Development and Integration of System-of-Systems Models for Unmanned Aircraft

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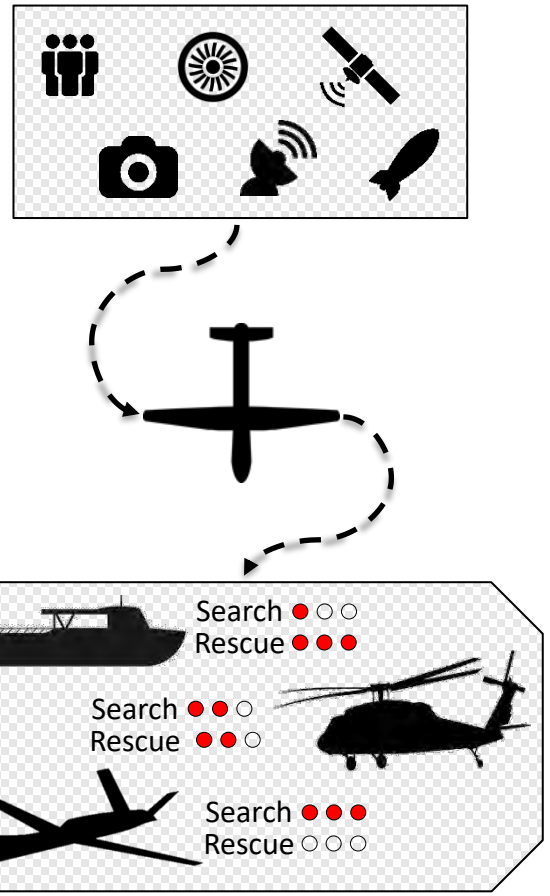
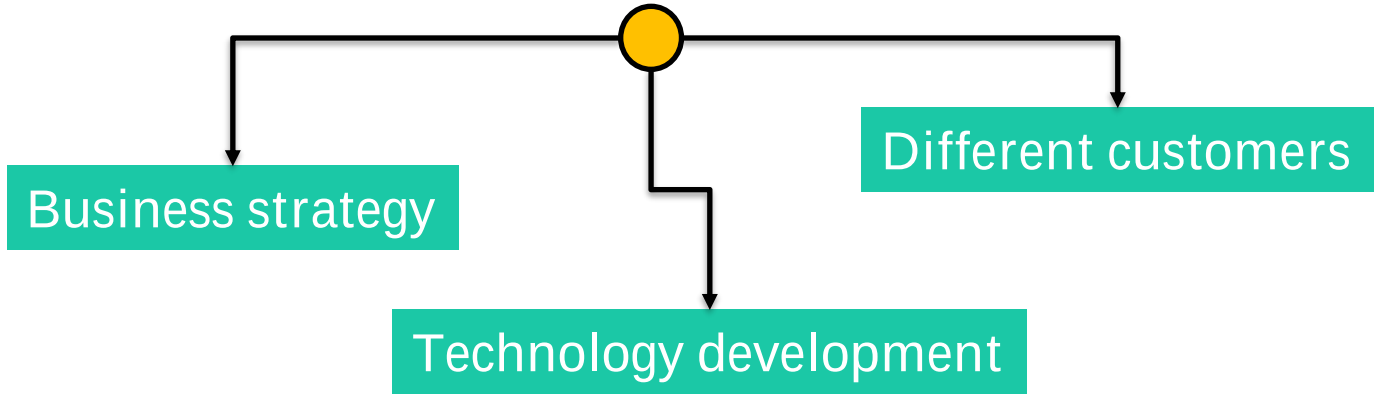
MODPROD 2020

LINKÖPING UNIVERSITY

Background

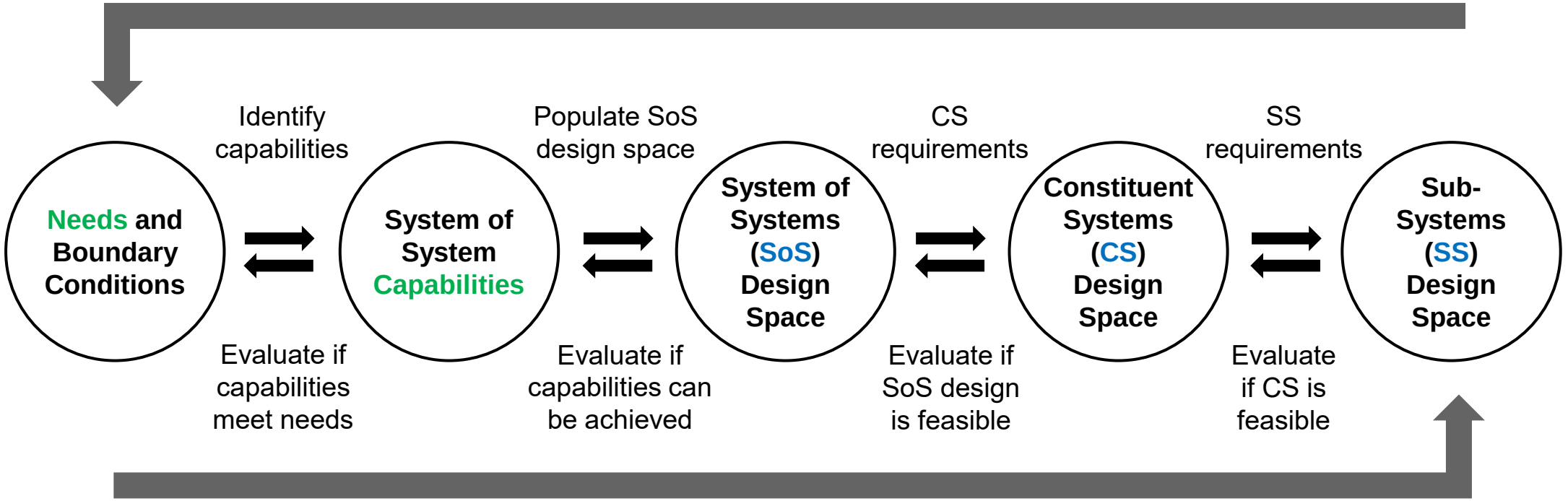
- Aerospace products are part of a network or a "System of Systems"
  - SoS analyses have been used in the way customer acquire new assets
  - Manufacturers should be able to perform similar analyses



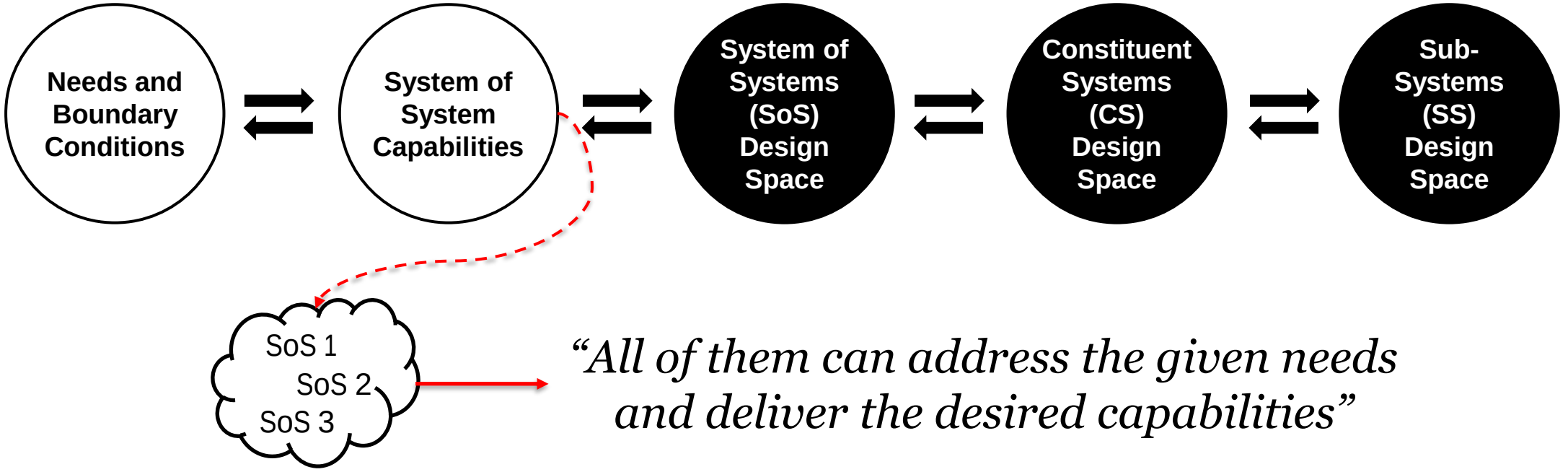


Background

"A holistic engineering approach to aeronautical product development"

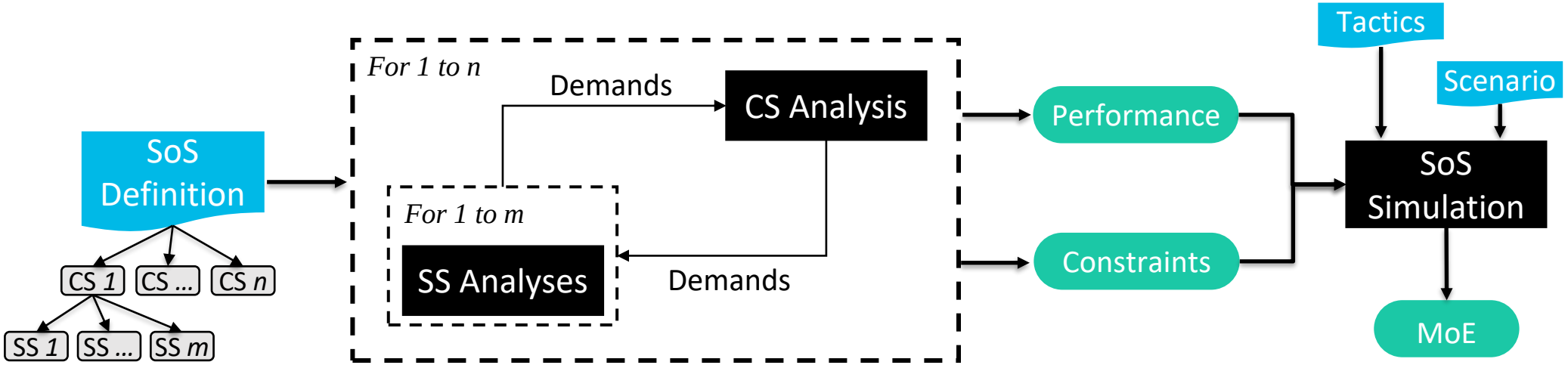


Aim


Needs and Boundary Conditions
System of System Capabilities
System of Systems (SoS) Design Space
Constituent Systems (CS) Design Space
Sub-Systems (SS) Design Space
SoS 1
SoS 2
SoS 3
"All of them can address the given needs and deliver the desired capabilities"
Which is better?
Can we get more?

