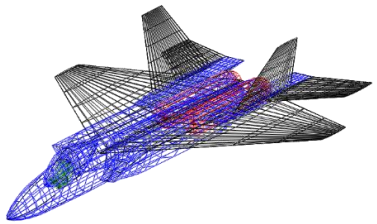
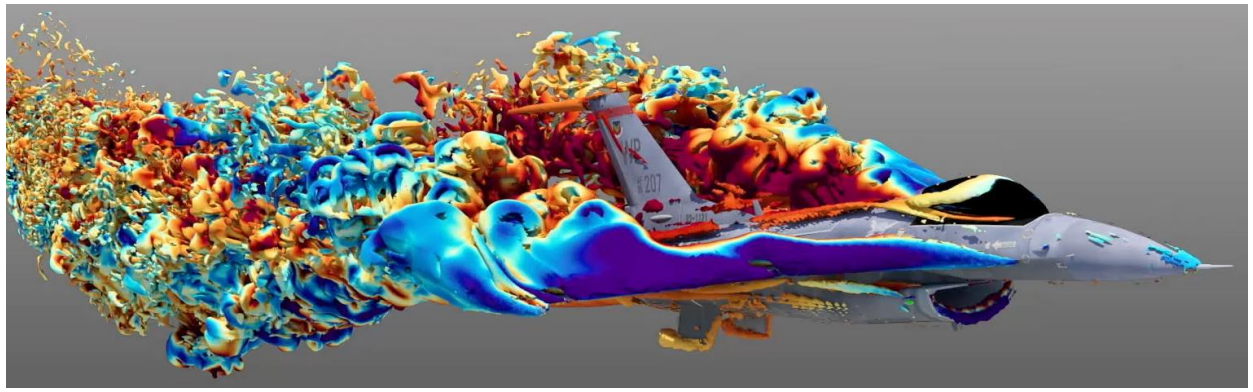
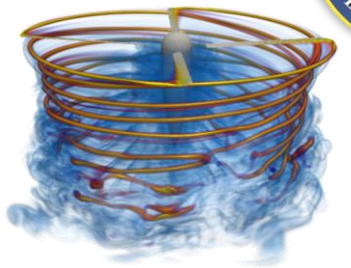






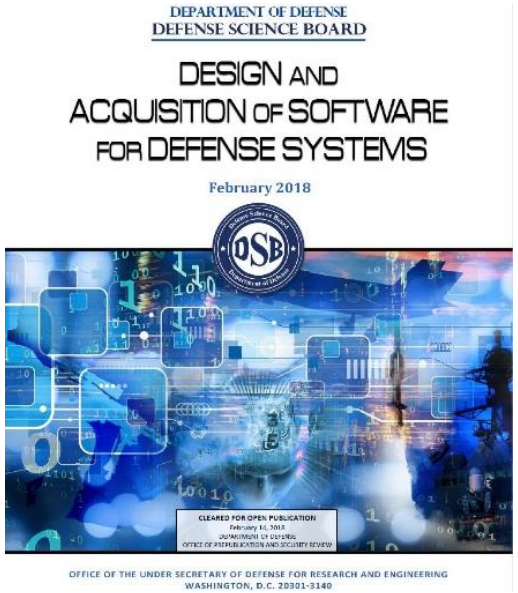
Government Built, Production Quality, Multi-Disciplinary, Multi-Fidelity Software for Acquisition Engineering Support

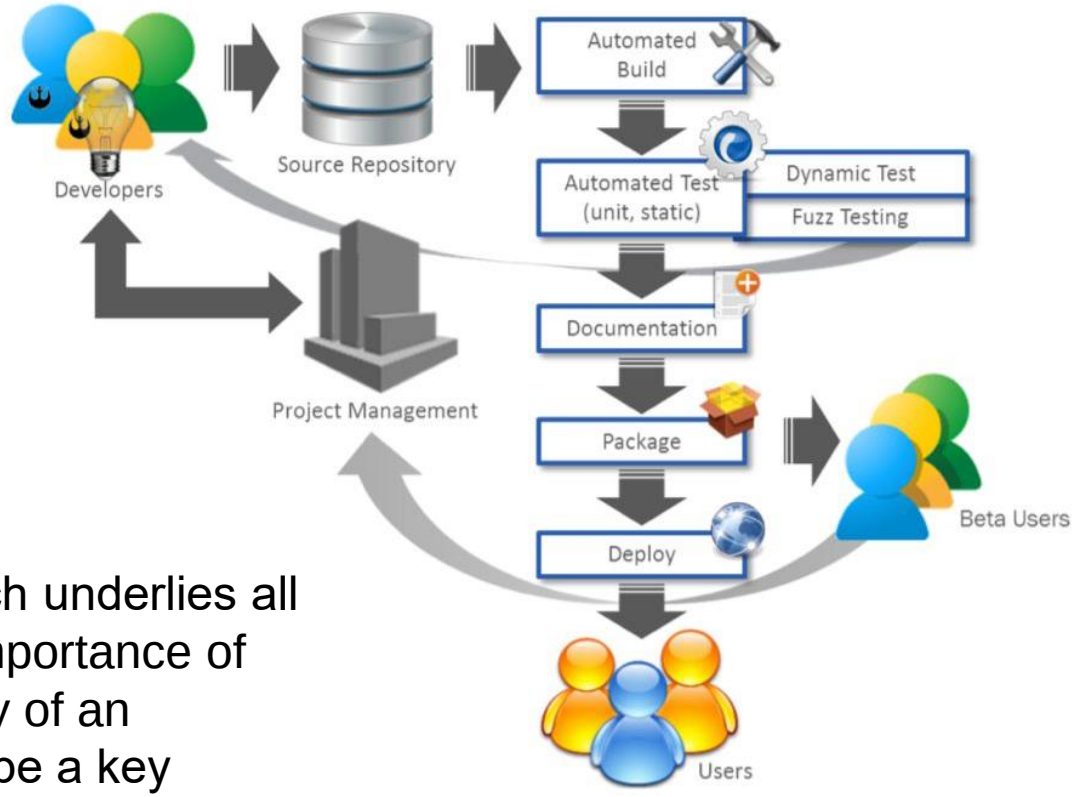
National Defense Industry Association
Systems and Mission Engineering Conference
6-8 December 2021

Dr. Scott A. Morton, Associate Director for CREATE
DoD HPCMP, US Army ERDC/Information Technology Laboratory
Scott.a.morton3.civ@mail.mil

Computational Research & Engineering Acquisition Tools and Environments (CREATE)

CREATE is an example of the ideal "Software Factory" described in Feb 2018 report of the Defense Science Board.

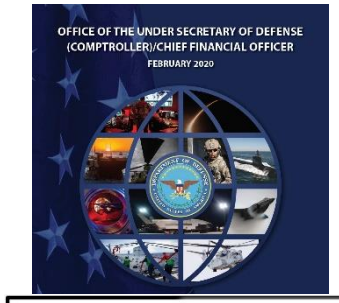




"Our base recommendation, which underlies all other recommendations, is the importance of the software factory – the efficacy of an offeror's software factory should be a key evaluation criterion in the source selection process for software."

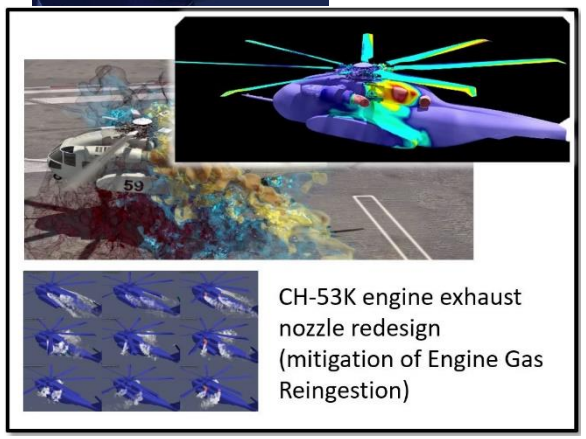
Computational Research & Engineering Acquisition Tools and Environments (CREATE)

CREATE "Software Factory" delivers impactful technology to the DoD



Directly Impacts Programs of Record

CREATE software products have been used to impact 38 Programs of Record in which the Department is scheduled to invest more than $54 Billion in FY2021. In addition to the Programs noted in the chart below (extracted from **Comptroller's Report**), CREATE software products are being used in support of **MANY** other important programs, e.g., Future Vertical Lift, Future Attack Submarine, Next Generation Combat Vehicle.



CH-53K engine exhaust nozzle redesign (mitigation of Engine Gas Reingestion)

NAVAIR/Sikorsky, 2018-2019

Using HPCMP CREATE™ Helios and HPC systems "…the combined cross-competency Tiger Team members [NAVAIR/Sikorsky] provided the CH-53K program a viable path forward to ensure continued development, execution of flight testing and completion of LRIP."

– PMA-261 Gold Star Award, May 2019

Major Weapon Systems Summary		FY2021 Base Budget ($ in M)	CREATE Software Used to Support Program
Aircraft and Related Systems – Joint Service			
F-35	Joint Strike Fighter	11,400	AV / RF
V-22	Osprey	1,828	AV
C-130J	Hercules	1,232	AV
MQ-1B / MQ-1C	Predator/Gray Eagle	72	AV / RF
MQ-9	Reaper	468	RF
MQ-4C / RQ-4	Triton/Global Hawk/NATO AGS	631	AV / RF
	Armed Overwatch / Targeting		
Aircraft and Related Systems – US Army (USA)			
AH-64E	Apache: Remanufacture/New Build	1,157	AV
CH-47	Chinook	241	AV
UH-60	Black Hawk	1,014	AV
Aircraft and Related Systems – US Navy (USN) / US Marine Corps (USMC)			
MQ-25	Stingray	267	AV
F/A-18	Super Hornet	2,062	AV
E-2D	Advanced Hawkeye	1,048	AV
P-8A	Poseidon	269	AV
CH-53K	Heavy Lift Replacement Helicopter	1,492	
Aircraft and Related Systems – US Air Force (USAF)			
B-21	Raider		
B-1, B-2, B-52	Bombers	884	AV / RF
KC-46A	Tanker	2,981	AV / RF
PAR	Presidential Aircraft Recapitalization		
F-22	Raptor	1,059	AV / RF
F-15	Eagle	2,414	AV / RF
CRH	Combat Rescue Helicopter		
T-7A	Advanced Pilot Training		
C4I Systems – USA			
WIN-T	Tactical Network Transport		
C4I Systems – Joint Service			
HMS	Handheld, Manpack, and Small Form Fit Radios		
Cyberspace	Cyberspace		
Ground Systems – Joint Service			
JLTV	Joint Light Tactical Vehicle	1,364	GV
Ground Systems – USA			
M-1	Abrams Tank Modification/Upgrades		
AMPV	Armored Multi-Purpose Vehicle	290	GV
NGSW	Next Generation Squad Weapon		
PIM	Paladin Integrated Management	863	GV
FMTV	Family of Medium Tactical Vehicles	122	GV
FHTV	Family of Heavy Tactical Vehicles	184	GV
GMV	Ground Mobility Vehicle		
Stryker	Stryker		
Ground Systems – USMC			
ACV	Amphibious Combat Vehicle		
Missile Defeat and Defense Programs – Joint Service			
GMD	Ground-based Midcourse Defense		
THAAD	Terminal High Altitude Area Defense		
Aegis	Aegis Ballistic Missile Defense		
Missile Defeat and Defense Programs – USA			
Patriot / PAC-3	Patriot Advanced Capability		
PAC-3 / MSE	PAC-3/Missile Segment Enhancement Missile		
Missiles and Munitions – Joint Service			
JDAM	Joint Direct Attack Munition	280	AV / RF
Hellfire	Hellfire Missiles	131	AV
SDB I	Small Diameter Bomb I	46	AV
SDB II	Small Diameter Bomb II	432	AV
JASSM	Joint Air-to-Surface Standoff Missile	546	AV
AIM-9X	Air Intercept Missile - 9X		
AMRAAM	Advanced Medium Range Air-to-Air Missile	876	AV
Chem-Demil	Chemical Demilitarization		
JAGM	Joint Air-to-Ground Missile		
LRASM	Long Range Anti-Ship Missile	224	RF
Missiles and Munitions – USA			
GMLRS	Guided Multiple Launch Rocket System		
Javelin	Javelin Advanced Anti-Tank Weapon		
Standard	Standard Missile-6		
RAM	Rolling Airframe Missile		
Tomahawk	Tactical Tomahawk Cruise Missile		
Missiles and Munitions – USAF			
GBSD	Ground Based Strategic Deterrent		
B61	B61 Tail Kit Assembly		
LRSO	Long Range Stand-Off Missile		
Shipbuilding and Maritime Systems – USN			
CVN 78	*Gerald R. Ford* Class Nuclear Aircraft Carrier	3,024	SH
SSBN 826	*Columbia* Class Submarine	4,412	SH
SSN 774	*Virginia* Class Submarine	4,658	SH
DDG 51	*Arleigh Burke* Class Destroyer	3,492	SH
FFG(X)	Guided Missile Frigate	1,135	SH
CVN	Refueling Complex Overhaul		
T-AO 205	*John Lewis* Class Fleet Replenishment Oiler	95	SH
T-ATS	Towing, Salvage, and Rescue Ship		
USV	Unmanned Surface Vehicle	464	SH
LPD	*San Antonio* class Amphibious Transport Dock ship	1,220	SH
Space Based Systems – USSF			
NSSL	National Security Space Launch		
GPS III	Global Positioning System III and Projects		
OPIR	SBIRS and Next Gen OPIR		
SATCOM	Satellite Communications Projects		
	TOTAL Budget (Impacted by CREATE Products)	**$54,377**	

