The CREATE-AV Project

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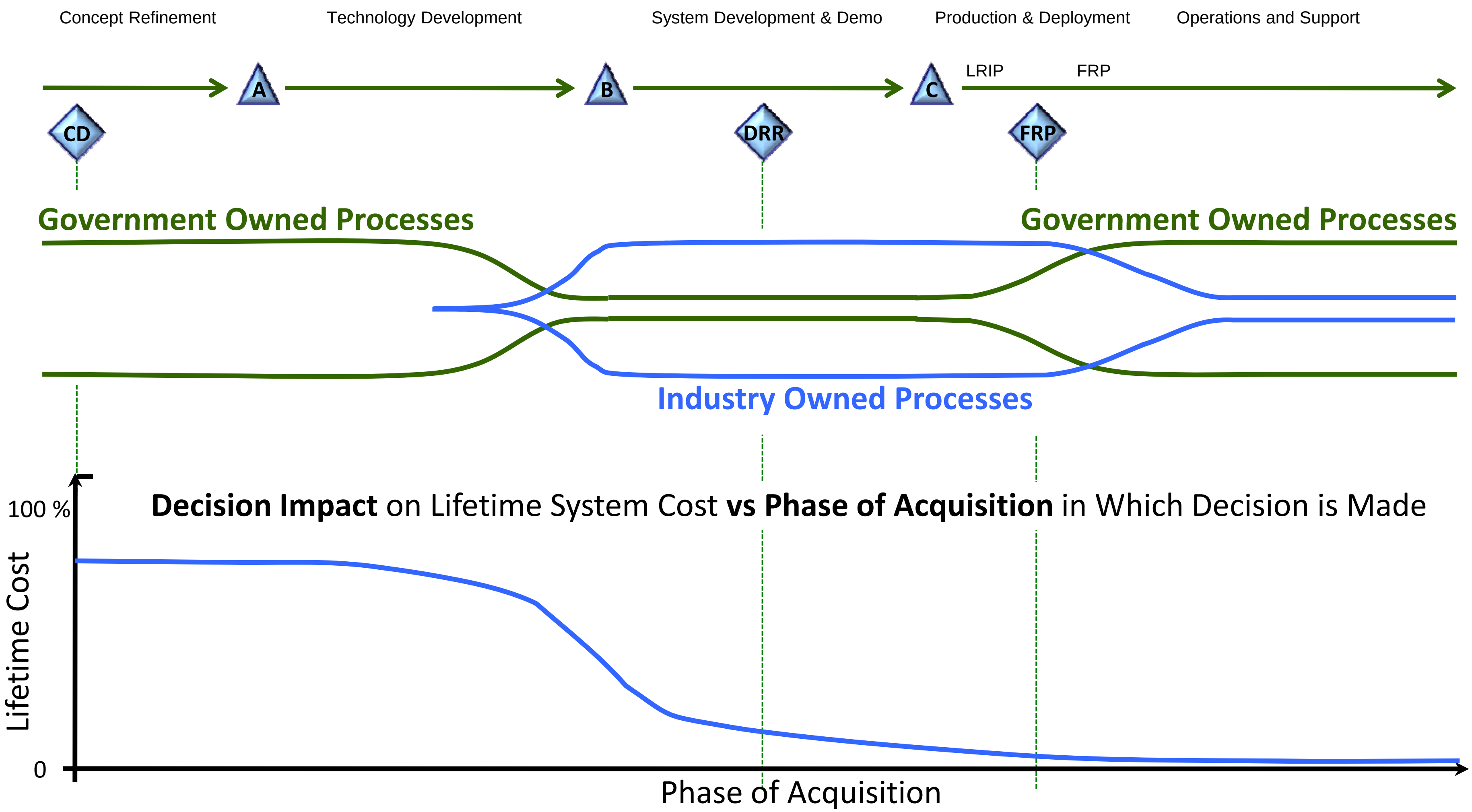
PROJECT MISSION

Develop and deploy a set of CBE Software Products that enable…

- **Increased capacity** of the acquisition engineering workforce of the services,
- Reduced workload through **streamlined** and more efficient acquisition **workflows**, and
- **Minimized need for rework** due to early detection of design faults or performance anomalies,