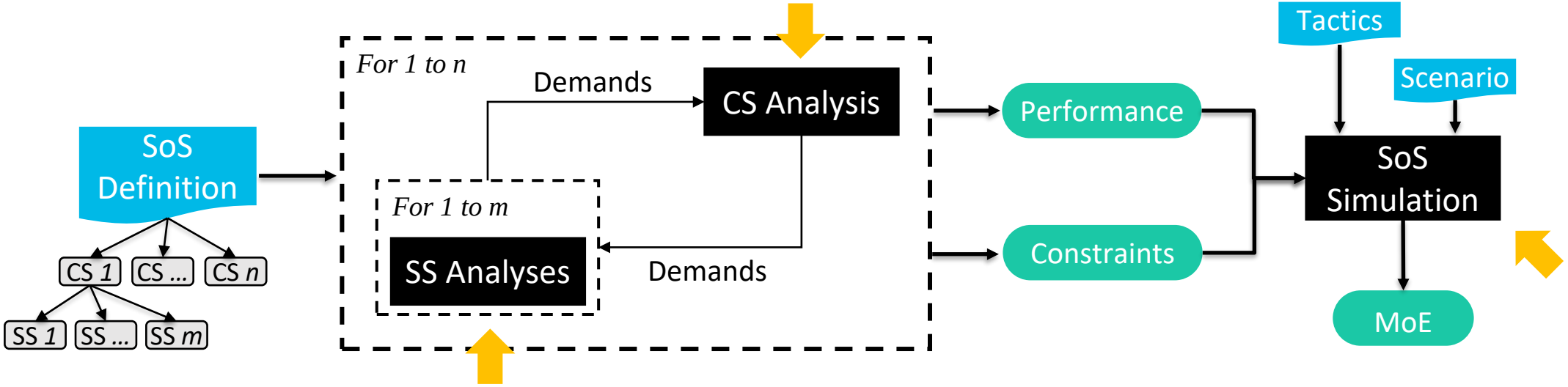
Identifying SoS Capabilities

- Framework for SoS design space population
  - First step is to define the SoS combinations to be evaluated
  - Second step is to identify the performance of each CS and SS
  - Third step is to simulate the entire SoS to extract the MoE

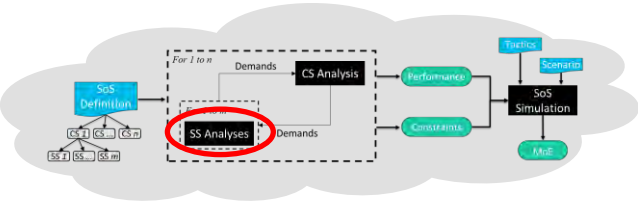


Identifying SoS Capabilities

- Framework for SoS design space population
  - Addresses all three levels of design
  - Not bound to any design space
  - Allows the use of multi-fidelity tools

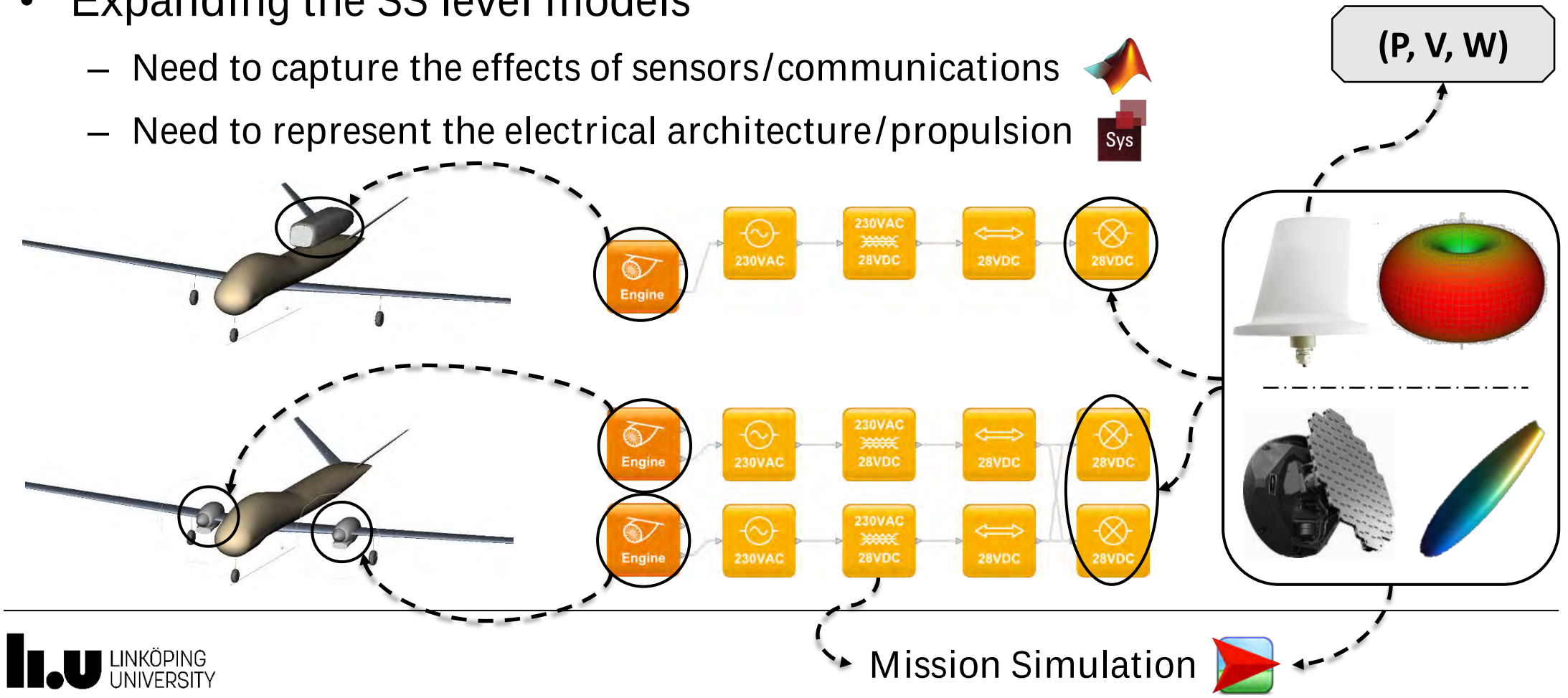


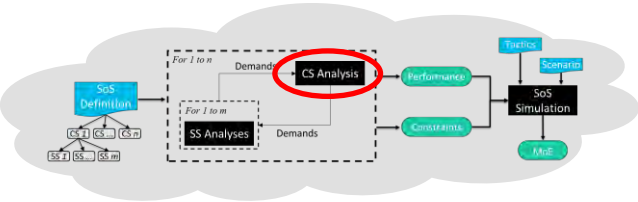
Implementation



Sub-System (SS) Models

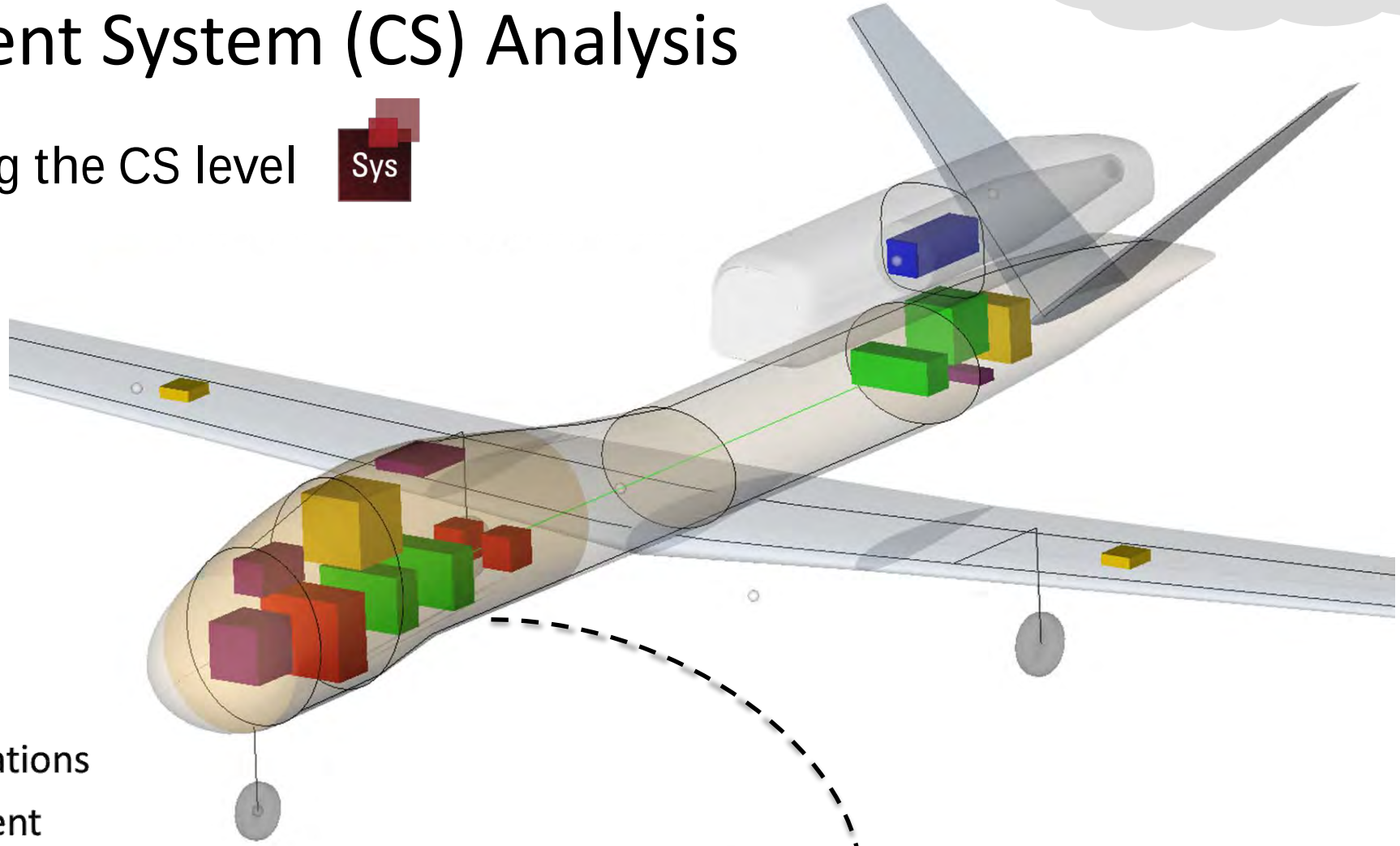
- Expanding the SS level models
  - Need to capture the effects of sensors/communications
  - Need to represent the electrical architecture/propulsion