Computational Research & Engineering Acquisition Tools and Environments (CREATE)

- **Paradigm change:**
  - **From** reliance on physical test as the driver for design iteration and primary source for "actionable engineering data", e.g. support warrant holder requirements, system certifications, etc.
  - **To** using physics-informed analysis and virtual test to drive design iterations and as a source of actionable engineering data.

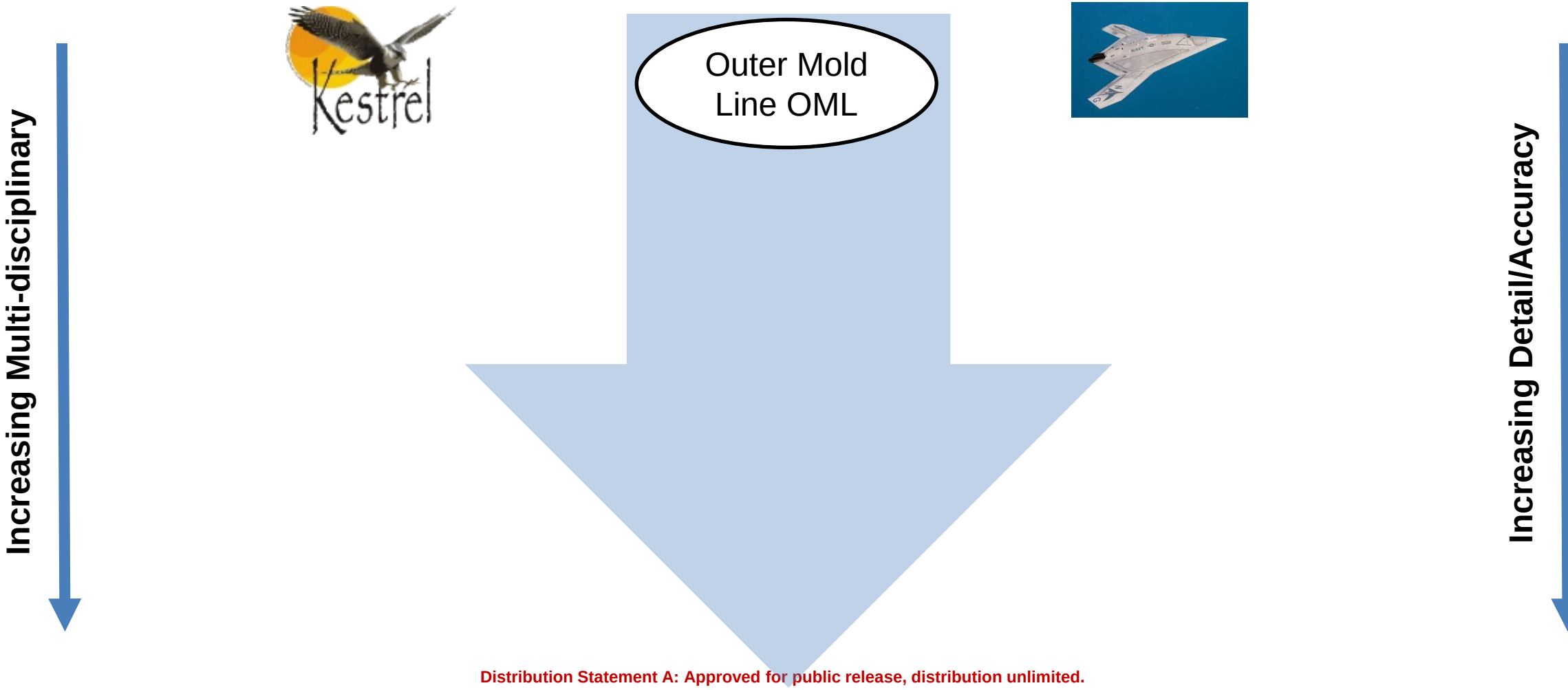
Use virtual test to drive design & analysis iterations

Use physical test to validate the result

Capstone, Helios, SENTRi, FLO-K, ADAPT, Kestrel, AURORA, iHDE, NESM, Kestrel, NAVYFOAM, ISDE

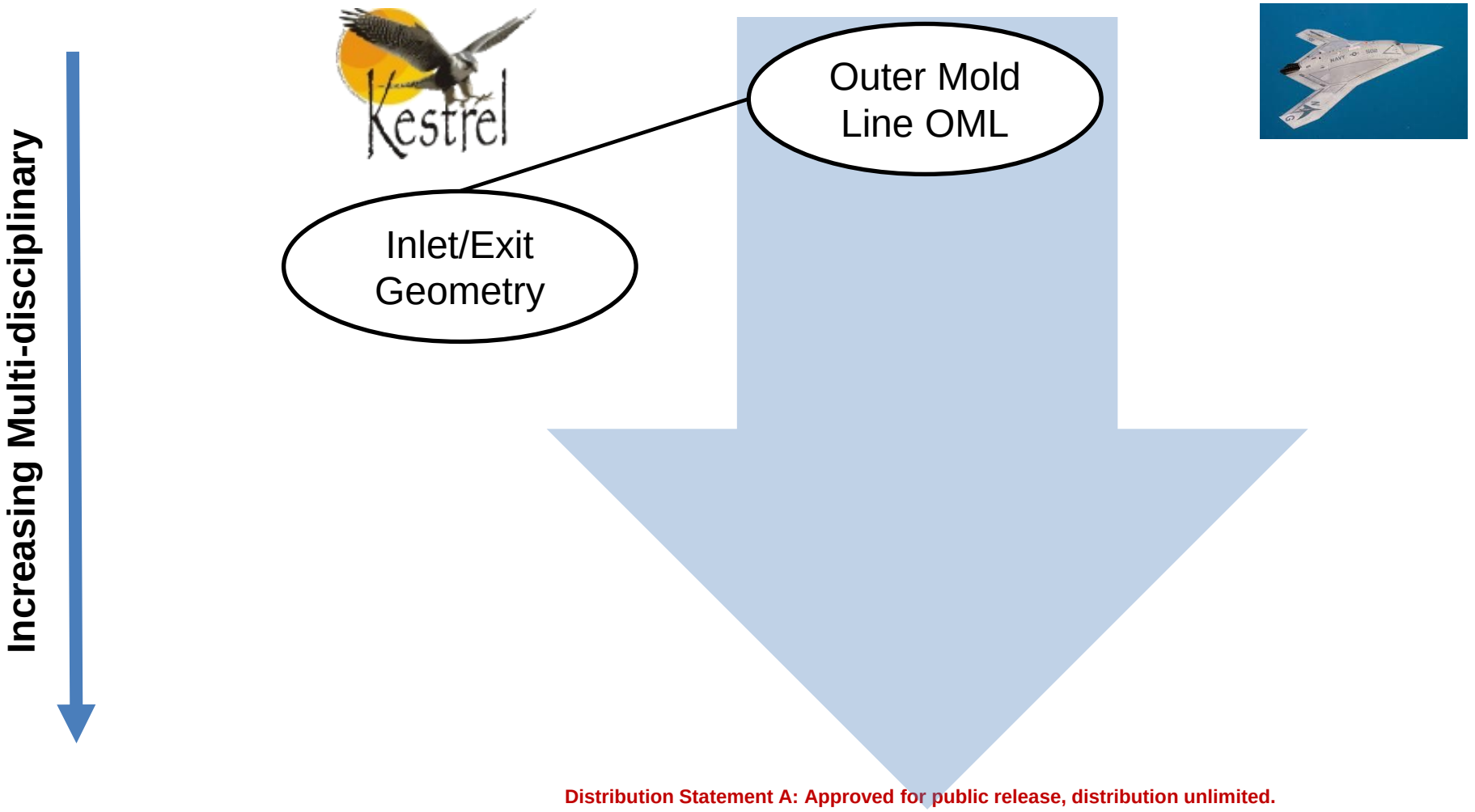
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



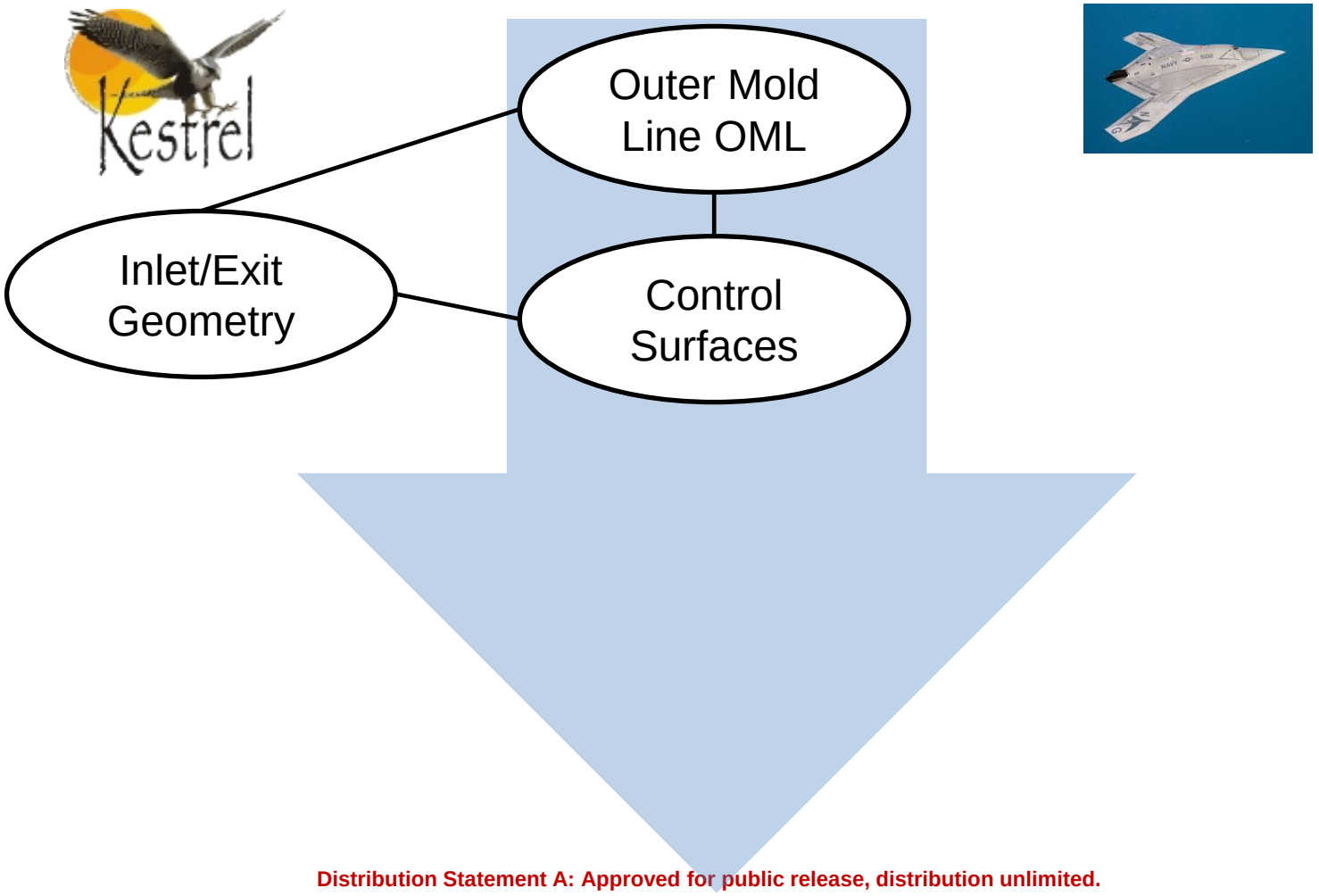
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



