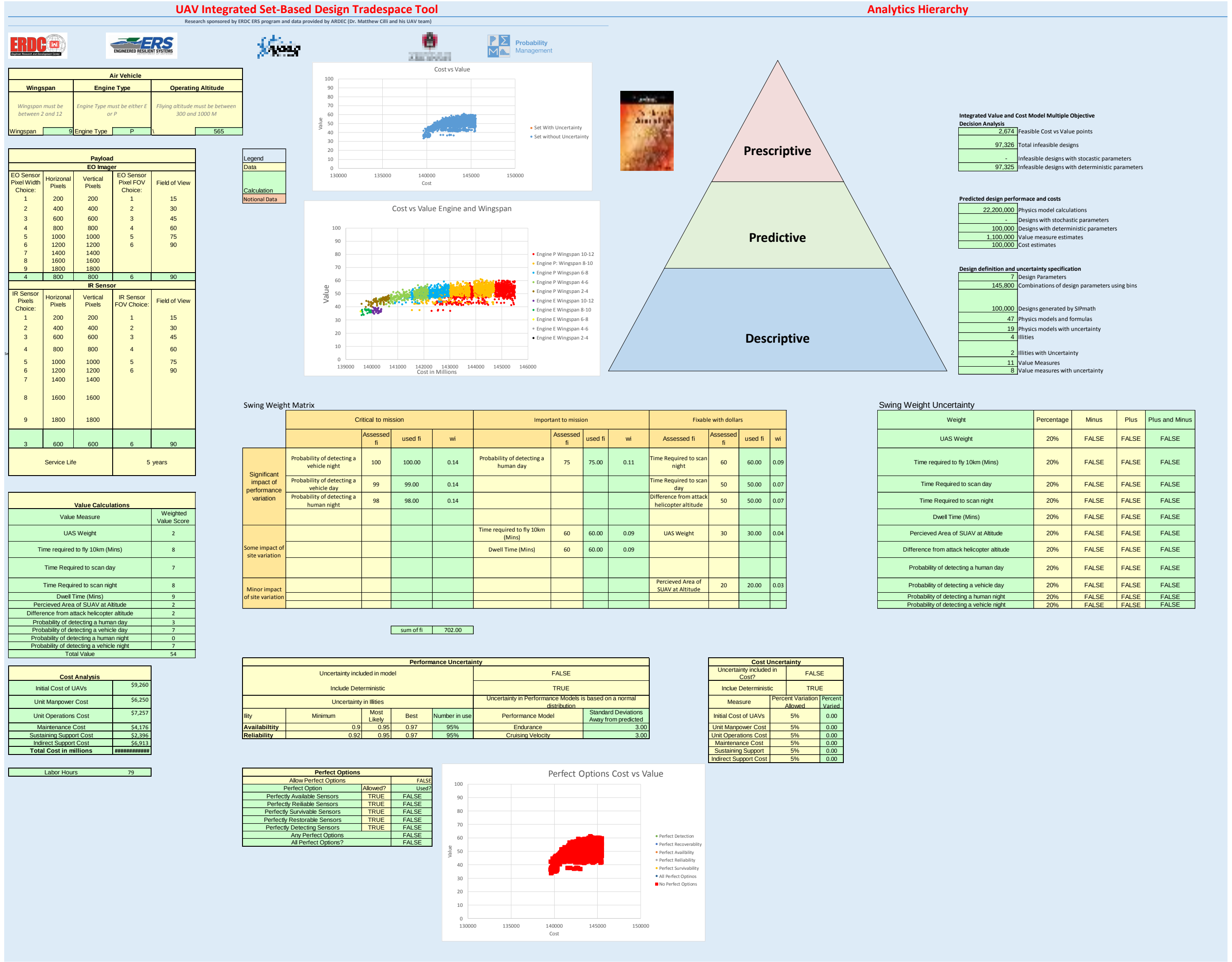




Cilli, Matthew. "Decision Framework Approach Using the Integrated Systems Engineering Decision Management (ISEDM) Process." *Model Center Engineering Workshop, Systems Engineering Research Center (SERC)*. 31 July 2017.

# UAV Case Study Control Panel

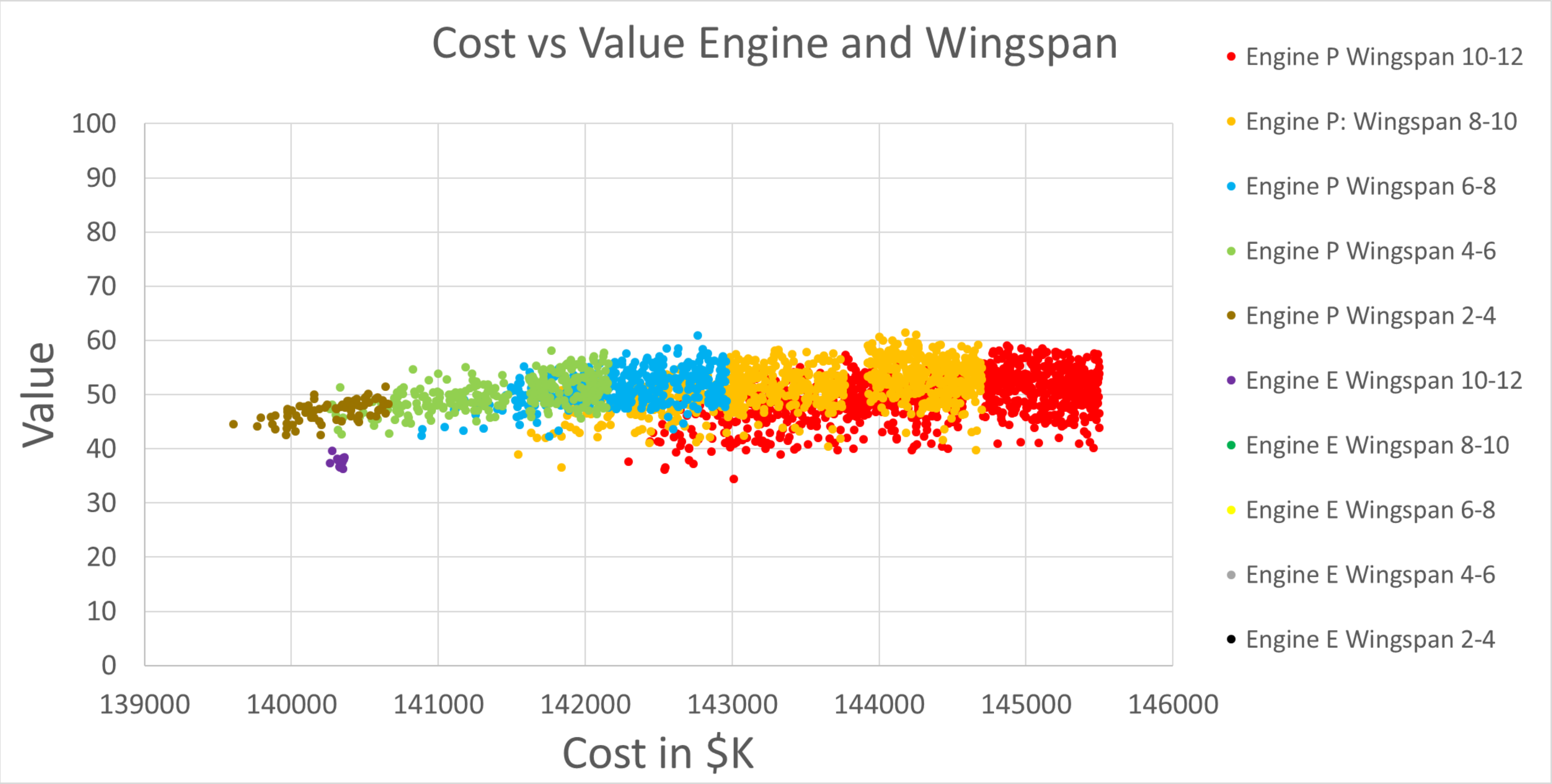
- Using random numbers generated by SIPmath, the tradespace tool uniformly explores the entire design space.
- In addition, the control panel allows the user to select the level of uncertainty on performance, cost, and preferences.




Small, C., Demonstrating Set-Based Design Techniques: A UAV Case study, Master's Thesis, Industrial Engineering, University of Arkansas, 2018

- The tool explores 100,000 design options and allows the user to control uncertainty in cost, performance, and preferences.
- In addition, the tool allows the user to explore perfect options (perfect availability, reliability, survivability, recoverability, and detection) to provide insight into resilience response decisions.

