MDAO - An Air Force Perspective

Phoenix Integration 2021 Virtual Event Program on MDAO
4 March 2021

RM Kolonay

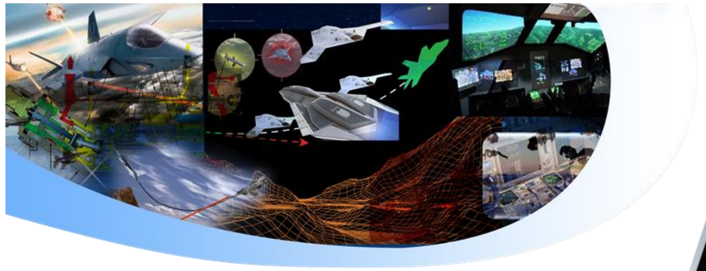
AFRL - Aerospace Systems Directorate

Mission: Boldly pioneering transformative space and air capabilities to make the fight unfair

Aerospace Vehicles Division (RQV)

Rocket Propulsion Division (RQR)

Power and Control Division (RQQ)



High Speed Systems Division (RQH)

Turbine Engine Division (RQT)

USSF

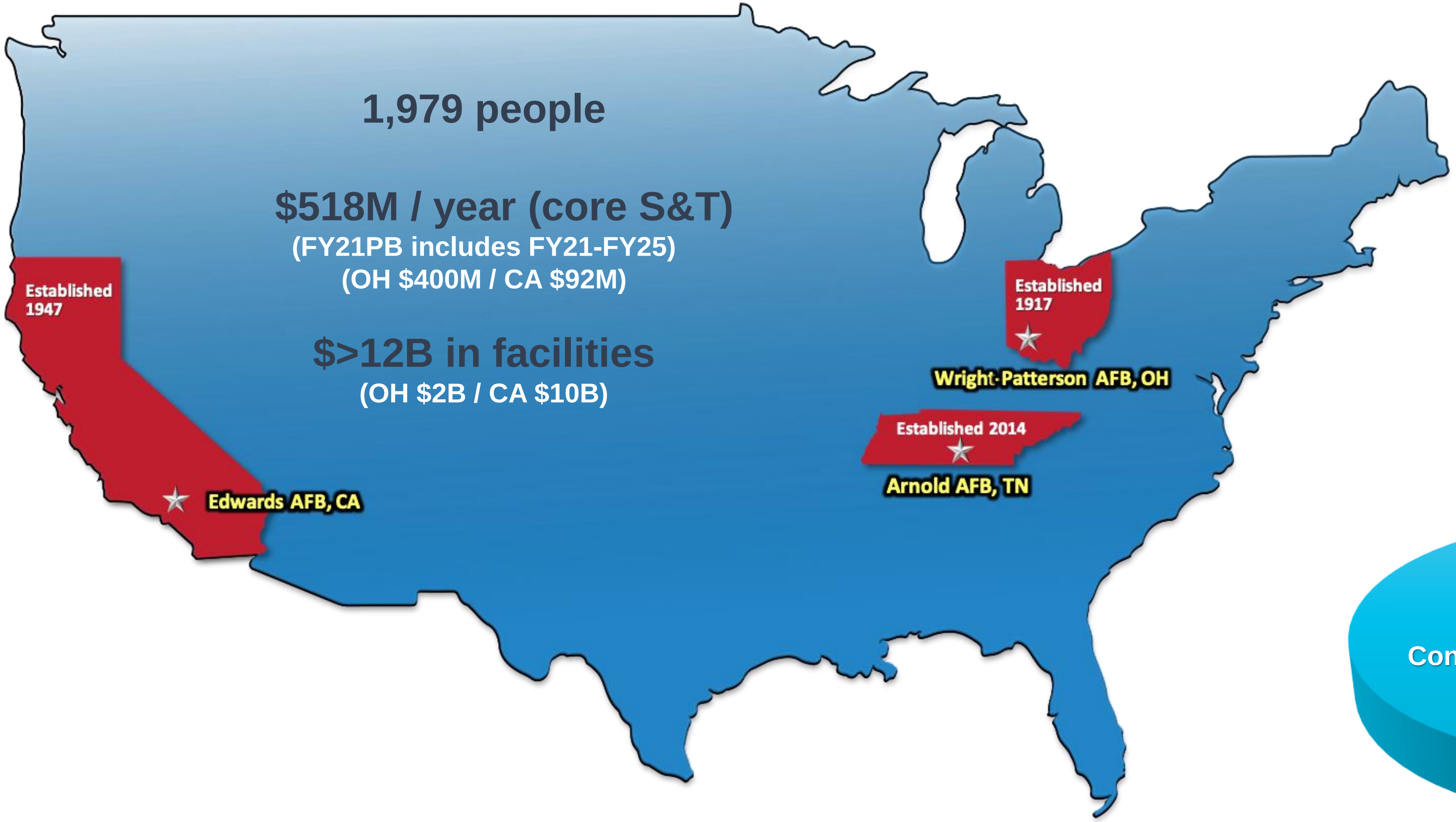
Vision: One team unleashing innovative aerospace weapon system capabilities

Aerospace Systems Directorate

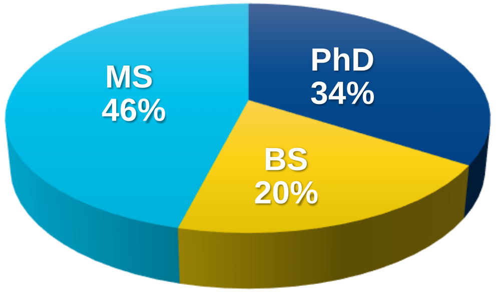
1,979 people

$518M / year (core S&T)
(FY21PB includes FY21-FY25)
(OH $400M / CA $92M)

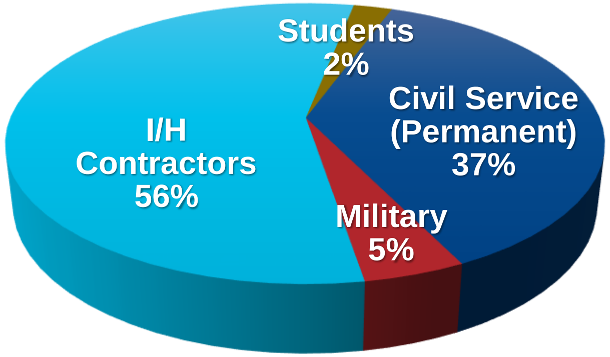
$>12B in facilities
(OH $2B / CA $10B)



Government S&E Education



Manpower Distribution



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"

High Level Products

- ***Discover, Develop, Demonstrate and Deliver :***
  - ***Multidisciplinary Technologies***
  - ***Physics-based design processes and methods***

Transition to industry for next generation aerospace vehicle designs/modifications

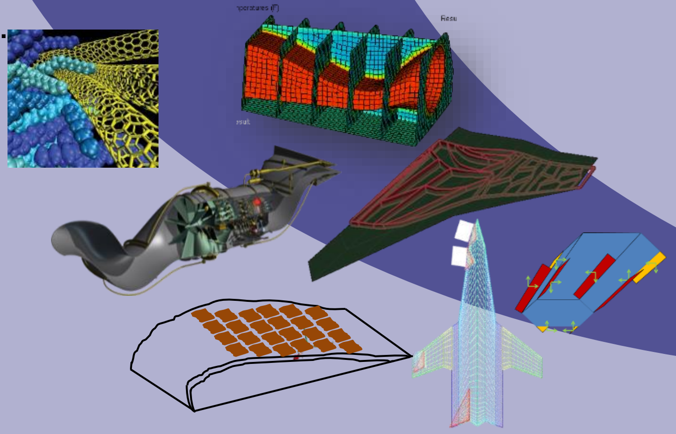
Goals

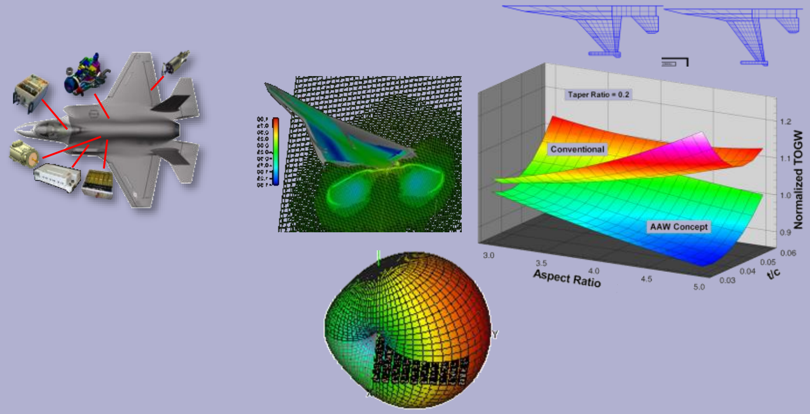
- Deliver vehicles that satisfy mission requirements in a timely manner
- Reduce the number of late defects due to un-modeled physics
- Trace technology to mission level capability impact based on physics – Effectiveness Based Design Optimization