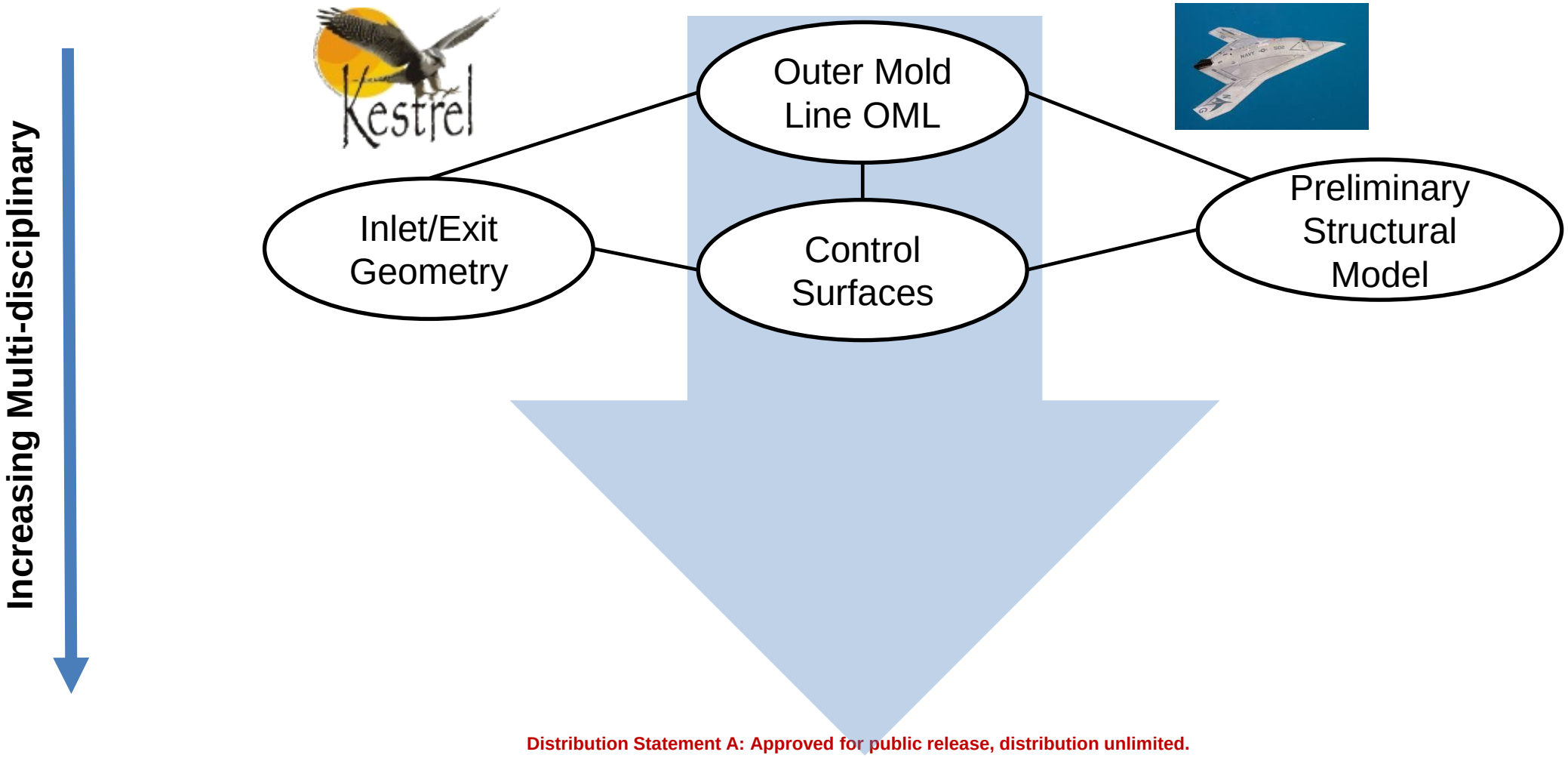
Physics Based System Analysis

- During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)



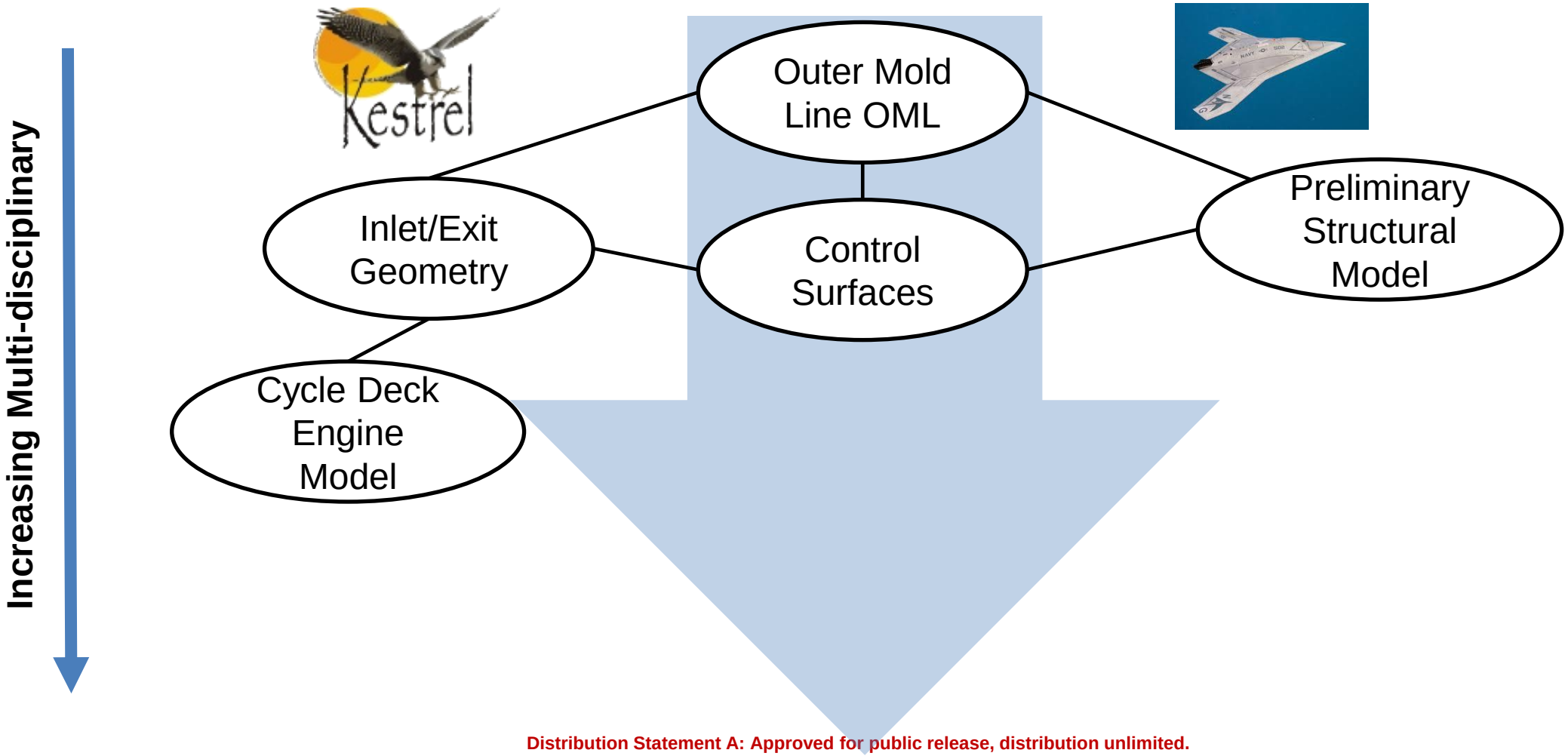
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



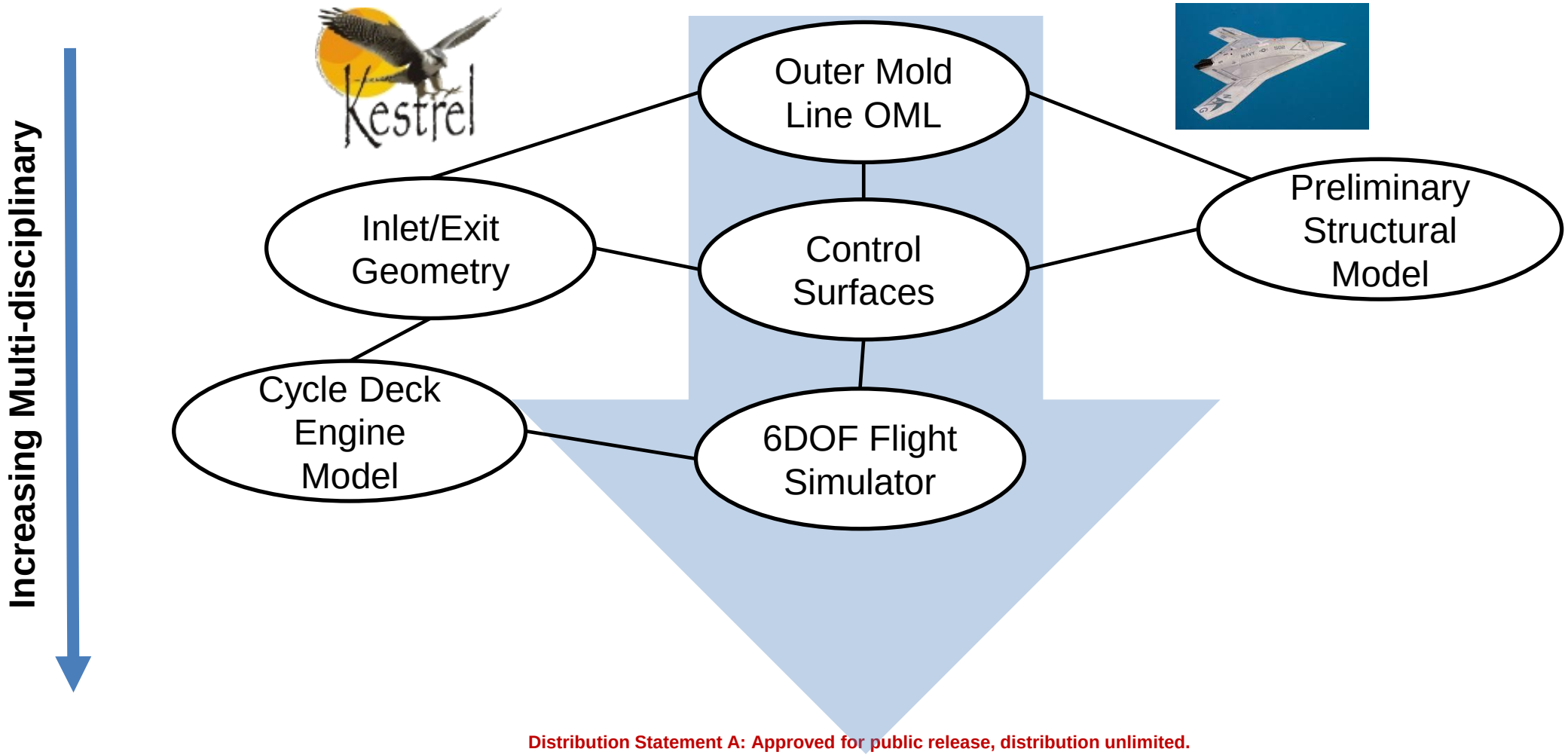
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



