Physics-Based Distributed Collaborative Design for Aerospace Vehicle Development and Technology Assessment

Phoenix Integration
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Reducing the Knowledge Deficit in Capability Prediction

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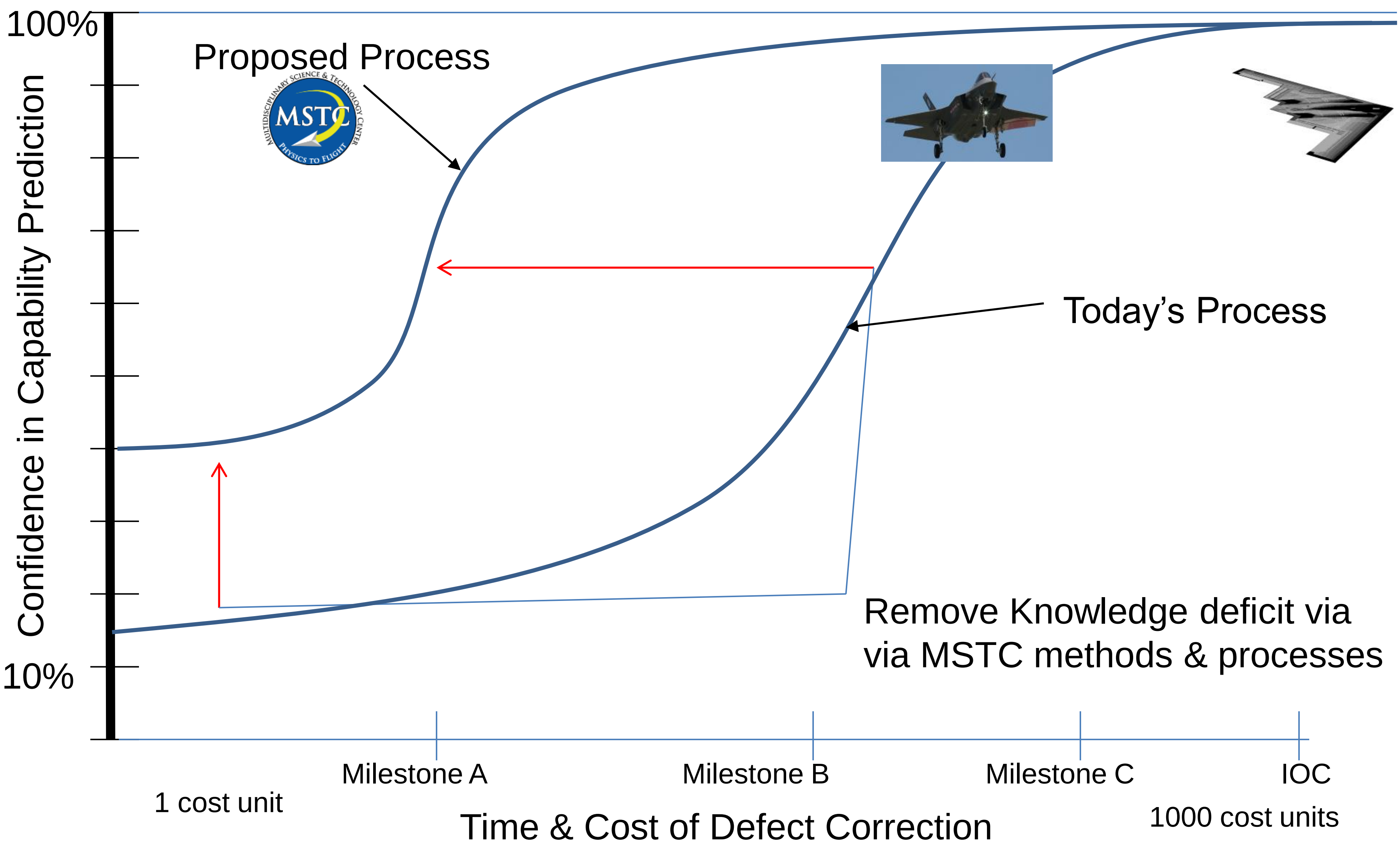

Some Goals

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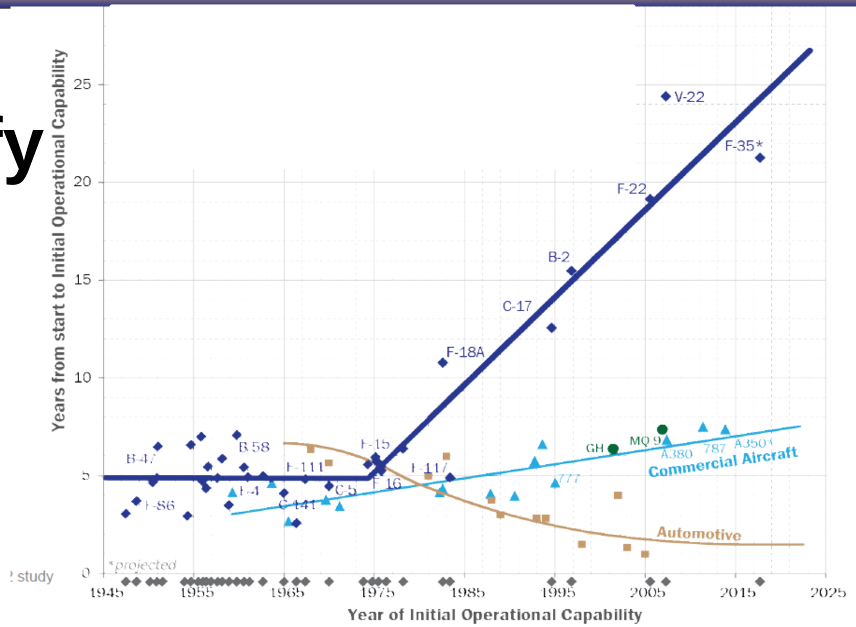
➢**Deliver vehicles that satisfy mission requirements in a timely manner**



➢**Reduce the number of late defects due to un-modeled physics**

➢**Trace technology to mission level capability impact based on physics – <u>Effectiveness Based Design</u>**

Develop & Trace Technology to Mission Level Capability Impact Based on Physics

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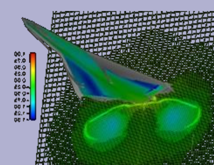
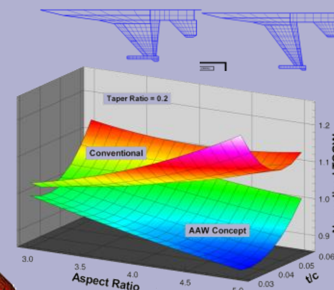
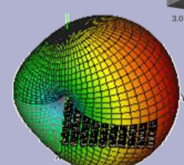
Technology

Aeroelastic Wing
Flutter Suppression
Third Stream Engine
Advanced Materials
Thrust Vectoring
Innovative Control Effectors
Directed Energy
Conformal Load Bearing Antennas
…
…

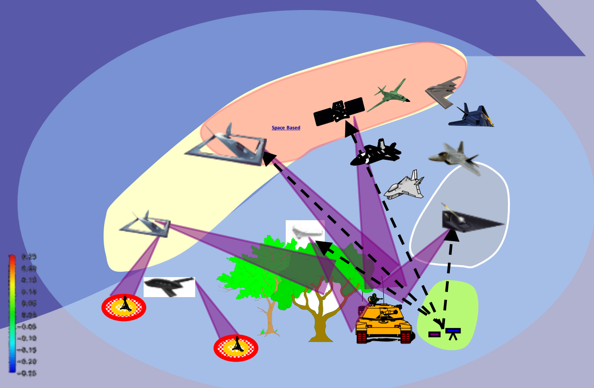


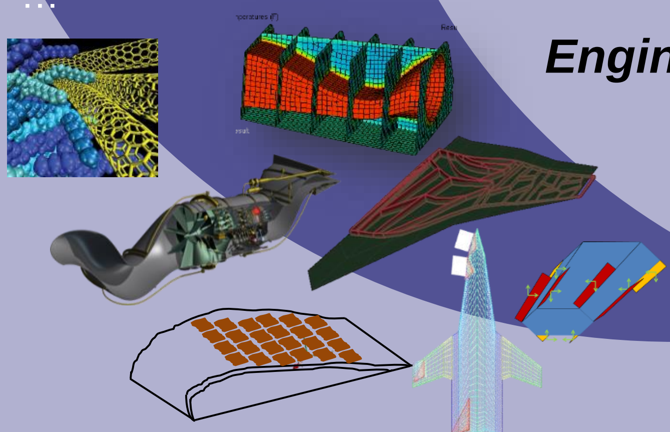




Mission Capability Impact

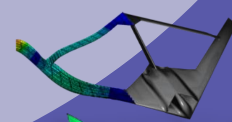
Combat effectiveness
Survivability
Kills/$
IDs/$
Mantainability
Life Cycle Cost
Sustainability
…