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

Technology

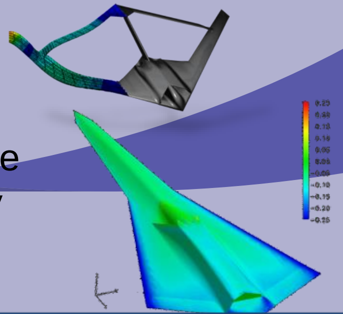
Aeroelastic Wing
Flutter Suppression
Third Stream Engine
Advanced Materials
Thrust Vectoring
Innovative Control Effectors
Directed Energy
Conformal Load Bearing Antennas
…
…



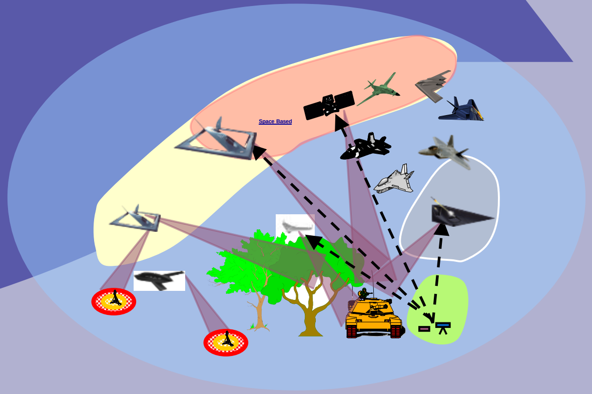


Engineering Capability Impact

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



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



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

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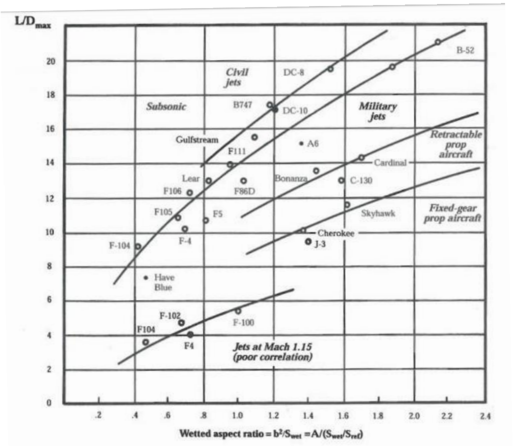
What We Mean by "Physics Based"

Not Physics Based

Regressions of historical data

BOPSAT

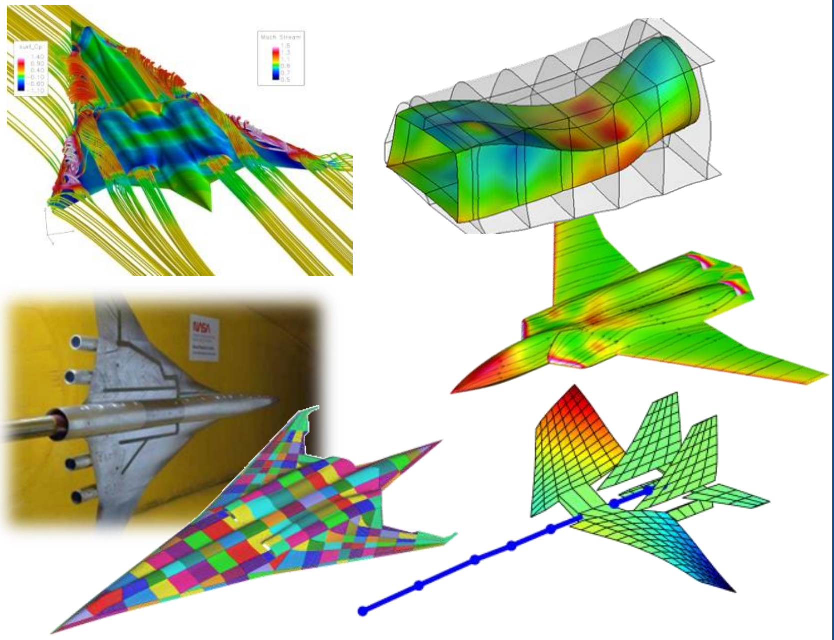


$$W_{wing} = (k_{tech\_factor}) * 0.0103 K_{dw} K_{vs} (W_{dg} N_z)^{0.5} S_w^{0.622} * A^{0.785} (t/c)_{root}^{-.04} (1+\lambda)^{0.05} (\cos \Lambda)^{-1} S_{csw}^{0.04}$$

(Raymer)