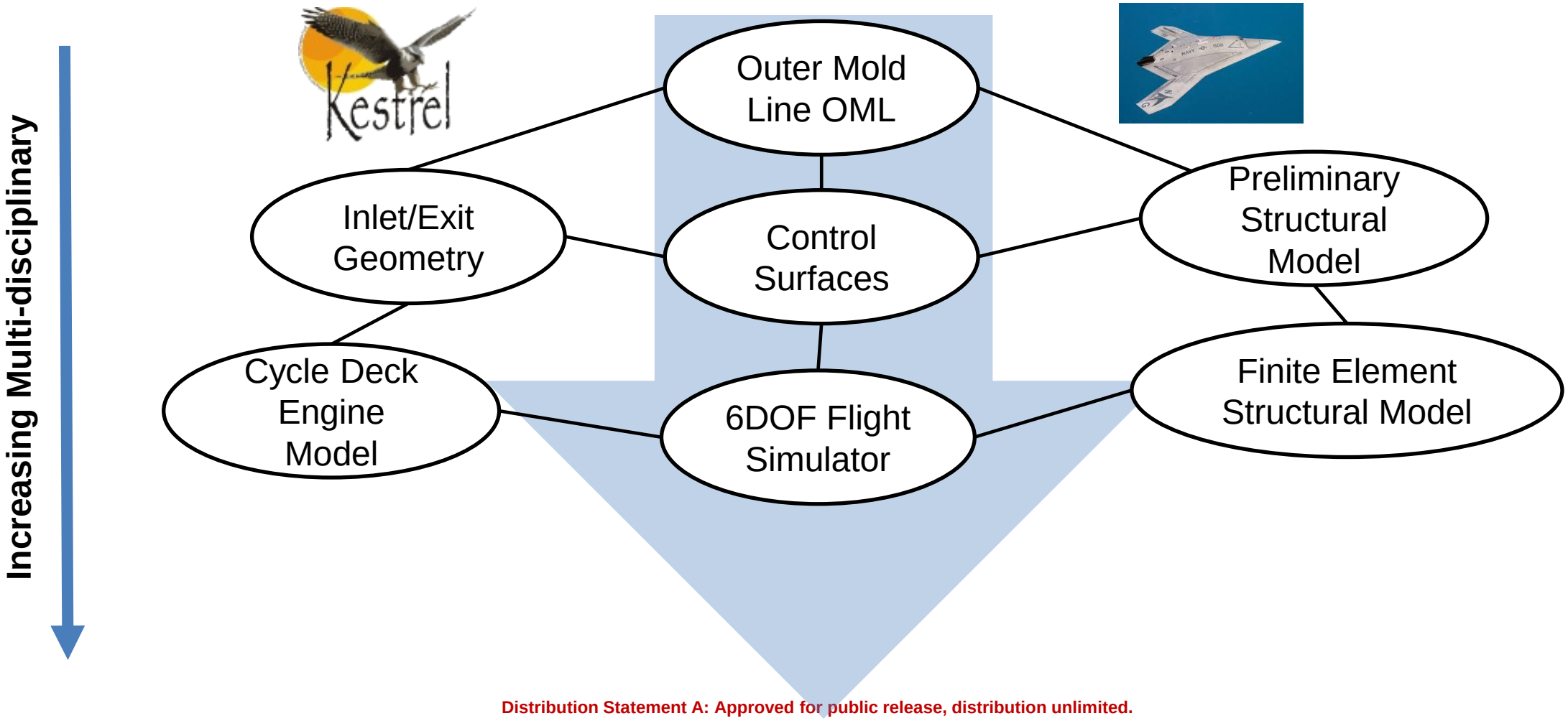
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



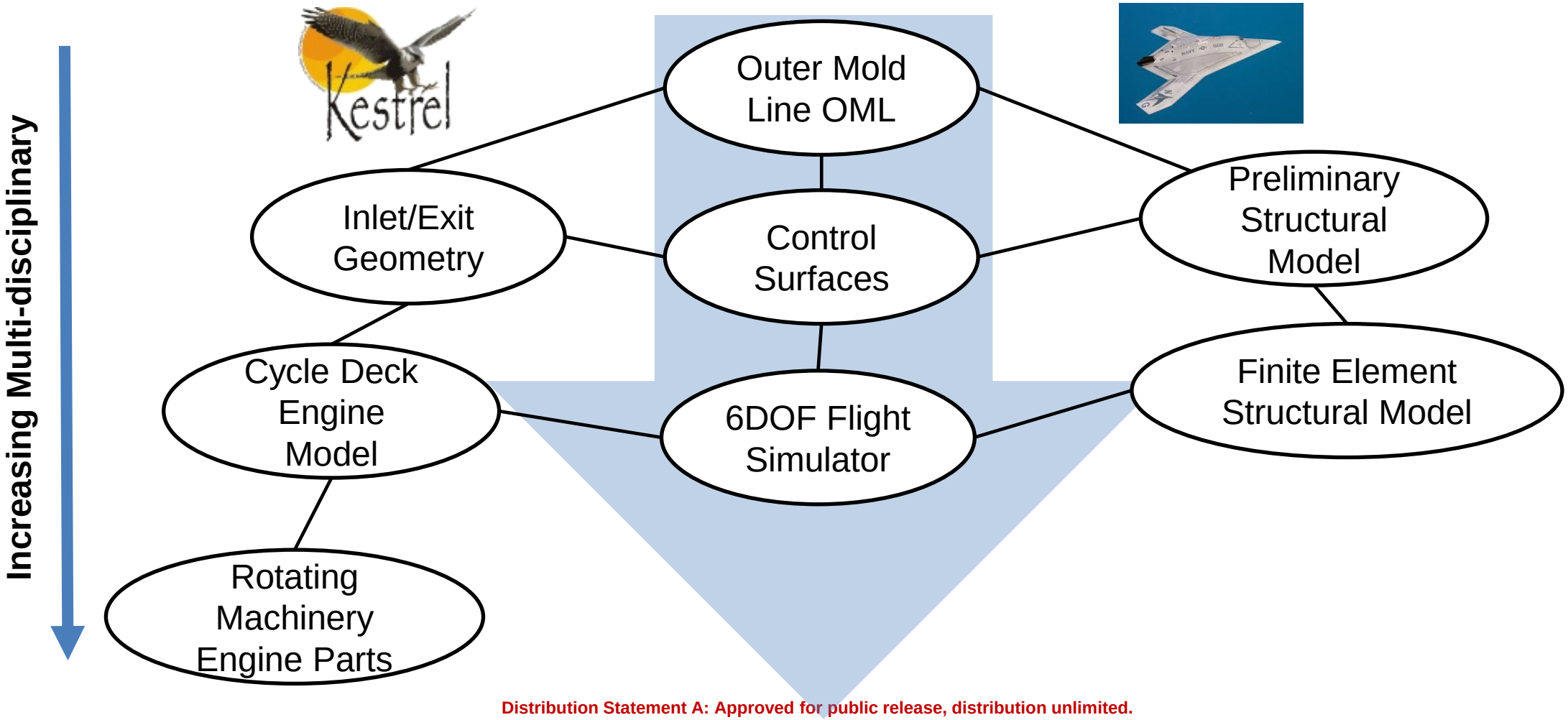
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



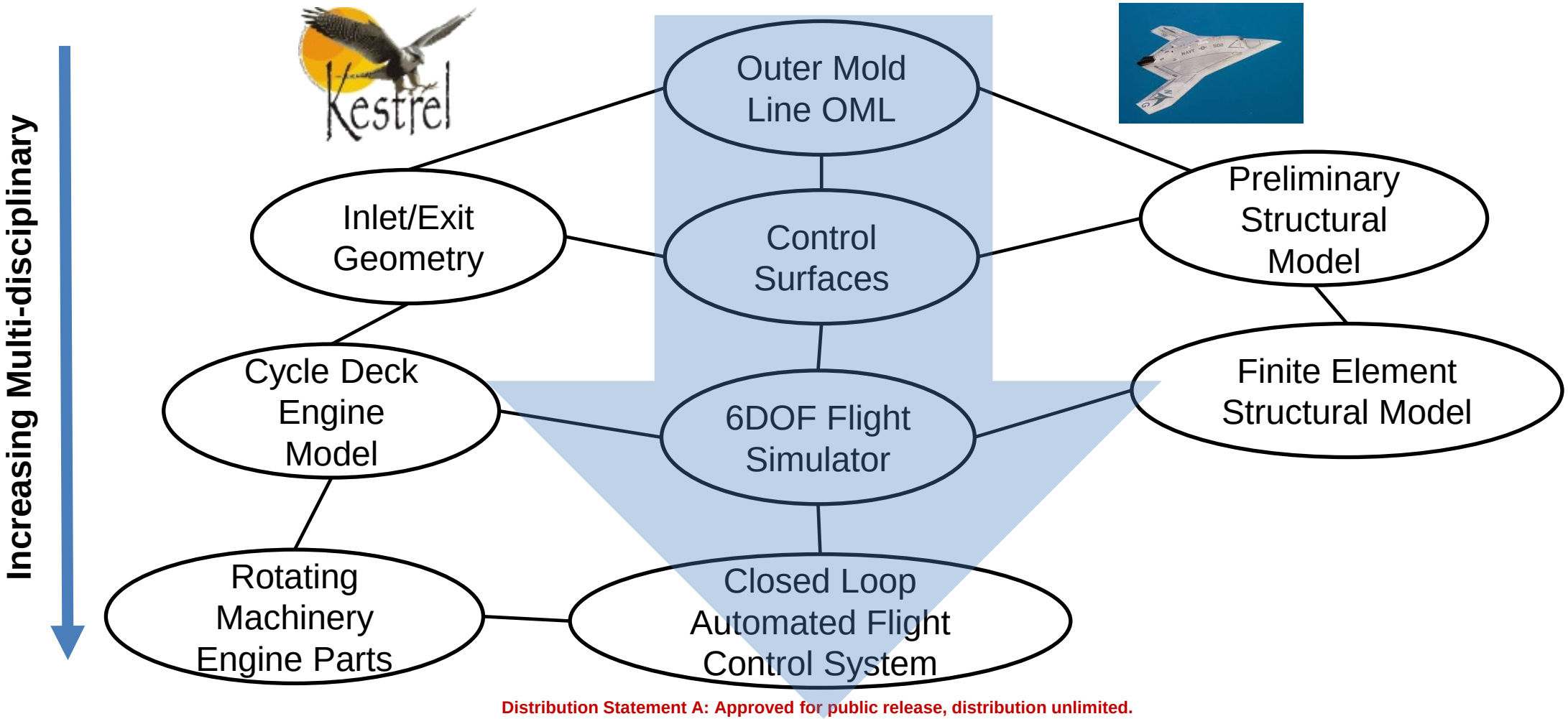
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