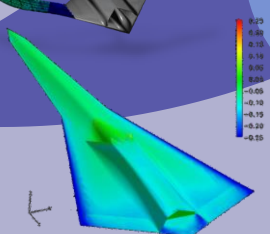




Engineering Capability Impact

Weight Reduction
Drag Reduction
RCS reduction
Fuel Efficiency
Roll Performance
Radar Efficiency
…





Want to find: $\frac{\partial Mission\_Capability}{\partial Technology}$

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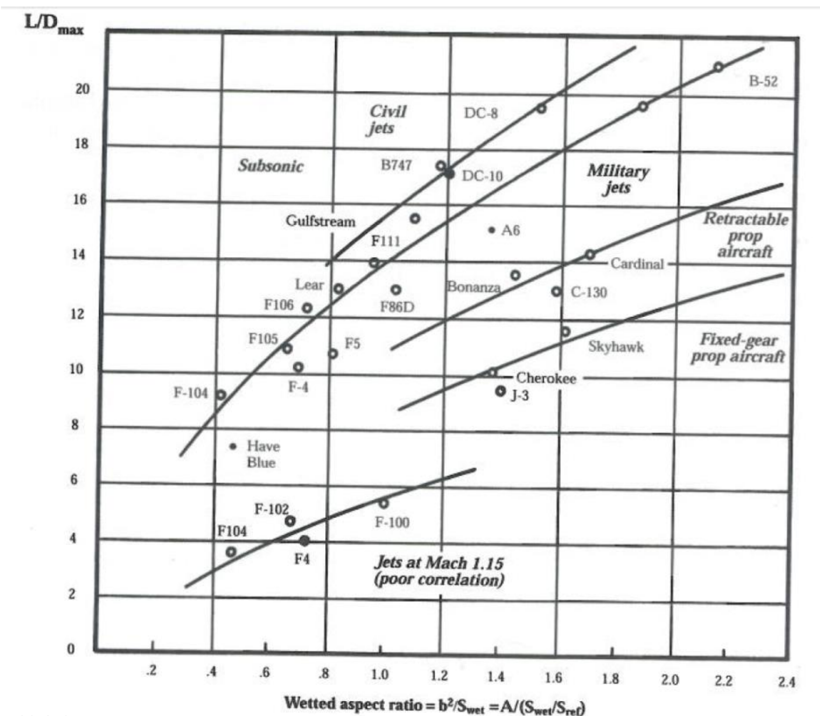
What we mean by "Physics Based"

Regressions of historical Data



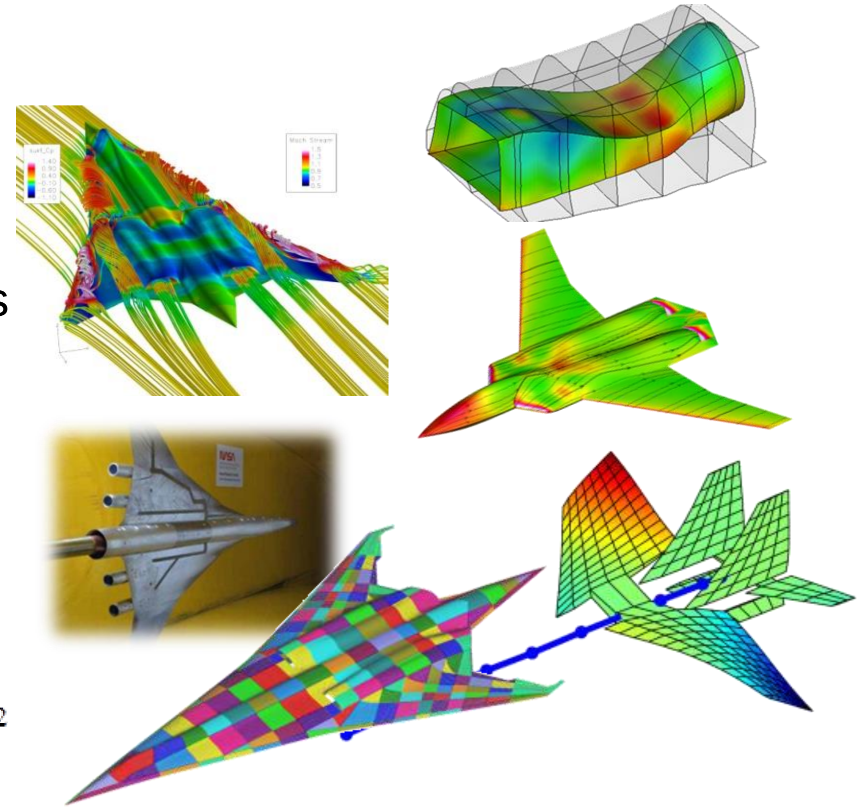
Raymer

$$W_{wing} = (k_{tech\_factor}) * 0.0103 K_{dw} K_{vs} (W_{dg} N_z)^{0.5} S_w^{0.622}$$

$$* A^{0.785} (t/c)_{root}^{-.04} (1+\lambda)^{0.05} (\cos \lambda)^{-1} S_{csw}^{0.04}$$

Computational or testing on actual configuration

Versus



Historical data insufficient for designing new/innovative configurations and assessing new technologies

MSTC Design Process Goals (System Level Multi-Fidelity MADO)

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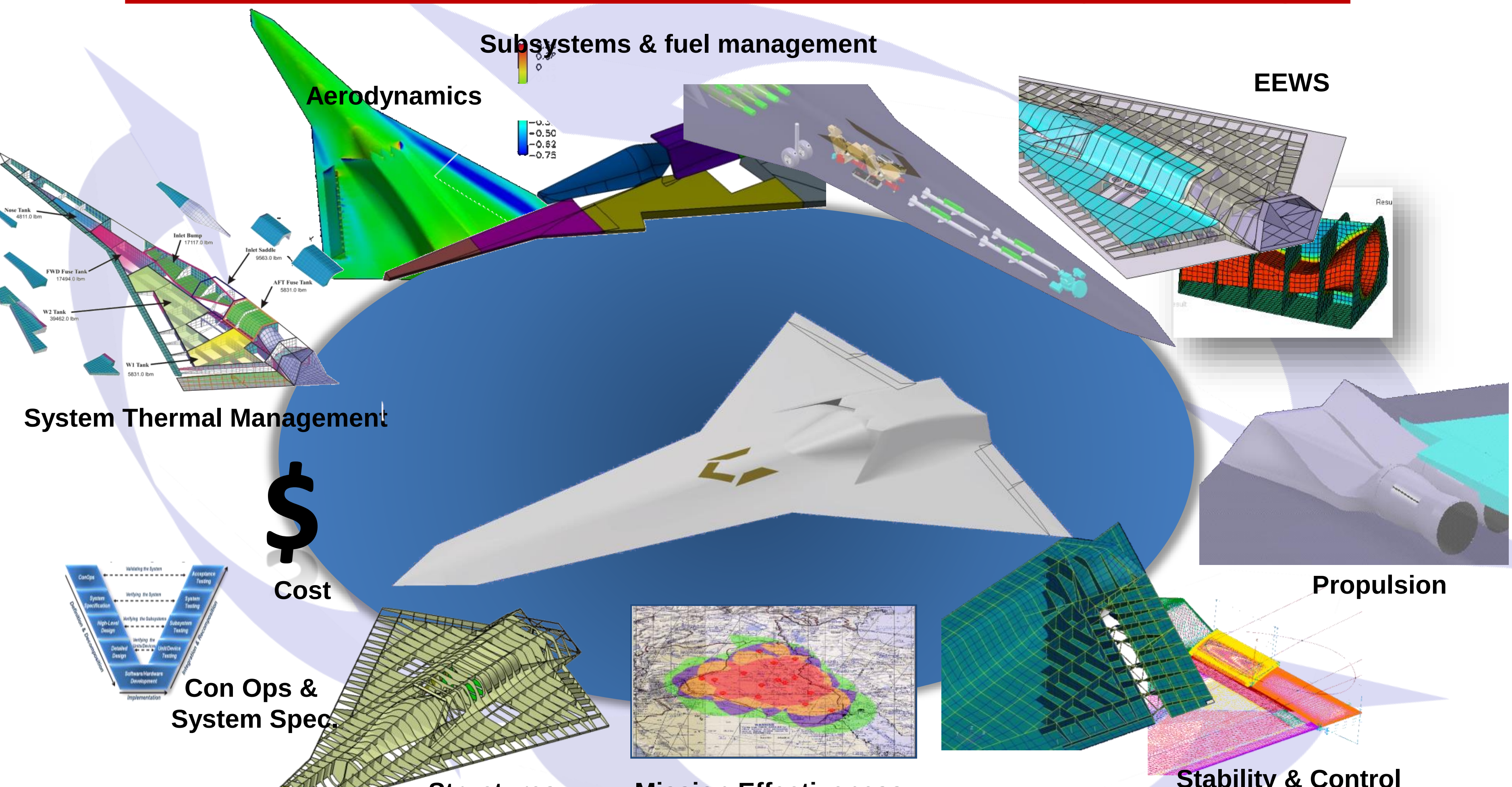
Merge Conceptual & Preliminary Design