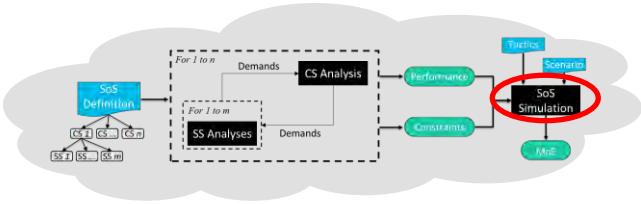


Constituent System (CS) Analysis

- Enhancing the CS level



Mission Simulation

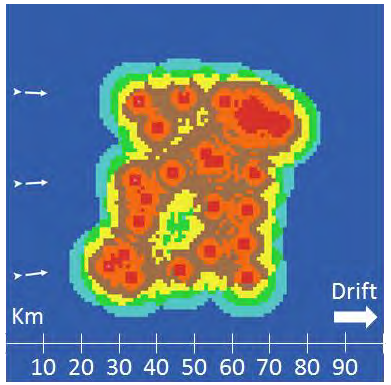


System-of-Systems (SoS) Simulations

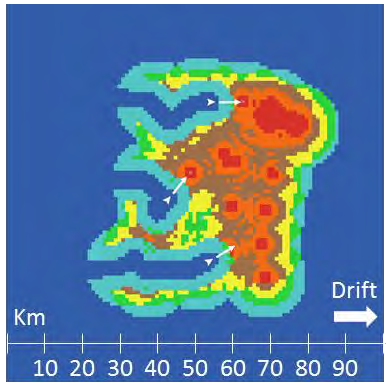
Agent-based in NETLOGO

- Capturing the SoS level interactions
  - Collaboration (divide search, avoid overlap)
  - Realism (failure modes, false positives, drift)