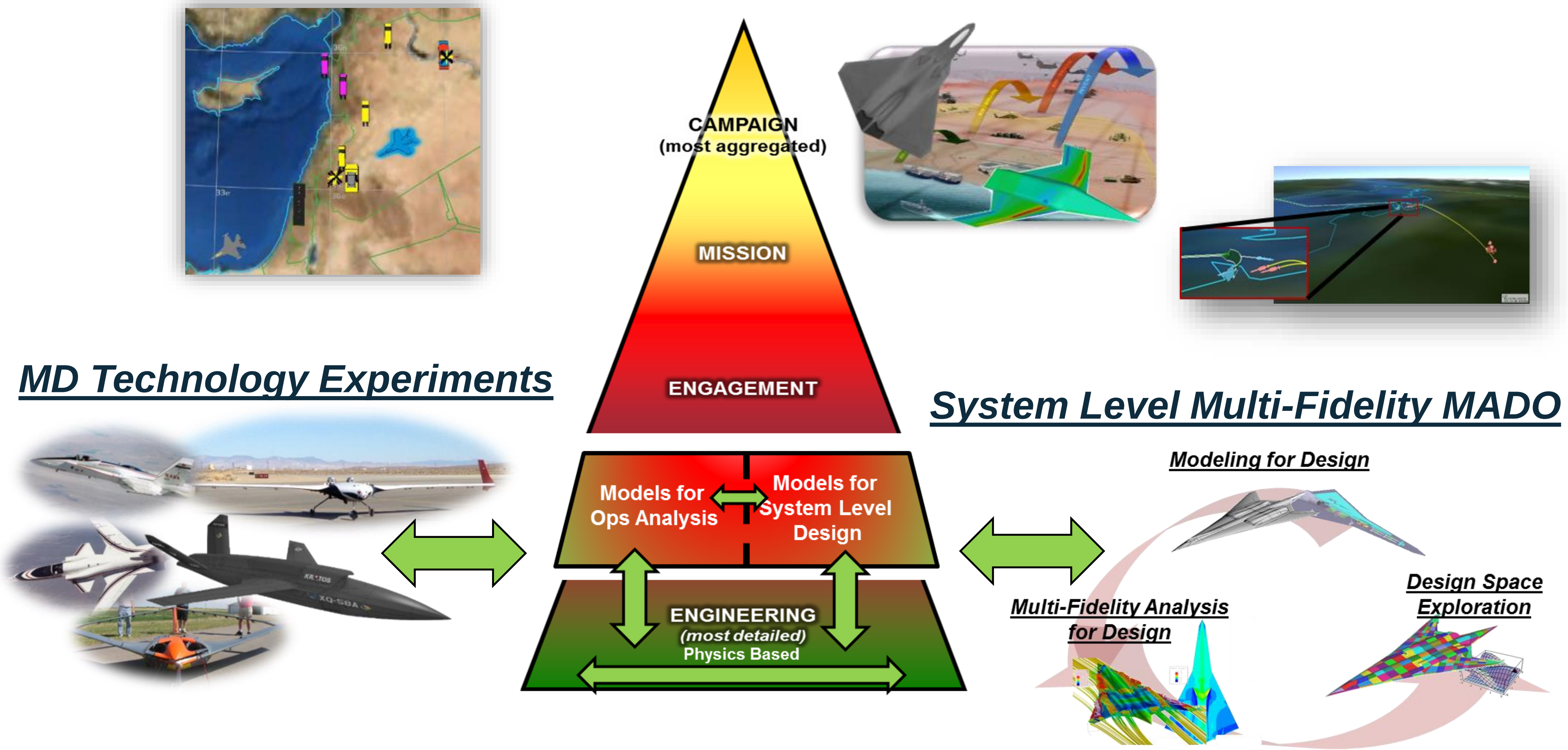
Physics Based

Interrogations of engineering models and test articles

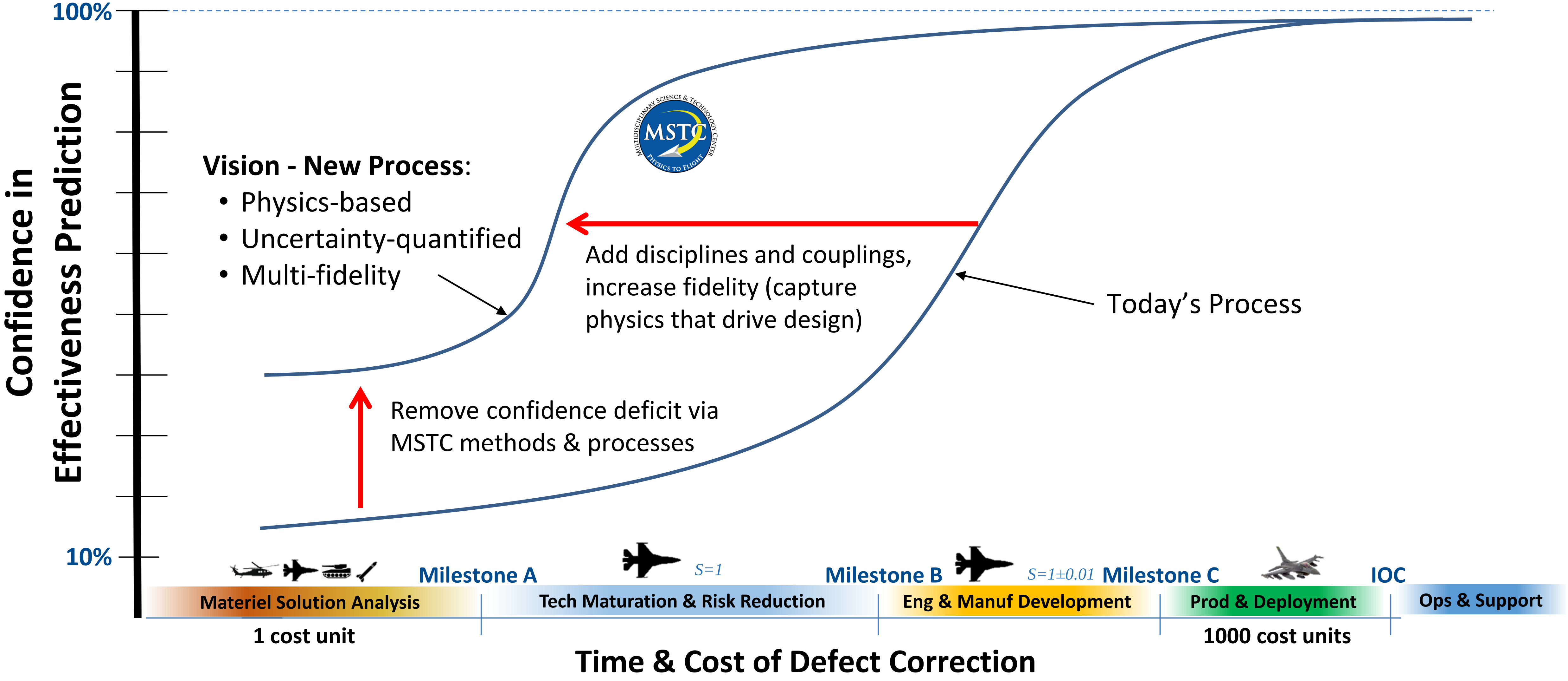


SME, BOPSAT, historical data insufficient for designing innovative configurations and assessing new technologies

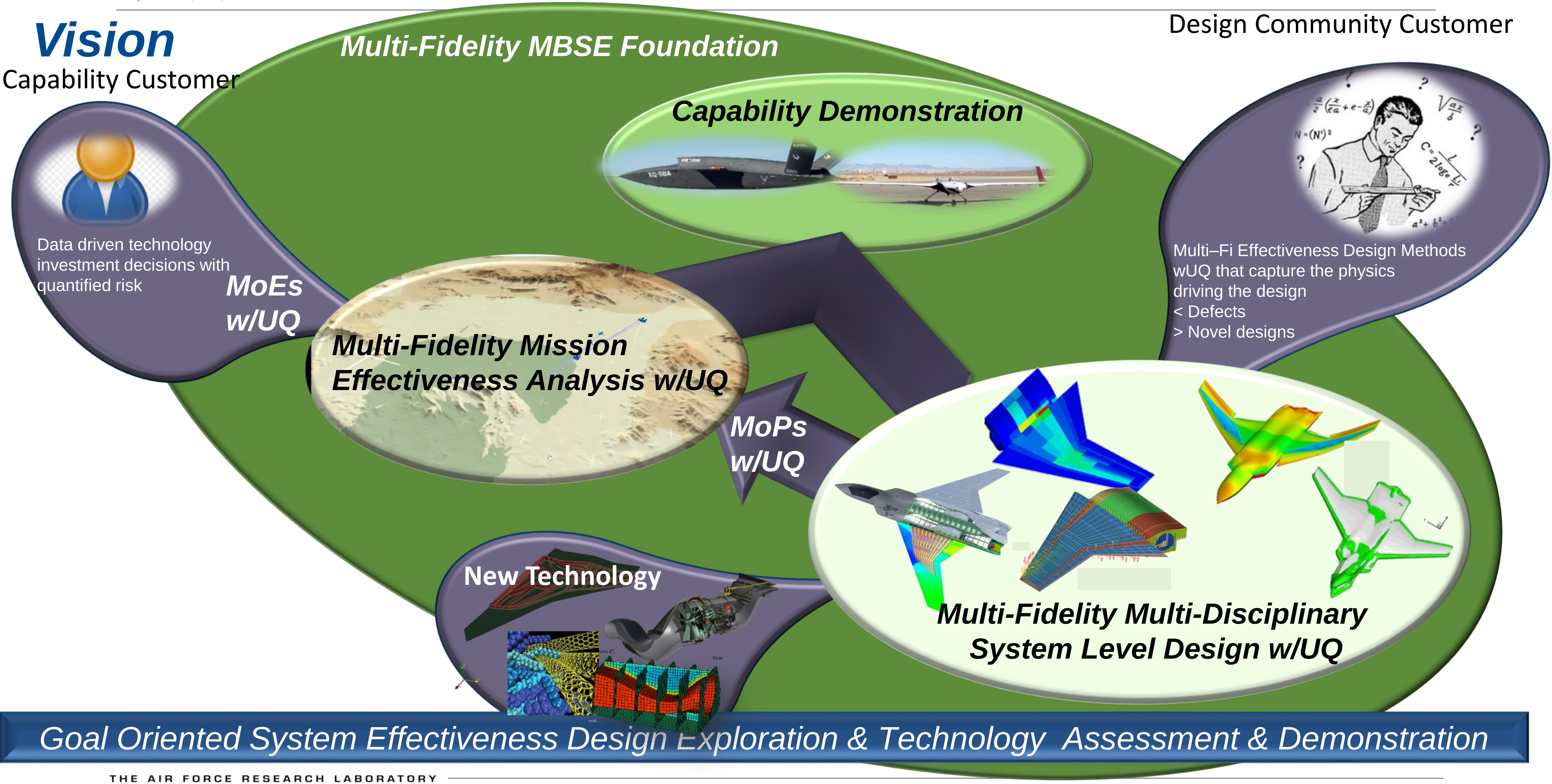
What we mean by Modeling, Simulation & Analysis (MS&A)