Add Disciplines, Couplings, & Fidelity - Early

How to Capture the Physics Driving the Design Pre-Milestone A

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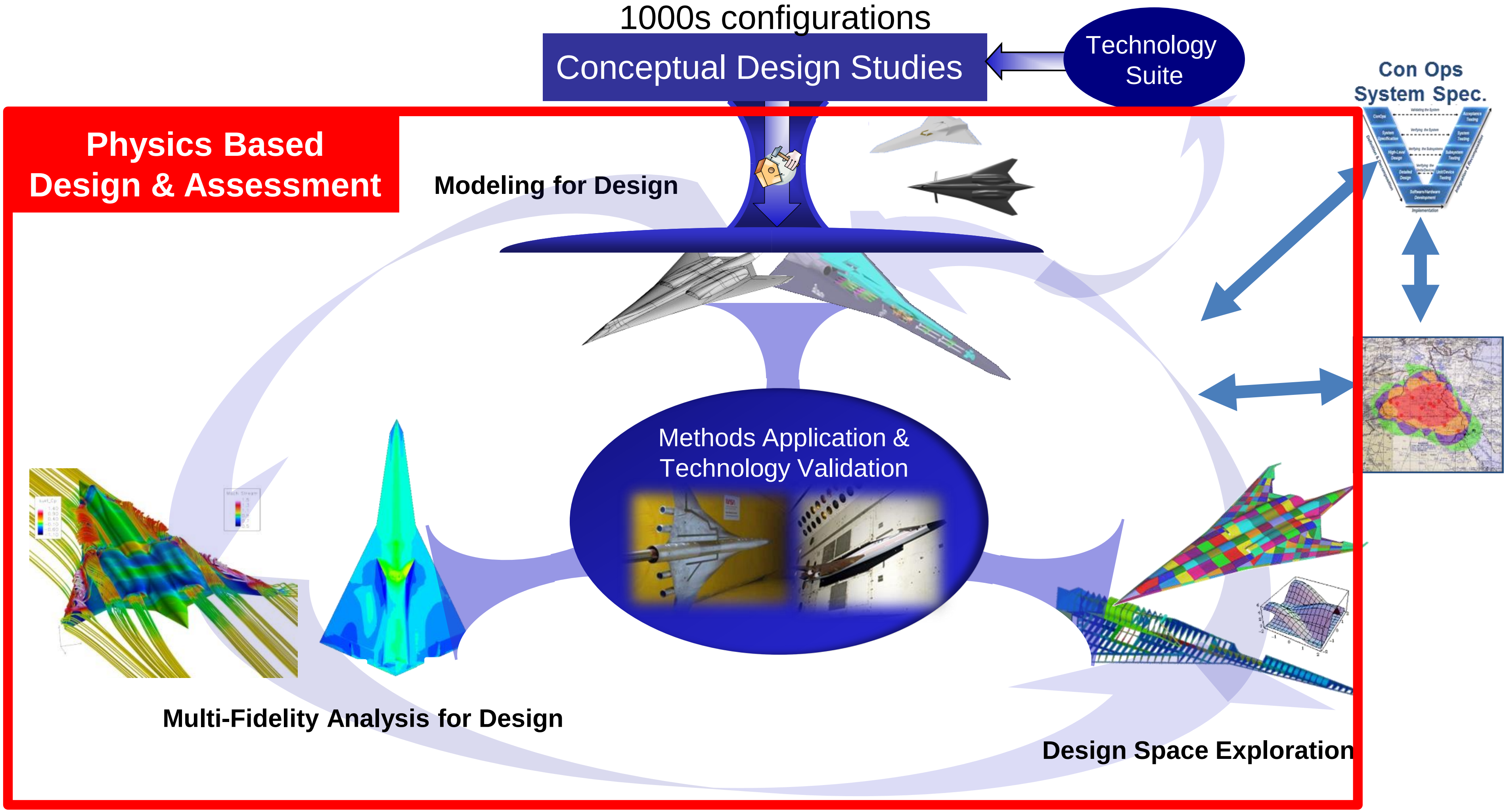
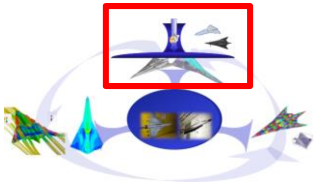


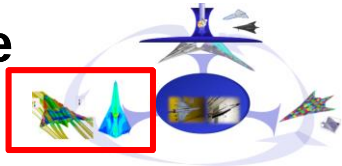
Get more (and Better) Information … and get it Earlier

Gaps to Achieving Desired Process

- Need rapid development of domain model construction from geometry (structural lay-outs, configurations, FEM, CFD Meshes, sub-systems etc..)



- Need coupling of all necessary engineering disciplines (structures, aero, thermal, controls, acoustics etc..) at the appropriate level of fidelity to predict static and dynamic responses



- Computational framework that supports hi-fidelity distributed collaborative design.

- Synthesis process does not currently include uncertainty & probabilistic design methods

- Culture

Need to be able to do 10's of HiFi Physics Based Configuration Design with the Same Resources & Time of Traditional Conceptual Design

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MADO N^3 Diagram

(aka design structure matrix, dependency structure matrix, spider diagram)

MSTC Develops, Executes & Validates

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Configuration
Parametric Associative Geometry & Discretization

Geographic Location A
Geographic Location B
Geographic Location C

Propulsion
Thrust, SFC

Mass Properties
Raymer Weights

Aeroelasticity
Linear

Structures
Linear FEM Based

Heat Transfer

S&C
Surface Effectiveness Control Pwr. Req

Aero(NS))

Aero(Euler))

Aero(Linear Potential)

Aero(Empirical)
...ds & Drag

Aero
Rigid Loads & Drag

∂Drag / ∂Sweep
∂Lift / ∂AspectRatio
∂Lift / ∂Camber
∂Lift / ∂SkinThickness
...

∂Flutter / ∂Sweep
∂RollEff / ∂AspectRatio
∂Stress / ∂SkinThickness
...