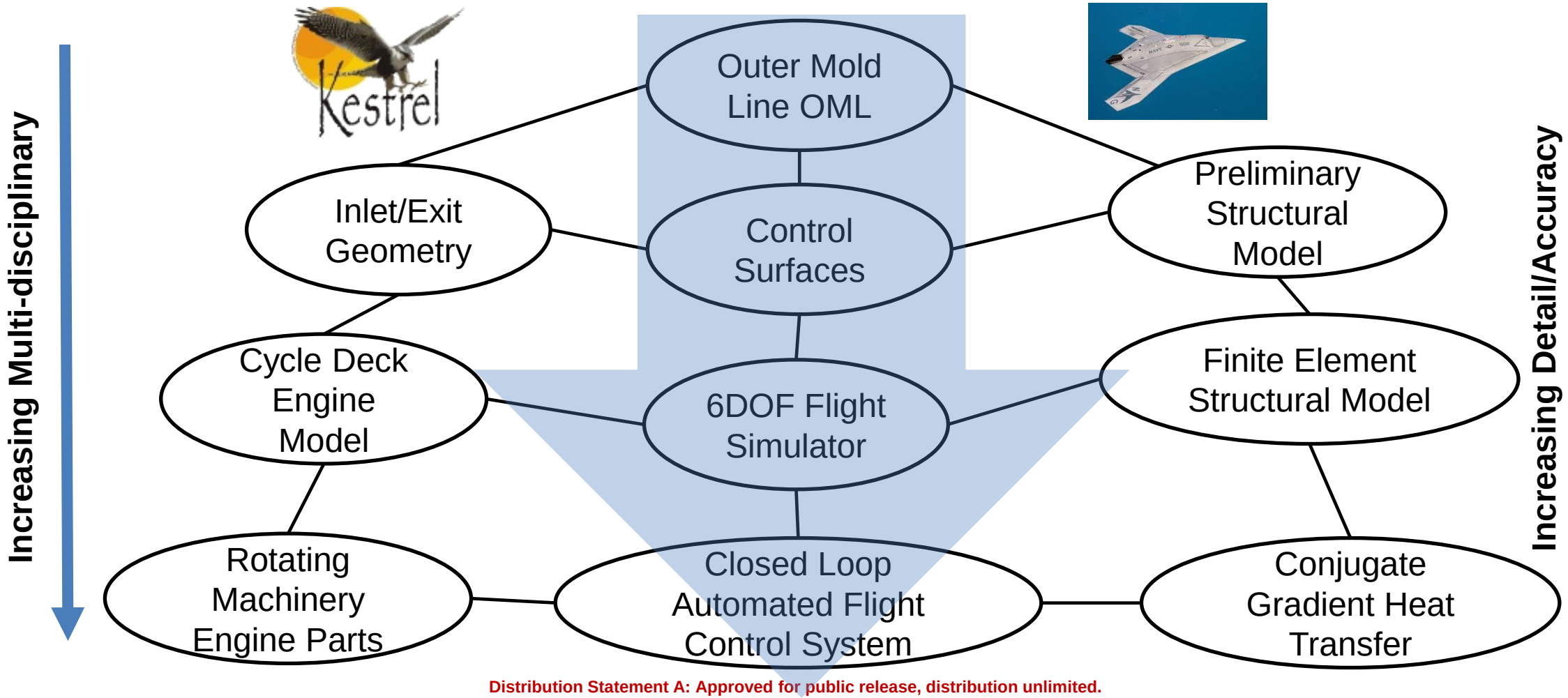
Physics Based System Analysis

- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



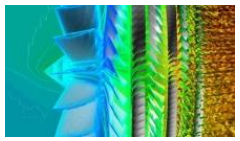
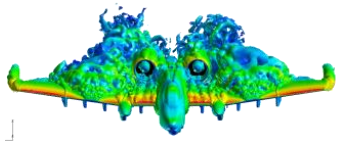
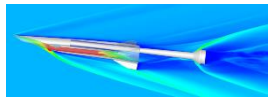
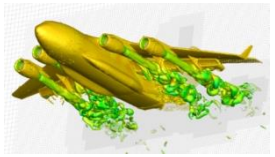
Physics Based System Analysis

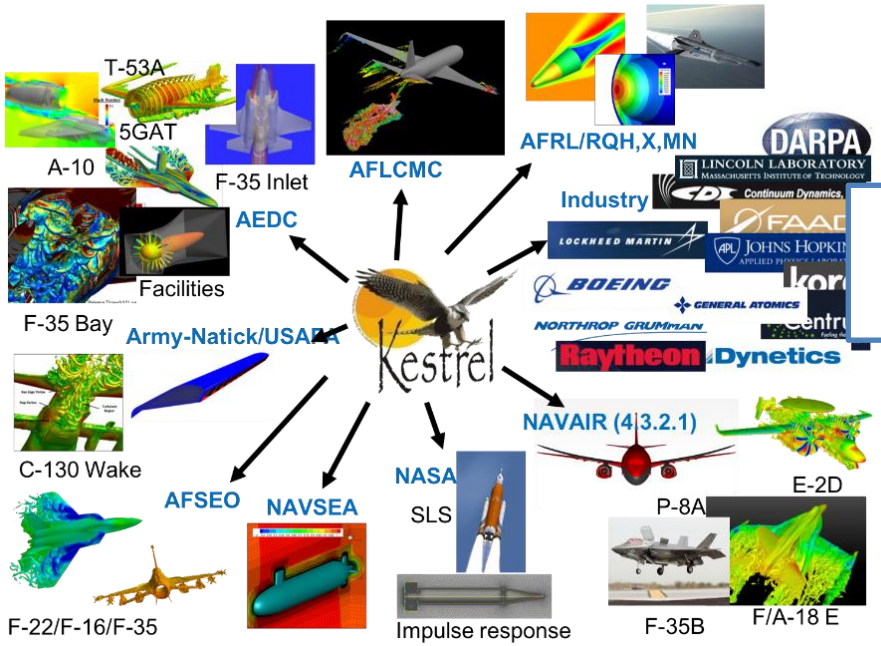
- **During the design process we can eliminate poor design choices by increasing the fidelity of the PBAs as more information is known (objects and connection notional)**



CREATE-AV Kestrel

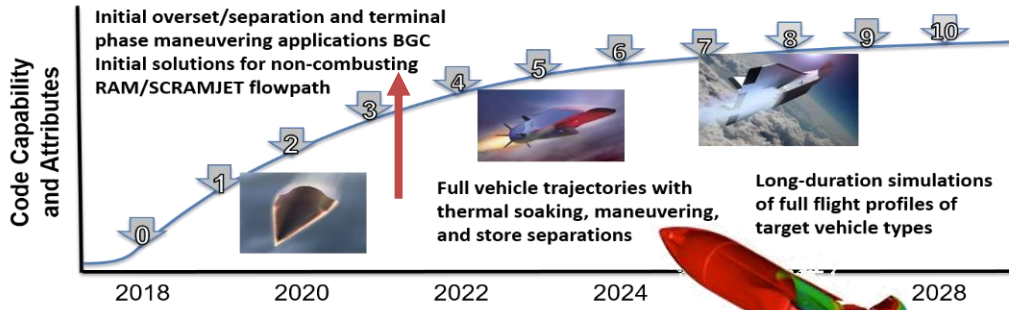
- **Coupled physics: aerodynamics, thermochemistry, structural dynamics and thermodynamics, propulsion, flight controls**
- **Fighter, Bomber, Tanker, Transport, UAV, Munitions**
- **Low-speed, transonic, supersonic, hypersonic**
- **Cruise, maneuver, take-off/land, refueling, formation flight, store carriage and release, pilot ejection, precision air-drop, and more…**
- ***Designed for change***

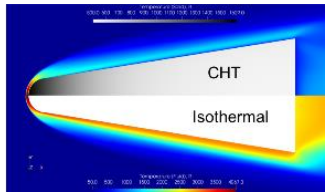





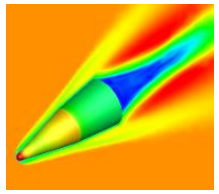
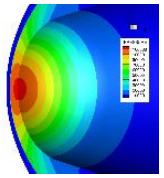


Large gov't and industry user community

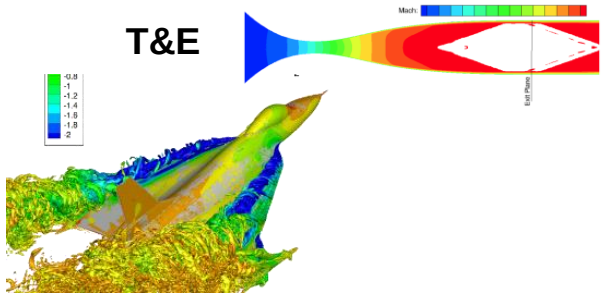
Hypersonic Roadmap Ahead of Schedule





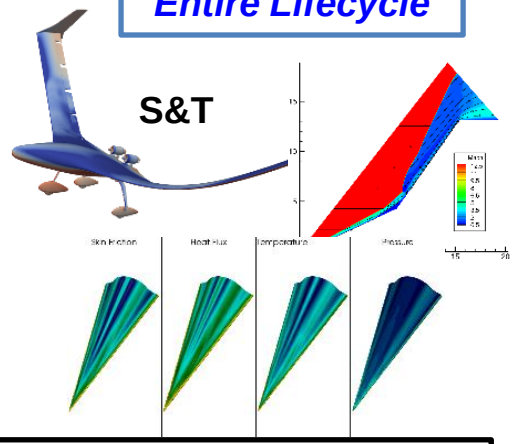



T&E

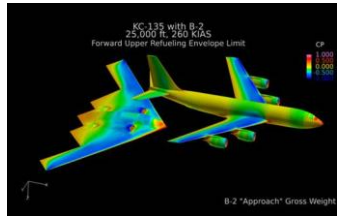


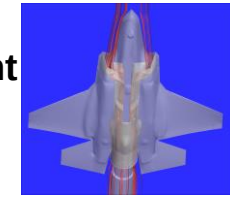
Relevance Over Entire Lifecycle

S&T



Sustainment

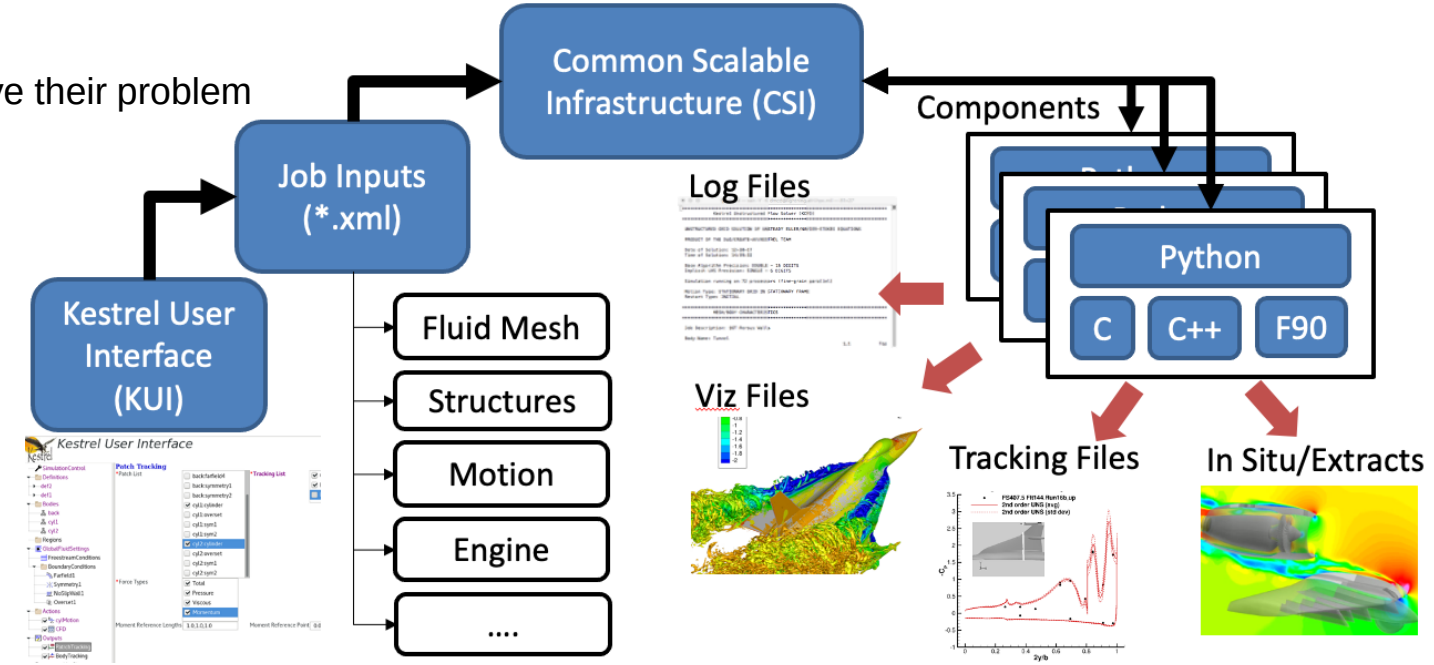




B-52 CERP Support: "1hr 35min from bug report to installed fix."