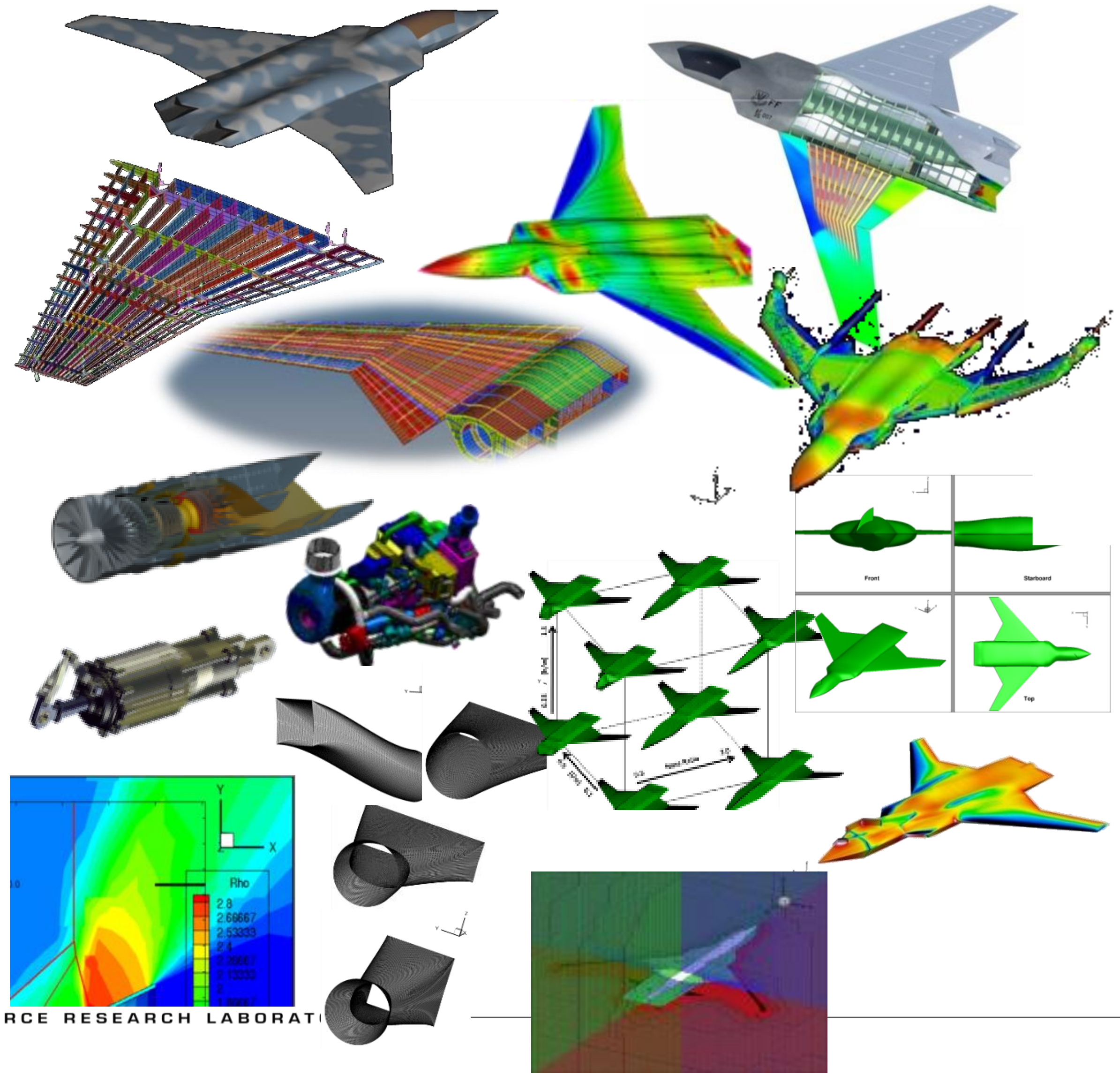
What Problem are We Trying to Solve? - *Reduce the Confidence Deficit in Effectiveness Prediction*



Vision


Capability Customer
Design Community Customer
Multi-Fidelity MBSE Foundation
Capability Demonstration
Data driven technology investment decisions with quantified risk
MoEs w/UQ
Multi-Fidelity Mission Effectiveness Analysis w/UQ
Multi–Fi Effectiveness Design Methods wUQ that capture the physics driving the design
< Defects
> Novel designs
MoPs w/UQ
New Technology
Multi-Fidelity Multi-Disciplinary System Level Design w/UQ
Goal Oriented System Effectiveness Design Exploration & Technology Assessment & Demonstration

Typical Target Application - Efficient Supersonic Configuration



Effectiveness Objectives
Access, Firepower, Reach, Speed/Agility

Engineering Objectives
Range, Weight, Specific Excess Power

Design Variables (10^4)
Aerodynamic (10's)
Controls (10's)
Engine (10's)
Subsystems(100's)
Structural (1000's)

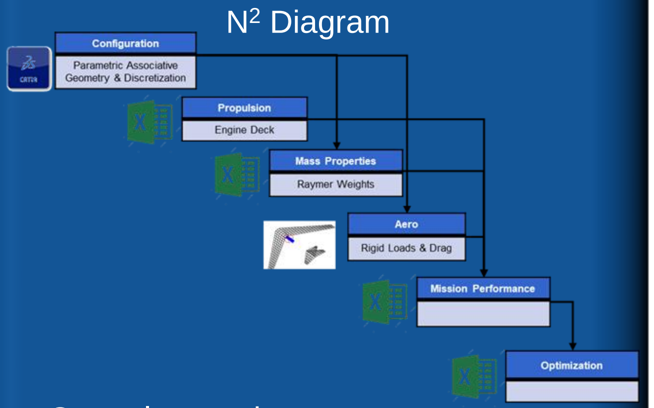
Constraints (10^5)
Strength, Stiffness, Thermal
Static and Dynamic Aeroelastic

