A Physics-Based Distributed Collaborative Design Process for Engineered Resilient Systems

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MSTC Vision & Mission

- **Vision**

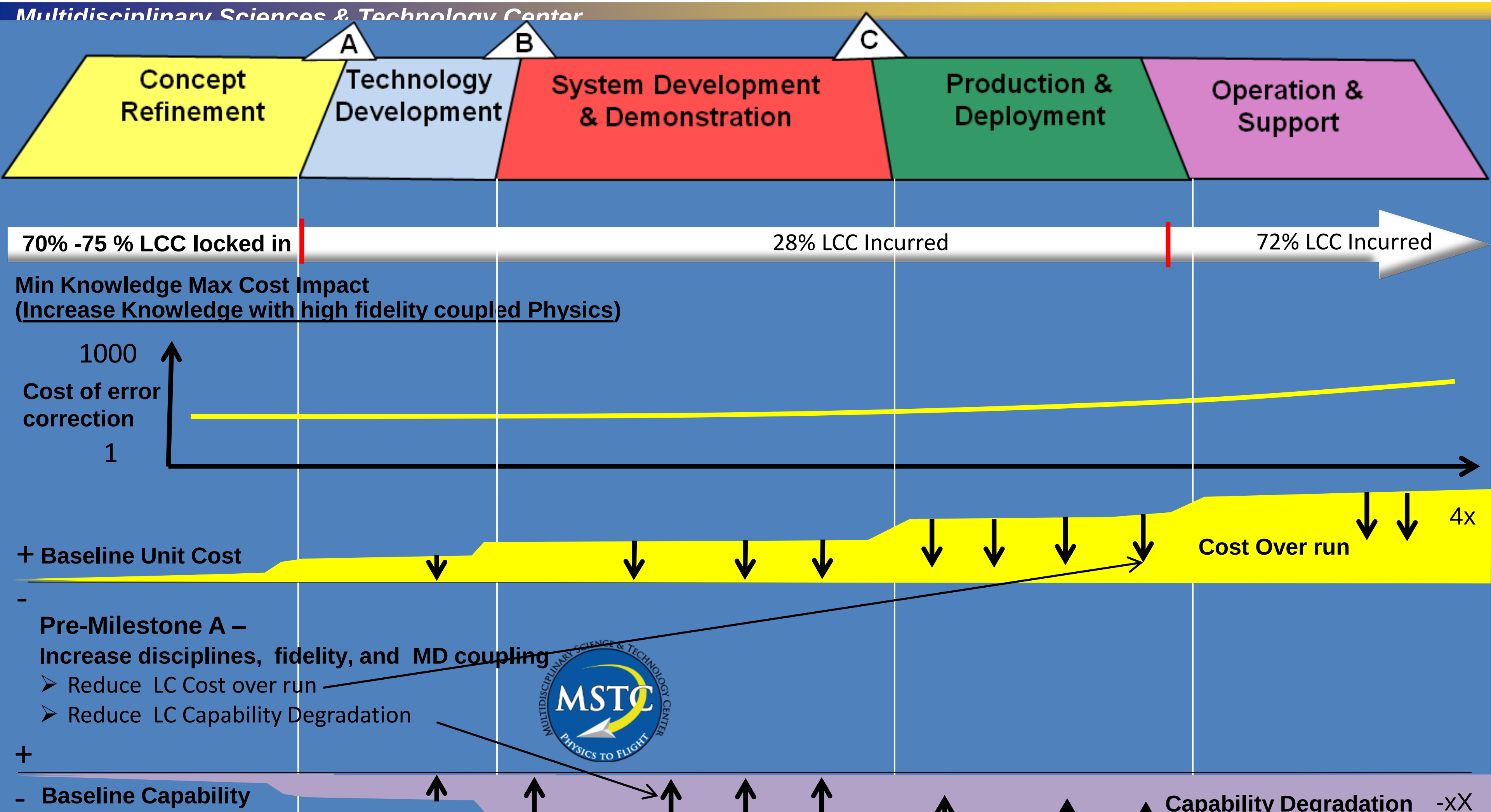
  Revolutionary aerospace vehicles through innovative multidisciplinary science & technologies

- **Mission**

  Discover, assess, and exploit coupled system behavior for optimization of revolutionary aerospace vehicles

"Physics to Flight"

Cost & Capability versus Life Cycle



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

*Extracted from Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition 2008

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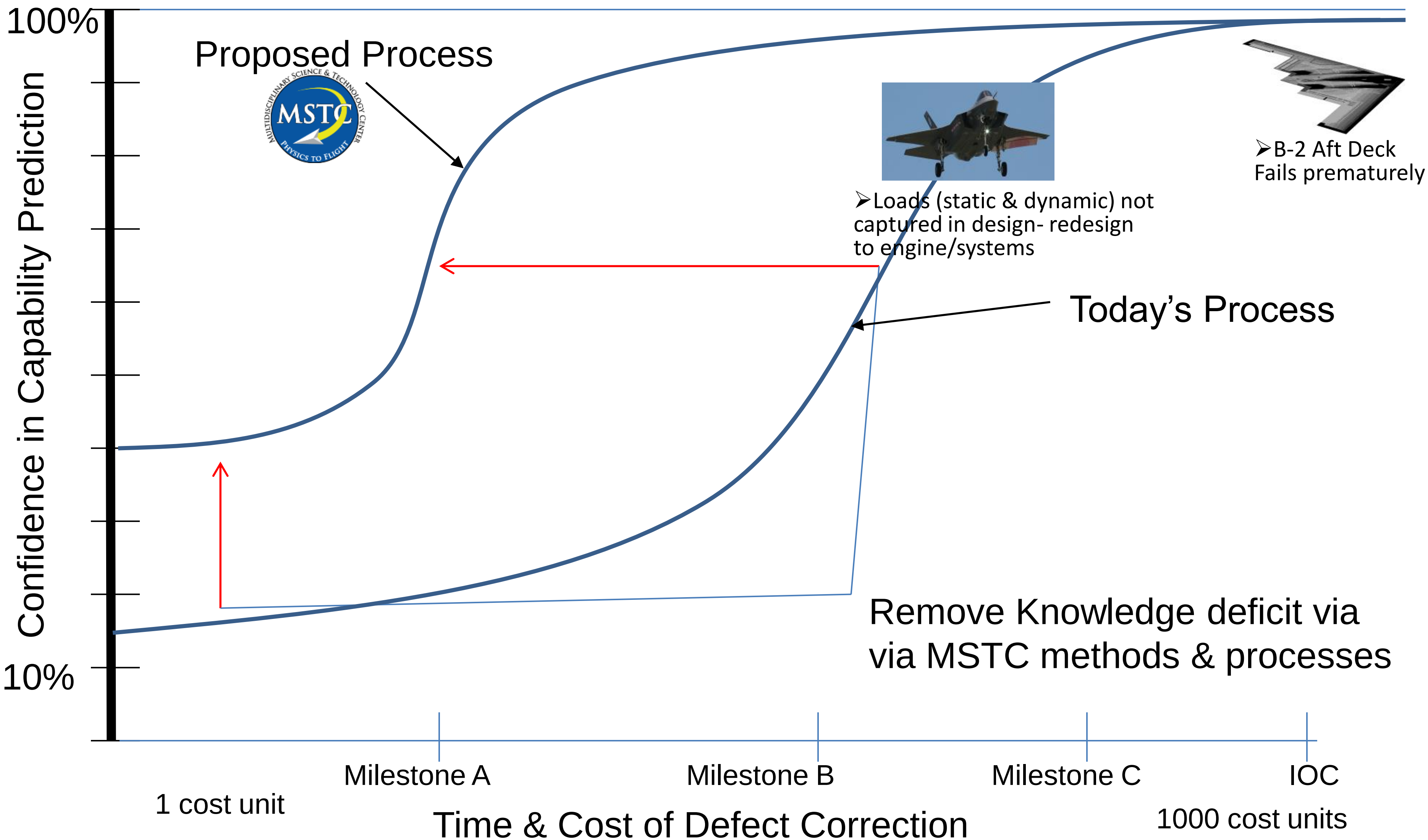
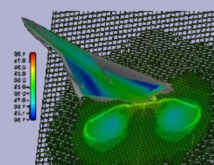
Reducing the Knowledge Deficit in Capability Prediction