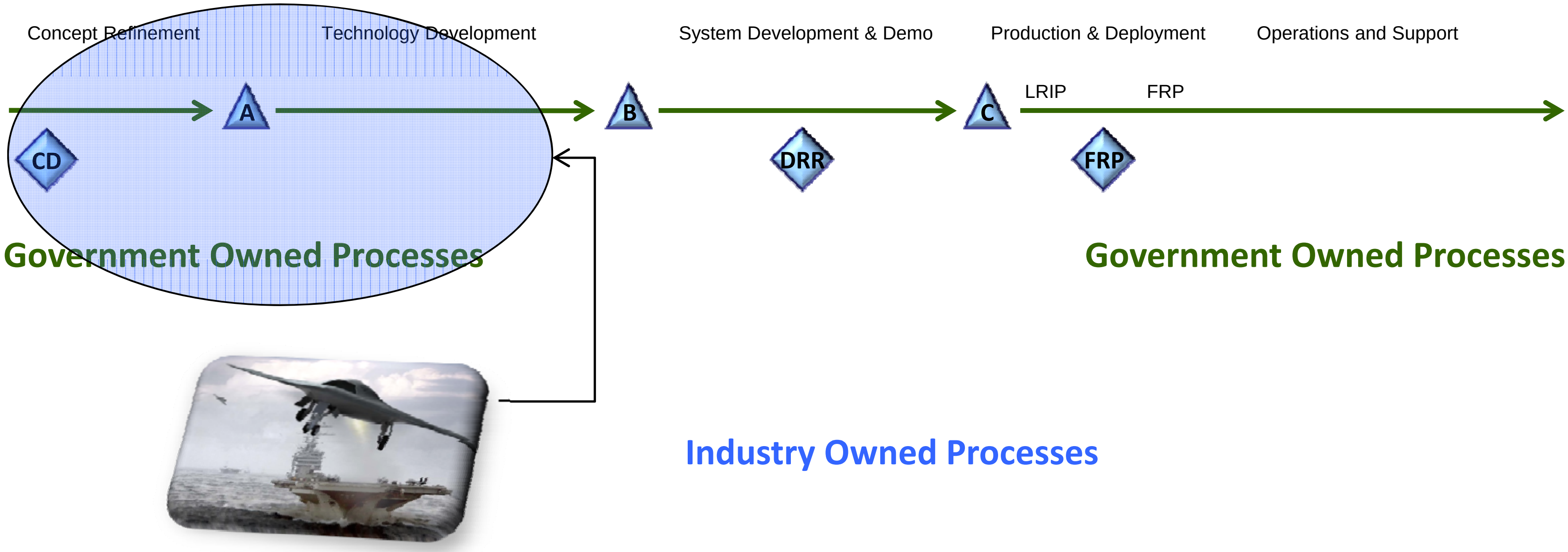
through exploitation of the capacity of next generation computer resources.

Ownership of Processes & Potential for Decision Impacts



EARLY-PHASE EXAMPLE

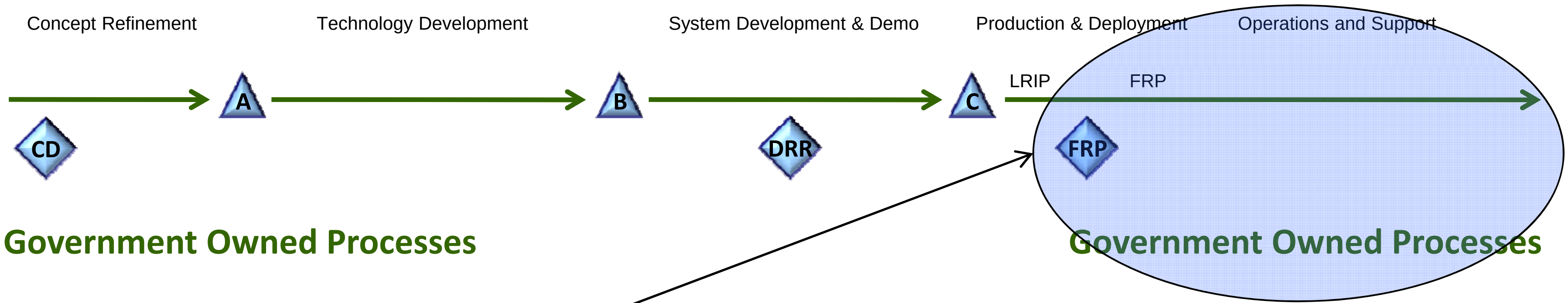
1 of Targeted Set of Government Owned Engineering Processes



ID	Process Name	Use Case
AV-026	**Navy Conceptual Design** Process	Rapidly produce physics-based, optimized conceptual designs in days to weeks. Quantification of design concept performance and sensitivity to new technology. (Benefits: Better decision data at the earliest phases of acquisition have potential to positively impact all subsequent acquisition costs.)