Fidelity Level 1-3 Fidelity

SOP, SOA, Vision for Pre-Milestone A Vehicle Design and Tech Assessment

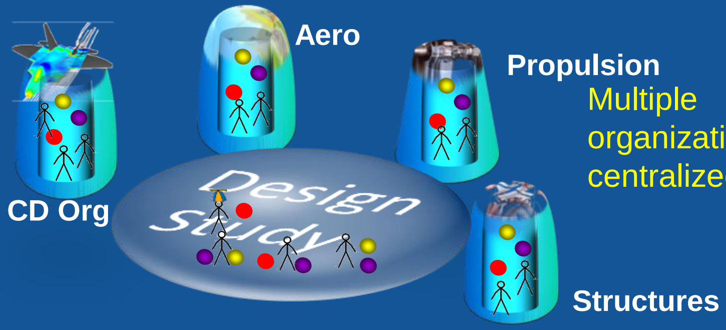
SOP

Single organization – centralized tools

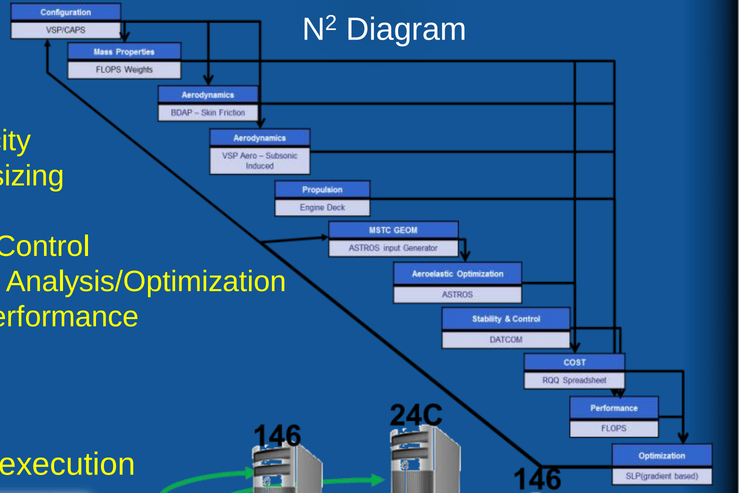


Central execution

SOA

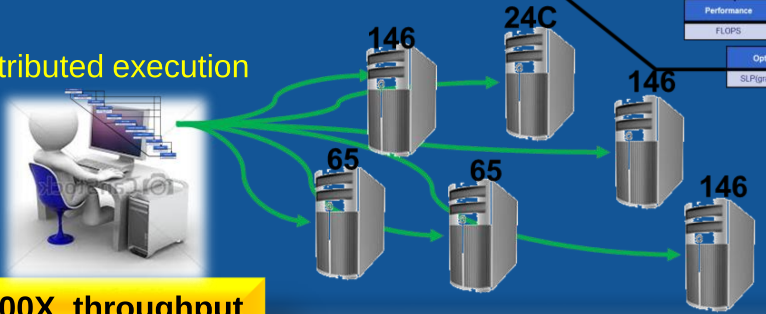


Multiple organizations – centralized tools



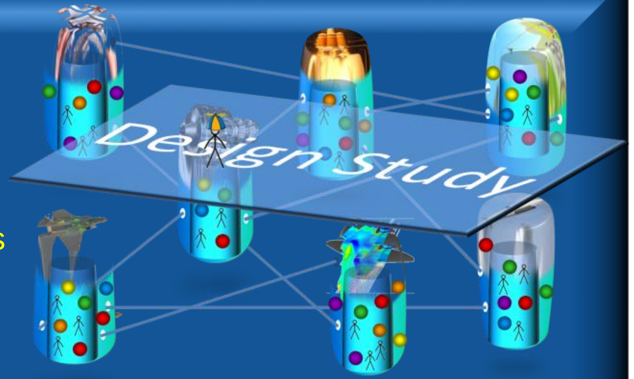
+ Aeroelasticity
+ Structural sizing
+ Cost
+ Stability & Control
+ Parametric Analysis/Optimization
+ Antenna performance
+ …

Distributed execution

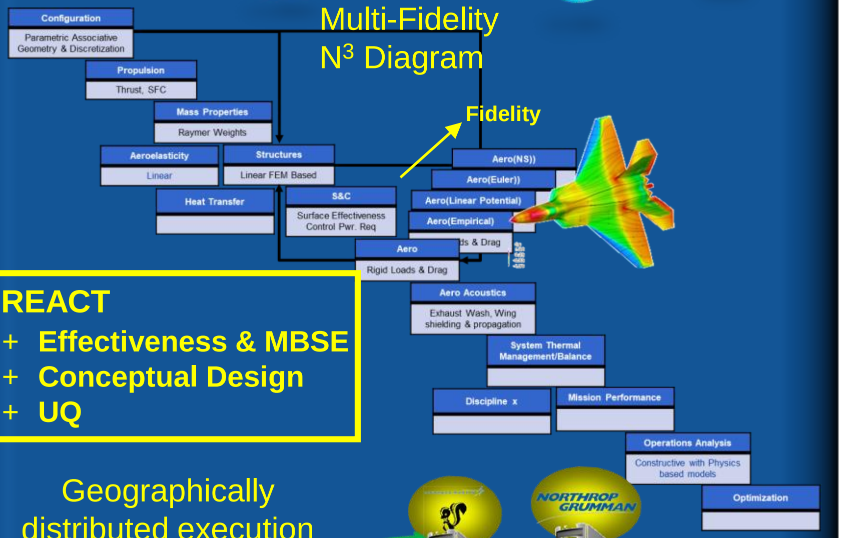


100X throughput

VISION



Multiple organizations – distributed tools

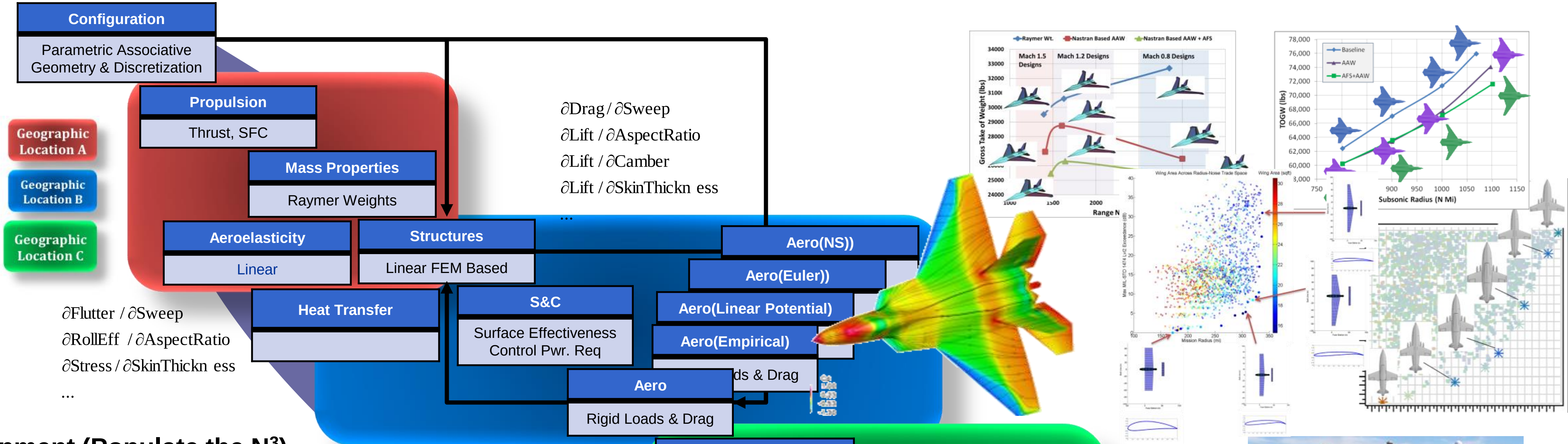


REACT
+ **Effectiveness & MBSE**
+ **Conceptual Design**
+ **UQ**

Geographically distributed execution

Protected IP

N^3 Diagram – Develop, Execute, Validate



MADO Development (<u>Populate the N^3</u>)

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

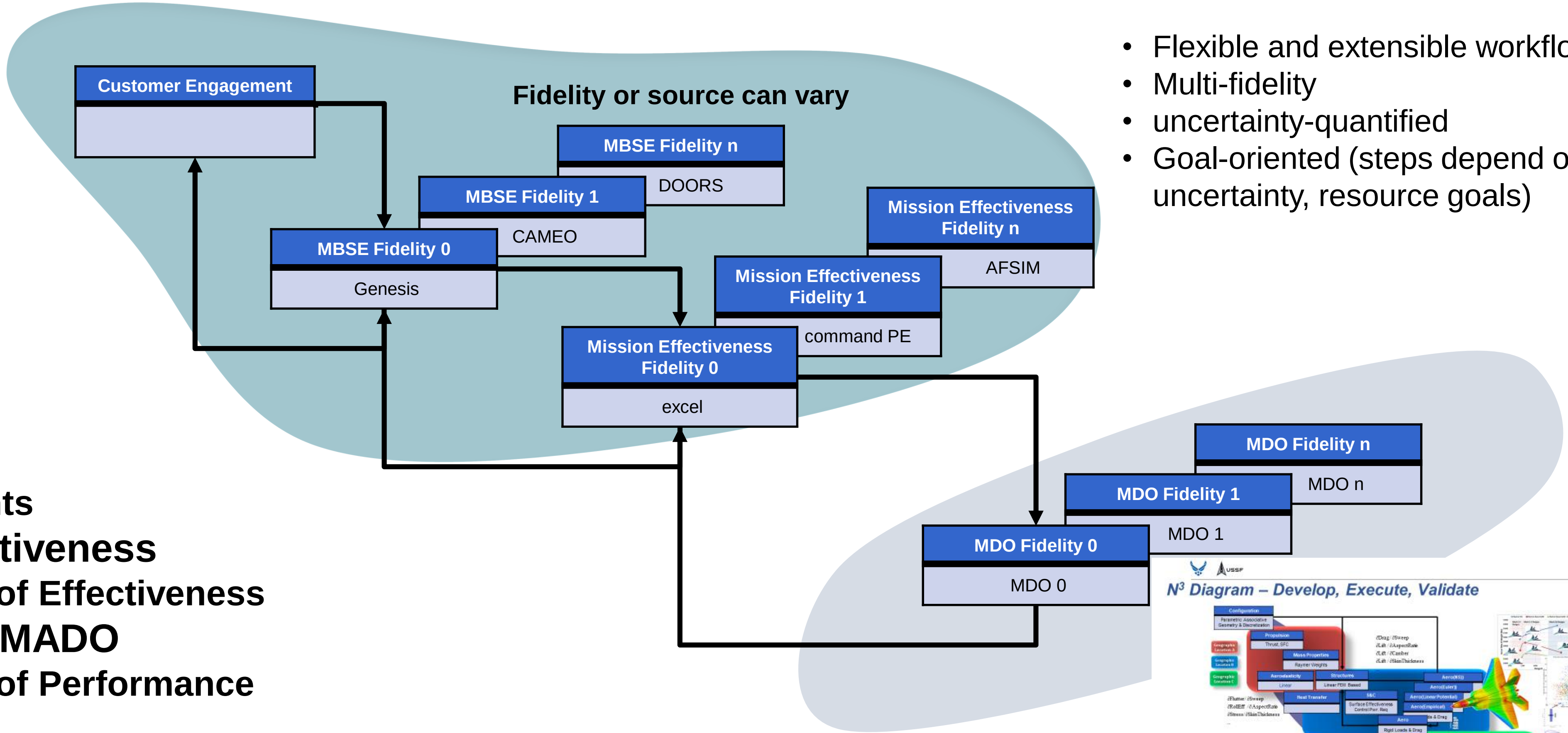
MADO Studies & Technology Assessment (<u>Execute N^3</u>)