Kestrel Architecture

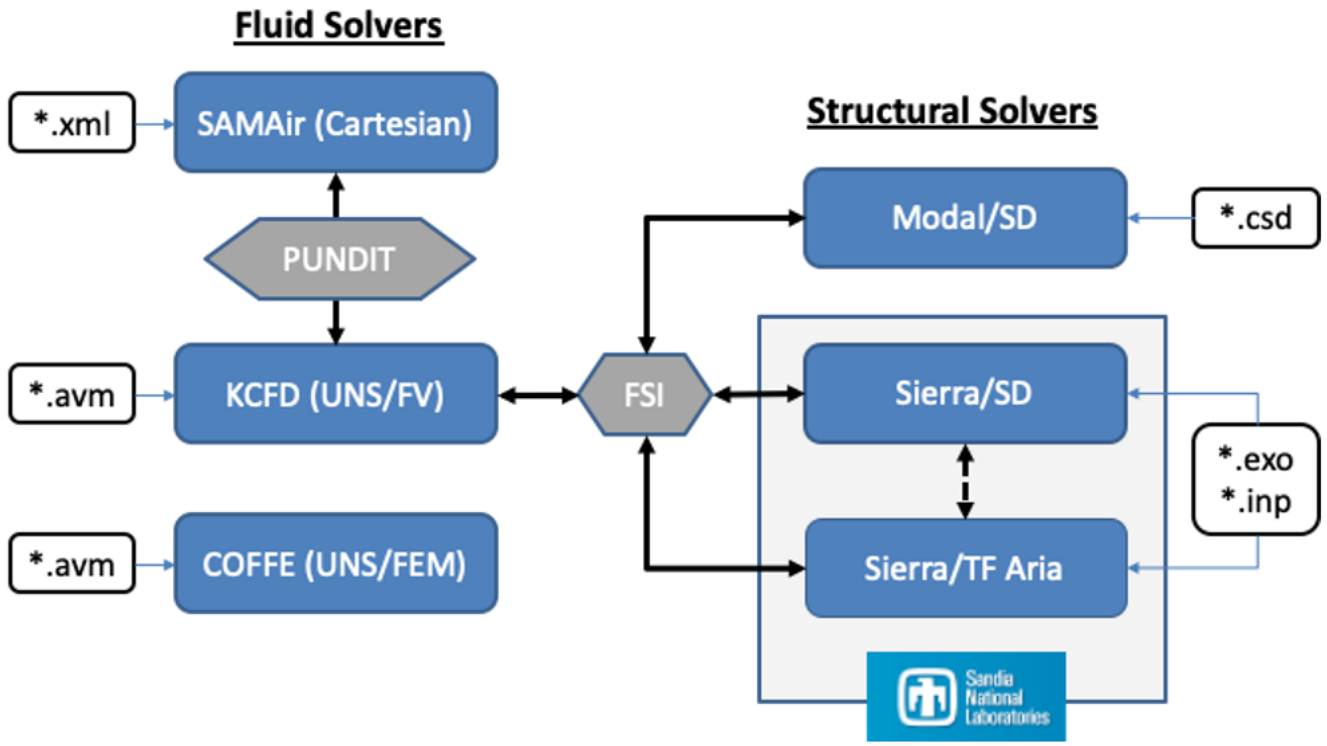
- **CREATE-AV/Kestrel: <u>Production-quality, high-fidelity, multiphysics</u> simulation of fixed-wing aircraft by DoD acquisition professionals**
  - Coupled physics: aerodynamics, thermochemistry, structural dynamics and thermodynamics, propulsion, 6DOF, S&C
  - Low-speed to hypersonic flight regimes, all aircraft types and ground test facilities
  - Cruise, maneuver, take-off/landing, refueling and formation flight, store carriage and release, …
- **Designed for change in anticipation of new requirements, models**
  - Complexity maintained in focused, modular components and managed through an event-based paradigm
  - Language-neutral data warehouse (WAND)
  - Users have choices for best approach to solve their problem



Kestrel Architecture

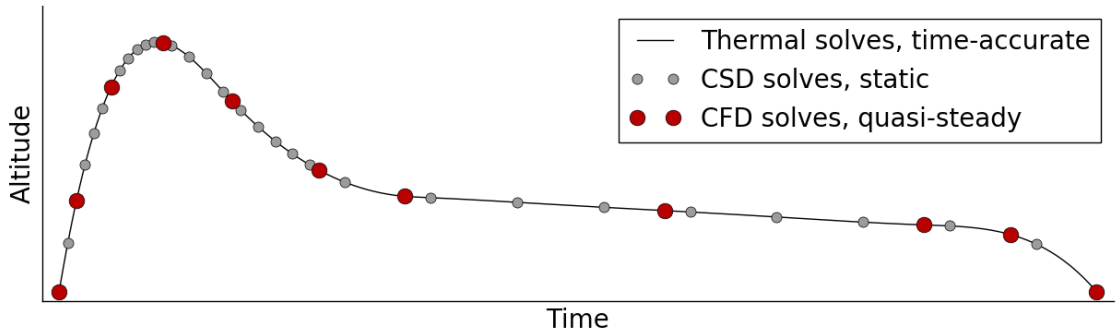
- **Designed for Multi-fidelity, Multidisciplinary Interactions**
  - Easy for Users to choose between various fidelity Aero, Structural, and Thermal solvers
  - Modules can be replaced by surrogates to execute with precomputed solutions
  - User Interface makes it easy for Users to choose between various modules

- **Continuous Testing Model**
  - Overnight Testing
    - Unit : ~29,000
    - Integration : ~2,000
    - System : 64
  - Acceptance Testing
    - Executed every 2 weeks
    - 275 Jobs including Full Aircraft Cases Compared to Flight/Ground Tests
    - ~158,000 CPU Hours

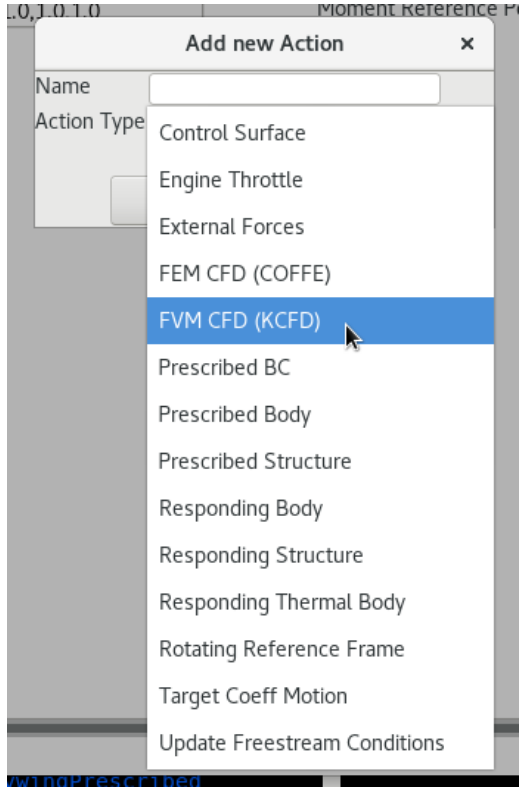


Approach to Multiphysics Simulations

- **Coupling previously driven by an unsteady, CFD-focused approach**
  - Non-CFD physics integrated into simulation via Kestrel “actions” in context of CFD solution
  - Notional hypersonic trajectory problems intractable in this context
  - Unable to run simulations without high-fidelity CFD
- **New approach (v11) moves towards a fully-flexibly coupling paradigm**
  - CFD solutions integrated via time-based Kestrel actions like other physics capabilities
  - Action-based CFD allows for steady / unsteady solution types
  - ”Iteration” defined as a monotonically increasing value independent of CFD solvers
  - Freestream conditions independent from a particular CFD solver and introduction of an action to change freestream conditions in time
  - Per-action recurrence settings and automatic convergence detection

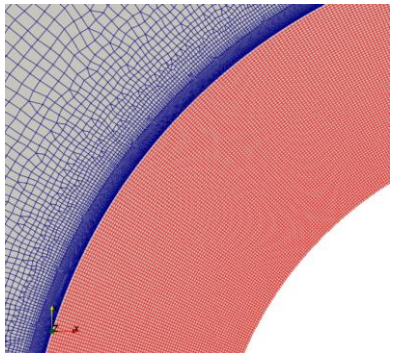


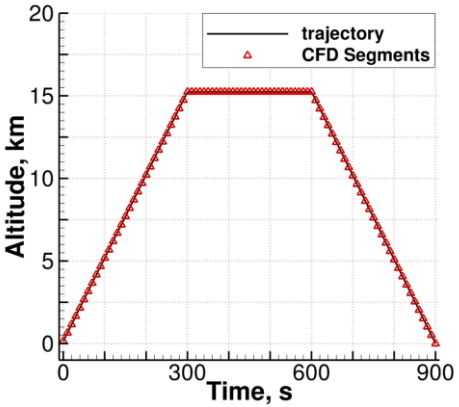
Notional trajectory problem requiring non-uniform physics coupling

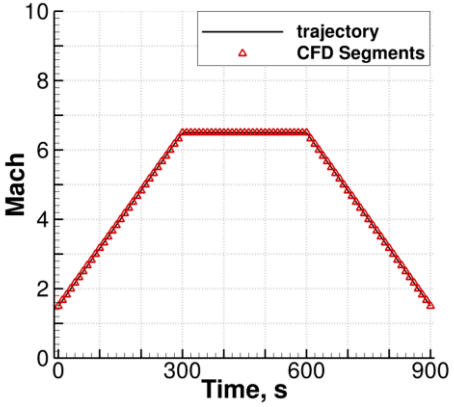


Example: Hypersonic Trajectory

- **2D hollow cylinder with aero-heating during notional hypersonic trajectory**
- **Solid**
  - 2D structured grid with ~77k quad elements
  - Inner wall at radius = 1 inch, isothermal boundary at 294.4 K
  - Outer wall radius = 1.5 inches, fluid-thermal interface
  - 321 stainless steel with constant material properties
  - Time-accurate thermal solution at **Δ**t = 0.01sec for 15 min (900 sec)using heat flux distribution from most recent fluid solution
- **Fluid**
  - 2D quad-dominant grid with ~80k triangle cells and ~1.16M quad cells
  - Air modeled as perfect gas
  - KCFD flow solver with Mentor SST turbulence model
  - Local time stepping with CFL = 1000 until converged (max 10k iterations) every 10 sec using T distribution from most recent thermal solution
- **Wall time (44 core, onyx at ERDC DSRC)**