Aero Acoustics
Exhaust Wash, Wing shielding & propagation

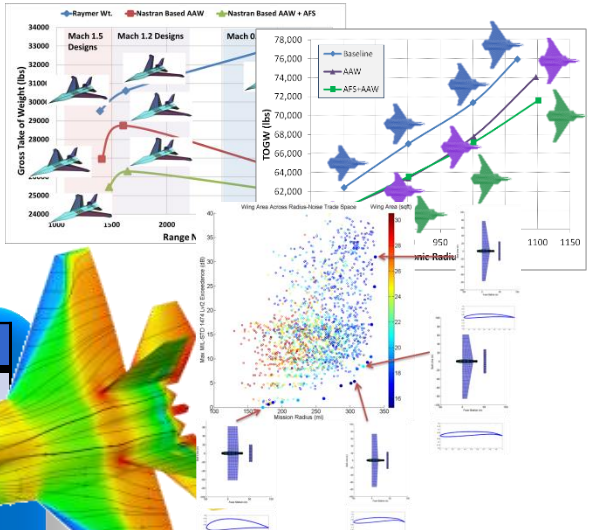
System Thermal Management/Balance

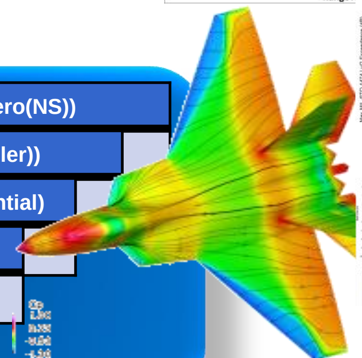
Discipline x

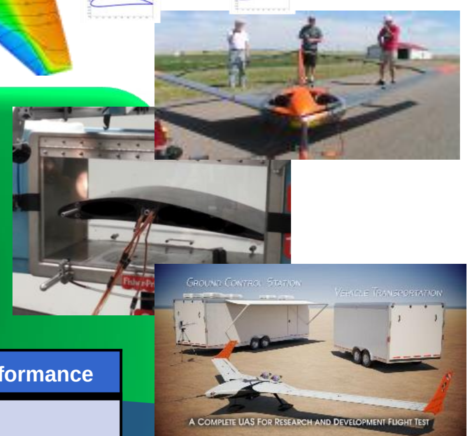
Mission Performance

Operations Analysis
Constructive with Physics based models

Optimization







MADO Development (populate the N^2)
- Add Disciplines & their Sensitivities (diagonals)
- Add Chained and Coupled Analysis (connections)
- Add Fidelity (depth)
- Distribute N^3

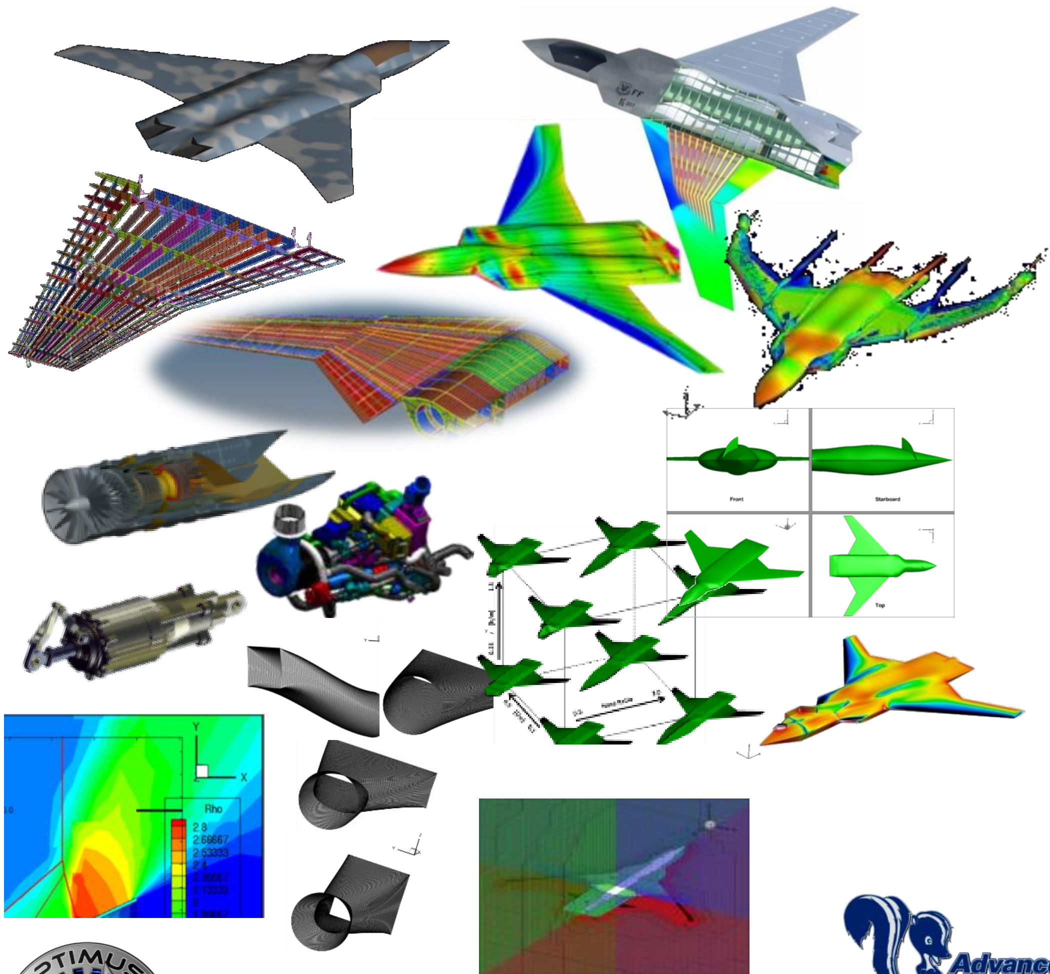
MADO Studies & Technology Assessment(Execute N^2)
- Select appropriate Disciplines, Couplings, Fidelities
- Formulate Optimization Problem
- Execute N^3

Need a Computational Environment to Achieve BCA MADO

MD Technology Validation (Validate results of N^2 Execution)
- Ground, Wind tunnel & Flight Experiments

Need to Maximize Reuse

Typical Target Application
Efficient Supersonic Configuration



Boeing

Northrop
ESAVE

ESAVE, EXPEDITE

Effectiveness Objectives
Access, Firepower, Reach, Speed/Agility

Engineering Objectives
Range, Weight, Specific Excess Power

Design Variables
Aerodynamic (10's)
Controls (10's)
Engine (10's)
Subsystems(100's)
Structural (1000's)

Constraints
Strength, Stiffness, Thermal
Static and Dynamic Aeroelastic

Level 1-3 Fidelity

Technology Evaluations

- Configuration
  - Compact Weapons,
  - Compact Launchers
- Aerodynamics
  - Subsonic Laminar Flow ,
  - Supersonic Laminar Flow
- Propulsion
  - Variable Cycle Engine
  - Advanced High Speed Inlet
- Structures
  - Active Aeroelastic Wing Active Flutter Suppression
- S & C
  - ICE Effectors (SSD)

MSTC High Level Requirements for System Level MADO (MDMFMSAOwUQ)

- # of components/applications/Services – 100's to 1000's
- Run times of services – secs to weeks
- Data
  - kilobytes to terabytes
  - ascii, binary, databases
- Distributed (across organizational boundaries) heterogeneous computing environment
  - Hand held devices to HPC resources
  - Seamless access to data and services
  - Process representation with secure communications
- 1E4 of design variables
- 1E5 constraints
- Multi-Objective

Physics Based Distributed Collaborative Design (Compute Resource View)