LATE-PHASE EXAMPLE

1 of Targeted Set of Government Owned Engineering Processes



Industry Owned Processes

ID	Process Name	Use Case
AV-006	Store Compatibility Cert Recommend for **Store Separation** Air Force	Evaluate separation characteristics of all store combinations for a given aircraft. The number of configurations necessary to analyze is growing exponentially. (Benefits: Expansion of flight envelope / improve effectiveness & reduce cost of test programs)

PRODUCT DEPLOYMENT SCHEDULE

ANNUAL release cycle – increasing functionality, physical accuracy, computational efficiency, usability

Technology Demonstration → **Engineering Development** → **Product Deployment** → **Operations and Support**

Initial Conceptual Design & Roadmap → Annual Product Prototyping Loop (O) → Final Product Design → "Next Gen" Annual Product Development Loop (O) → Final Product Implementation Loop (O)

2008 … Kestrel **v3.0**, Helios **v3.0** — **2012** DaVinci **v3.0** … Kestrel **v8.0**, Helios **v8.0** — **2017** DaVinci **v8.0** … **2019**

Deploy to targeted government workforce for **DoD owned** acquisition engineering processes. **Engage industry via technical advisory boards and professional societies.**

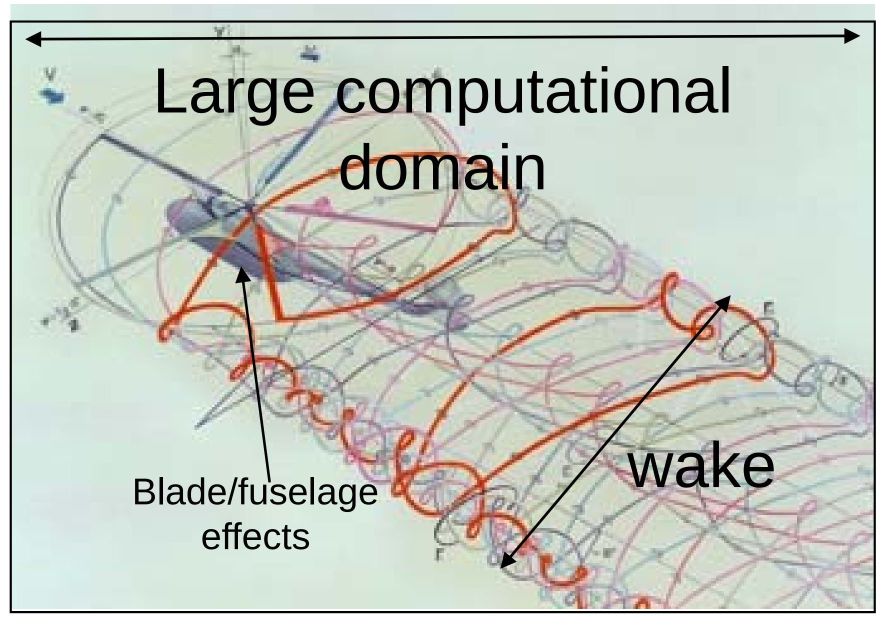
Expand industry involvement via Beta-test events

Full deploy to government and industry for DoD acquisition engineering

A LOOK AT ONE OF THE CREATE-AV PRODUCTS

PHYSICS-BASED DRIVERS OF HELIOS DEVELOPMENT

- **Multiple scales**
  - – Large computational domain
  - – Small scales in boundary layers
  - – Vortical structures in wake
- **Fluid-structure coupling**
  - – Rotor blade aeroelasticity
  - – Trim and pilot controls
- **Complex fluid dynamics**
  - – Highly unsteady flowfield
  - – Shock waves on advancing rotor
  - – Dynamic stall on retreating rotor
- **Interactional aerodynamics**
  - – Rotor/fuselage, main rotor/tail rotor
- **Numerical modeling**
  - – High-order accuracy
  - – Grid adaptation
  - – Unsteady low Mach preconditioning