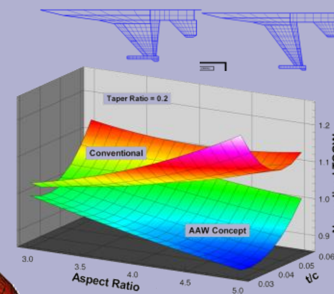


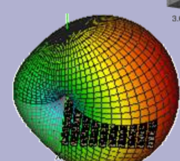
Develop & Trace Technology to Mission Level Capability Impact <u>Based on Physics</u>

Technology

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

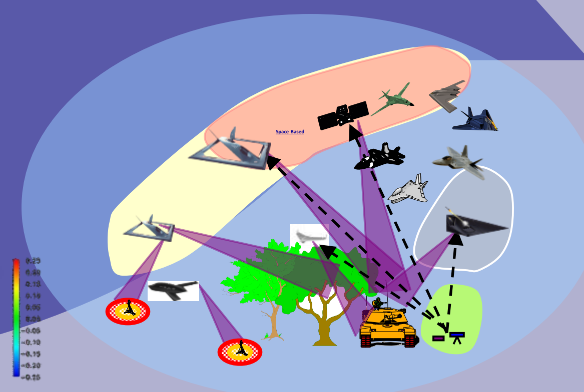


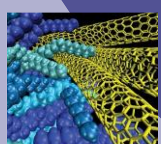


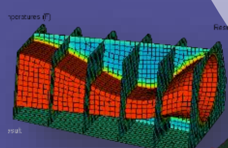


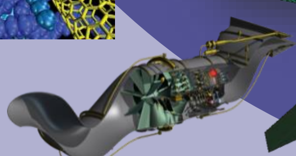
Mission Capability Impact

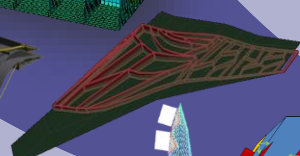
Combat effectiveness
Survivability
Kills/$
IDs/$
Mantainability
Life Cycle Cost
Sustainability
…

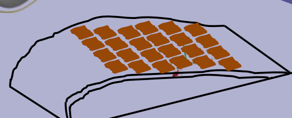


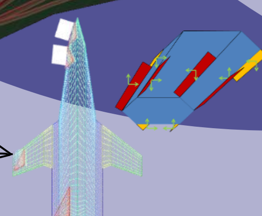






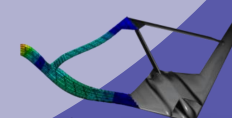


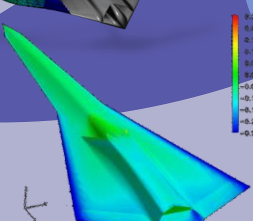




Engineering Capability Impact

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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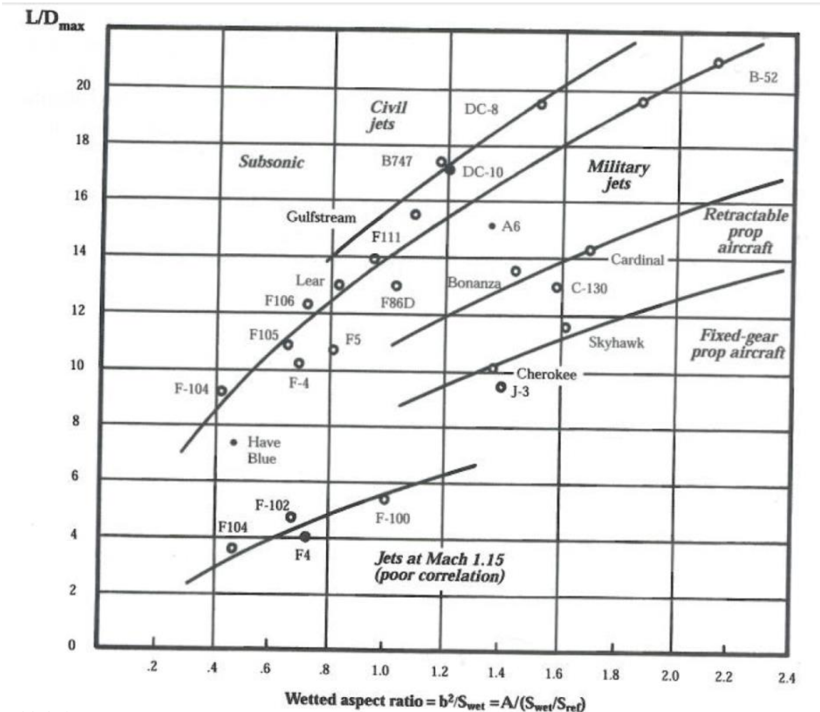
What we mean by “Physics Based”