# UAV Deterministic Affordability Analysis




Small, C., Demonstrating Set-Based Design Techniques: A UAV Case study, Master's Thesis, Industrial Engineering, University of Arkansas, 2018

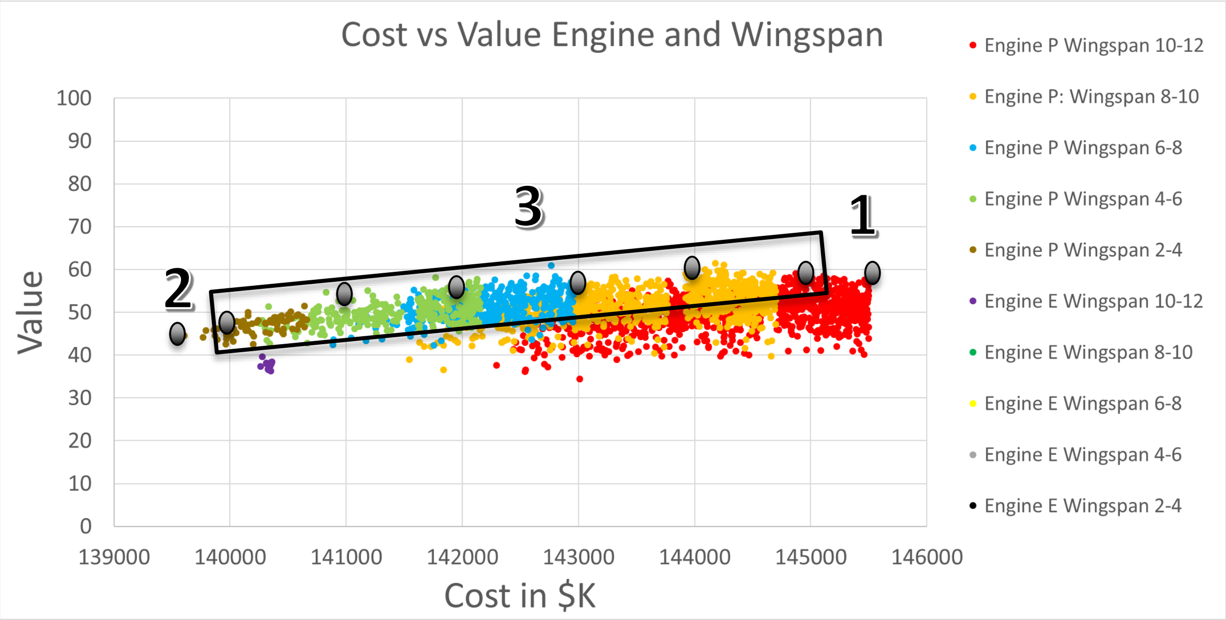
TSE with SBD explored design space with 100,000 design points.

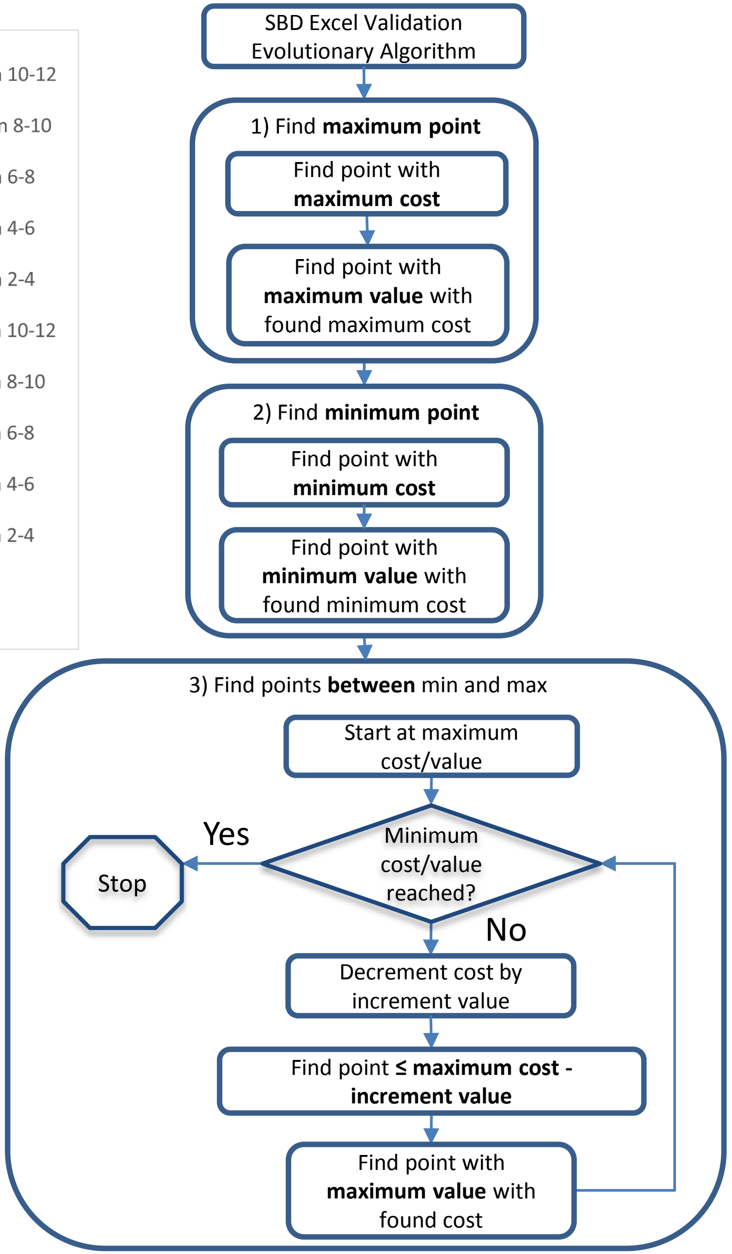
1) Is TSE with SBD process valid?

2) Does TSE with SBD find the efficient frontier?

3)If so, how many design points needs to be considered?

# TSE Validation Process



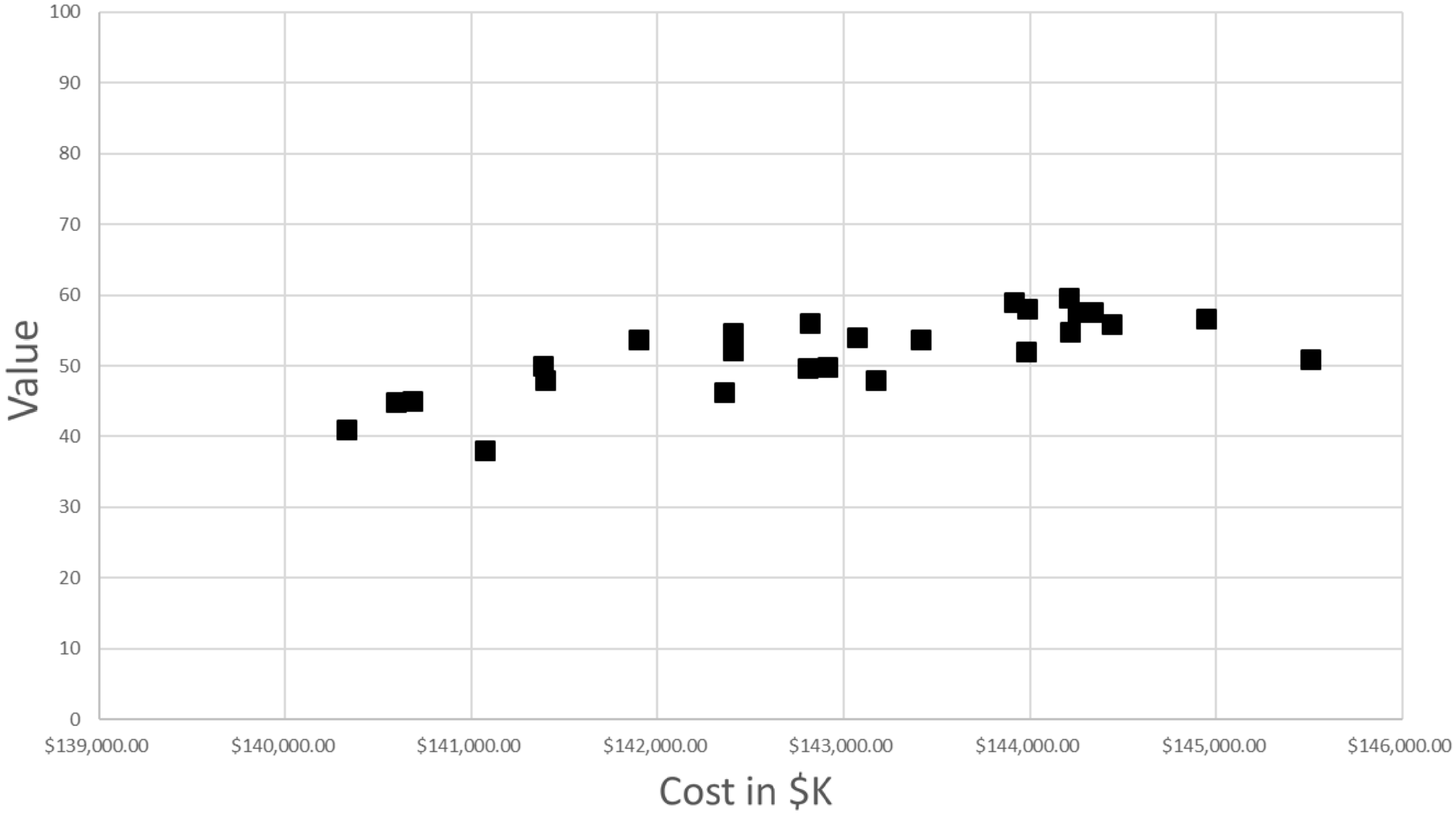




Genetic algorithms are commonly used to find efficient design points.