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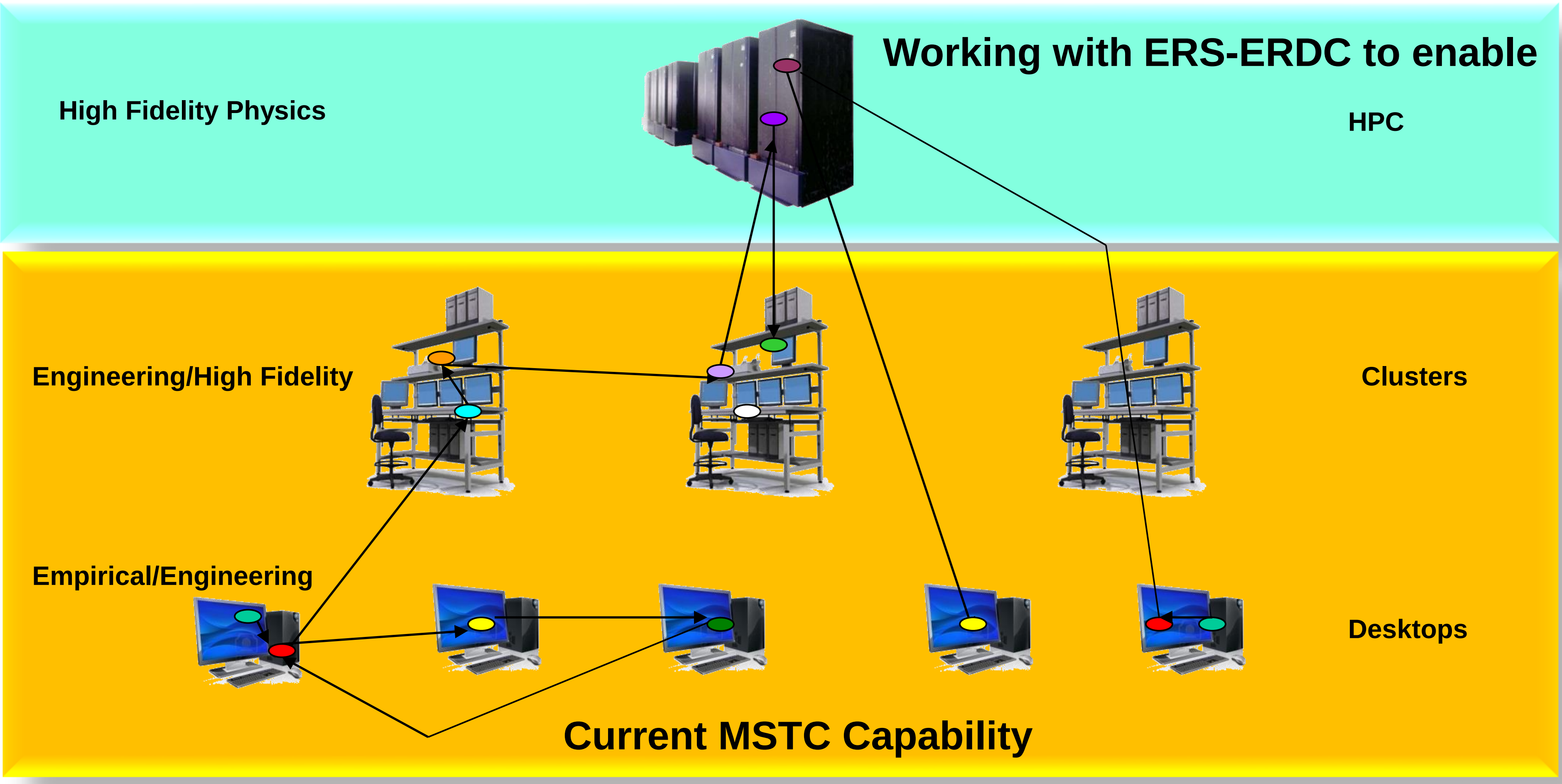
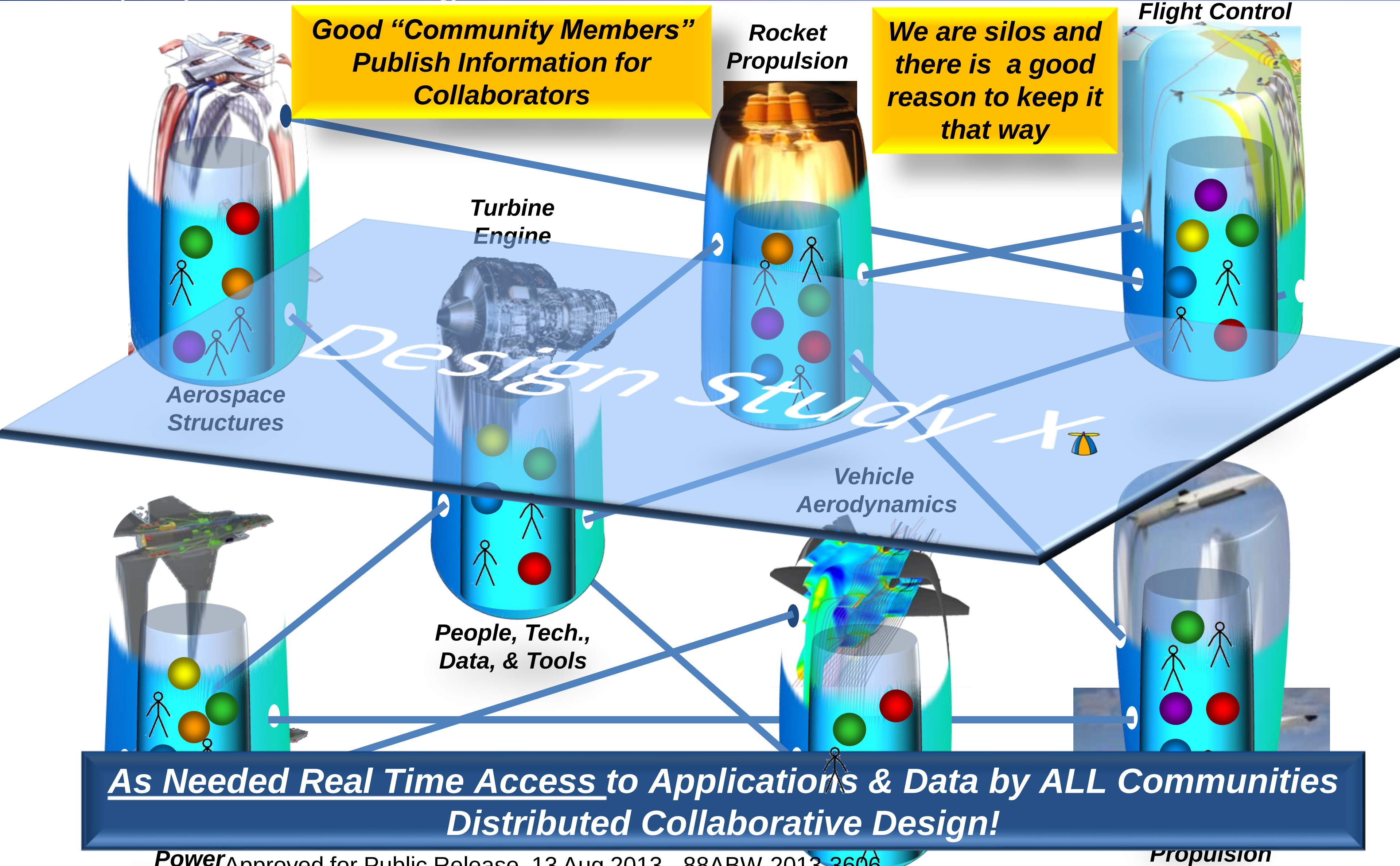


Seamless Access to All Methods, Models, Data, and Compute Resources Across the Network

Physics Based Distributed Collaborative Design (Org View)



As Needed Real Time Access to Applications & Data by ALL Communities
Distributed Collaborative Design!