Regressions of historical Data



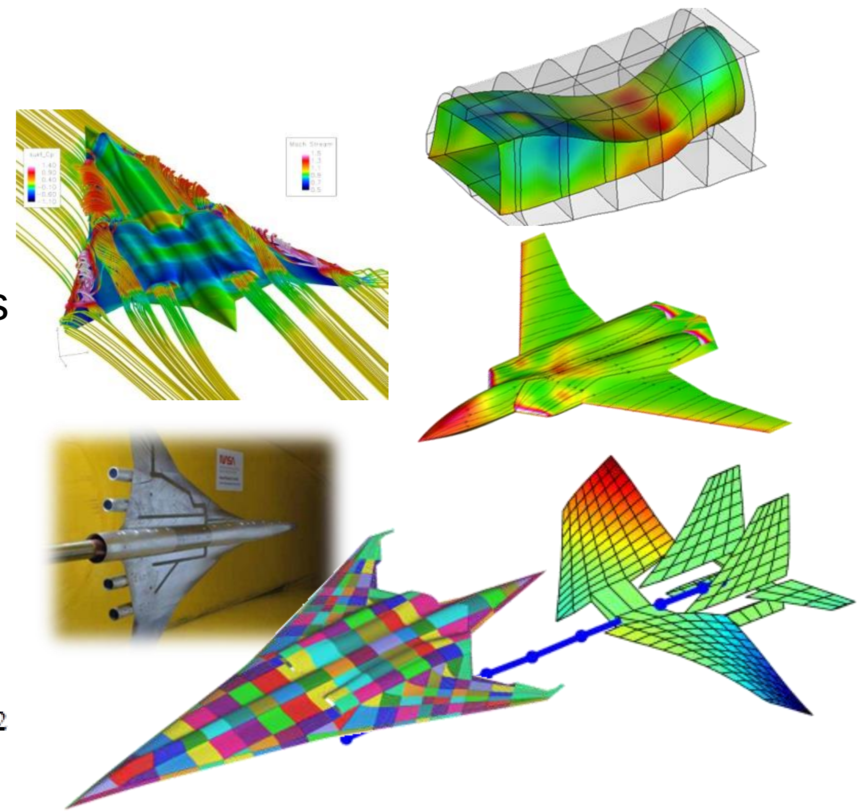
Raymer

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

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

Computational or testing on actual configuration

Versus



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

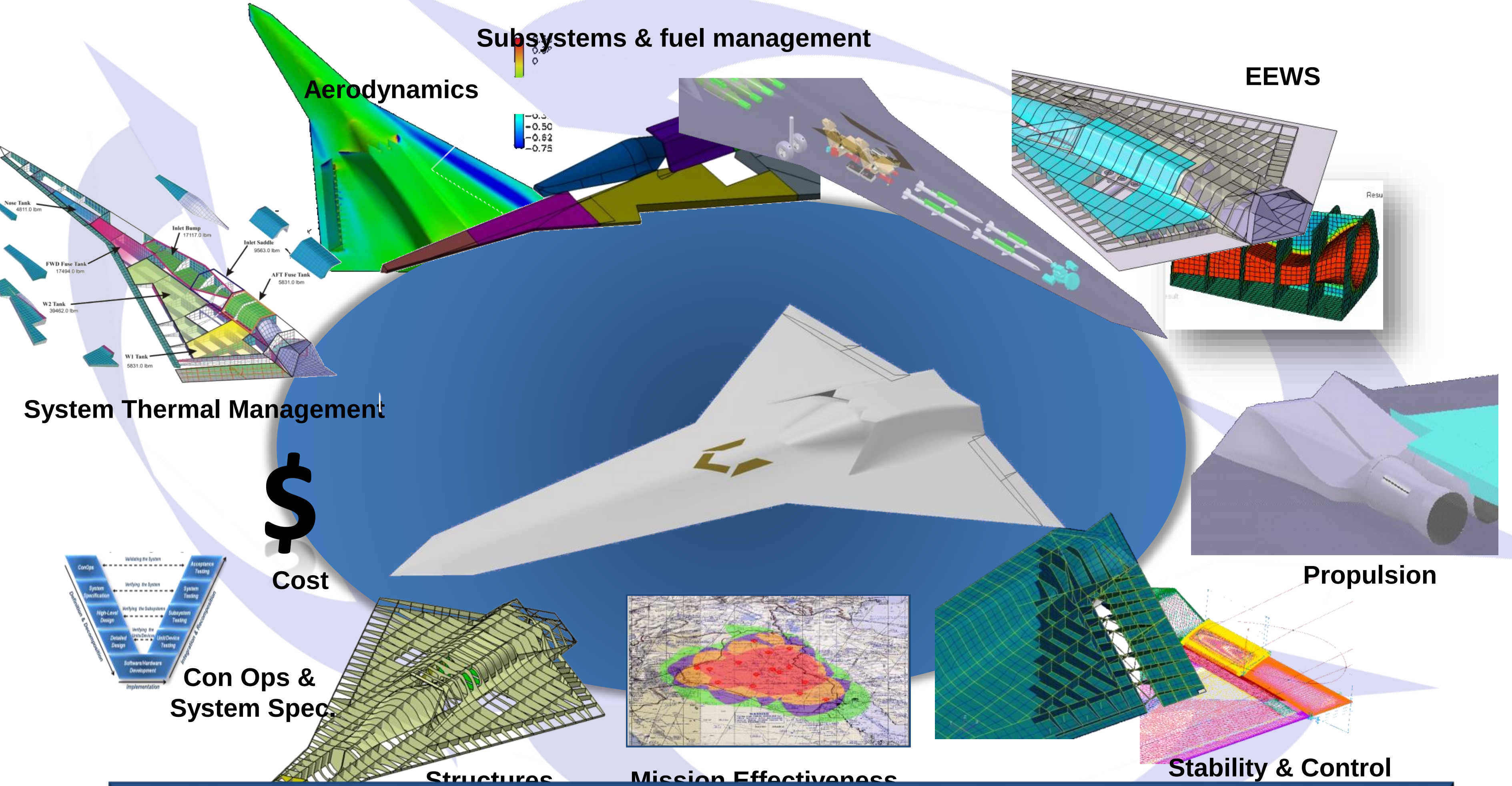
MSTC Products

- ***Discover, Develop, Demonstrate and Deliver :***
  - ***multidisciplinary technologies***
  - ***and the physics based design processes and methods that allow industry designers to incorporate those technologies into their next generation designs/modifications***

Develop processes, physics based methods, and <u>designs</u> for the purpose of AF technology discovery, development, demonstration, & delivery

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

Merge Conceptual & Preliminary Design



Add Disciplines, Couplings, & Fidelity - Early

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

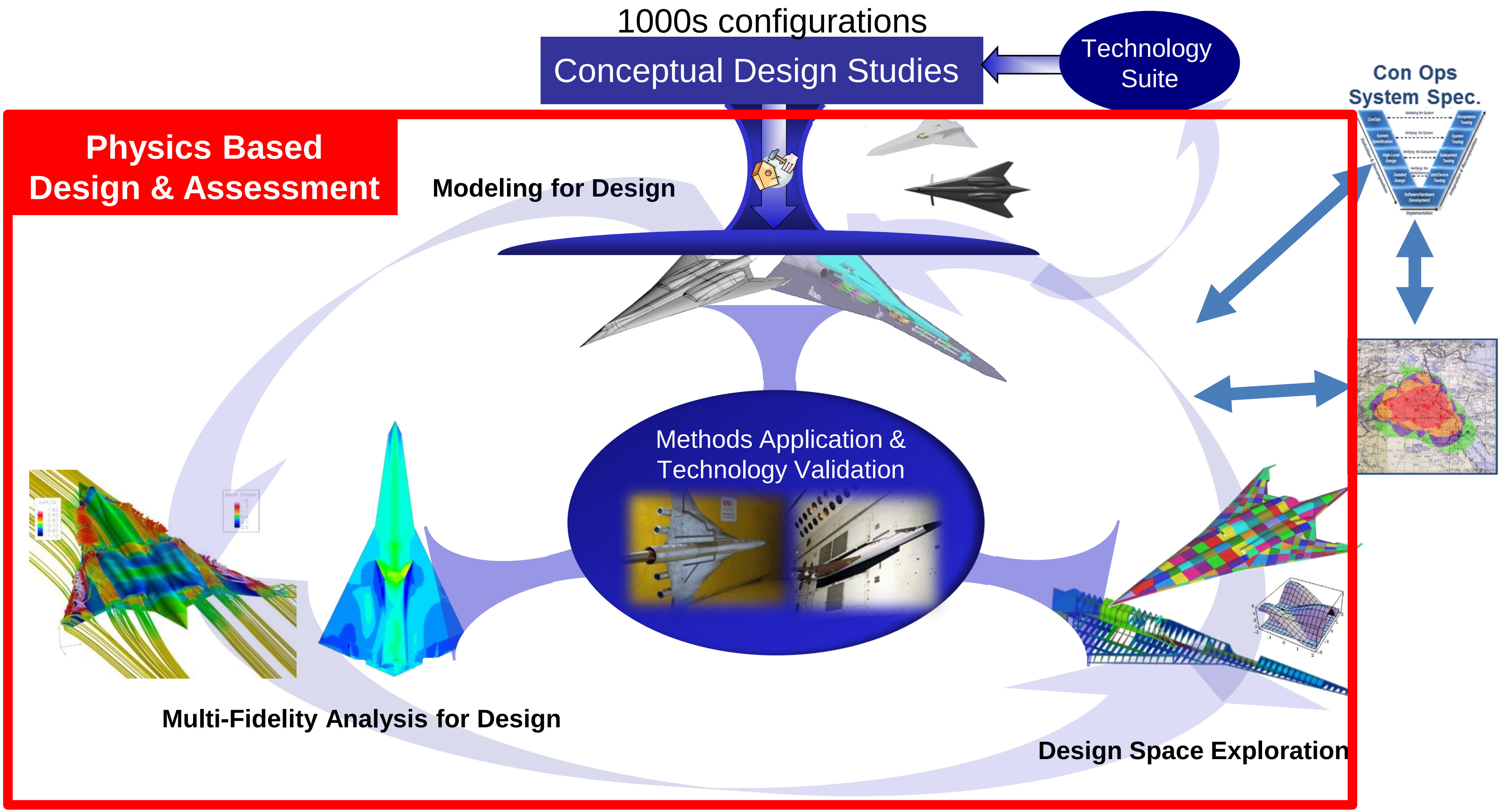
Reduce discovery of late defects due to un-modeled physics