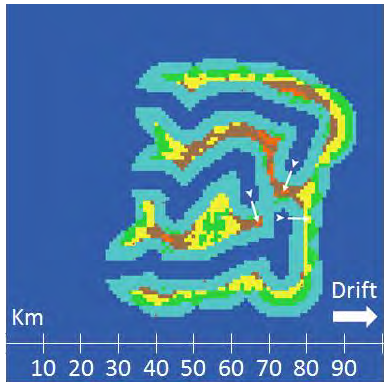
t = 26min
P_d = 0%

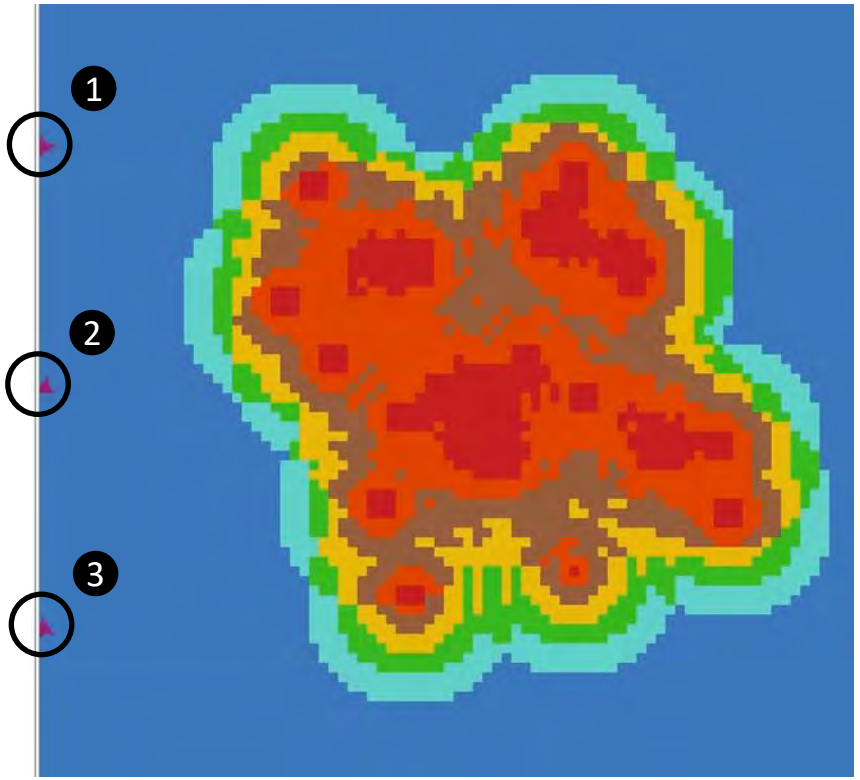


t = 39min
P_d = 34%



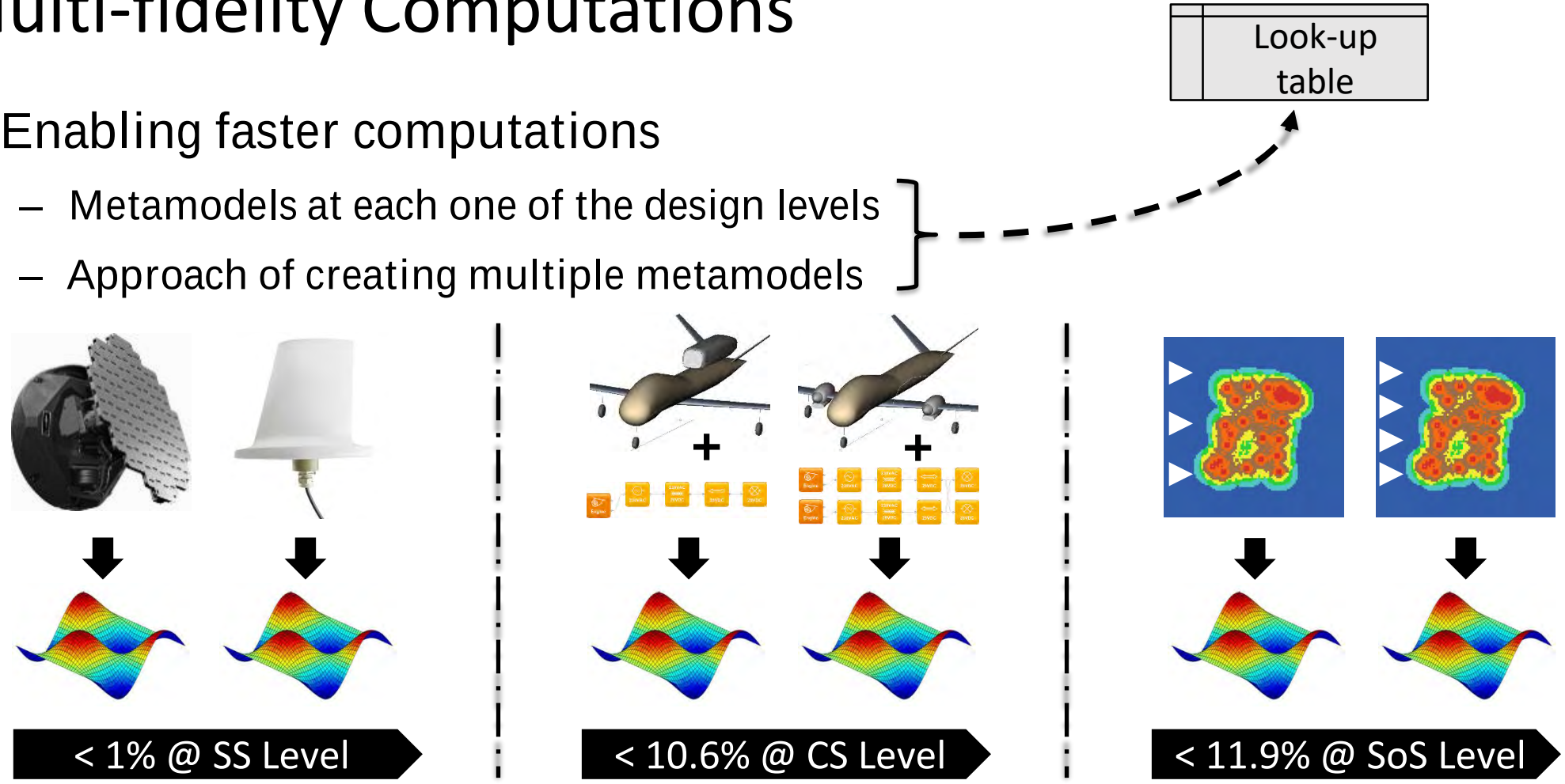
t = 52min
P_d = 82%

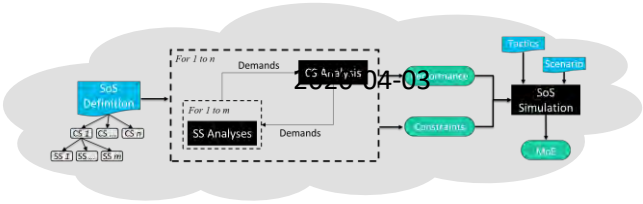




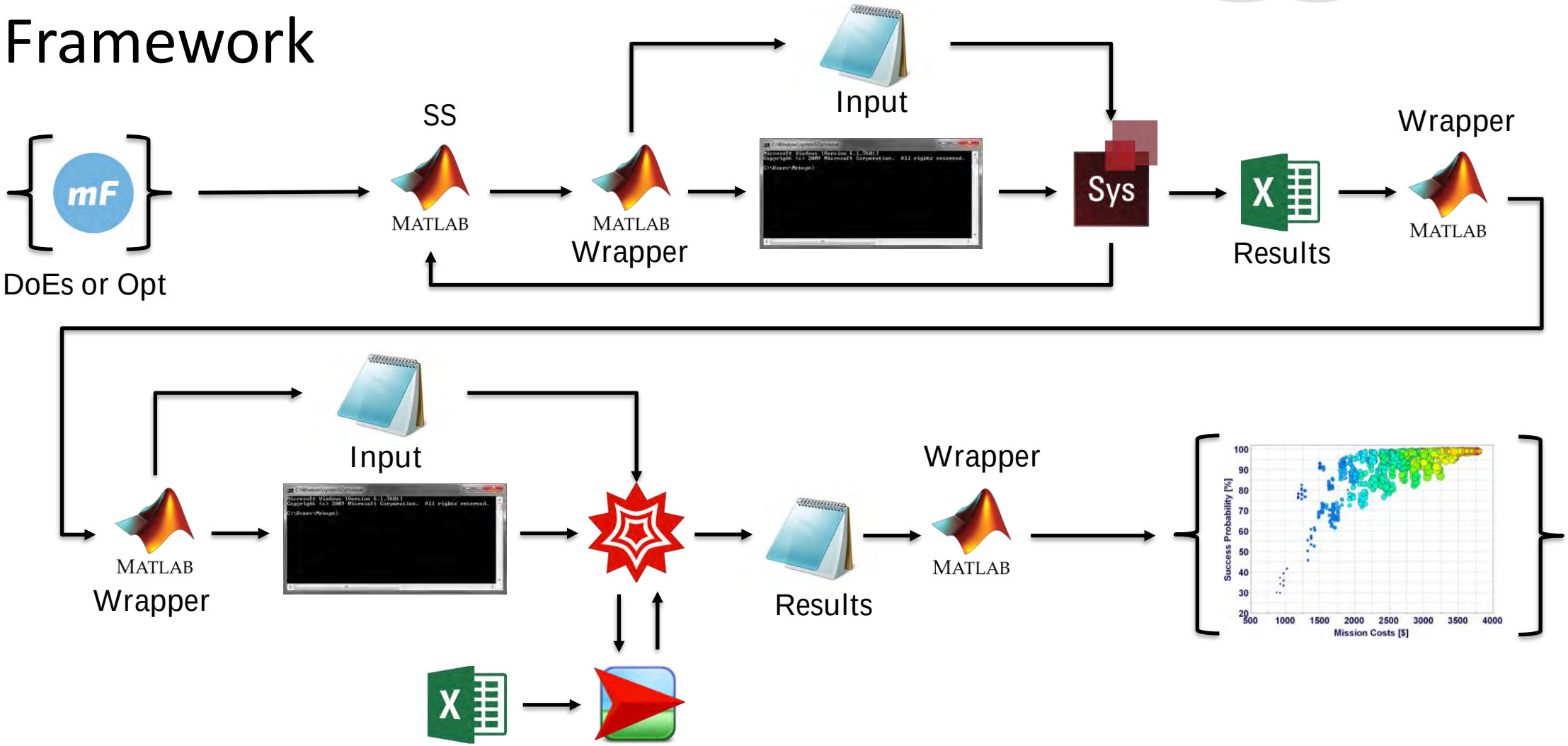
Multi-fidelity Computations

- Enabling faster computations
  - Metamodels at each one of the design levels
  - Approach of creating multiple metamodels




SoS Definition
For 1 to n
Demands
CS Analysis
For 1 to m
SS Analyses
Demands
Enablers
Scenario
SoS Simulation
Constraints
MoE

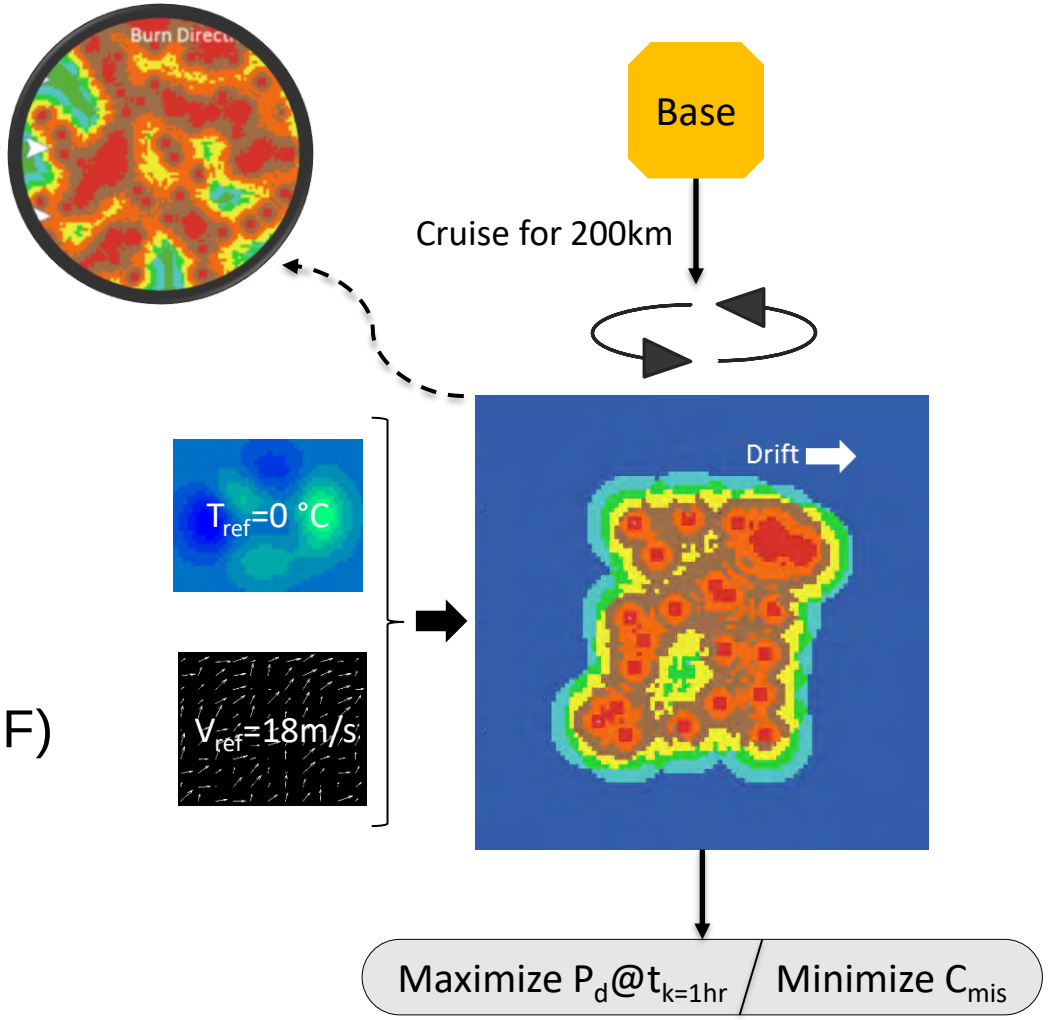
Framework


mF
DoEs or Opt
SS
MATLAB
MATLAB
Wrapper
Input
Sys
Results
Wrapper
MATLAB
Input
MATLAB
Wrapper
Results
Wrapper
MATLAB
Success Probability [%]
Mission Costs [$]
Weather
data

Proof Of Concept

Identifying SoS Capabilities

- Setting up a case study
  - Search for missing survivors/objects
  - Dynamic weather (sea & air) conditions
- Two operational scenarios
  - A) fleet of 3 existing UAV designs (HF)
  - B) fleet of 2-4 yet-to-be-designed UAVs (LF)
- Monitored capabilities (MoEs)
  - Detection probability VS Mission costs
  - Total payload / Fleet maintenance costs



Case Study 1 (HF)

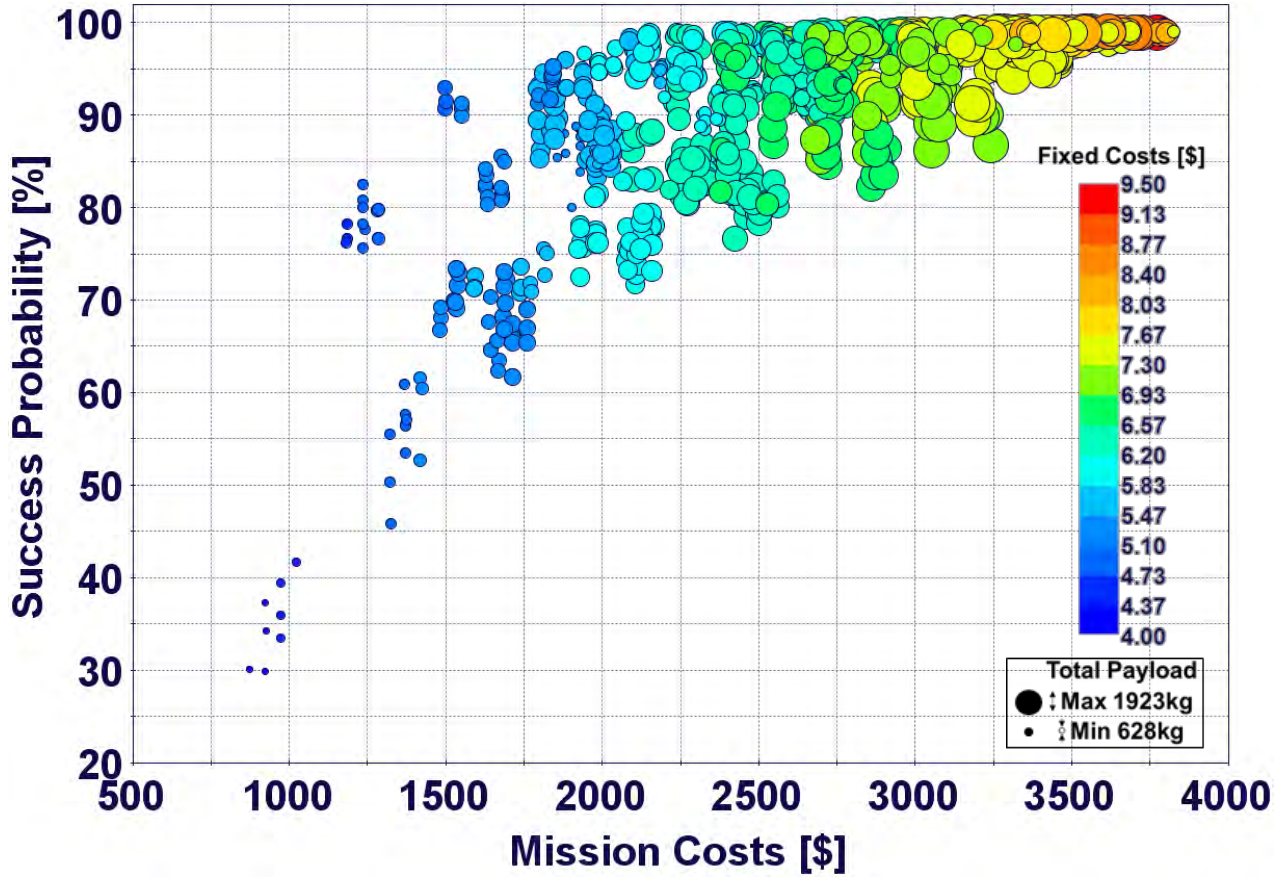
10 existing UAV designs (A-J)