- **Other complexities**
  - – Complex geometry
  - – Bodies in relative motion

PHYSICAL ACCURACY TARGETS

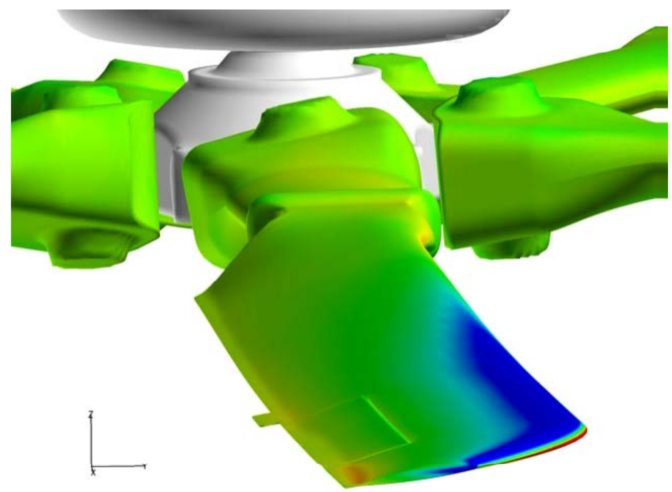
Year / Measures	Metric 2008	2009	2010	2011	2012	2013	2014	2015	2016	Metric End of CREATE/AV
pp: Peak-to-Peak Vb: Vibratory Ph: Phase Mg: Magnitude Bp: Blade passage	SoA -- Conventional Geometries -->		Capability/% Error in Accuracy				Advanced / Arbitrary Geometries -->			Vision for 10 Yrs
Airloads	pp 6% Vb 20% Ph 20%									pp 1% Vb 3% Ph 3%
Structural loads	pp 35% Vb 40% Ph 20%									pp 3% Vb 5% Ph 5%
Stress / Strain	-None-									Prediction
Hub loads	Mg 40% Ph 20%									Mg 5% Ph 5%
Fuselage Frequencies up to 40 Hz	Bp1 20% Bp2 40%									Bp1 5% Bp2 5%
Vibration Pilot/co-pilot seat Selected stations	-None- Mg 100% Ph 100%				Aero – tail boom impingment			Fuselage Dynamic Coupling		Prediction Mg 10% Ph 10%

	Goal	Engineering Tool	Physics-Based Model
Forward flight performance	1%	4%	20%
Hover performance	0.5%	2%	2% (but flow-field not correct)
Airloads (c_n/c_m), without mean	1%	10% / 35%	6% / 20%
Airloads (c_n/c_m), with mean	1%	10% / 35%	15% / 40%
Blade loads (flap / chord / torsion)	3%	20 / 35 / 25%	20 / 35 / 25%
Vibration	10%	100%	Not available
Stability (fraction critical damping)	0.002	0.02	Not available
Noise	3 dB	10 dB	15 dB

From: ***Johnson and Datta 2008***

HELIOS v3.0 (RAINIER) CAPABILITIES

- **Full Rotorcraft configurations**
  - Fuselage + multiple rotors, tail rotor, etc.
    - Resolution of time-step mismatch problem between main rotor and tail rotor (high tail rotor-RPM results in very small global time steps for main rotor simulation)
  - Free-flight trim with CFD-based fuselage loads



- **General control surfaces**
  - Support for integral/conformal control surfaces (single grid with re-meshing or mesh motion)