Failure to account for multi-disciplinary effects have and continue to **cost billions of dollars to correct** or place operating limits on the systems
(80 out of 120 late defects due to inadequate loads prediction)

Identification of Critical Flight Loads Contract #F33615-95-D-3214 D.O. 0007

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

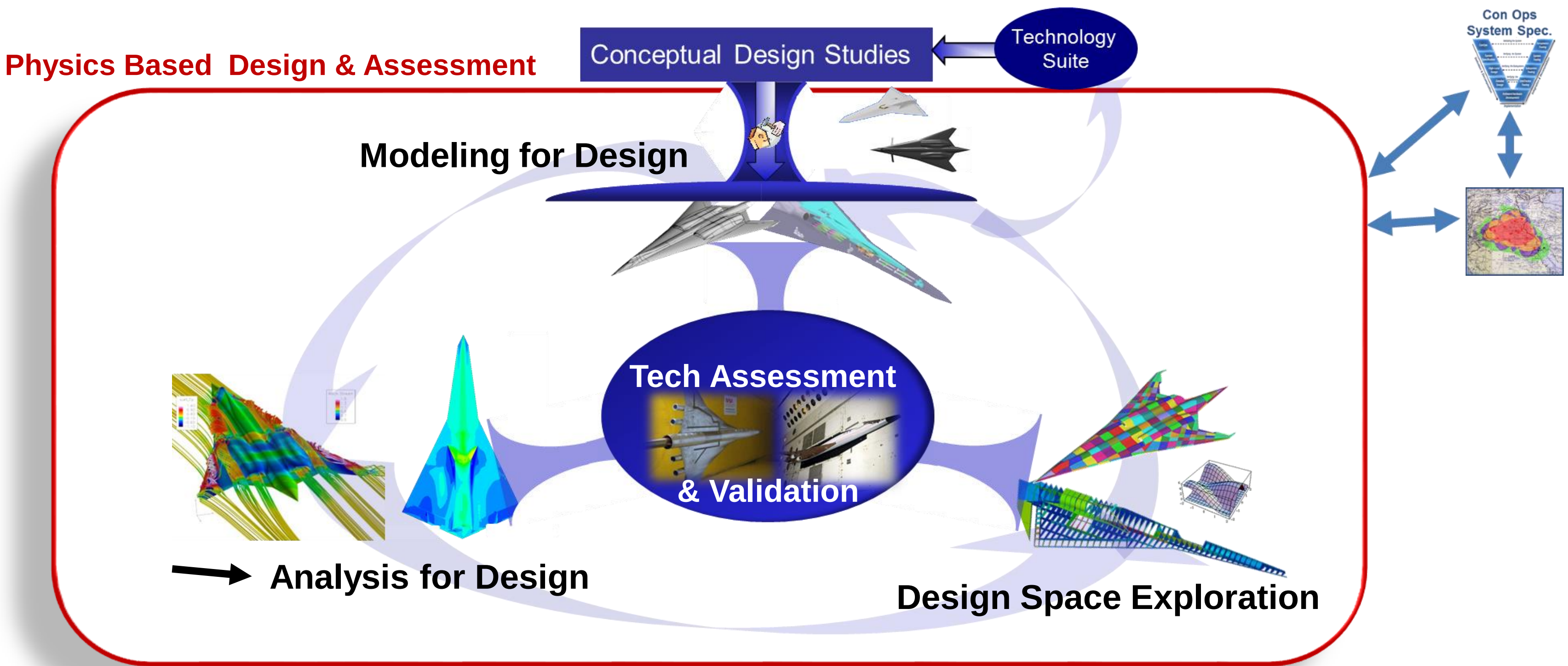
How to Capture the Physics Driving the Design Pre-Milestone A



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

MSTC Process & MDAO Methods KPPs

Multidisciplinary Sciences & Technology Center



KPPs

#1-15X Hi-Fidelity Design Configs forward for same cost

#2 - Coupling 2X

- -Aero, struct, controls
- -Acoustics, propulsion
- -- thermal, subsystems

#3- Fidelity Forward – level 0, 1,2,3 etc.. (target is level 3)

#4 - Reduce Modeling Uncertainty to within 5% of “truth”

#5 - Quantify impact to outputs due to variations to Inputs

MADO N^3 Diagram

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

MSTC Develops, Executes & Validates

Multidisciplinary Sciences & Technology Center

Configuration
Parametric Associative Geometry & Discretization

Propulsion
Thrust, SFC

Mass Properties
Raymer Weights

Aeroelasticity
Linear

Structures
Linear FEM Based

Geographic Location A
Geographic Location B
Geographic Location C

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

Aero(NS))

Aero(Euler))

Aero(Linear Potential)

Aero(Empirical)

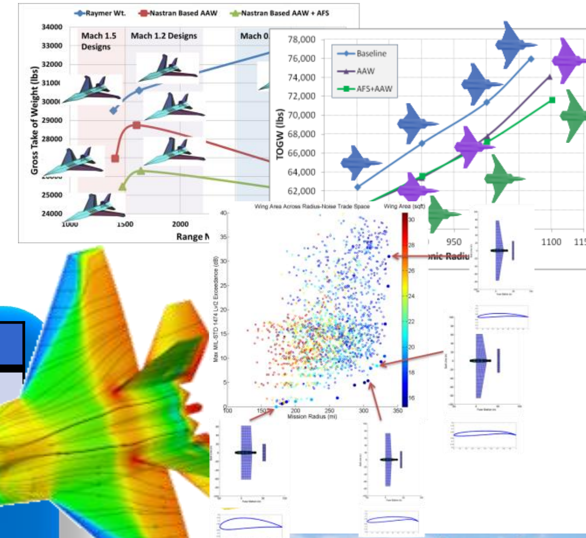
…ds & Drag

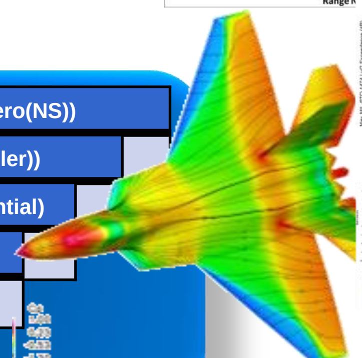
Heat Transfer

S&C
Surface Effectiveness Control Pwr. Req

Aero
Rigid Loads & Drag

∂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

MD Technology Validation (Validate results of N^2 Execution)