3 ACs combinations

Original framework

Identifying SoS Capabilities

- Results part A
  - A fleet of 3 existing UAV designs

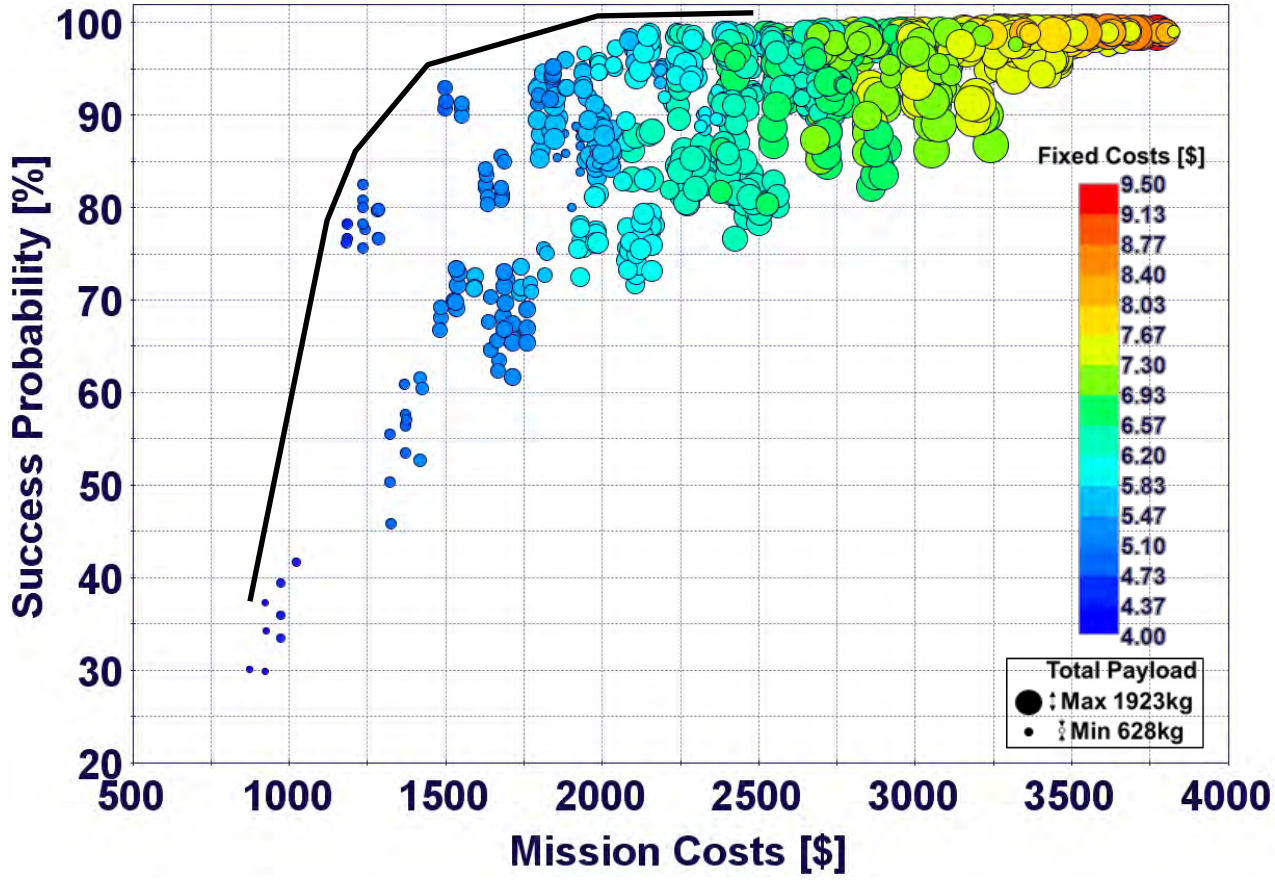


Original framework

Identifying SoS Capabilities

- Results part A
  - A fleet of 3 existing UAV designs

Pareto front



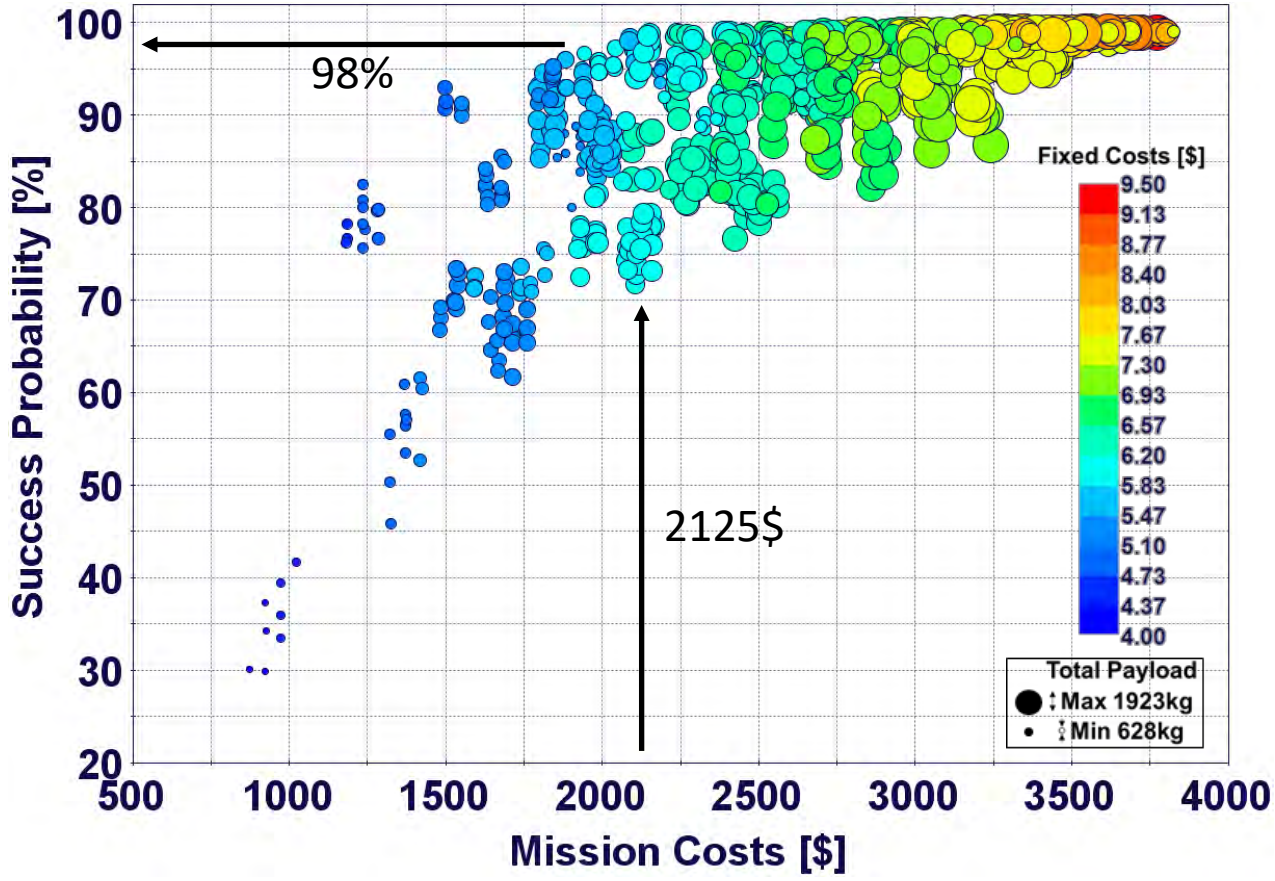
Original framework

Identifying SoS Capabilities

- Results part A
  - A fleet of 3 existing UAV designs

Pareto front

"Stagnation points"