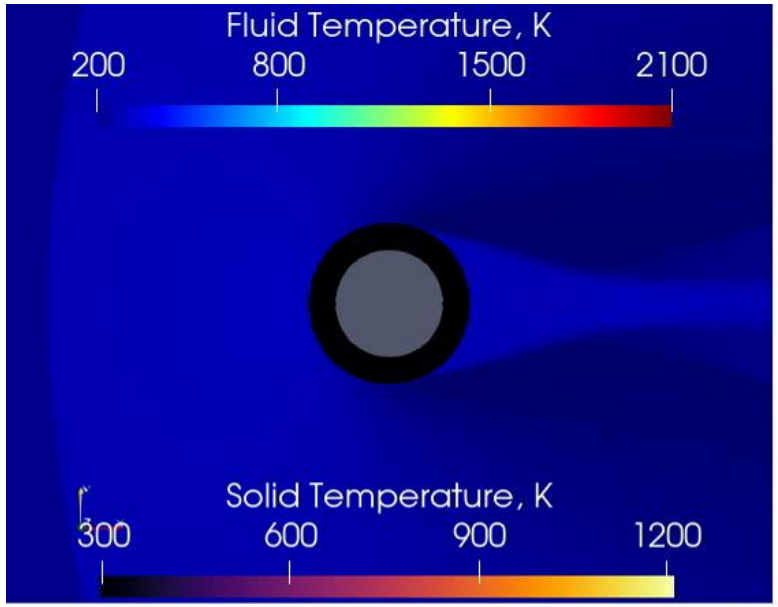


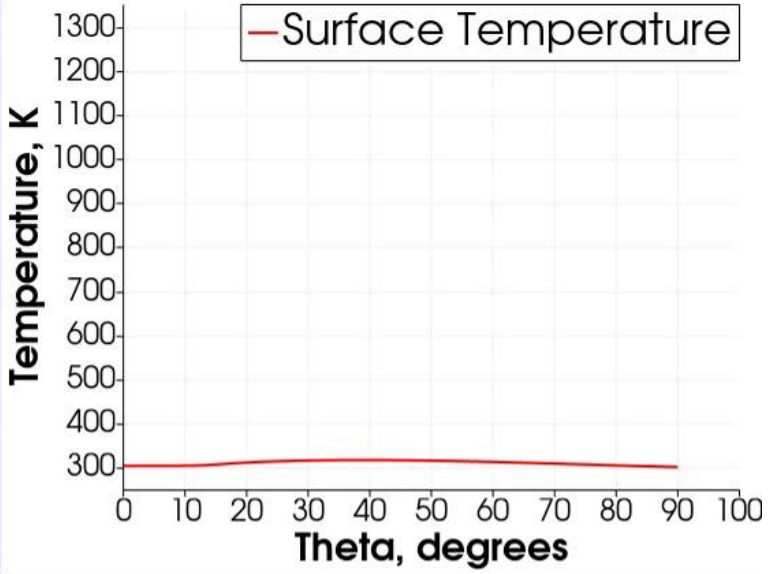


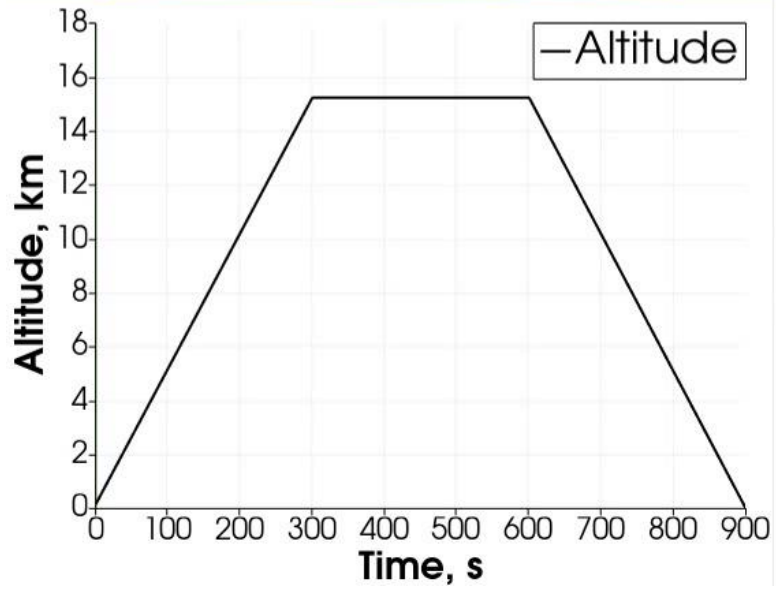


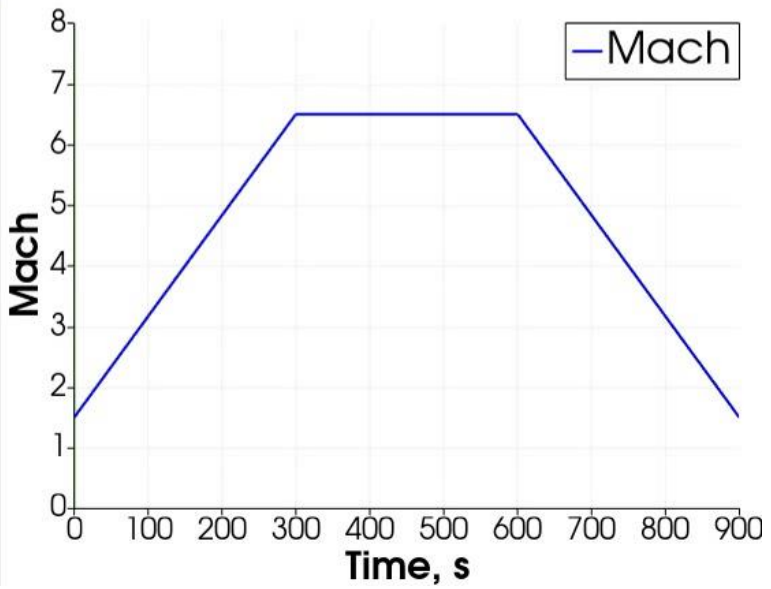
Present Work	No Convergence Detection	Couple every iteration **Δ**t=0.001 (predicted)	Couple every iteration **Δ**t=0.00001 (predicted)
28 hrs	54 hrs	87.5 hrs	8,750 hrs

Example: Hypersonic Trajectory







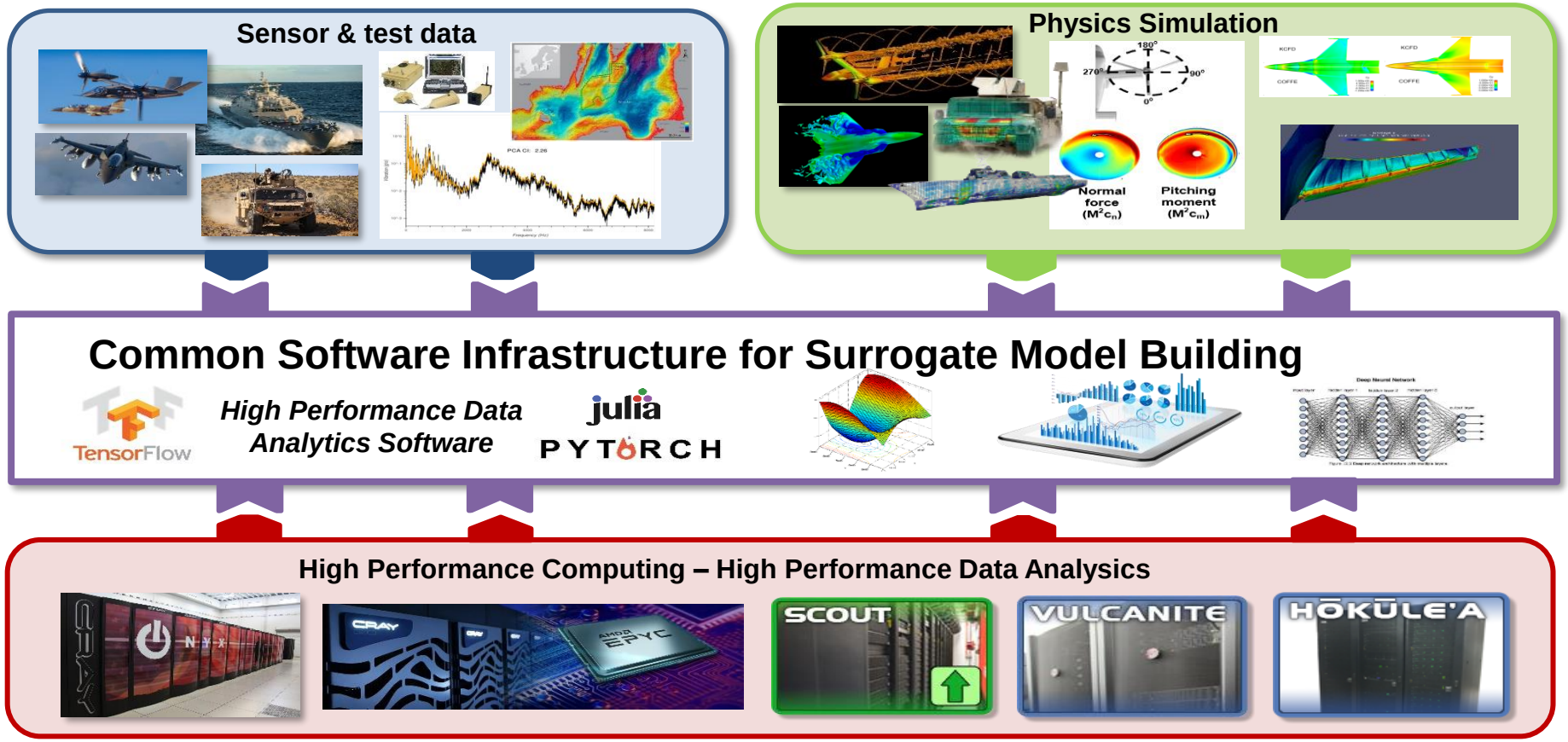


Surrogate Building

Software infrastructure to enable *surrogate model generation from data-driven analytics and physics-based analytics for DoD Air, Land, and Sea Vehicles

*Surrogate = approximate model used when a full-physics computational model is intractable