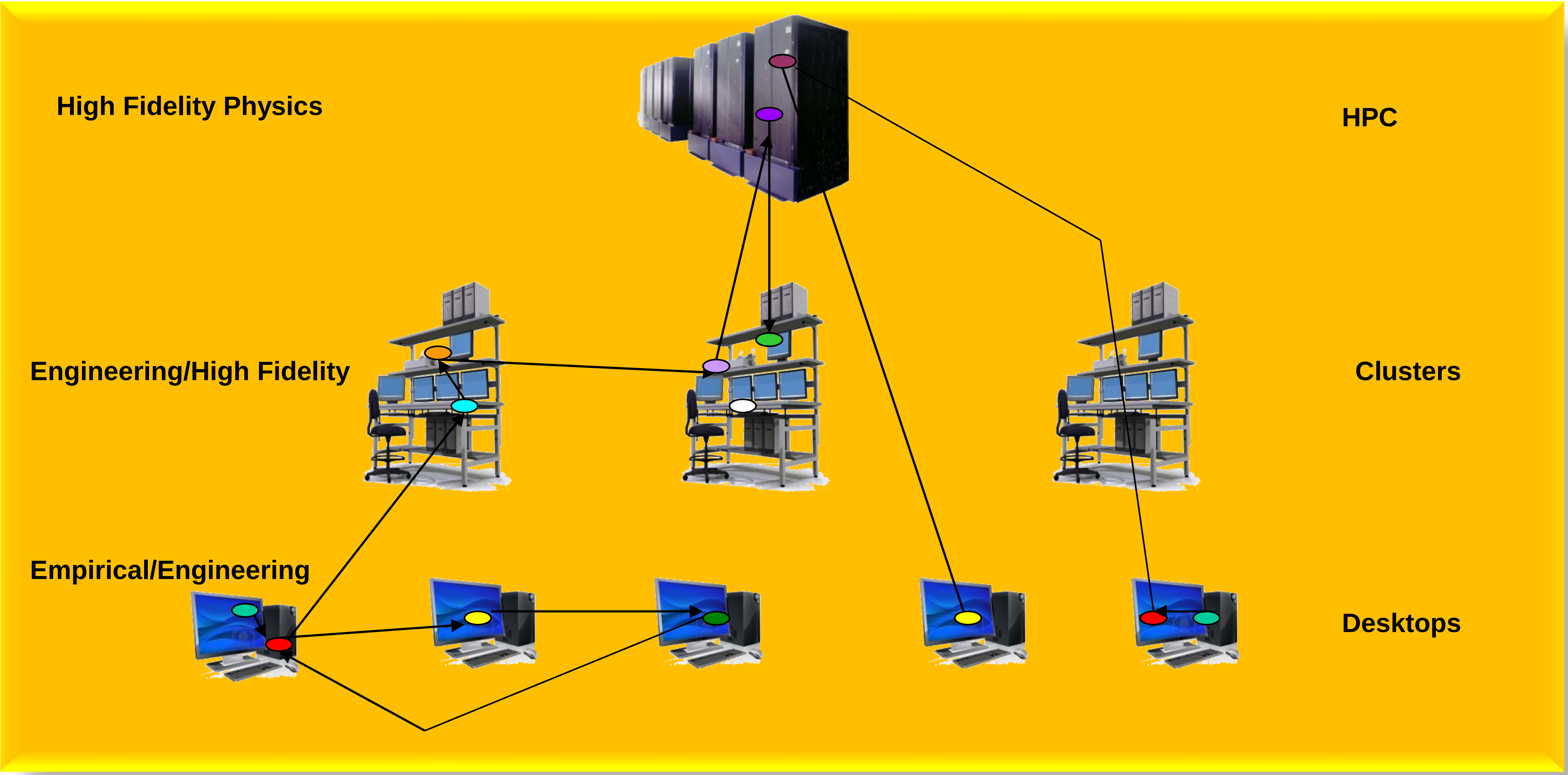
- Ground, Wind tunnel & Flight Experiments

High Level Requirements for System Level Variable Fidelity MADO

- # of components/applications/Services – 100's to 1000's (no single application, no single machine)
- Run times of services – secs to many days
- 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

Physics Based Distributed Collaborative Design (Compute Resource View)

Multidisciplinary Sciences & Technology Center



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

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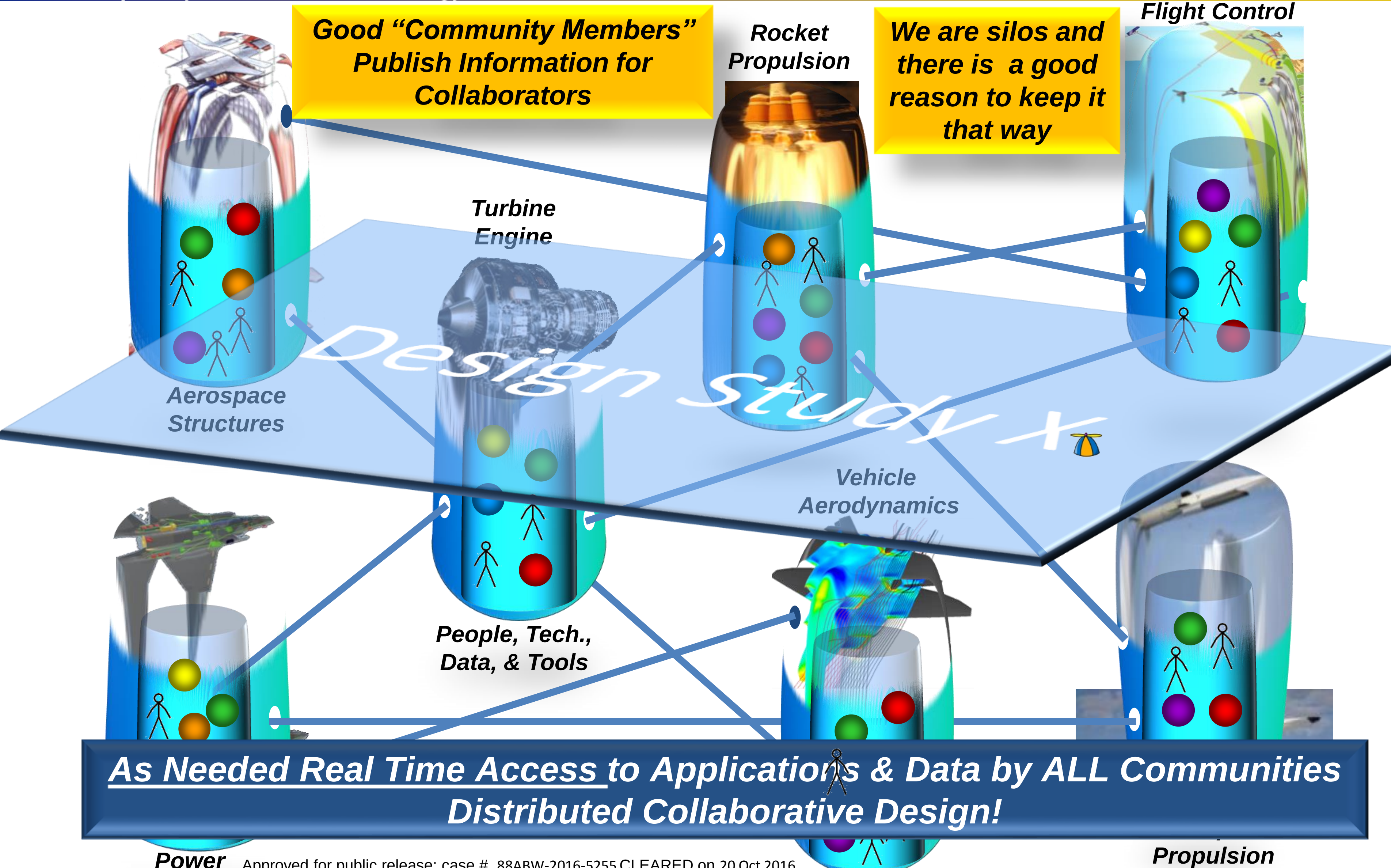
Physics Based Distributed Collaborative Design (Org View)