3 Step validation process using Excel's native genetic algorithm in Solver (evolutionary) coded into a custom macro.


Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

# Genetic Algorithm Found Points




**Run Information**:
8 runs
~350 hours of runtime

**Found**:
26 unique points
15 duplicate points
Total: 41

Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

# Genetic Algorithm Results

| | Total |
|---|---|
| Engine P Wingspan 10-12 | 2 |
| Engine P: Wingspan 8-10 | 12 |
| Engine P Wingspan 6-8 | 7 |
| Engine P Wingspan 4-6 | 4 |
| Engine P Wingspan 2-4 | 0 |
| Engine E Wingspan 10-12 | 1 |
| Engine E Wingspan 8-10 | 0 |
| Engine E Wingspan 6-8 | 0 |
| Engine E Wingspan 4-6 | 0 |
| Engine E Wingspan 2-4 | 0 |

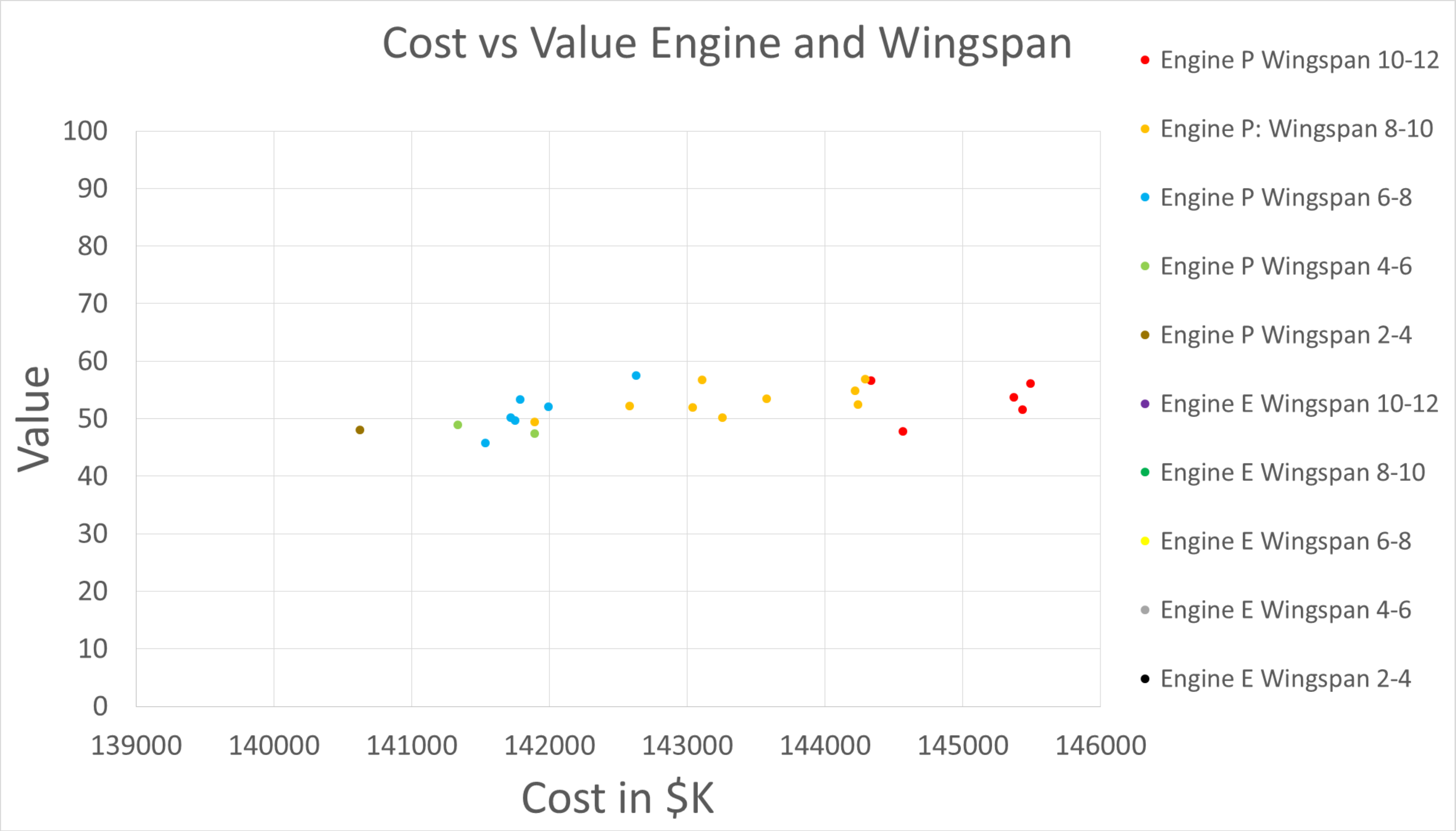
| Wingspan | Engine Type | Operating Altitude | EO Width | EO FOV | IR Width | IR FOV | Total Value | Total Cost in millions |
|---|---|---|---|---|---|---|---|---|
| 11.8 | 0 | 449.5 | 2 | 5 | 2 | 5 | 41 | $ 140,326 |
| 4.9 | 1 | 477.8 | 2 | 4 | 2 | 4 | 45 | $ 140,593 |
| 5.1 | 1 | 758.1 | 2 | 3 | 2 | 3 | 45 | $ 140,679 |
| 7.1 | 1 | 383.7 | 1 | 3 | 1 | 3 | 38 | $ 141,072 |
| 5.7 | 1 | 548.3 | 3 | 4 | 2 | 3 | 50 | $ 141,387 |
| 6.9 | 1 | 423.2 | 2 | 4 | 2 | 4 | 48 | $ 141,395 |
| 5.3 | 1 | 674.3 | 3 | 4 | 3 | 3 | 54 | $ 141,896 |
| 9.3 | 1 | 447.5 | 2 | 3 | 2 | 3 | 46 | $ 142,358 |
| 6.6 | 1 | 595.4 | 3 | 3 | 3 | 4 | 55 | $ 142,404 |
| 6.6 | 1 | 533.8 | 2 | 3 | 4 | 4 | 52 | $ 142,407 |
| 7.6 | 1 | 568.3 | 2 | 4 | 4 | 2 | 50 | $ 142,805 |
| 7.6 | 1 | 608.8 | 3 | 4 | 3 | 3 | 56 | $ 142,820 |
| 7.8 | 1 | 545.7 | 4 | 3 | 2 | 3 | 50 | $ 142,910 |
| 8.3 | 1 | 659.2 | 4 | 4 | 2 | 3 | 54 | $ 143,072 |
| 8.5 | 1 | 449.5 | 2 | 3 | 4 | 3 | 48 | $ 143,169 |
| 9.1 | 1 | 611.1 | 4 | 4 | 2 | 3 | 54 | $ 143,411 |
| 8.1 | 1 | 666.4 | 3 | 4 | 4 | 4 | 59 | $ 143,917 |
| 8.2 | 1 | 470.2 | 3 | 4 | 4 | 3 | 52 | $ 143,980 |
| 8.2 | 1 | 674.3 | 4 | 4 | 3 | 3 | 58 | $ 143,987 |
| 8.8 | 1 | 607.5 | 4 | 4 | 3 | 4 | 60 | $ 144,210 |
| 8.8 | 1 | 565.2 | 4 | 6 | 3 | 6 | 55 | $ 144,218 |
| 8.9 | 1 | 549.2 | 4 | 5 | 3 | 5 | 58 | $ 144,256 |
| 9.1 | 1 | 540.6 | 4 | 5 | 3 | 5 | 58 | $ 144,336 |
| 9.3 | 1 | 658.6 | 4 | 3 | 3 | 3 | 56 | $ 144,441 |
| 10.6 | 1 | 661.9 | 4 | 3 | 3 | 3 | 57 | $ 144,946 |
| 12.0 | 1 | 623.4 | 4 | 3 | 3 | 2 | 51 | $ 145,505 |

Majority of set classifications not found.