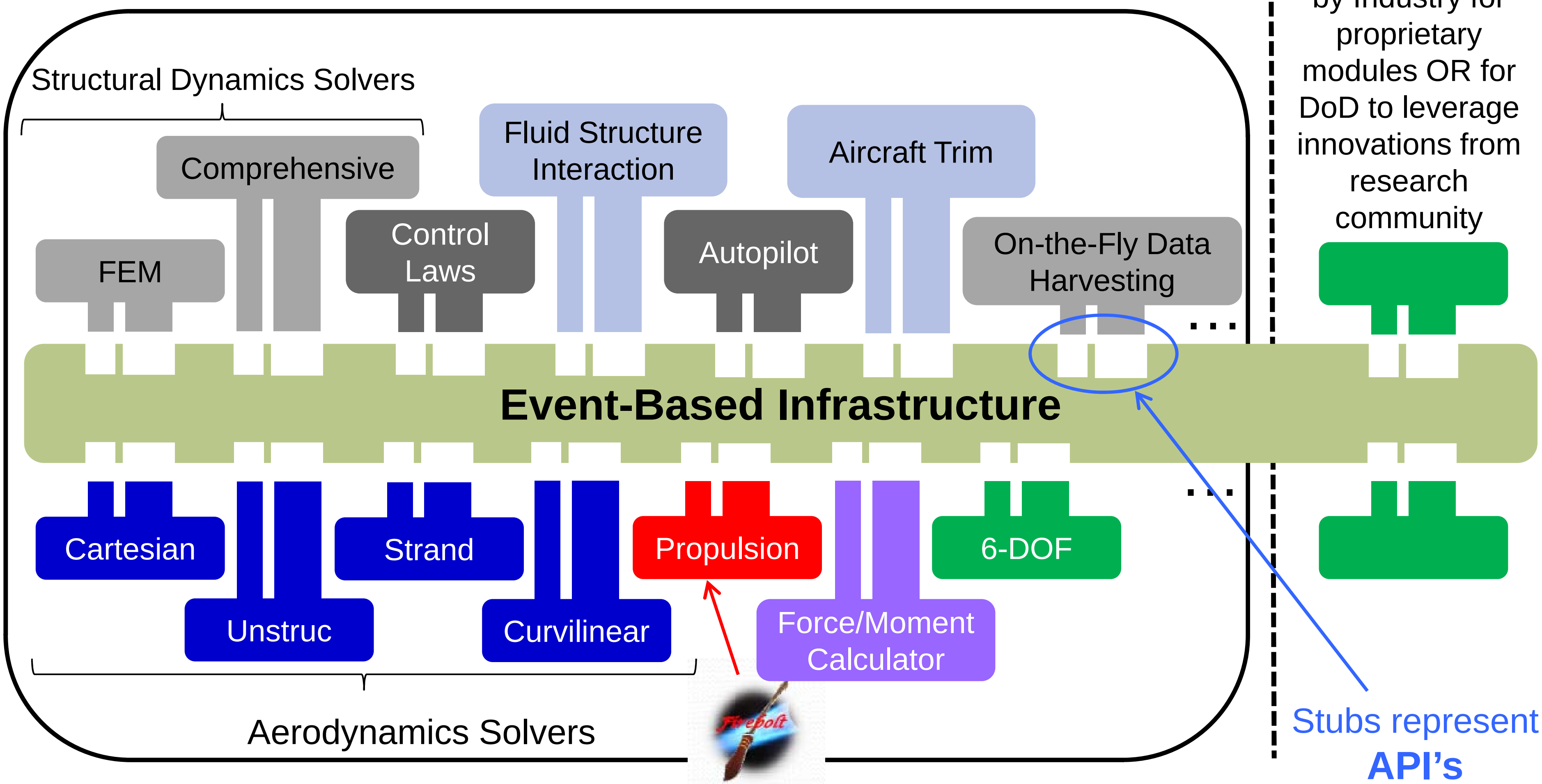
- **Engine module integration for propulsion effects**
  - 0-D engine model from CREATE-A/V Firebolt program)

- **Store Separation with 6-DOF motions**
  - Most of this software will be adapted from existing Kestrel modules using published interface definitions
    - Prescribed mesh motion
    - Rigid mesh motion
    - Mesh deformation
    - 6-degree of freedom body motion

SOFTWARE ARCHITECTURE (Helios AND Kestrel)

“Light-Weight” Infrastructure – Highly Scalable and Modular (available as executable)

Well Defined APIs available for use by Industry for proprietary modules OR for DoD to leverage innovations from research community



REMARK

Frameworks versus Infrastructures

Both offer compelling development and maintenance advantages for multi-physics software products, but differ in method of delivery. It is important to recognize that the choice of one over the other is a development decision (as opposed to a *management* decision).

Both are intimately intertwined with the multi-physics product.