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

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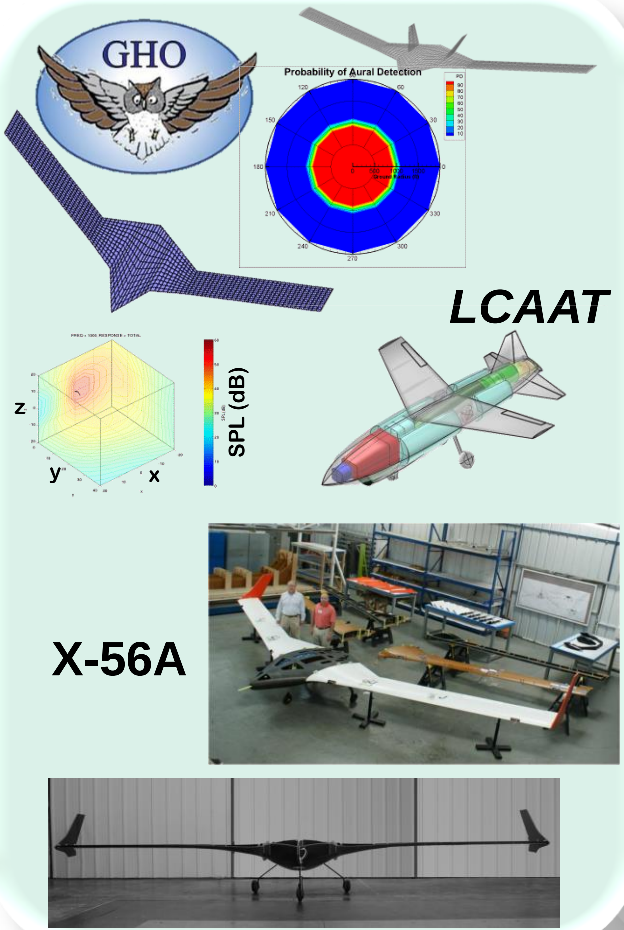
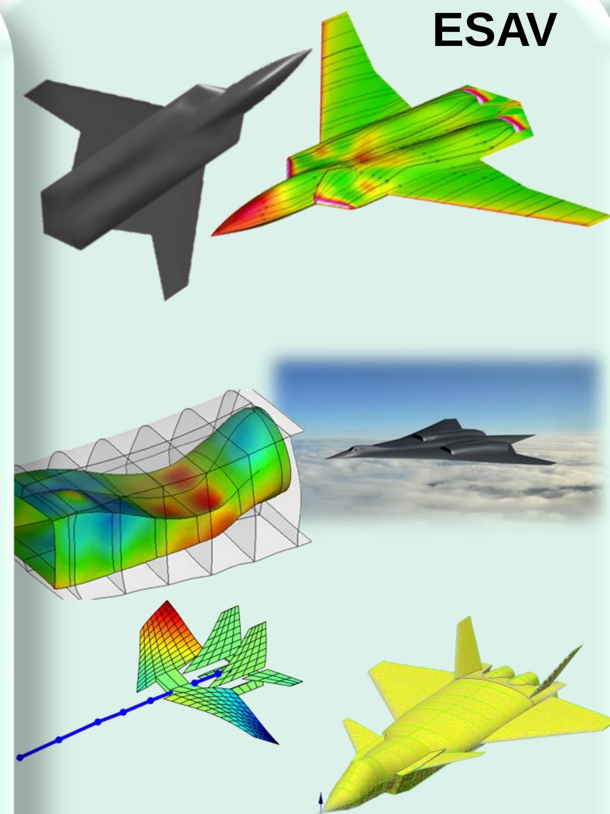
MSTC Focus Applications & Products

Multidisciplinary Sciences & Technology Center

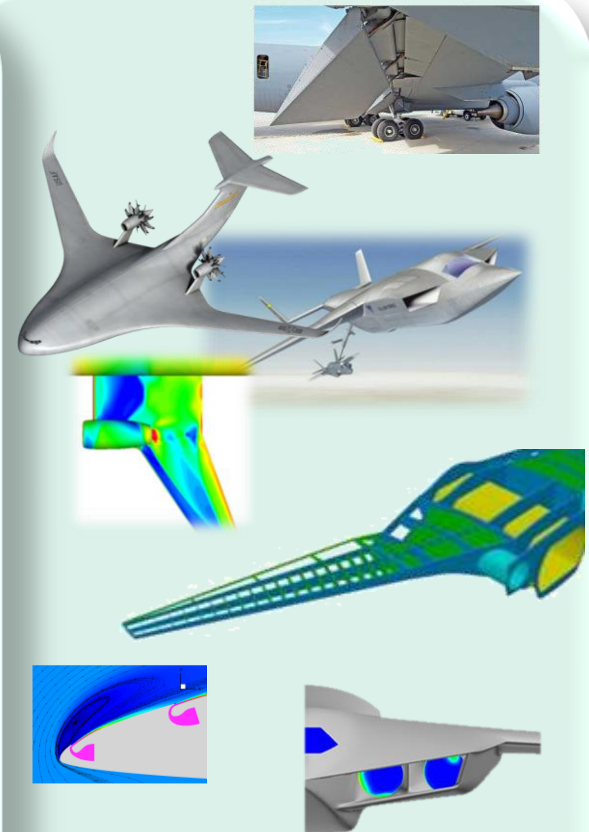
SUAVs
Reich/Szczublewski



Efficient Supersonic Air Vehicles
Alyanak/Iden/Allison



Mobility
Joo/Szczublewski

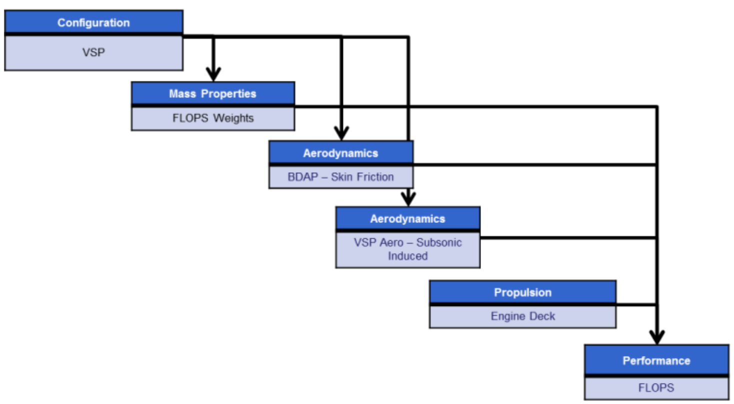


CSD
Without Distributed Collaborative Design (RQVA)