Found 8 (boxed) dominating design points.

Specking, E., Parnell, G., Pohl, E., Buchanan, R., “Evaluating a Set-Based Design Tradespace Exploration Process,” 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

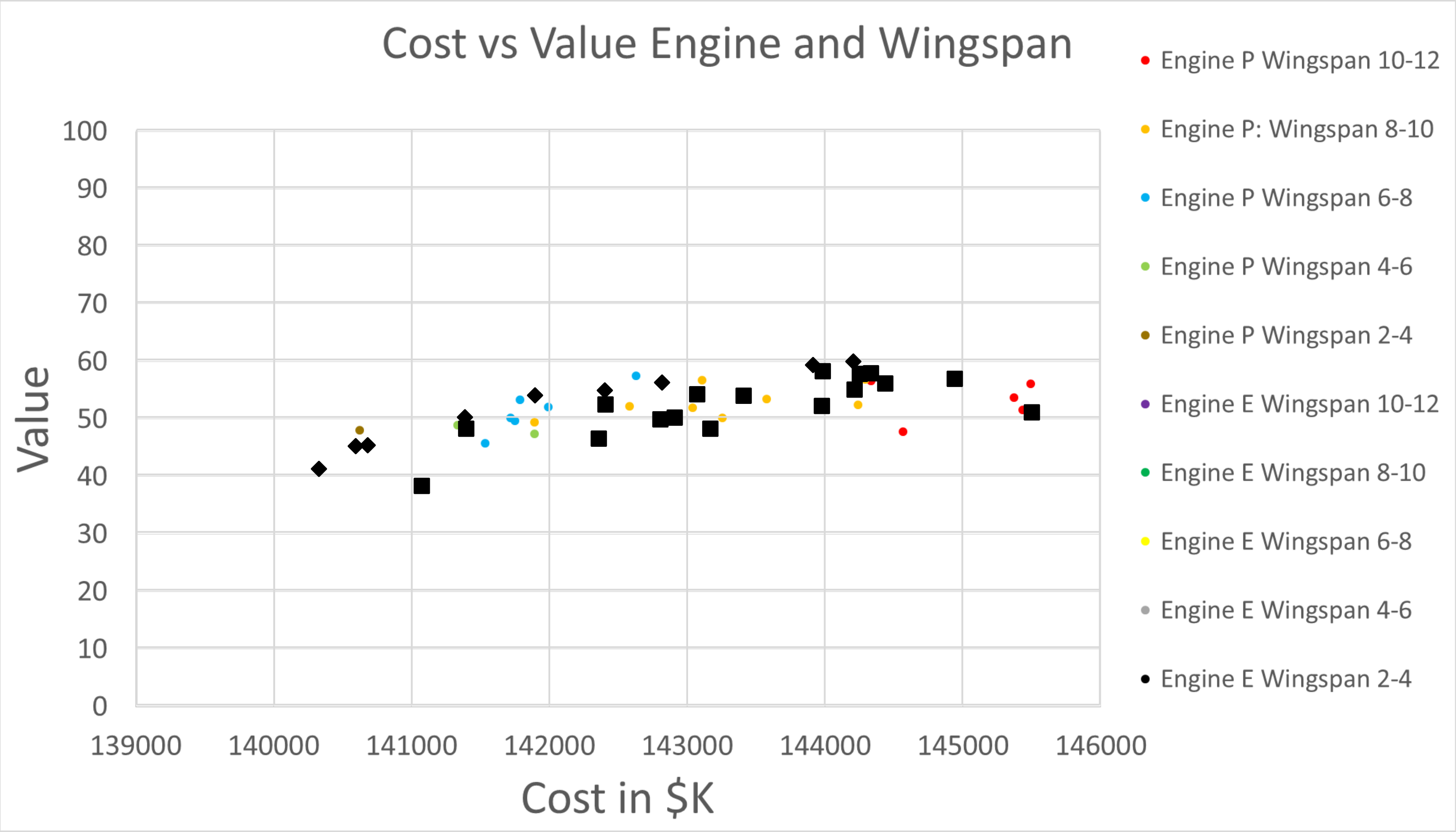
# 1,000 SBD Points




Specking, E., Parnell, G., Pohl, E., Buchanan, R., “Evaluating a Set-Based Design Tradespace Exploration Process,” 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

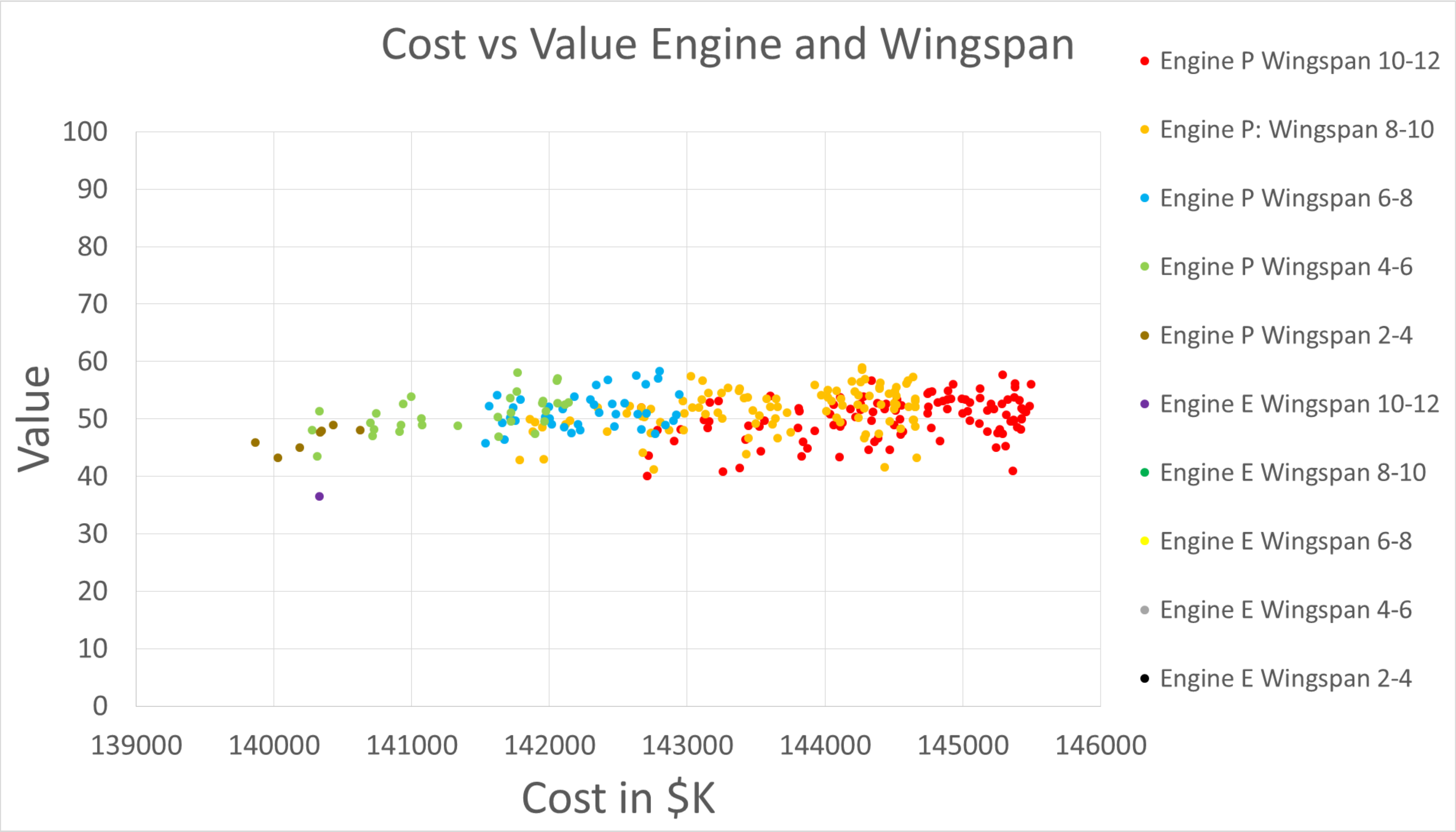
# 1,000 SBD Points with Genetic Algorithm Points




TSE with SBD methodology found **2** design points that dominated the genetic algorithm points!

Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

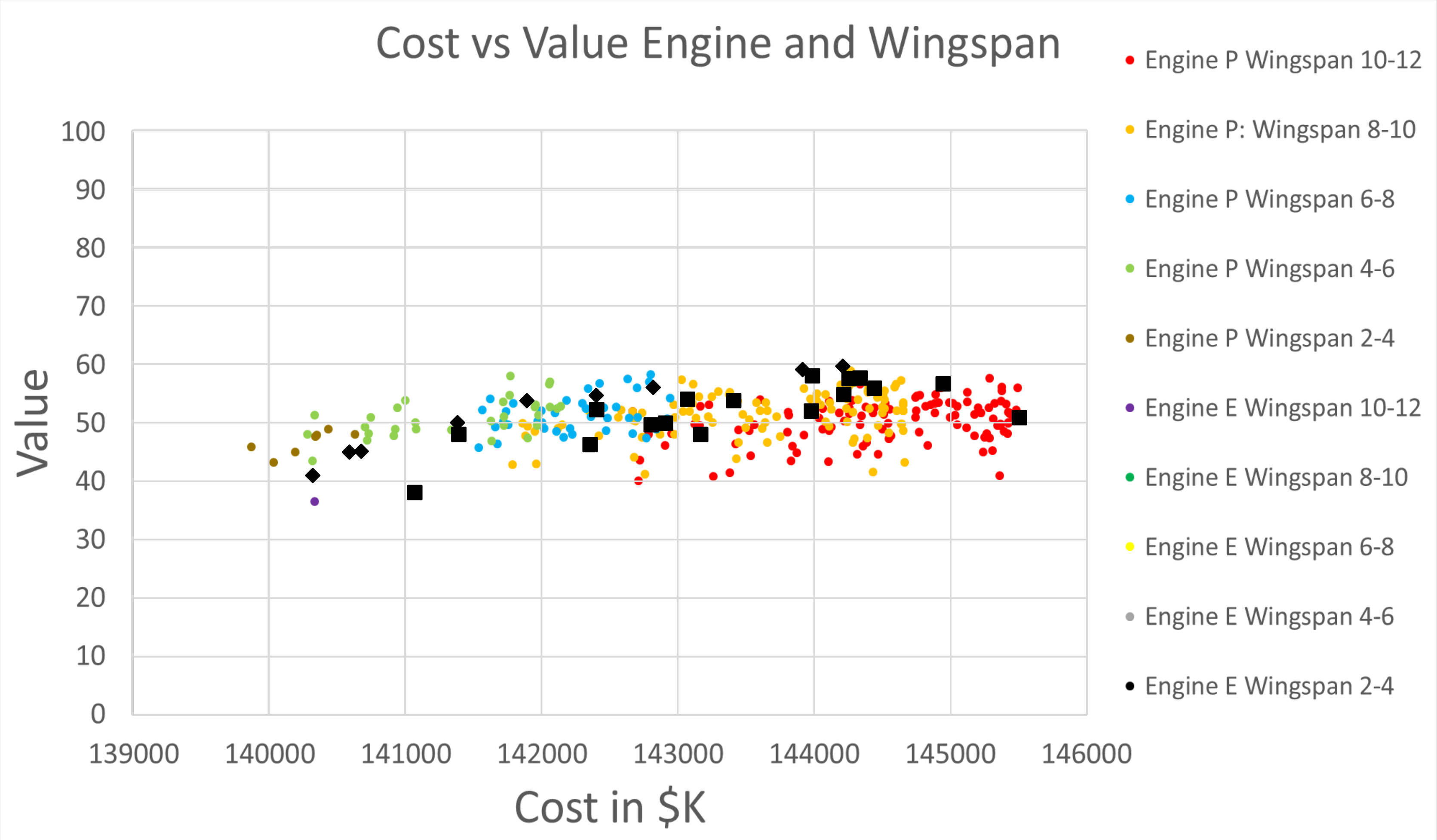
# 10,000 SBD Points




Specking, E., Parnell, G., Pohl, E., Buchanan, R., “Evaluating a Set-Based Design Tradespace Exploration Process,” 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

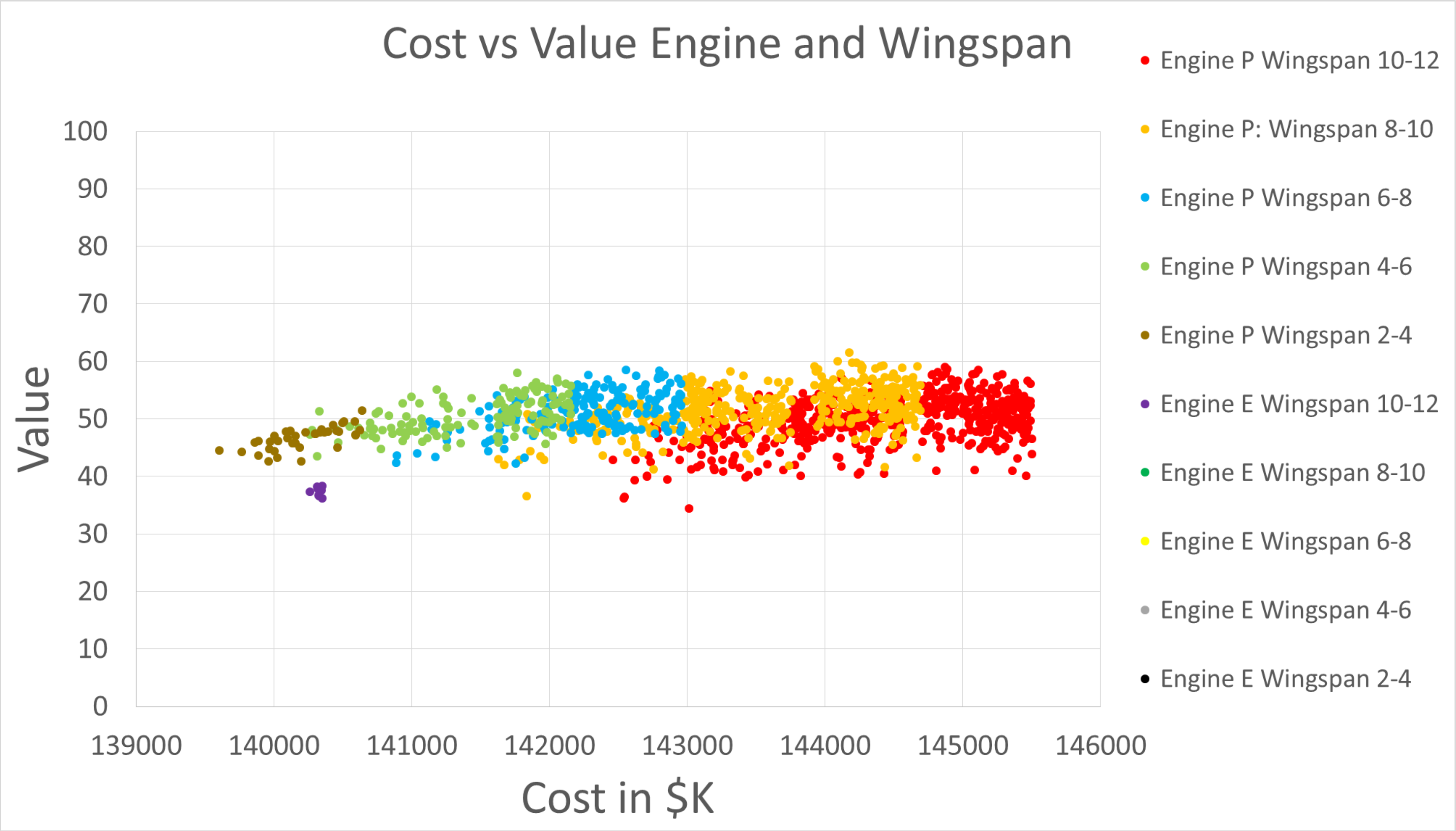
# 10,000 SBD Points with Genetic Algorithm Points




TSE with SBD methodology found **25** design points that dominated the genetic algorithm points!