- Select appropriate Disciplines, Couplings, Fidelities
- Formulate Optimization Problem
- Execute N^3

MD Technology Validation (<u>Validate Results of N^3 Execution</u>)

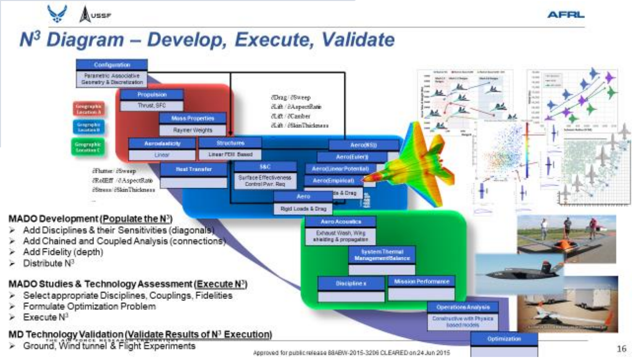
- Ground, Wind tunnel & Flight Experiments

RQV Effectiveness Assessment of Concepts & Technologies (REACT)



- Flexible and extensible workflows
- Multi-fidelity
- uncertainty-quantified
- Goal-oriented (steps depend on time, uncertainty, resource goals)

- MBSE
  - Desirements
- Mission Effectiveness
  - Measures of Effectiveness
- Multi-Fidelity MADO
  - Measures of Performance



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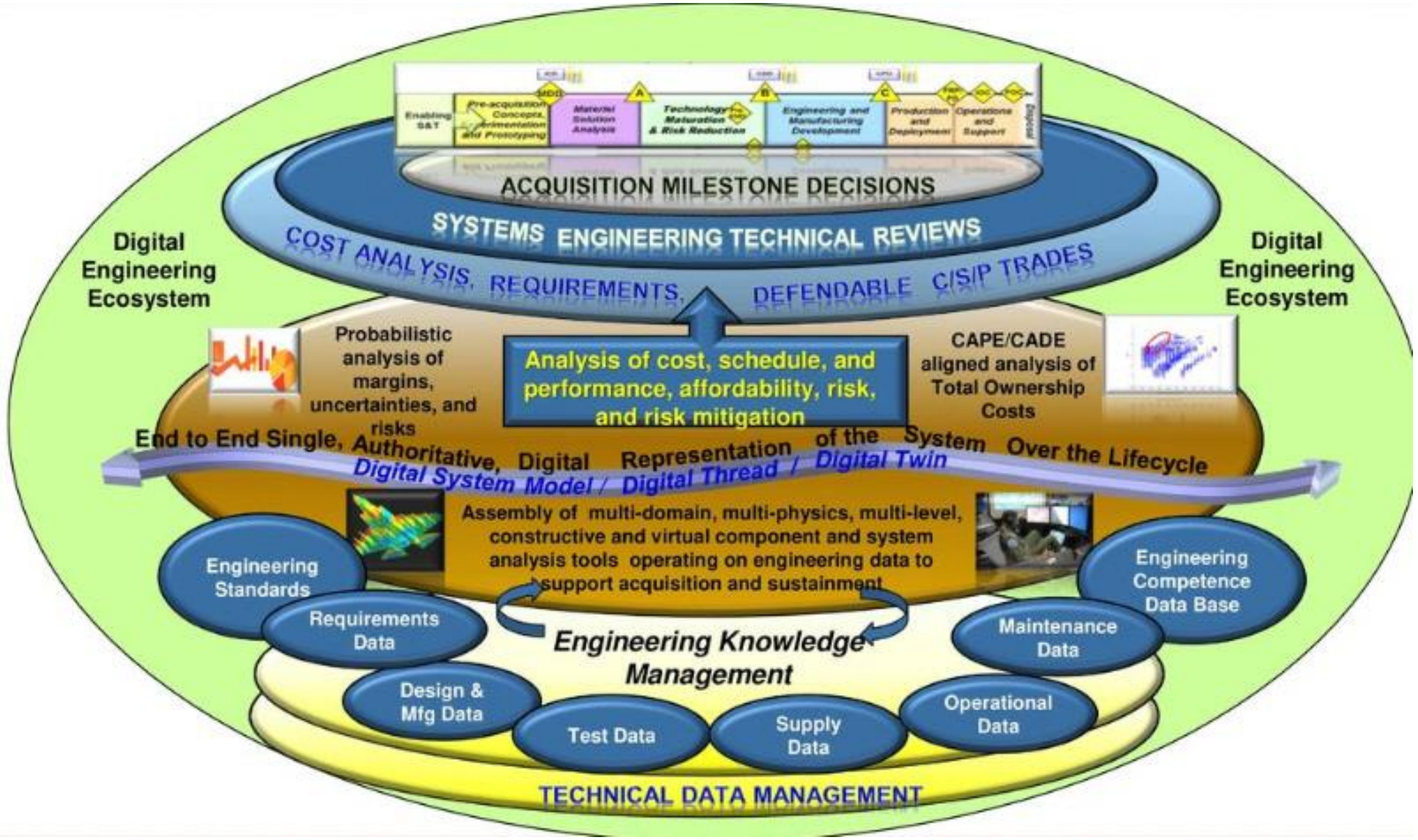
Relationship to Digital Engineering

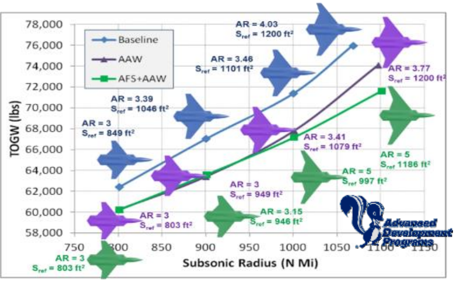


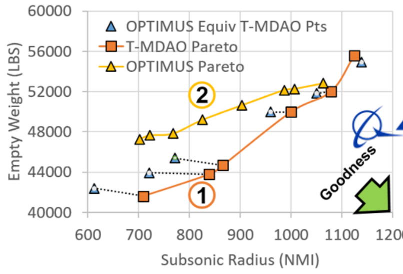
A Holistic View of Digital Engineering Support to DOD Acquisition – Kristin Baldwin, 2016, Acting DASD for System Engineering