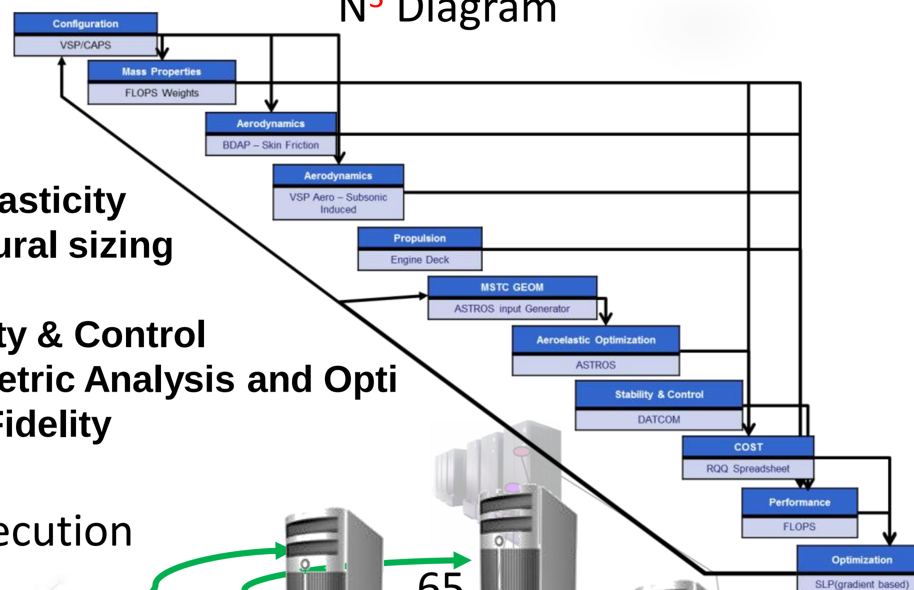
CSD With Collaborative Distributed Design (RQVA, RQVC, RQQ, RQT)

RQVA

N^2 Diagram



N^3 Diagram



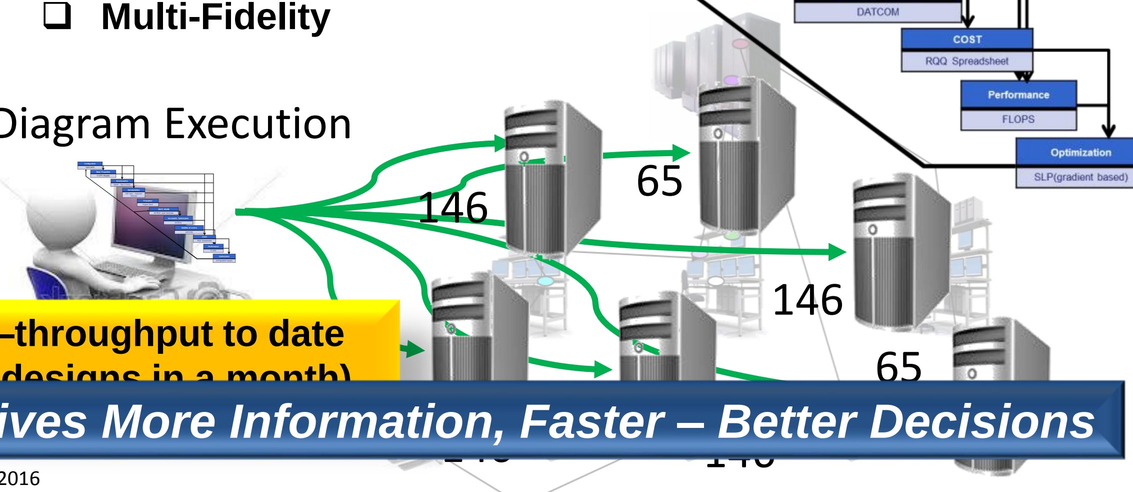
- ❑ **Aeroelasticity**
- ❑ **Structural sizing**
- ❑ **Cost**
- ❑ **Stability & Control**
- ❑ **Parametric Analysis and Opti**
- ❑ **Multi-Fidelity**

N^2 Diagram Execution

24C

N^3 Diagram Execution

24C

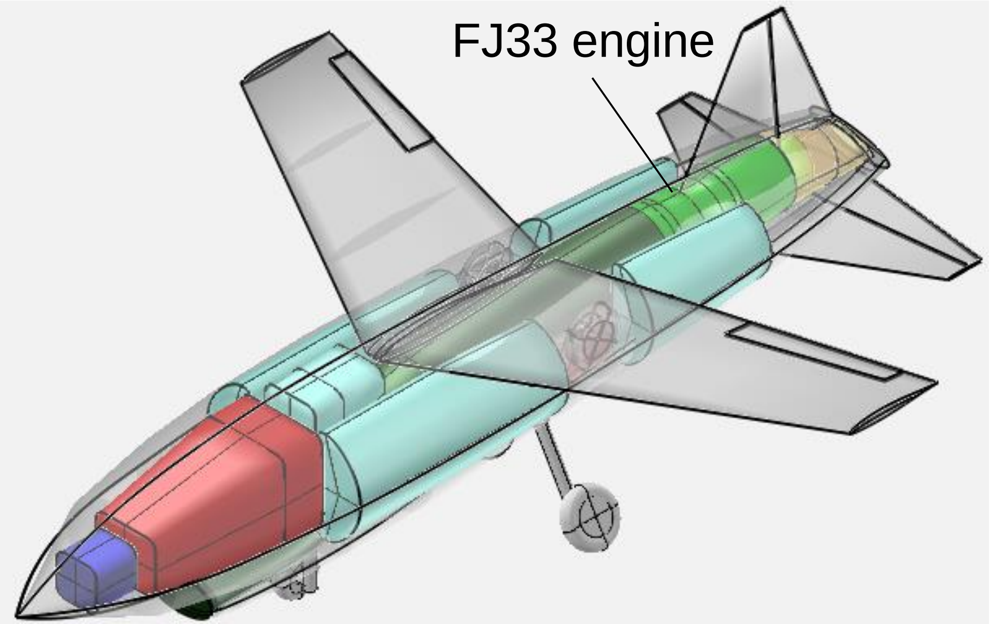


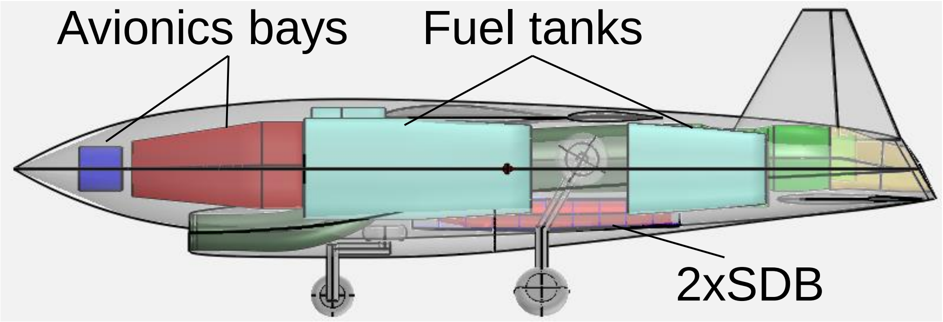
100X –throughput to date (250K designs in a month)