Specking, E., Parnell, G., Pohl, E., Buchanan, R., “Evaluating a Set-Based Design Tradespace Exploration Process,” 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

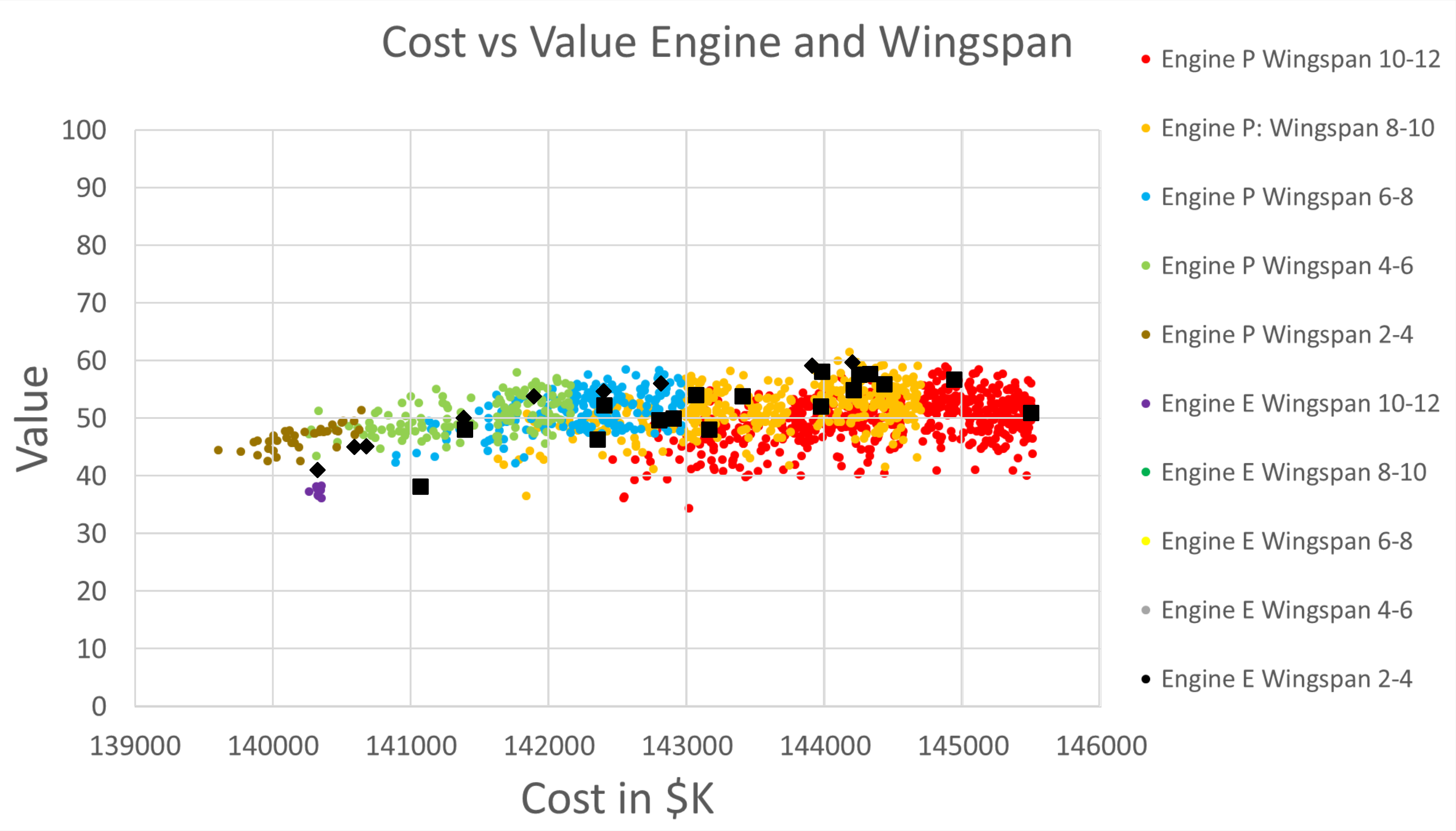
# 50,000 SBD Points





Specking, E., Parnell, G., Pohl, E., Buchanan, R., “Evaluating a Set-Based Design Tradespace Exploration Process,” 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

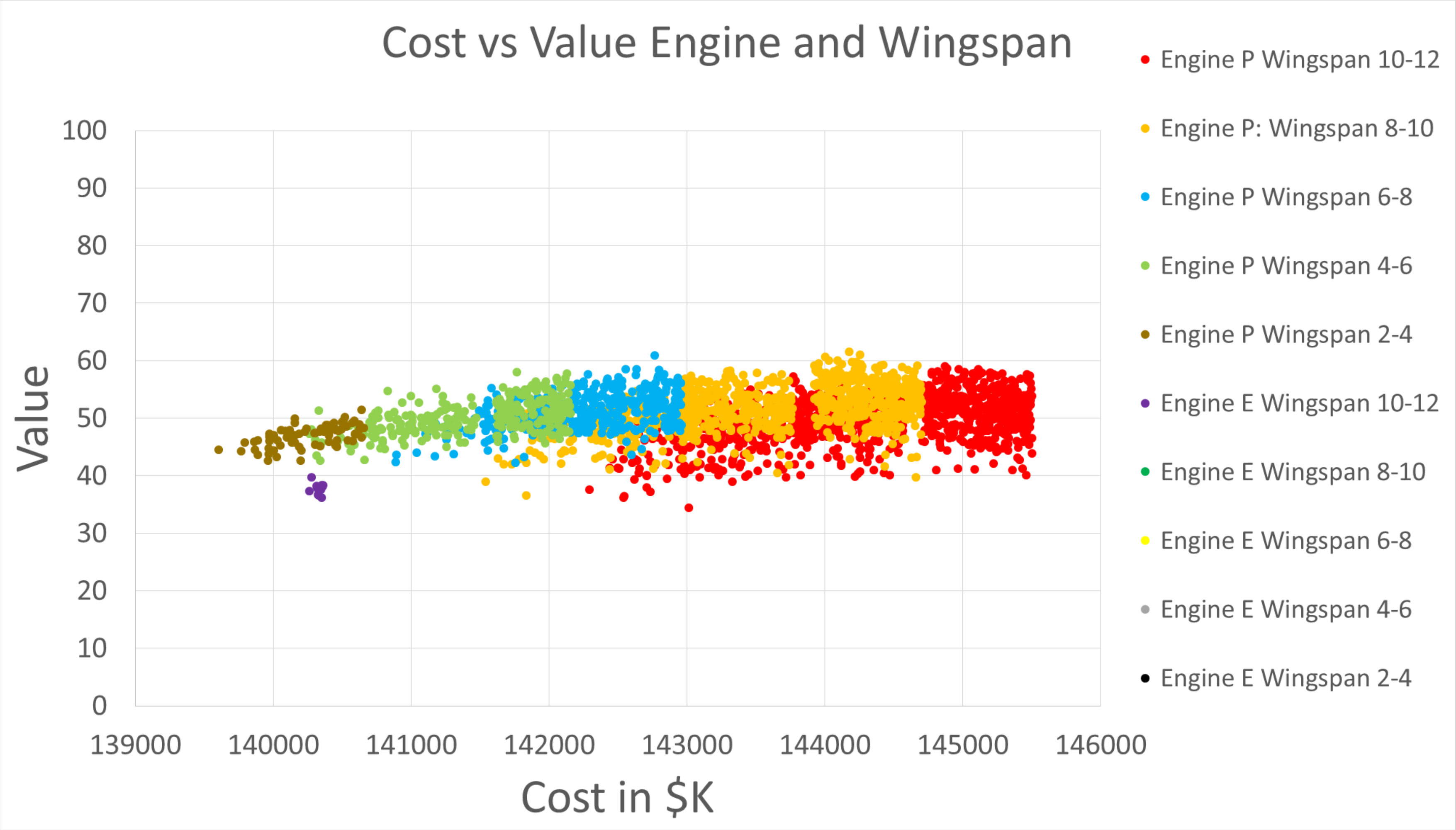
# 50,000 SBD Points with Genetic Algorithm Points




TSE with SBD methodology found **107** design points that dominated the genetic algorithm points!