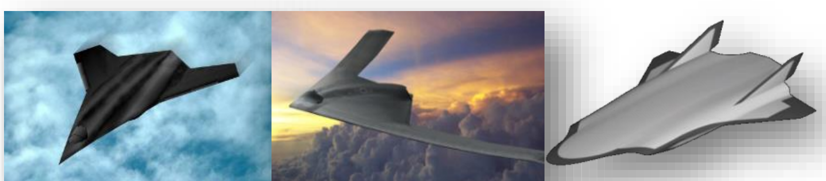
Impact

Scientific Impact

Past

Exploiting the **synergism** of mutually interacting phenomena to **produce a capability that cannot be obtained otherwise**

Future



Multi-disciplinary Science is an ***enabler*** for the development of the next generation air and space vehicles

Acquisition Impact

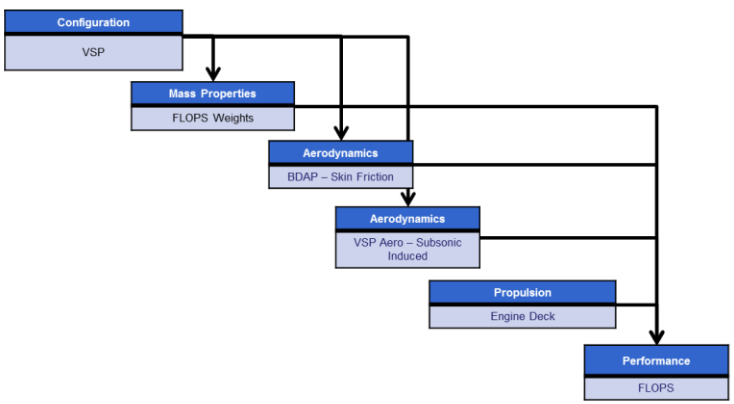
Reduce discovery of late defects due to un-modeled physics

It is essential to determine early on the pertinent interactions between coupled engineering disciplines

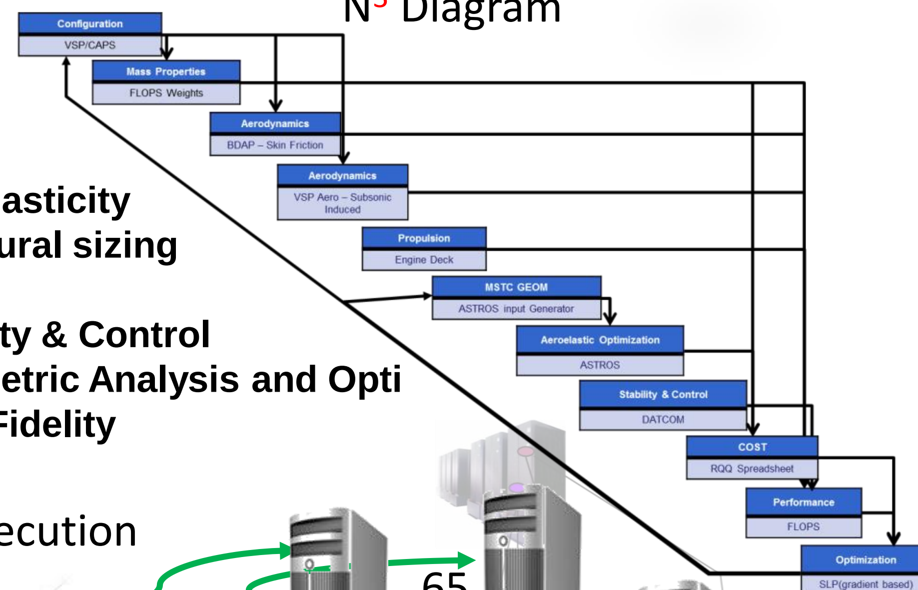
Small UAV Design Without Distributed Collaborative Design (RQVA)

Design With Collaborative Distributed Design (RQVA, RQVC, RQQ, RQT)

N^2 Diagram



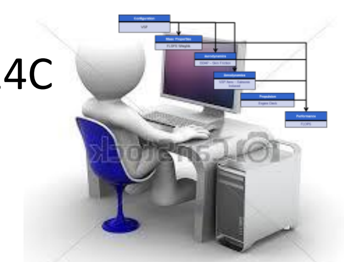
N^3 Diagram



- ❑ **Aeroelasticity**
- ❑ **Structural sizing**
- ❑ **Cost**
- ❑ **Stability & Control**
- ❑ **Parametric Analysis and Opti**
- ❑ **Multi-Fidelity**

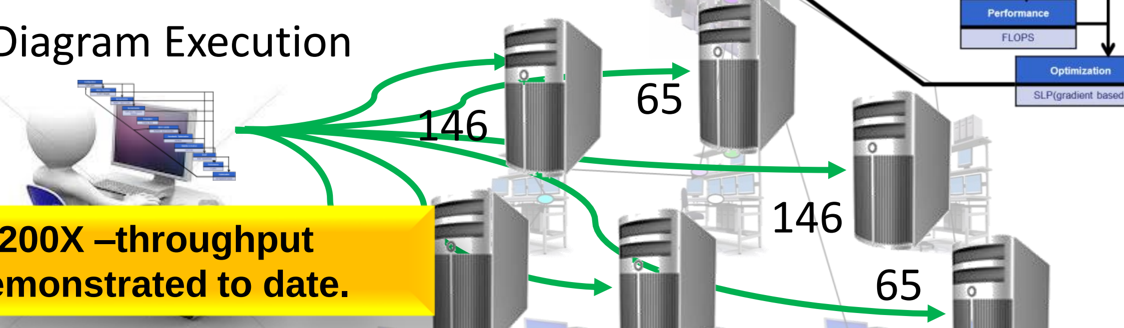
N^2 Diagram Execution

24C



N^3 Diagram Execution

24C



200X –throughput demonstrated to date.

Significant Cultural Change - Gives More Information, Faster – Better Decisions

Small UAV Design Study with MSCT-Engineering

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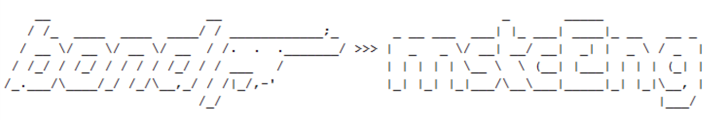
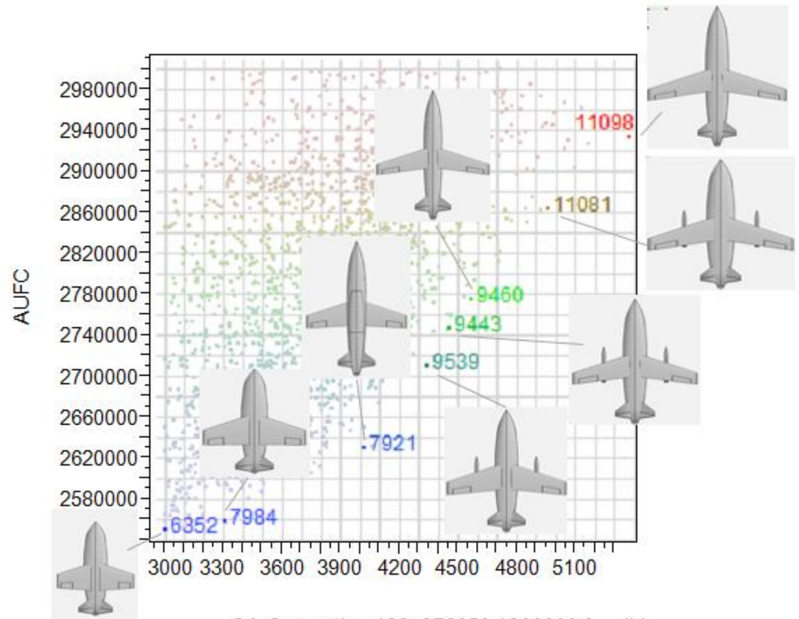
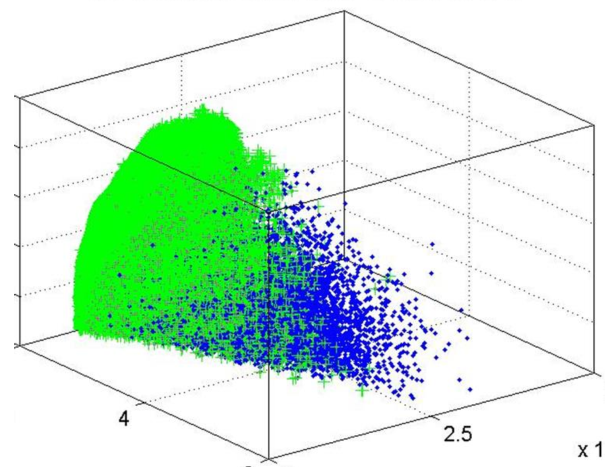