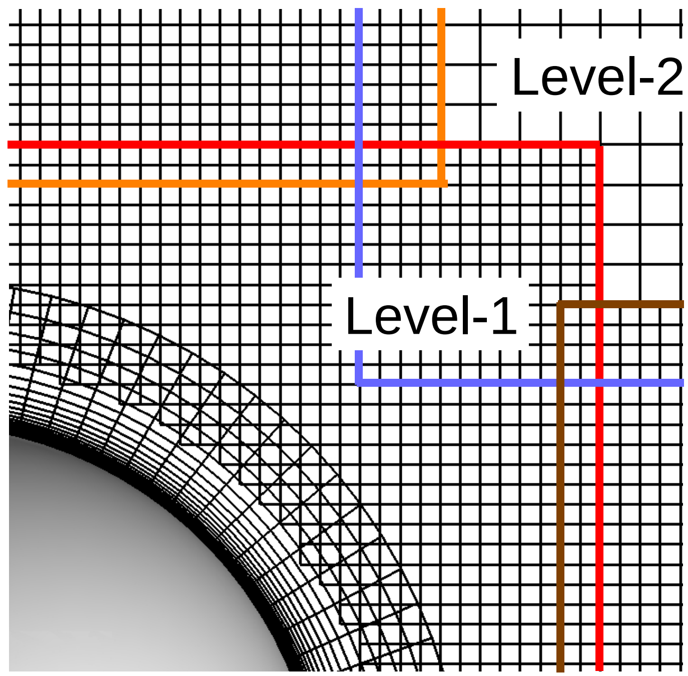
Framework: written to be GENERIC to meet diverse needs and are shared by multiple software products.

Infrastructure: developed for single product and target specialized needs.

Given the targeted long-life and operational constraints on CREATE-AV CBE products, an "infrastructure" path has been chosen by our principal developers.

SOME KEY HELIOS TECHNOLOGIES

<u>Dual-Mesh</u> (aka near-body/off-body spatial partitioning)



off-body
(overlapping uniform Cartesian grids of variable levels of refinement)

near-body
(overlapping curvilinear grids)

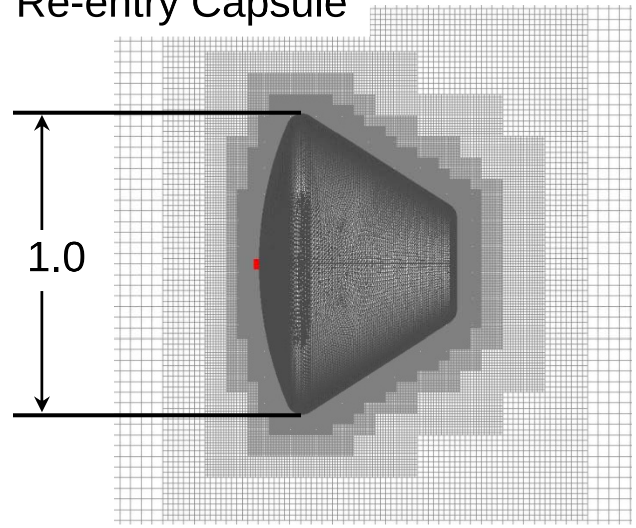
Dual-Mesh: Why do it?

Ideally, use uniform Cartesian grids all the way to the vehicle surface. However, resolution required for viscous boundary layer is prohibitive.

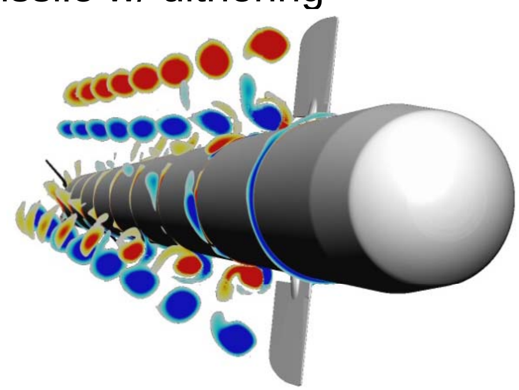
Spacing Requirement*	Δ_{min}	N_{total}
NB/OB Transition	1.0×10^{-2}	$1.86 \times 10^{+6}$
Inviscid Wall	5.0×10^{-3}	$5.89 \times 10^{+6}$
Viscous Wall	1.0×10^{-6}	**$8.43 \times 10^{+12}$**

* assumes Re = $2.5 \times 10^{+6}$ and an AMR Factor = 2

Re-entry Capsule



spinning missile w/ dithering canards



Combined with overset mesh technology, Dual-Mesh enables arbitrary relative motion between bodies, or components of multi-component bodies.