Original framework

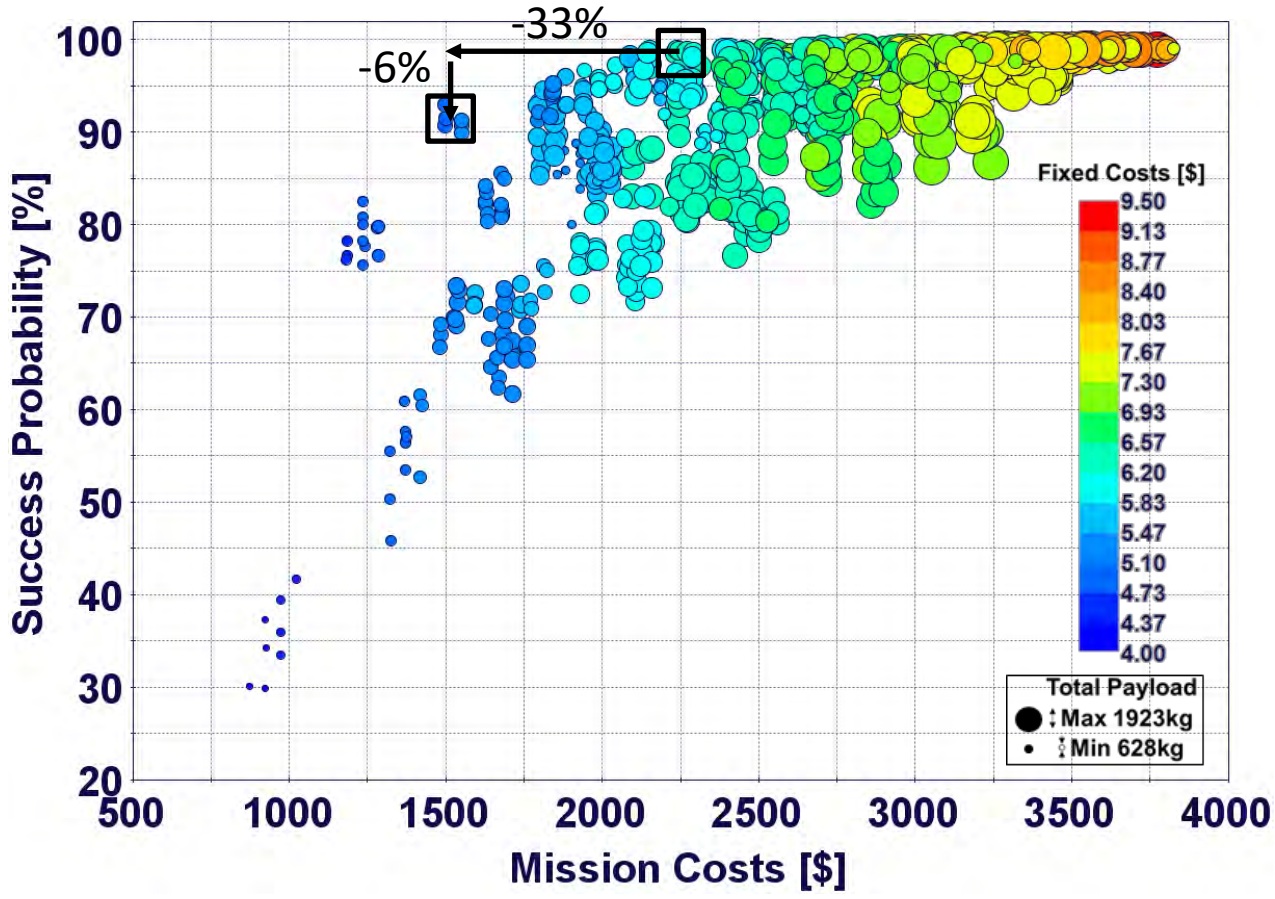
Identifying SoS Capabilities

- Results part A
  - A fleet of 3 existing UAV designs

Pareto front

“Stagnation points”

Trade-off studies



Identifying SoS Capabilities

Original framework

- Results part A
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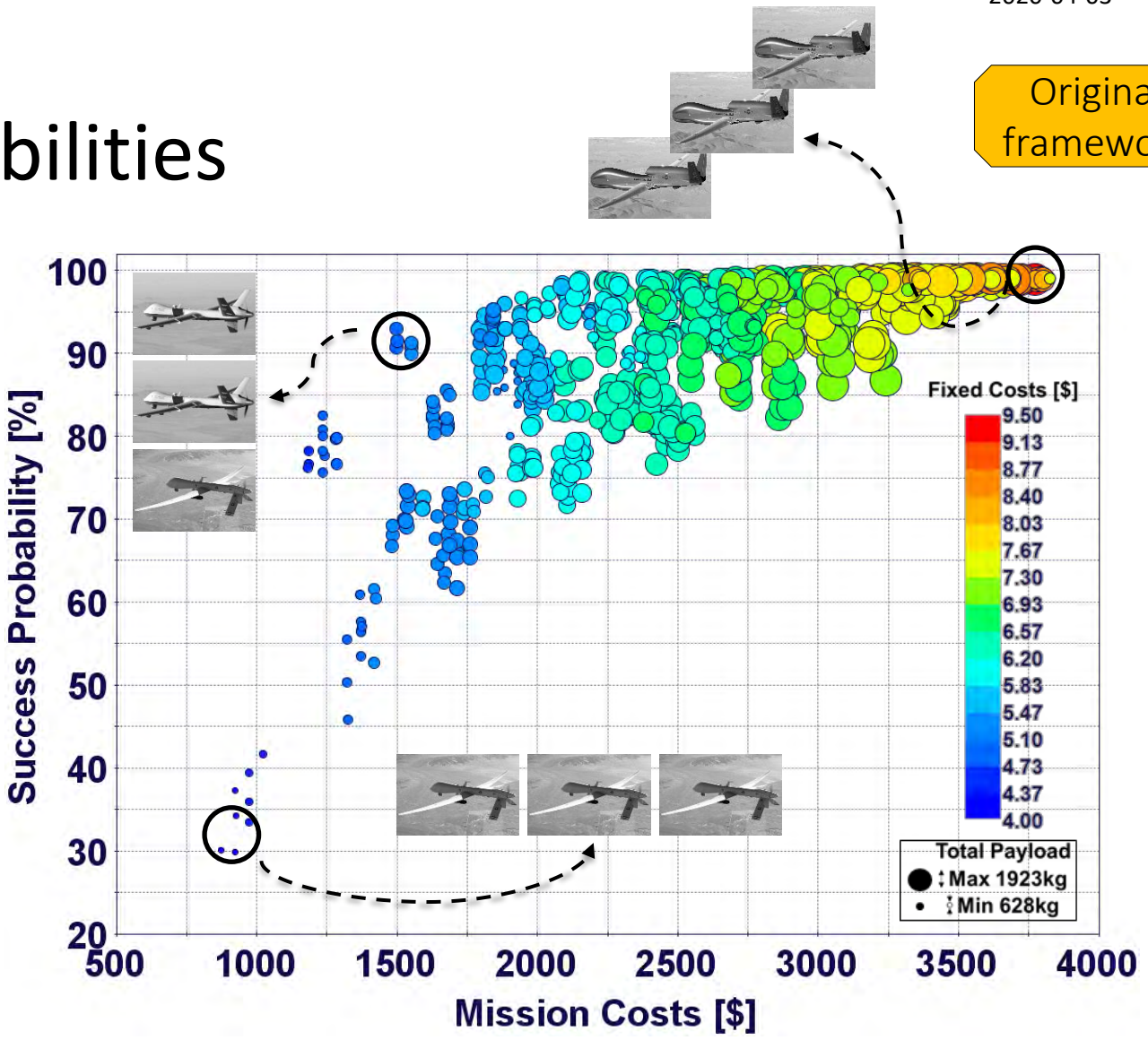
Pareto front

“Stagnation points”

Trade-off studies

UAV combinations



Original framework

Identifying SoS Capabilities

- Results part A
  - A fleet of 3 existing UAV designs

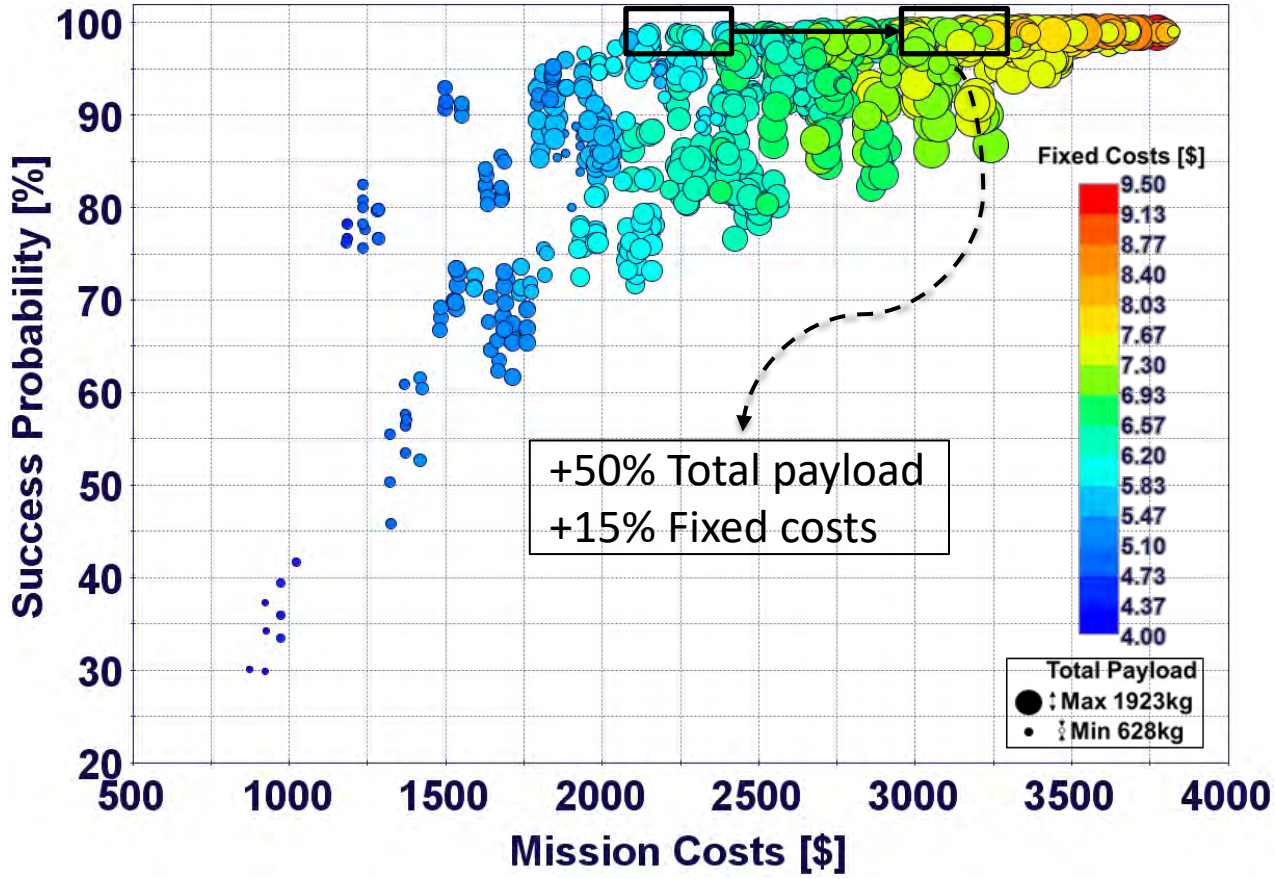
Pareto front

"Stagnation points"