/---welcome to the bond system, cloud computing by mstc-eng---/

- **MSTC-Eng Environment**
  - ~26 MSTC-Eng Providers
  - ~10 Windows Workstations / ~16
  - ~520 workers
  - Avg thruput ~1.75 sec/run (avg run ~7min)
- **Multiobjective Genetic Algorithm**: gamultiobj (variant NSGA-II)
- **Three objectives:** min AUFC, max range, max tacAvgAlt
- **Nine design variables:** 'wingSpan1', 'wingSweep1', 'wingArea', 'wingTaper', 'fuseLength', 'fuseWidth', 'timeOnStation', 'cruiseMach', 'loiterMach'
- **Constants:**
- **GA Parameters**
  - Population: 3000
  - Generations: 135
  - Total runs: 400k



GA Generation 133: 376950 / 399000 feasible



Results courtesy Burton, White, Kao and team

Small UAV Design Study with MSCT-Engineering

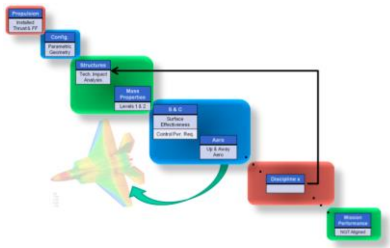
gaMovie_8Gen.mp4

Some Future Technologies that will impact Aerospace Vehicle Design

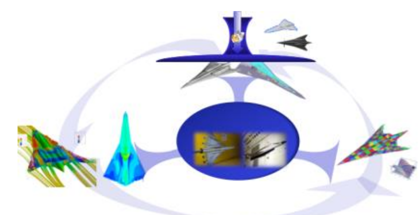
- **Modeling for design**
  - Rapid Attributed, associative parametric OML & IML with geometric sensitivities
  - Human machine interface to design process/environments (VR)
    - Ironman JARVIS (Just a Rather Very Intelligent System)
    - Minority report
- **Analysis for design**
  - Mathematize selection of disciplines & couplings based on decisions being made
  - Multi-scale multi-fidelity analysis & sensitivities
  - System of systems
- **Design Space Exploration**
  - Additive Manufacture
  - Multi-scale Optimization (topology optimization)
  - Faster to 3D print & test then create computational models?
  - Big data – database technology, search algorithms (achieve every run)
  - Distributed Collaborative Design (multi-tier vendor participation)
- **Computation Resources**
  - Cloud
  - Security

Concluding Remarks

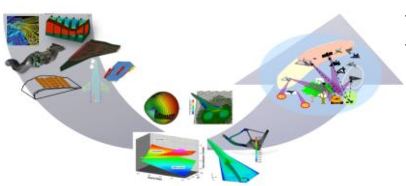
- ***Historical data & traditional conceptual design processes are insufficient for designing new/innovative configurations and technologies***



- ***A physics-based distributed collaborative design Environment for aerospace vehicle development and technology assessment has been developed (leverages MSTC Engineering)***



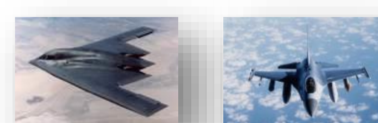
- ***Enables 10's of HiFi Physics Based Configuration Design with the Same Resources & Time of Traditional Design evaluates 1 or 2.***

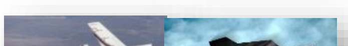


- ***Enables AFRL technology developers to have a quantifiable, physics based and traceable trail of the impact of their technologies on system effectiveness** – lethality, survivability, sustainability, affordability etc…*

- ***Creates info. with less uncertainty for making decisions for system capabilities, technology assessment, and technology risk reduction***

- ***Reduction of late Defects due to physics***





If you can change the culture, everything else is "easy"

Thank you!

Questions?

Some Closing Thoughts

- *If you can change the culture, everything else is "easy"*

- ***Very often, today's experts achieved their accomplishments by doing what the previous generation experts said should or could not be done.***

  - *Significant Investment Still Needed – Substantial ROI Available*

Cost & Capability versus Life Cycle

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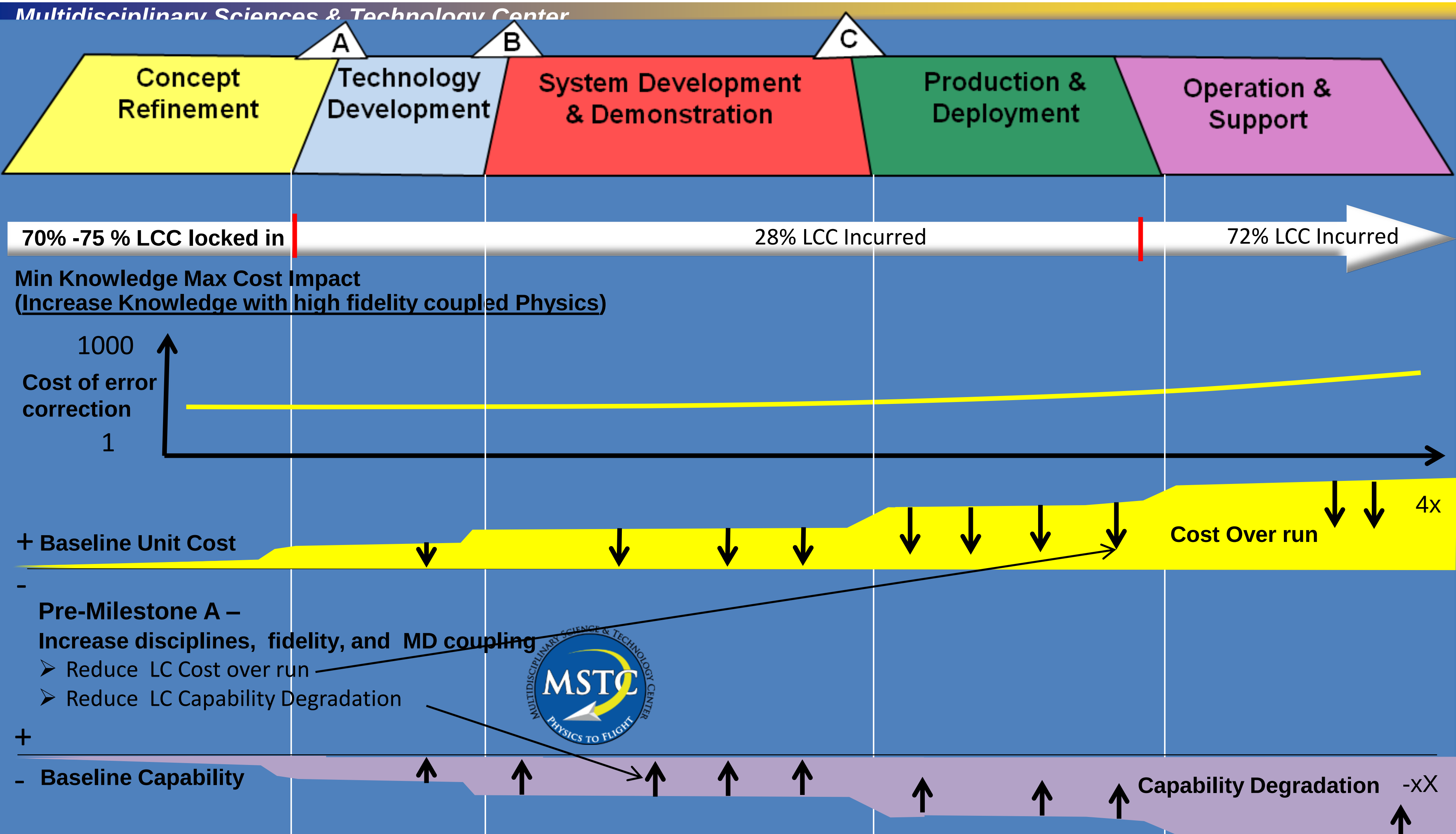

Driving High Fidelity Physics Based Design Early in the Process Produces More Capability & Lower Cost Over Life Cycle ("Bend the Cost Curve")