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

Baseline SUAV Design

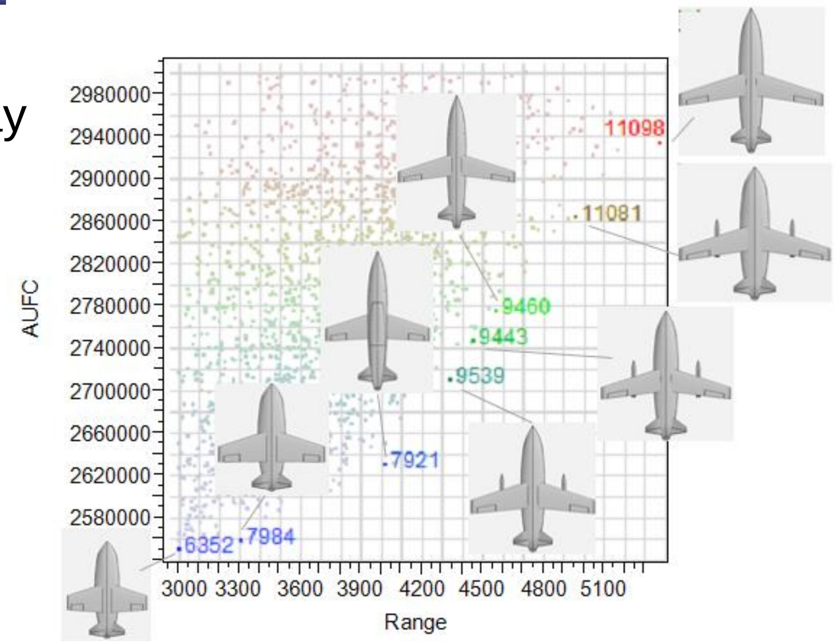
Cost (AUFC)	$2.65M
Length	21’
Span	15’
Sweep	30 deg
Gross Weight	3335 lb
Empty Weight	1301 lb
Payload	500 lb
Fuel Weight	1534 lb
Range	3220 NM
Cruise Speed	M0.62
Max Speed	M0.86
Turn Loading	6 G



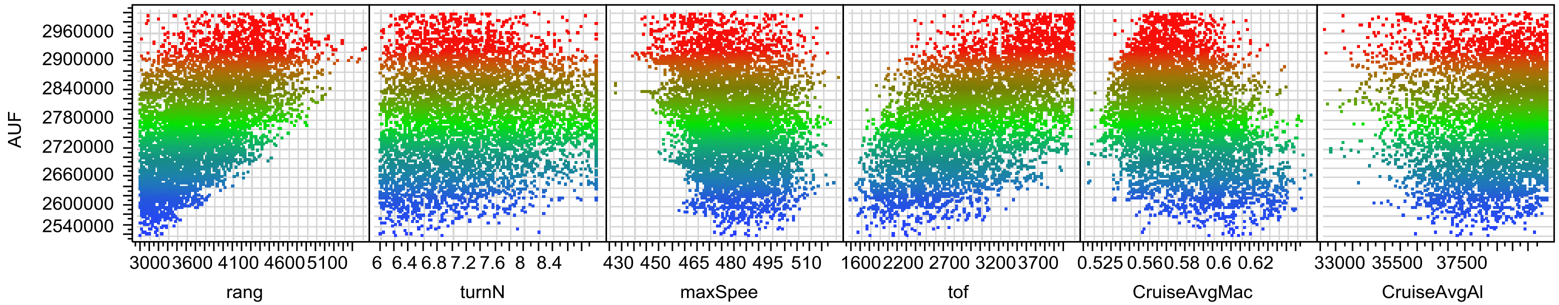


Cost and Performance Trades

- Cost trades against range performance, but decreases with improved up-and-away performance
  - Discrete engine means smaller size / lower cost = better up-and-away performance
- 5794/24000 configurations satisfy all constraints (for this DoE)
  - Range > 3000 NM
  - Turn Nz > 6
  - Climb Rate > 5000 fpm
  - Max Speed > 425 knots
  - TOFL < 4000 ft
- Cost vs range shows a front of best range designs for a given cost

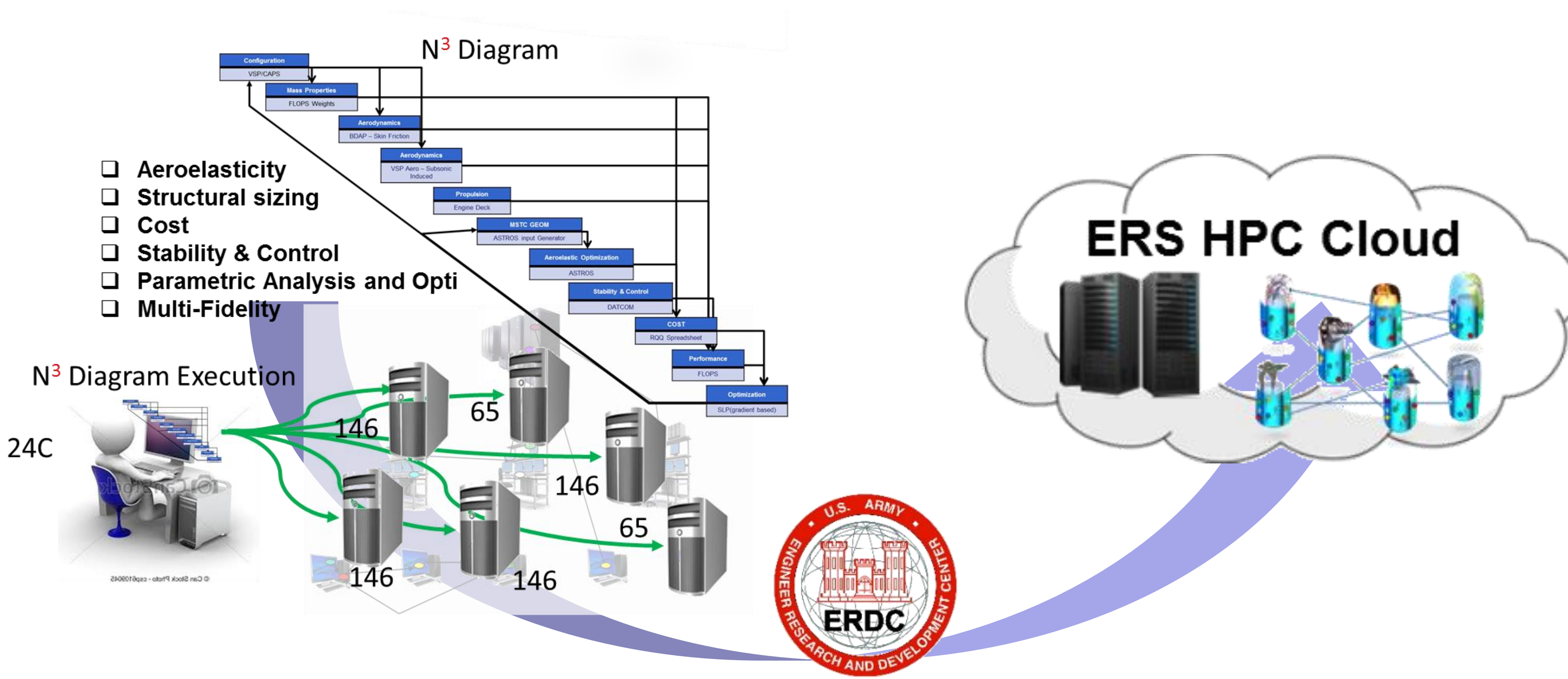


MOP	Baseline	Design 11098	% Difference
Range	3220 NM	5374 NM	67%
Turn Nz	6 G	6.8 G	13%
AUFC	$2.65M	$2.93M	10%



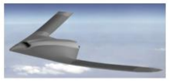
CSD ERS-ERDC Collaboration

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

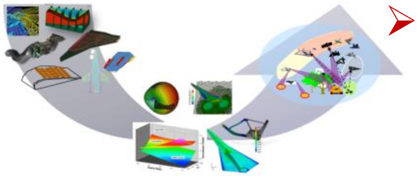


Another 100X –throughput Expected

Concluding Remarks

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



- ***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***
- ***Essential for reduction of late Defects due to physics***


- ***Expands the design space yielding capabilities not other wise obtainable***