Trade-off studies

UAV combinations

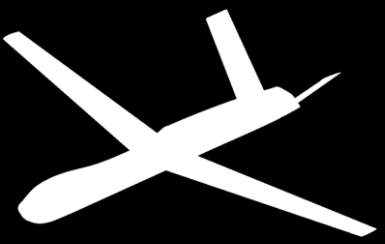
More capabilities



Case Study 2 (LF)

Yet-to-de-designed UAVs

Combinations of 2-3-4 ACs

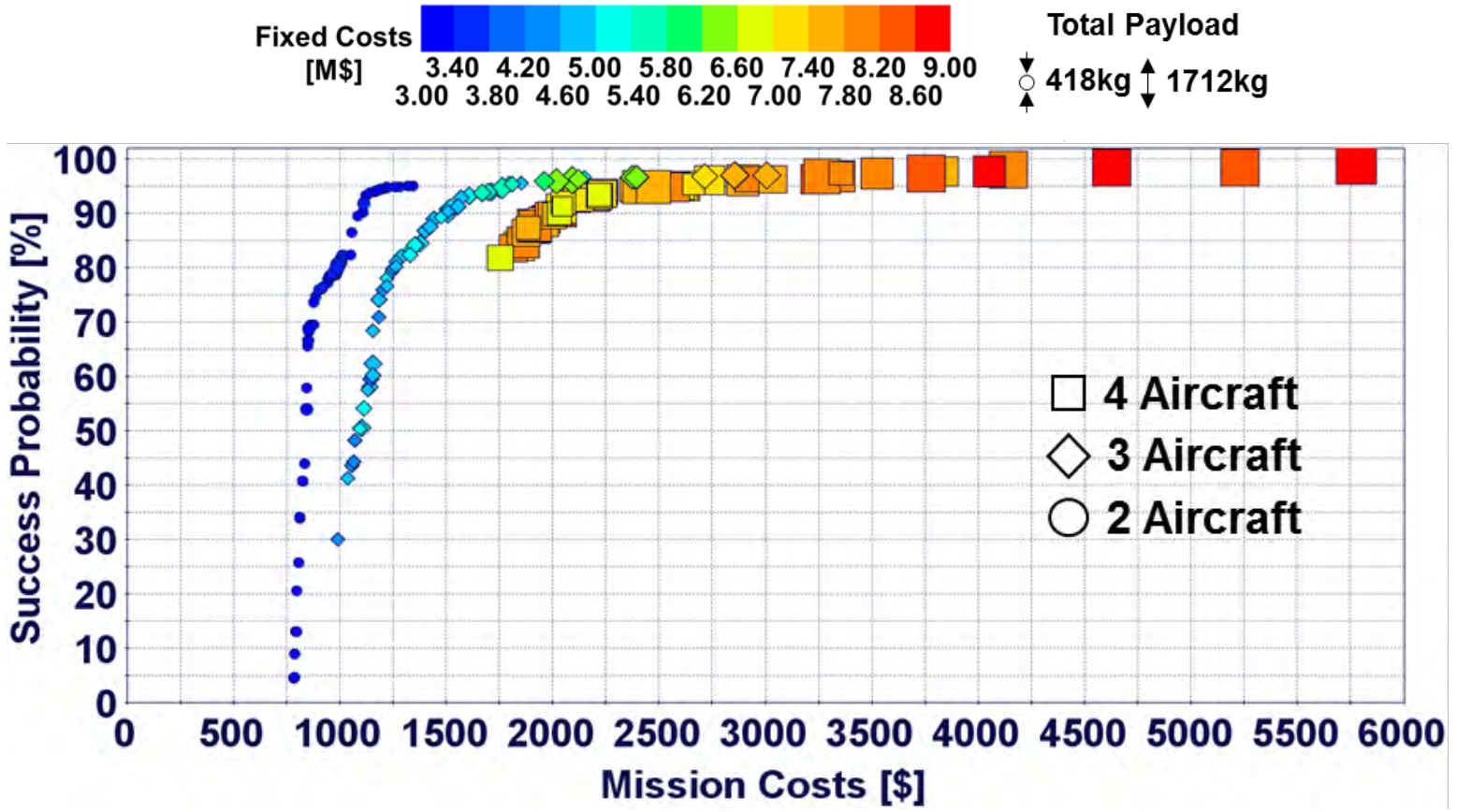


?