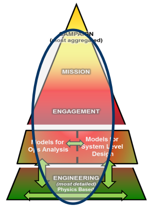
- **Modeling, Simulation, & Analysis** – MS&A and its integration into the *design* processes
- **Single authoritative source of "truth"** – Early multi-fidelity models with UQ
- **Tech Data Management –** The creation / capture, curation, and exploitation of technical data – pre-milestone A data artifacts
- **Engineering Workspaces –** The digitalization of Scientist & Engineers technical *design* activities

MSTC Computational Design Evolution

Changing the Way Industry Does Design



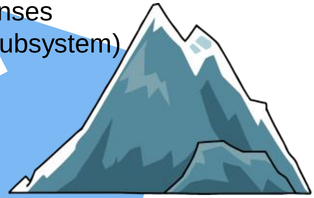




Ops in MDO

MDMFMSAOwUQ

Multi-Discip, Multi-Fidelity, Multi-Scale w/ UQ
∇ Opti. 10^4 DV, 10^5 Responses
DV - shape, sizing, topo, subsystem)
Effectiveness Objectives



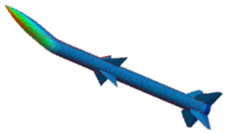
Including Uncertainty

(EQUATE)

Expanding the # of Design Parameters

QUAD NORTHROP GRUMMAN

- Non-Linear Aerothermoelastic
- ∇ Opti. 10^3 DV, 10^3 Responses (shape, sizing)
- Engineering Objectives



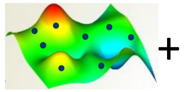
IH Design Studies

- Mission Level Objective Function
- Multidisciplinary Coupled Analysis
- Integrated Controls (RW) & Materials (RX)

IH Design Studies

- **25 Design Variables**
- **Extensive Discipline Analysis**
- **Incl. *Cost***

Expanding the Disciplines & Fidelity



\+

EXPEDITE PC KA

- OPTIMUS + transients + EBD
- ∇ Opti. 10^1 DV, 10^1 Responses (shape, sizing, subsystem vars)
- Effectiveness Objectives

OPTIMUS BOEING

- ESAVE + Level 1 Propulsion, Power, & Thermal Mtg
- ∇ Opti. 10^1 DV, 10^1 Responses (shape, sizing, subsystem vars)
- Engineering Objectives

ESAVE NORTHROP GRUMMAN

- Non-Linear Aero (Level 2) aeroelastic shape and sizing
- ∇ Opti. 10^1 DV, 10^1 Responses

ASTROS NORTHROP GRUMMAN **UAI**

- Linear static & dynamic aeroelastic sizing
- ∇ Opti. 10^3 DV, 10^3 Responses

SAMS I & II

- 6.1, 6.2, 6.5 SAMS Coupled
- Non-linear Aerothermoelastic ∇

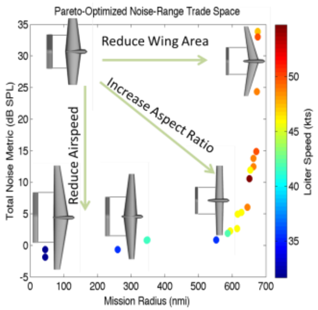
CAPS I & II caps

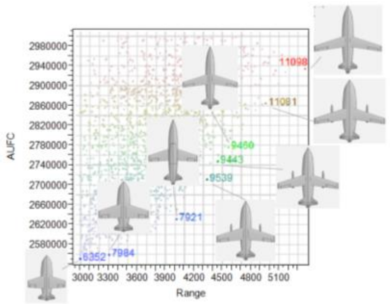
- 6.2 Parametric, Associative
- OML & IML Geometry with ∇ esp

IH Design Studies

- 7 Design Variables
- Aero, Wt Est, Power/Prop,
- Mission Perf, *Acoustics*

FUN3D Georgia Tech





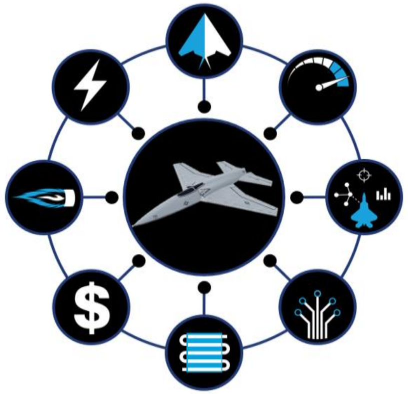
EXPanded MDO for Effectiveness based DesIgn TEchnologies (EXPEDITE)

- Expansion of a Multi-Disciplinary Optimization (MDO) based design process to cover path/state based, transient subsystem operation, UQ, reliability, and cost
- Develop **Effectiveness Based Design Framework** allowing mission effectiveness objectives through integration of operations analysis
- Exercise high-performance and high-fidelity computational framework tool supporting expanded MADO including **distributed-computer and distributed-geographic design optimization**
- Application of the MDO process to multidisciplinary design problem of interest to Air Force

Advanced Development Programs

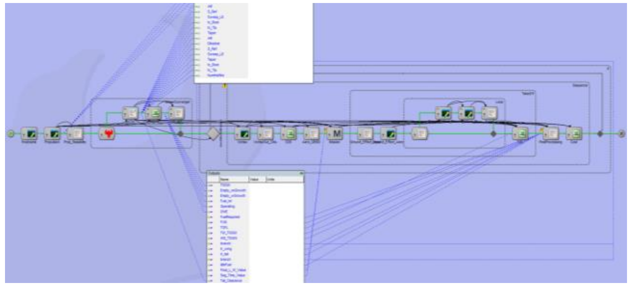
PCKA

EXPEDITE



PRATT & WHITNEY DEPENDABLE ENGINES

PHOENIX INTEGRATION



EXPEDITE - EBD

Propulsion

Aerodynamics

S & C

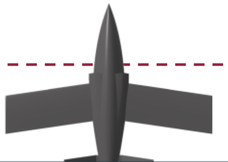
PTMS

...