Specking, E., Parnell, G., Pohl, E., Buchanan, R., “Evaluating a Set-Based Design Tradespace Exploration Process,” 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

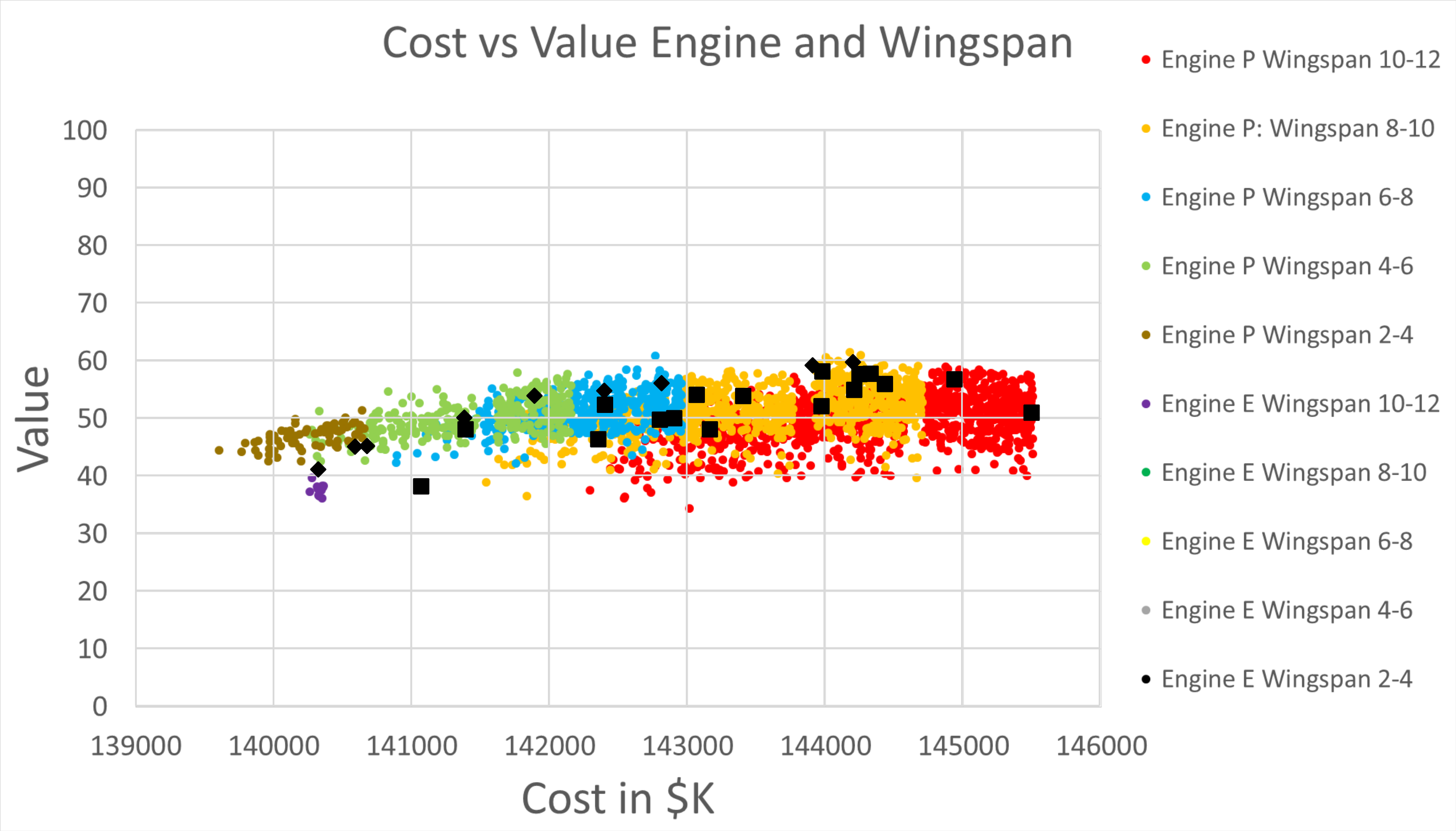
# 100,000 SBD Points




Specking, E., Parnell, G., Pohl, E., Buchanan, R., “Evaluating a Set-Based Design Tradespace Exploration Process,” 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

# 100,000 SBD Points with Genetic Algorithm Points

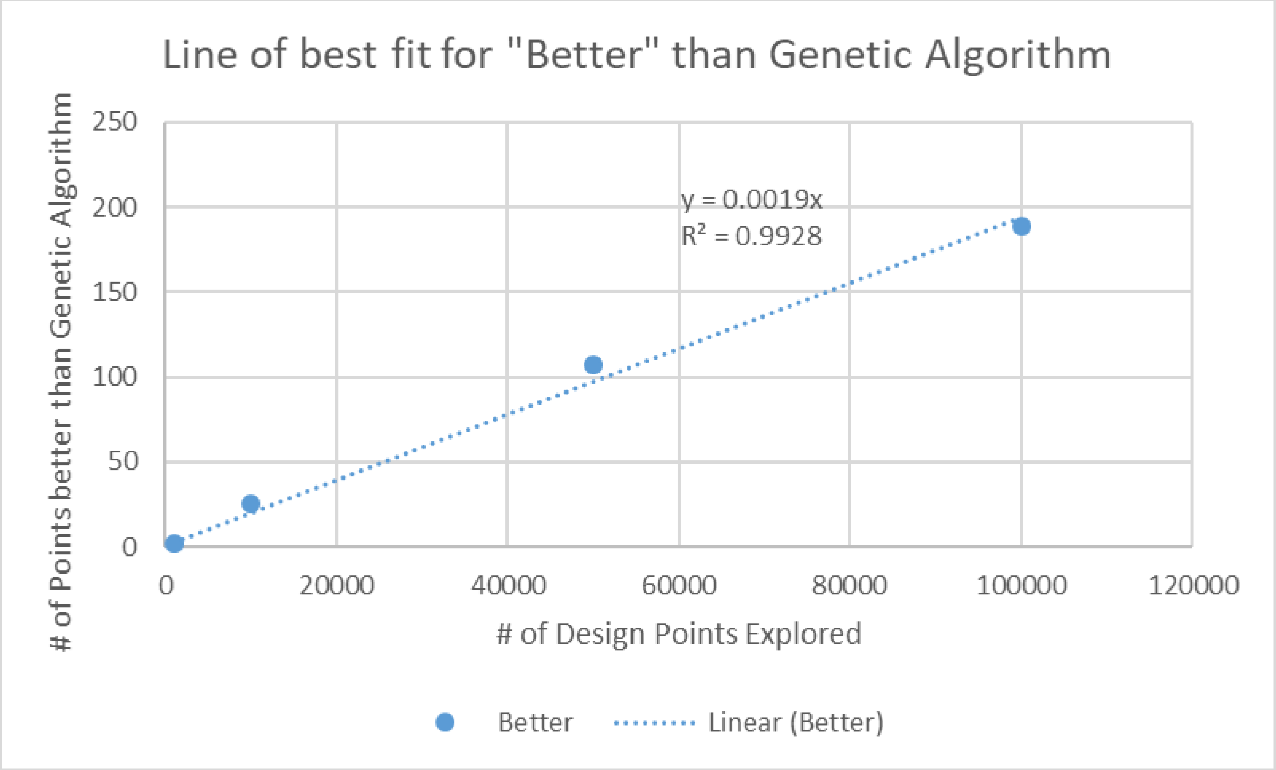



TSE with SBD methodology found **189** design points that dominated the genetic algorithm points!

Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

# TSE with SBD Validation Conclusion

| | Points Explored | | | |
|---|---|---|---|---|
| Compared to Genetic Algorithm | 1000 | 10000 | 50000 | 100000 |
| Better | 2 | 25 | 107 | 189 |
| As good or worse | 21 | 268 | 1241 | 2337 |
| Total | 23 | 293 | 1348 | 2526 |
| | | | | |
| % Better | 9% | 9% | 8% | 7% |
| % As good or worse | 91% | 91% | 92% | 93% |

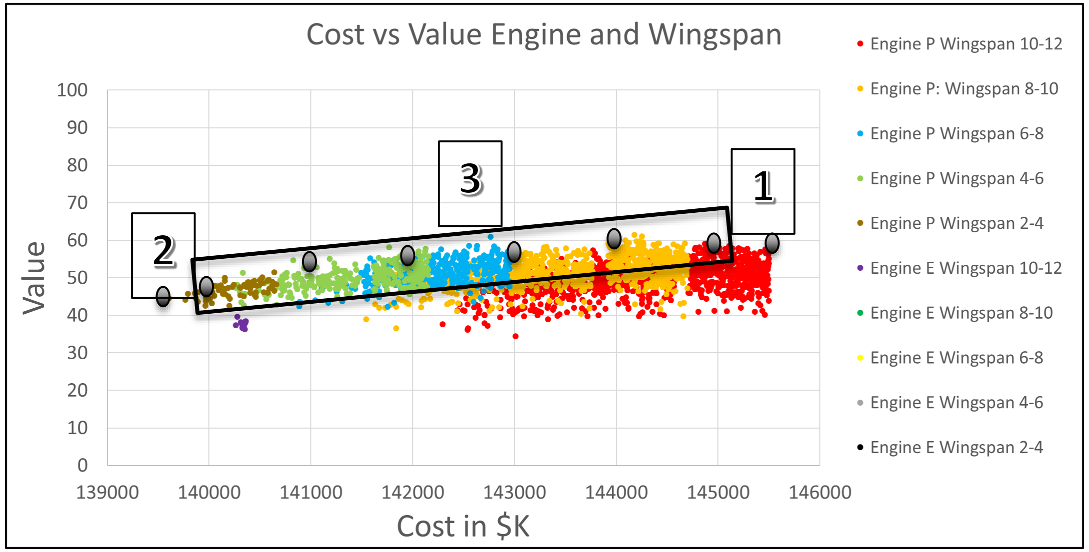



SBD is a good method to use to explore the design space.