Metamodel framework

Identifying SoS Capabilities

- Results part B
  - A fleet of 2-4 yet-to-be-designed UAVs

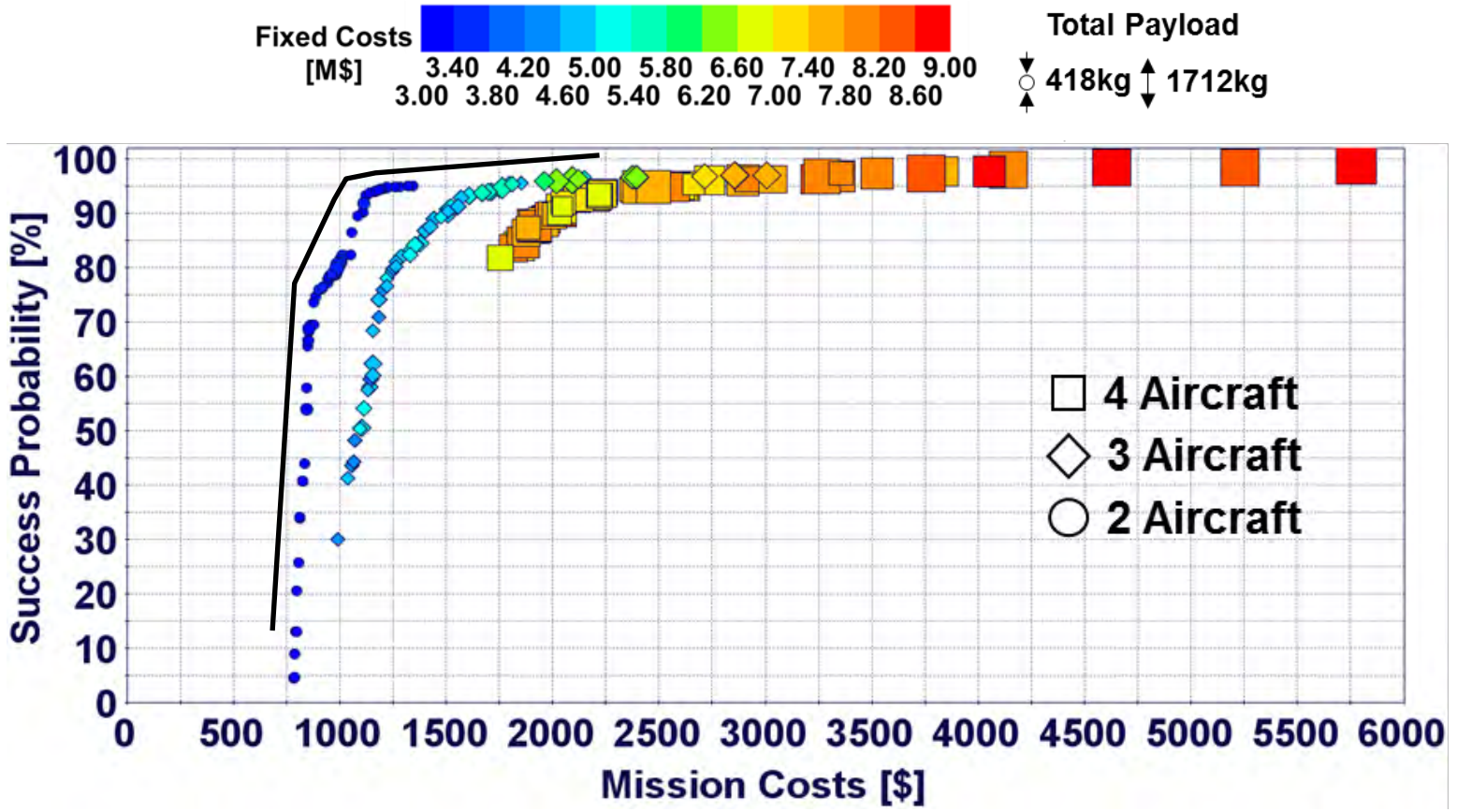


Metamodel framework

Identifying SoS Capabilities

- Results part B
  - A fleet of 2-4 yet-to-be-designed UAVs

Extended Pareto front



Metamodel framework

Identifying SoS Capabilities

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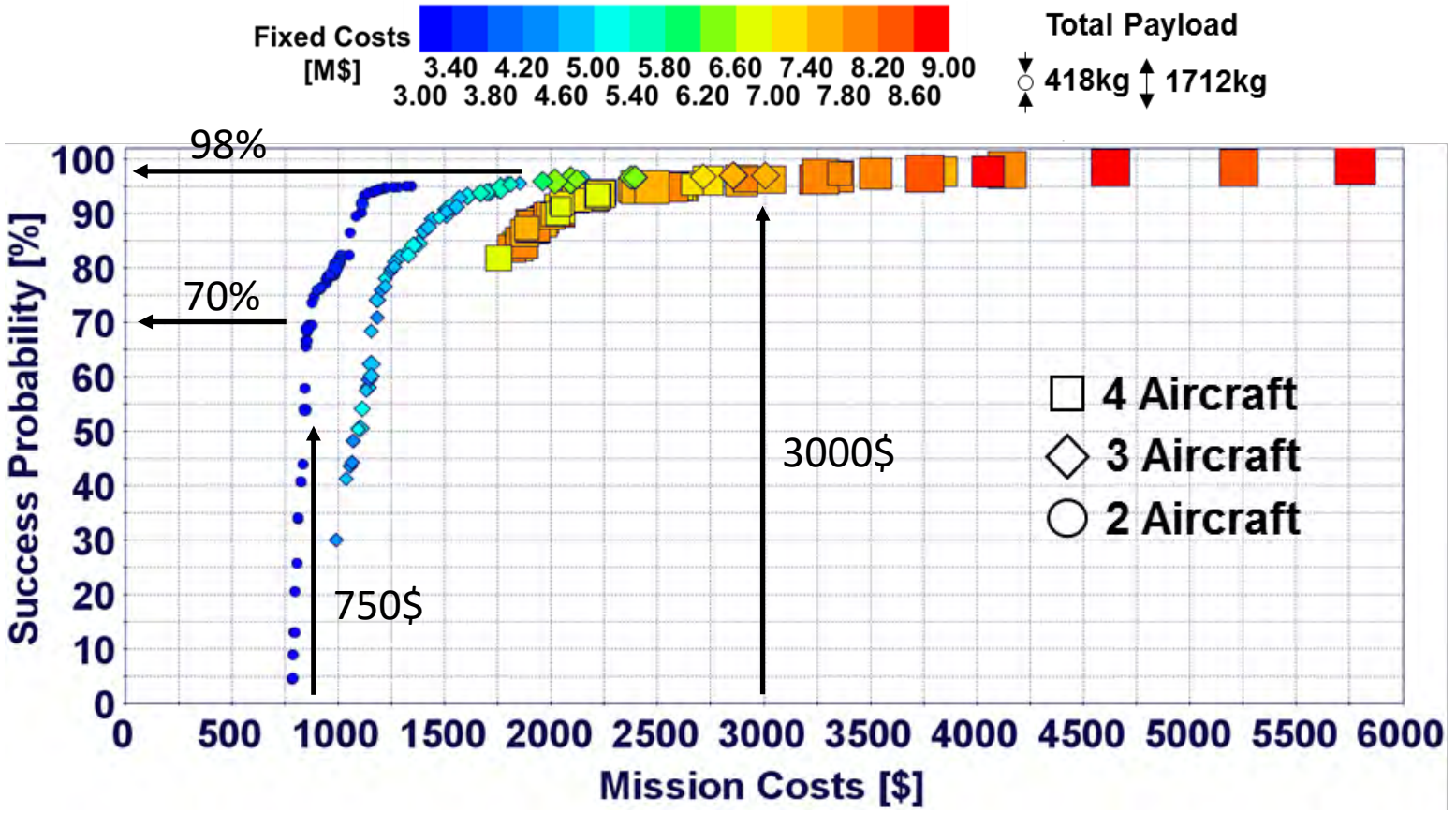
Extended Pareto front

"Stagnation points"



Metamodel framework

Identifying SoS Capabilities

- Results part B
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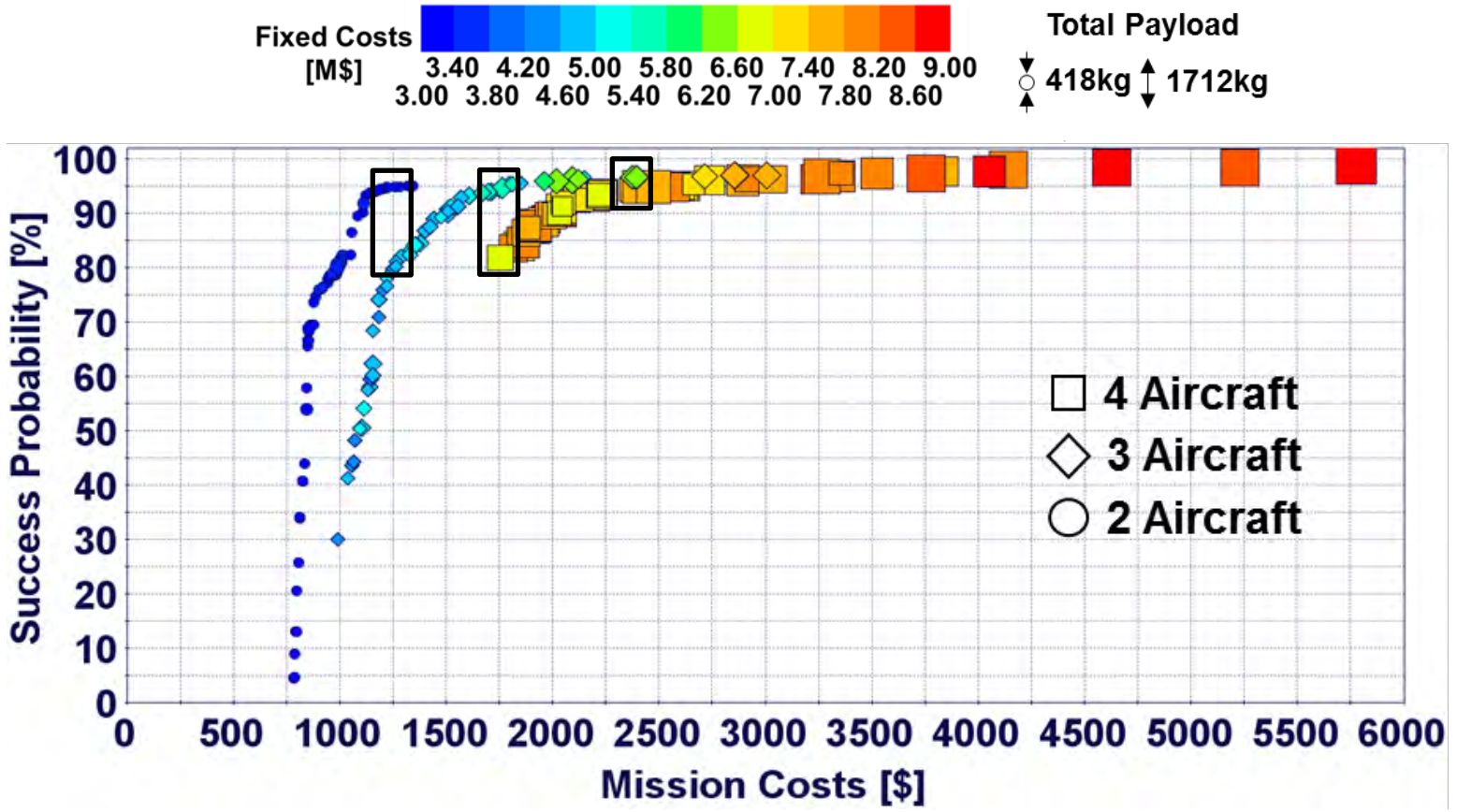
Extended Pareto front

"Stagnation points"

Trade-off studies



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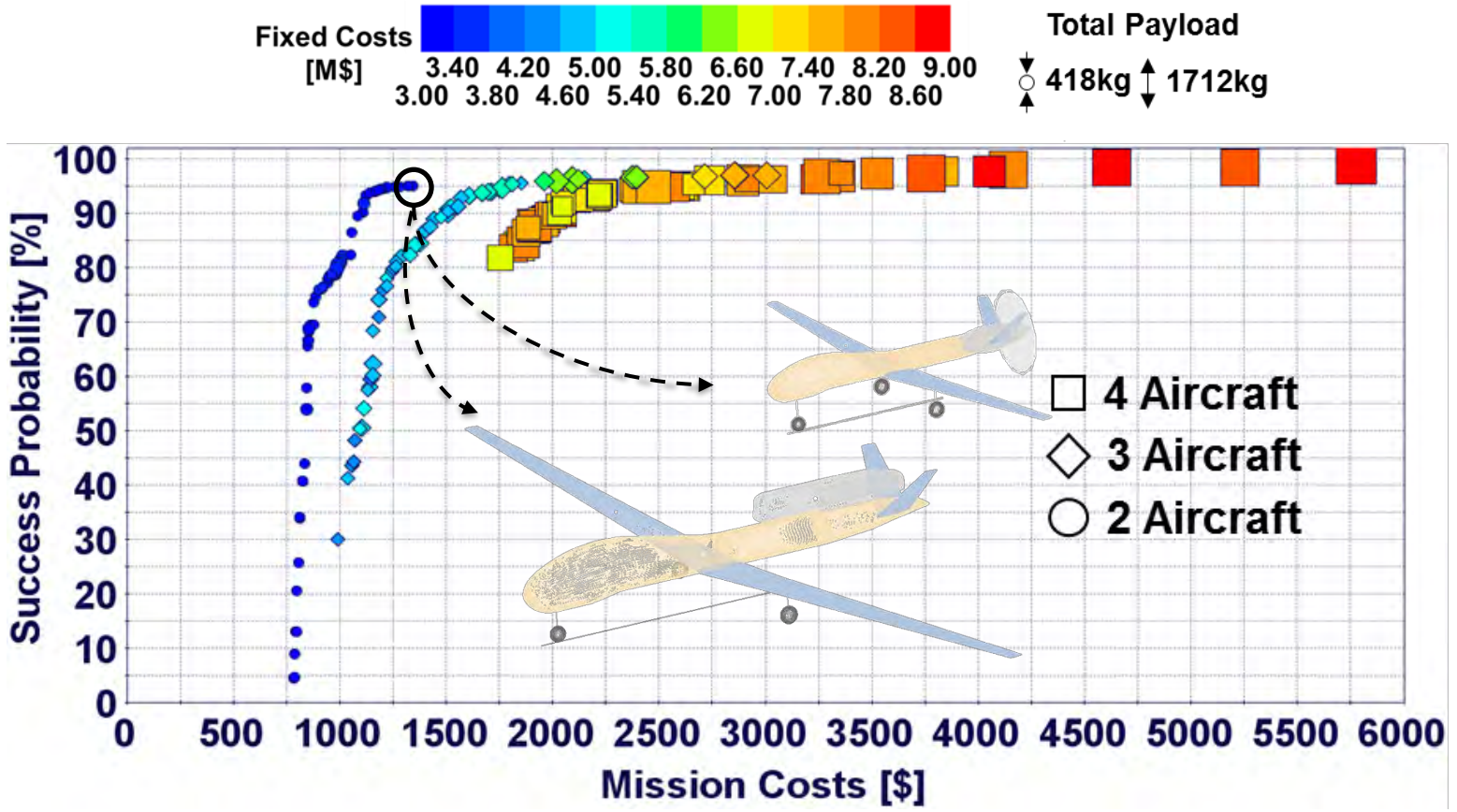

Concluding Remarks

Summary

- Technical developments
  - A methodology for populating the design space
  - Model development at all three system levels
  - A multi-fidelity design exploration framework
  - Surrogate models as a low-fidelity alternative
- Case study results
  - MoE depend on the chosen SoS
  - SoS bring forward new capabilities
  - Strong effect of scenario, tactics, and fidelity

What comes next?

- Airborne Early Warning & Control (AEW&C)

Thank you for your attention

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