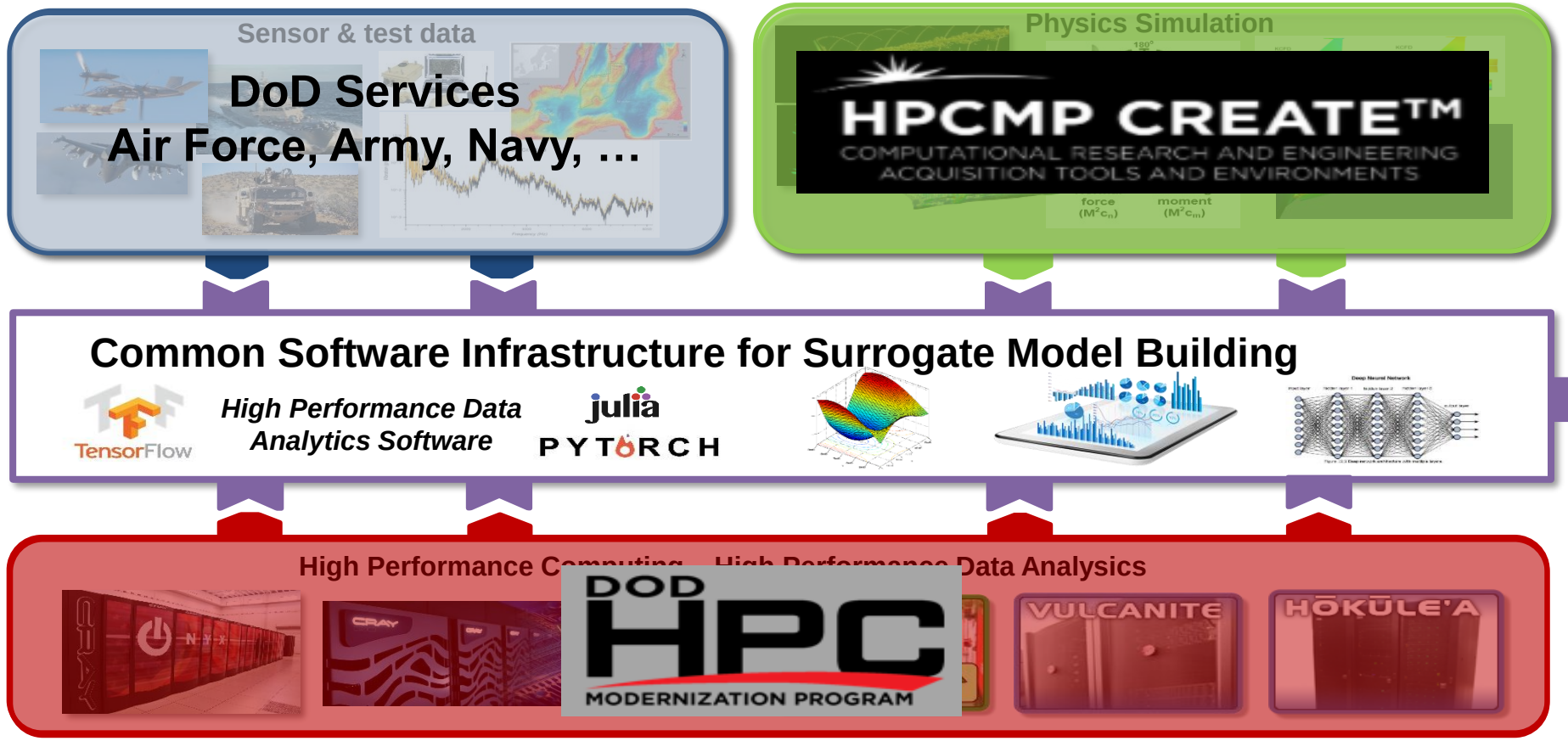
CREATE Software Product



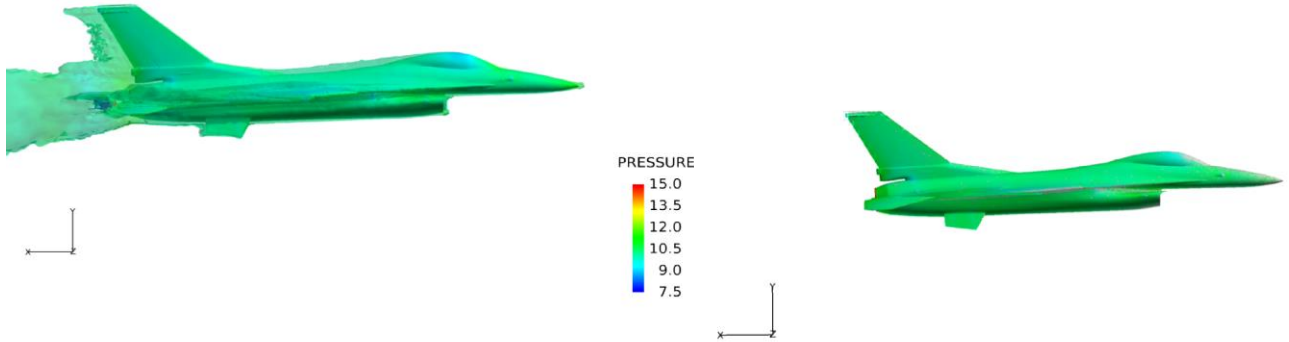
Surrogate Building

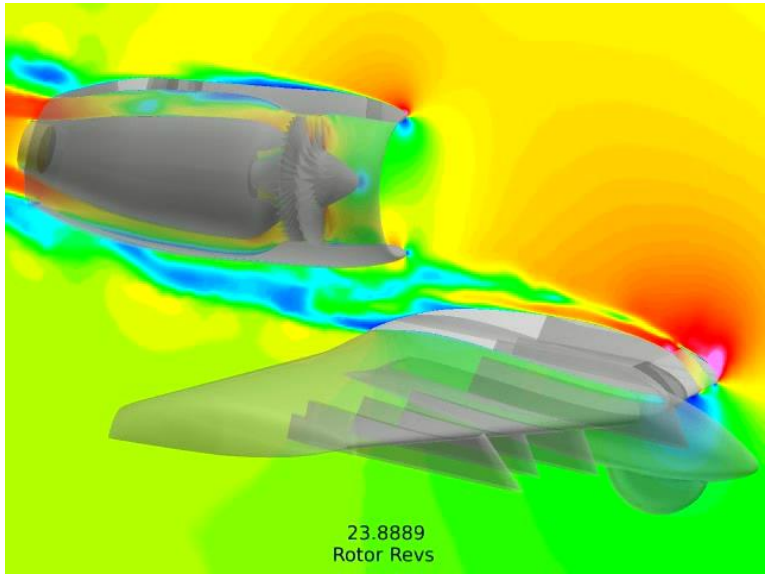
Software infrastructure to enable *surrogate model generation from data-driven analytics and physics-based analytics for DoD Air, Land, and Sea Vehicles

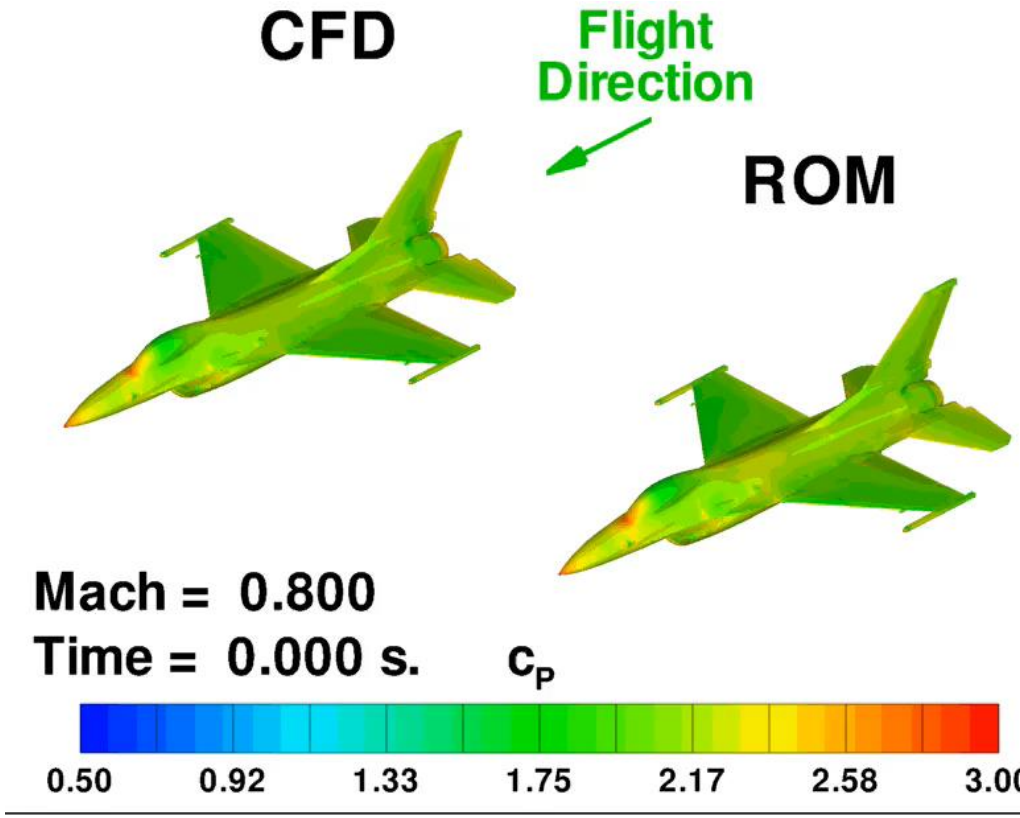
*Surrogate = approximate model used when a full-physics computational model is intractable



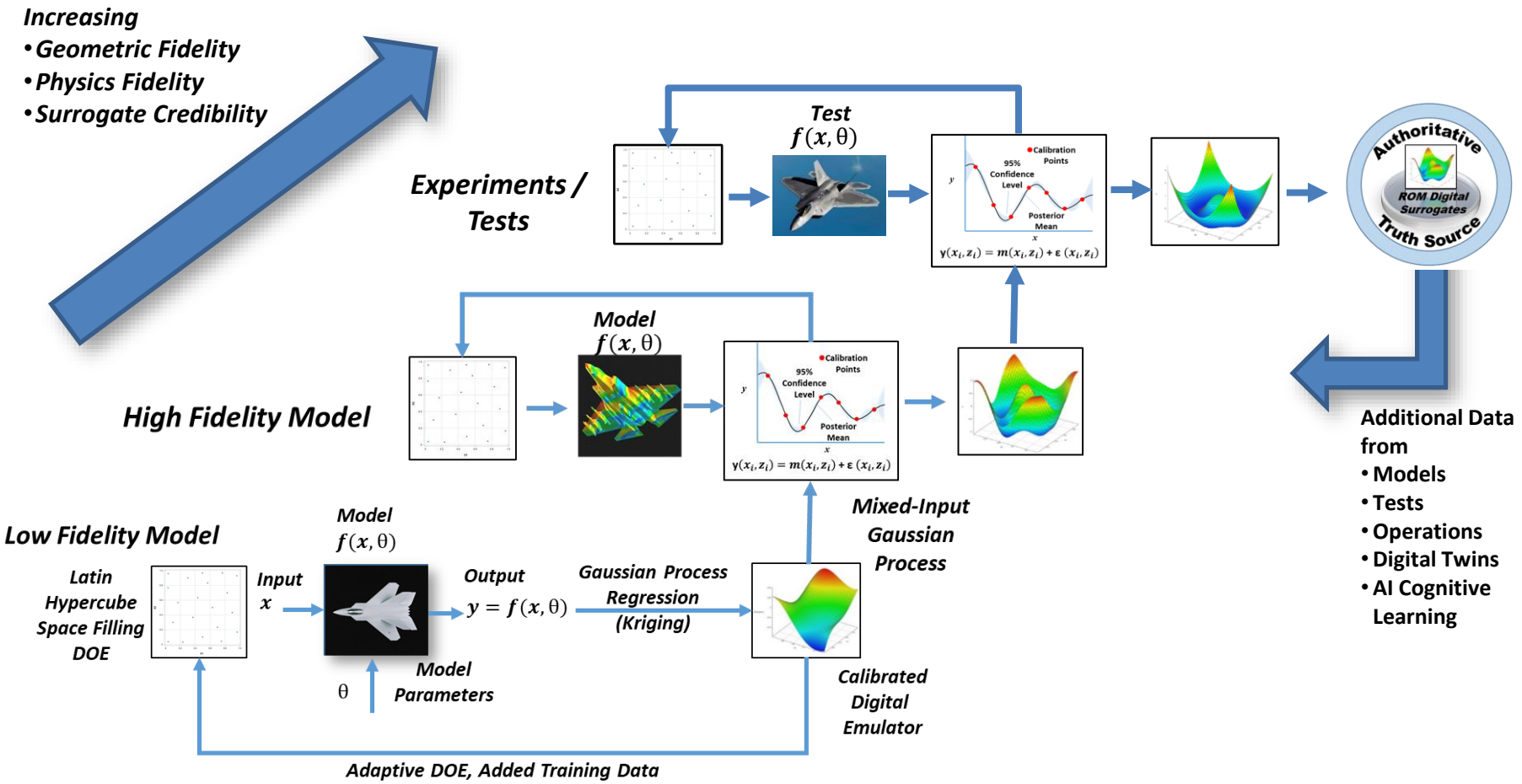
Example of Surrogate Building Elements Reduced-Order Modeling







Example of Developing an Authoritative Digital Surrogate Reduced Order Model for Aerodynamics



Edward M. Kraft, "Development and Application of a Digital Thread / Digital Twin Aerodynamic Performance Authoritative Truth Source," AIAA-2018-4003. Aviation Systems Conference, Atlanta, GA, June 25-29, 2018

Concluding Remarks and Discussion

- CREATE is a 13+ year program created to meet the needs of the acquisition community moving towards Virtual Test and Digital Engineering
- Kestrel is a production-quality multidisciplinary simulation tool for fixed-wing air vehicles targeting DoD acquisition professionals
- Kestrel strives to fill the gaps between high-fidelity physics modeling and engineering decisions while balancing usability, robustness, accuracy, and maintainability
- Modifications to allow a less CFD centric approach have opened up simulation capability that includes more disciplines and variations in fidelity – Direct impact on OEM developers
- Authoritative digital surrogates are required by the DoD Programs of Record and their creation is possible with the current and future CREATE capabilities

Acknowledgements

- Material presented in this presentation is a product of the CREATE-AV element of the Computational Research and Engineering for Acquisition Tools and Environments (CREATE) Program sponsored by the U.S. Department of Defense HPC Modernization Program Office
- ***Huge*** thanks to Dr. Dave McDaniel, Dr. Andrew Wissink, the CREATE-AV Development Team, the CREATE-AV Quality Assurance Team and all of our collaborators for their contributions to this presentation
- Thanks to the CREATE Management Team, the 96th Test Wing RNCS/RNCE, and AEDC for their financial management and facility support and the DoD HPCMP DSRC's for their computational resource support

Questions?