Cost

Reliability

MPX plugin



AFSIM Scenario

Flight Physics

Flight Path/Trajectory

Tactics

Fuel Burn

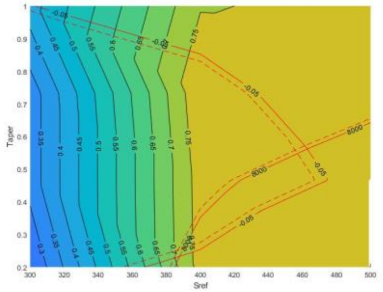
Blue Weapons Capability

Threat Capability

Threat Laydown

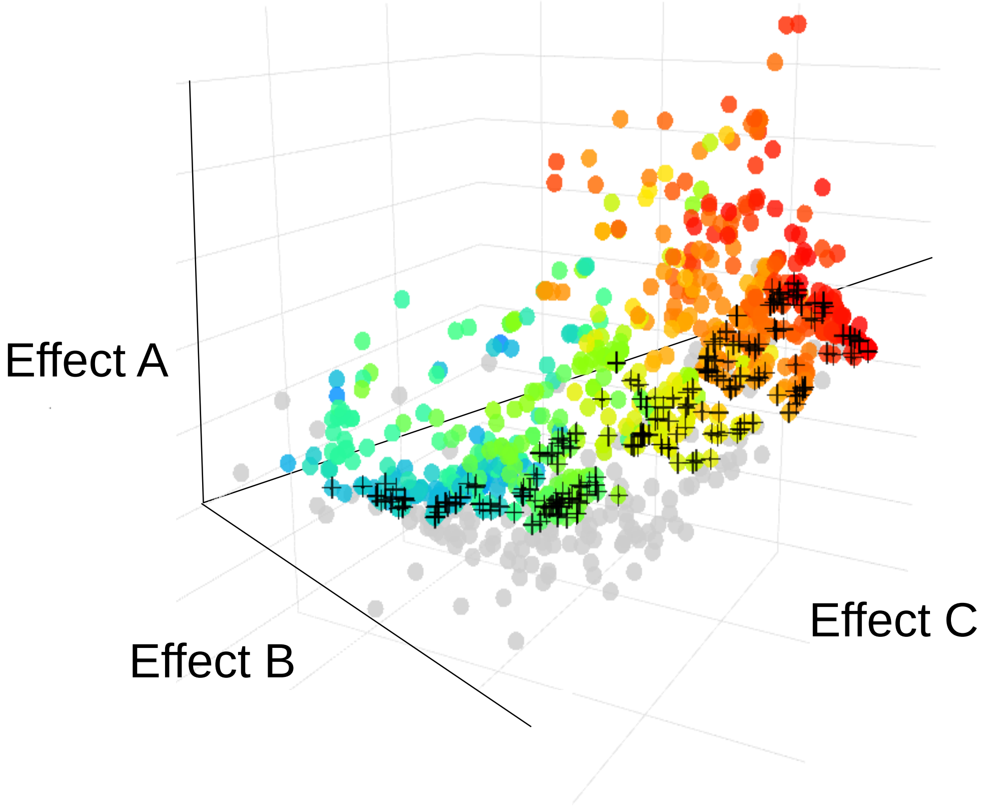
Wing Sref	Wing Tape	CAS_survi	time_on_	Heli_survi	Blue_wea	ISIL_fight	arrived	bingo_bef	dead_bef	fuel_
300	0.2	0.597403	626.825	0.003247	0.285714	0.00974	0.25	0.603896	0.220779	840.
300	0.46667	0.603896	815.6609	0.00974	0.344156	0.016234	0.321429	0.535714	0.194805	825.
300	0.73334	0.561688	817.7181	0.025974	0.350649	0.006494	0.321429	0.525974	0.194805	798.
300	1	0.551948	1109.85	0.012987	0.522727	0.016234	0.428571	0.441558	0.142857	795.
400	0.2	0.233766	2078.814	0.071429	0.980519	0.022727	0.769481	0.100649	0.12987	246.
400	0.46667	0.25	2105.88	0.142857	0.970779	0.032468	0.772727	0.103896	0.123377	273.
400	0.73334	0.254072	2162.943	0.019544	0.928339	0.039088	0.791531	0.078176	0.130293	329.
400	1	0.224026	2037.433	0.058442	0.892857	0.019481	0.746753	0.081169	0.172078	251.
500	0.2	0.123377	2246.312	0.198052	1.00974	0.019481	0.785714	0.061688	0.152597	116.
500	0.46667	0.146104	2298.818	0.233766	1.042208	0.045455	0.792208	0.051948	0.155844	177.
500	0.73334	0.155844	2273.949	0.217532	1.035714	0.029221	0.785714	0.061688	0.152597	169.
500	1	0.155844	2185.464	0.188312	0.974026	0.016234	0.762987	0.094156	0.142857	116.

Effectiveness Results

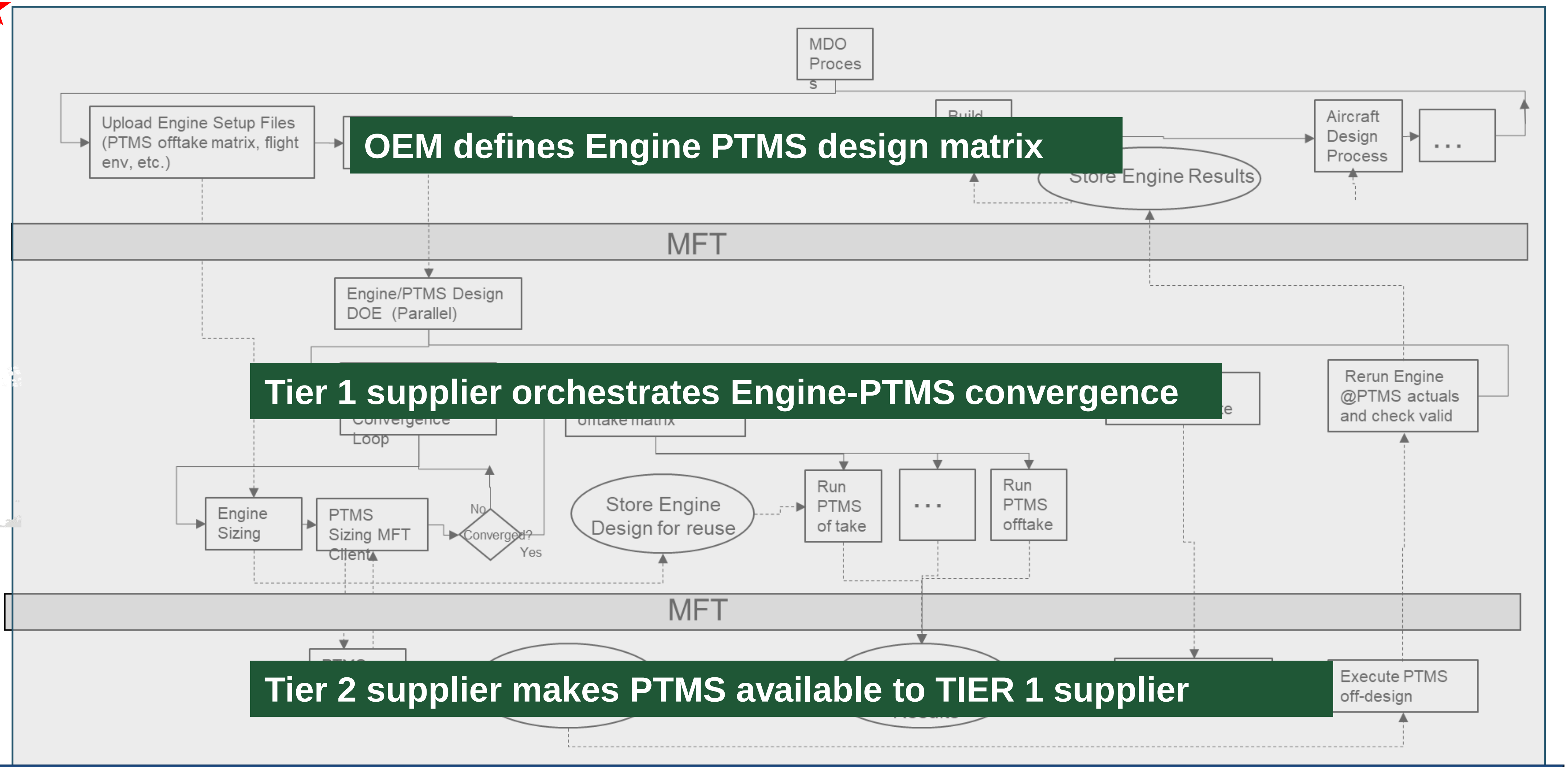


Working in-house to close the optimization loop

Typical EXPEDITE EBD Results



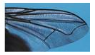
EXPEDITE B2B Architecture

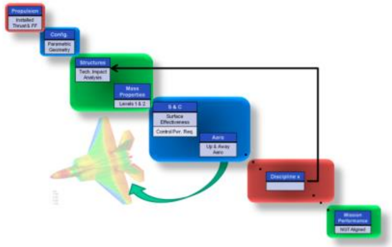


LM Sequential 230 Runs (8hr 40min) B2B 230 Parallel Runs from (40min)

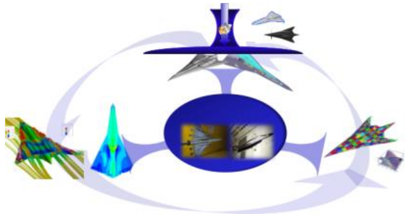
Concluding Remarks

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

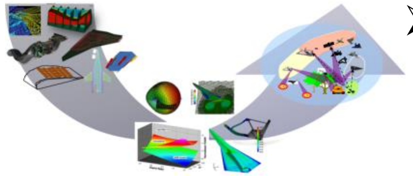




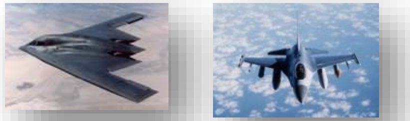
- *A physics-based distributed collaborative design Environment for aerospace vehicle development and technology assessment has been developed (leverages MSTC Engineering)*



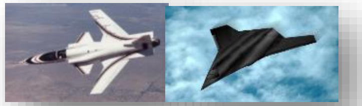
- *Enables 10's of HiFi Physics Based Configuration Design with the Same Resources & Time of Traditional Design evaluates 1 or 2.*



- *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*



- *Expanded design space yielding capabilities not other wise obtainable*

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Questions?