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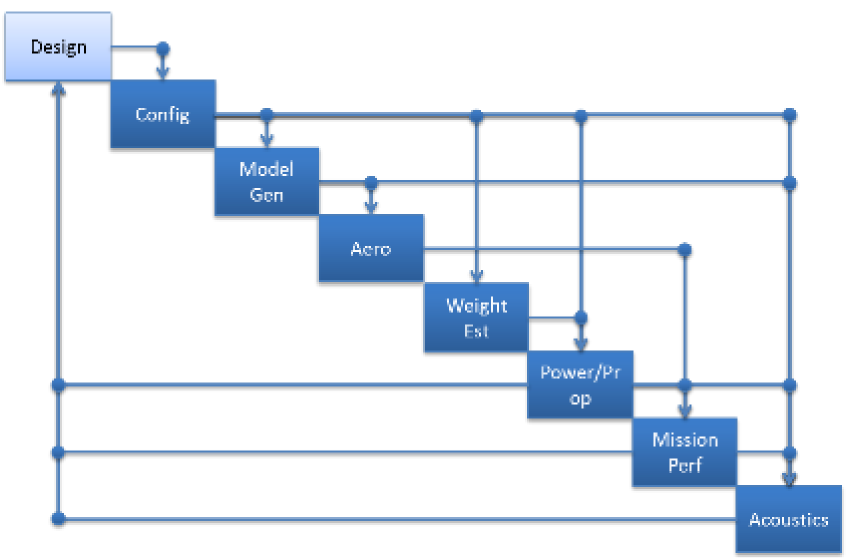
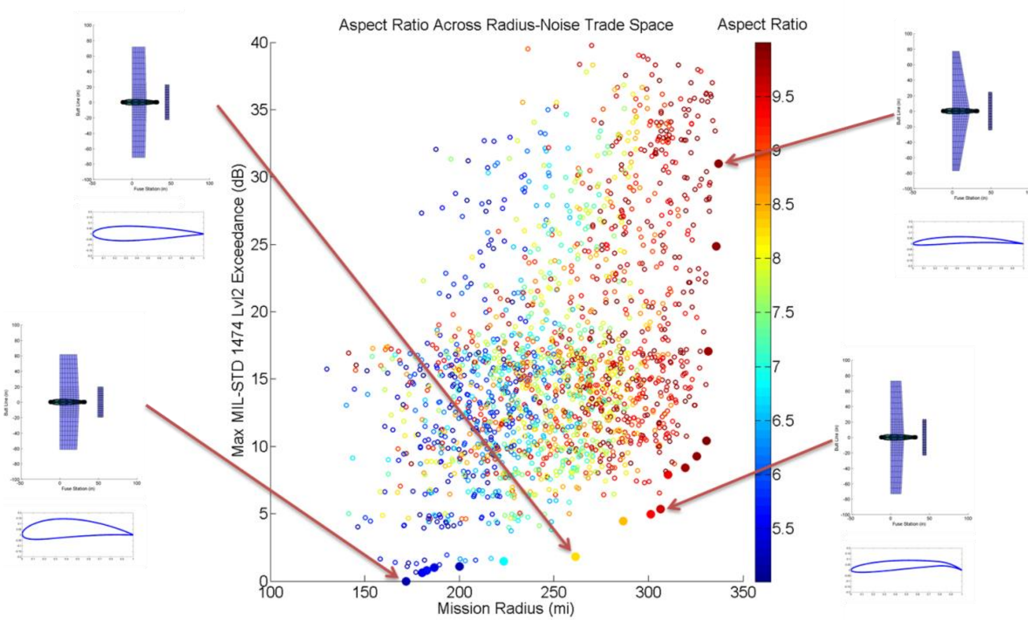
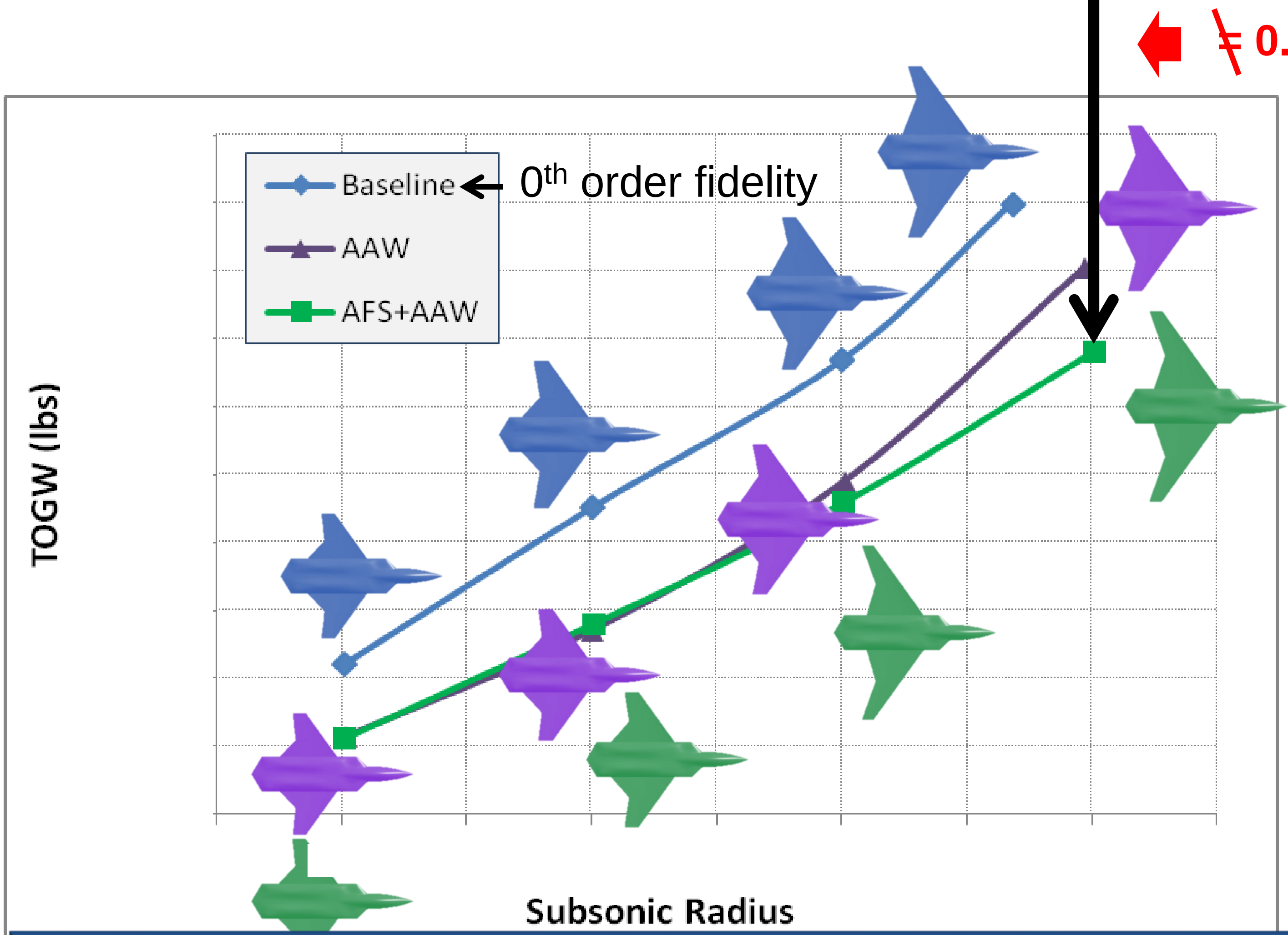
Small UAV Design Study with MSCT-Engineering

- Design of vehicle for minimum airframe noise
  - Vary area, aspect ratio, taper ratio, airfoil (NACA 4-digit), loiter speed
- Maximize mission radius while minimizing noise
- Produced viable designs and design guidance for customer
- Developed distributed design process in MSTC-Eng.
- Solved with GA – 10^5 runs





Impact on Efficient Supersonic Air Vehicle Design & Technology Assessment



Using traditional Level 0 Conceptual Design
- Active flutter suppression benefit 0.6% Empty Wt

Increasing Physics Disciplines & Coupling has a Significant Impact on the Resulting Vehicle Configuration, Performance, & Technology Impact