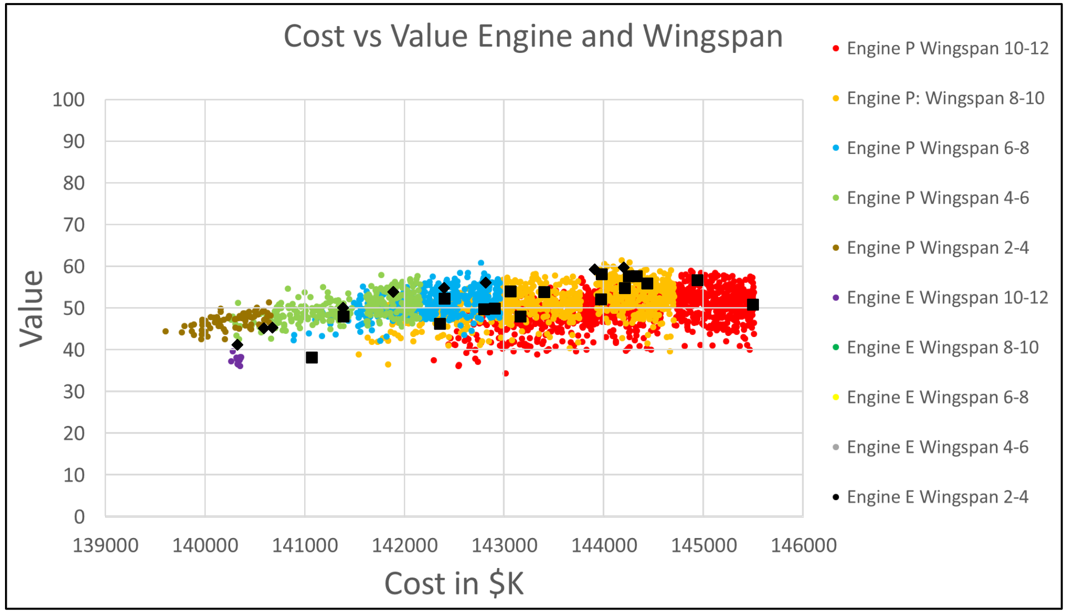
1. Found design points that dominated points found by a genetic algorithm
2. Found more dominating points when the total number of points explored in the model is increased

Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

# SBD TSE Validation Process




**100,000 SBD Points with Genetic Algorithm Points**




Initial Goal: Use optimization to validate SBD.

Genetic algorithms are commonly used to find efficient design points.

Validation process using Excel's genetic algorithm in Solver (evolutionary) coded into a custom macro to vary cost and find maximum value.

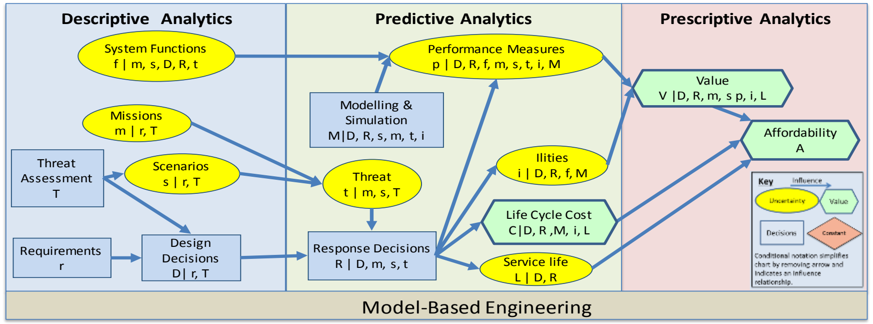
TSE with SBD methodology found **189** design points that dominated the genetic algorithm points!


Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019

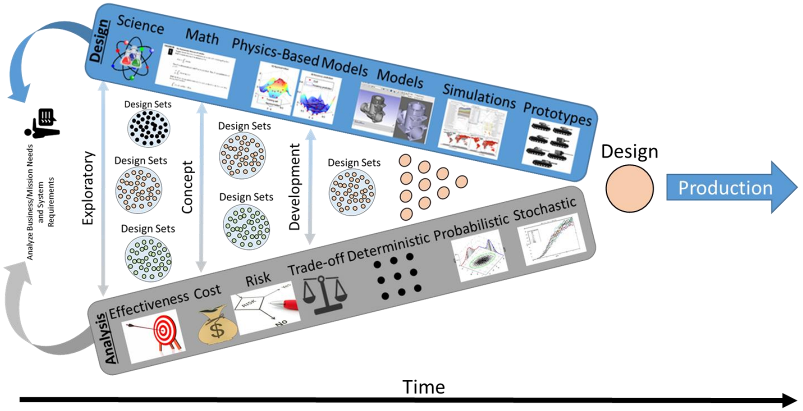
UNIVERSITY OF ARKANSAS
COLLEGE OF ENGINEERING

# Summary

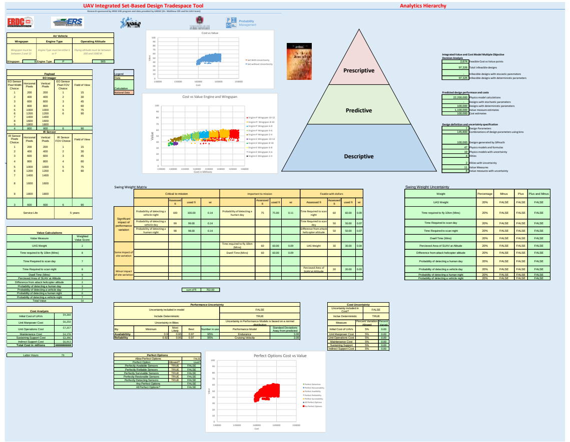
## Integrated Trade-off Analytics Framework



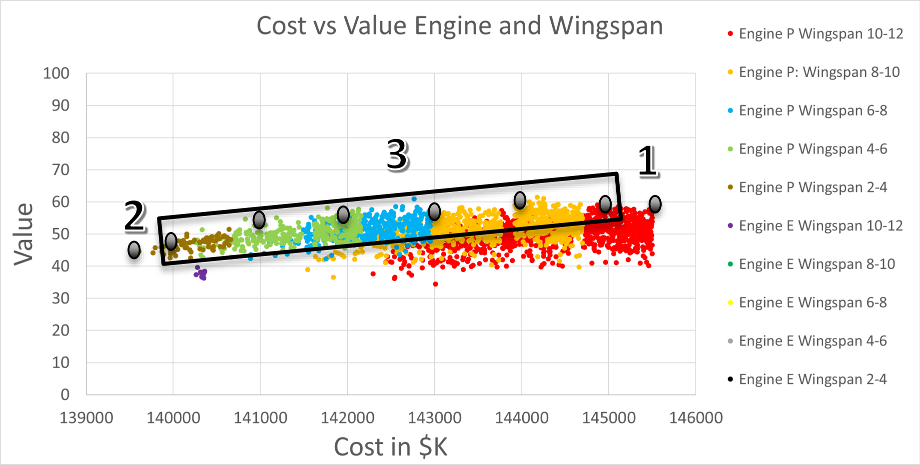

## Set-Based Design for Tradespace Exploration




## Demonstration Model

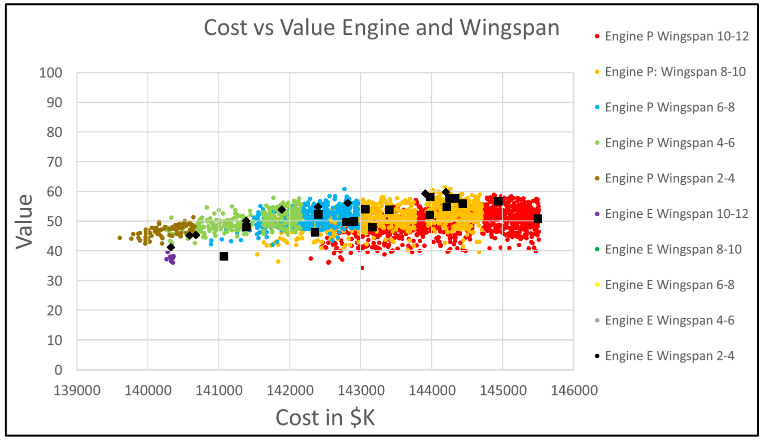


## SBD TSE Evaluation Method




TSE with SBD methodology found <u>189</u> design points that dominated points found by a genetic algorithm.

## Evaluation Results





Specking, E., Parnell, G., Pohl, E., Buchanan, R., "Evaluating a Set-Based Design Tradespace Exploration Process," 17th Annual Conference on Systems Engineering Research, April 3-4, 2019