Adaptive Mesh Refinement (AMR)

Technology Drivers

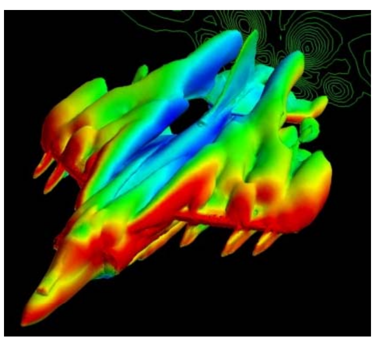
- Physical accuracy (sufficient for aircraft design analysis)
- Timeliness (on-schedule delivery of design analysis results)

CREATE-AV Examples

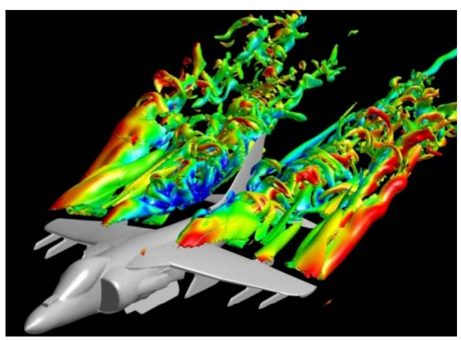
Legacy technology: static mesh, 2nd order accuracy in space and time

Deficiencies: rapid loss of fidelity of flow physics (e.g., vortices and shocks) away from aircraft surfaces, leading to loss in ability to predict downstream physics evolution and possible impacts to aircraft and interactional (aero-structural) dynamics

AV-8B

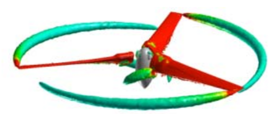


legacy

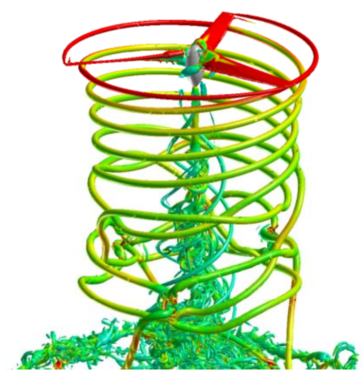


AMR via Helios product

¼-scale V-22 rotor



legacy



AMR via Helios product

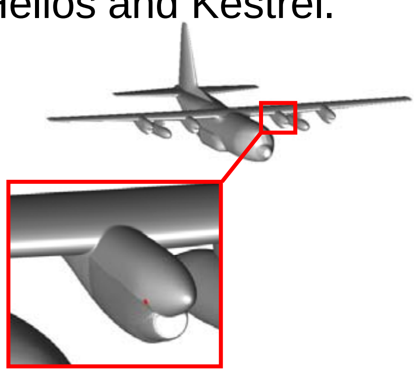
Strand Technology

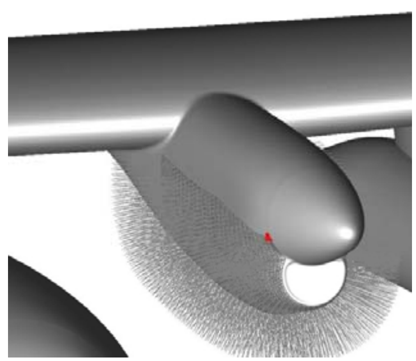
Technology Drivers

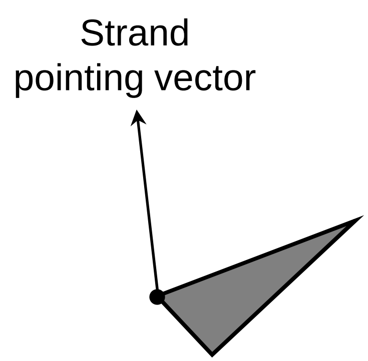
- Timeliness (automation of mesh generation)
- Timeliness (automation and scalability of domain connectivity)
- Timeliness/Physical accuracy (computational efficiency and scalability of aerodynamic solvers)
- Processor architecture (small memory footprint maps well to hierarchical memory architectures, e.g., multi-core, GPU)

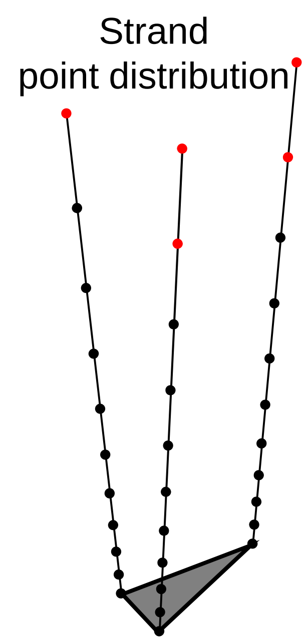
CREATE-AV Example

This is a new meshing paradigm introduced in 2007 by current members of the CREATE-AV technical staff. The technology is being matured in the Helios product and will be deployed through both Helios and Kestrel.

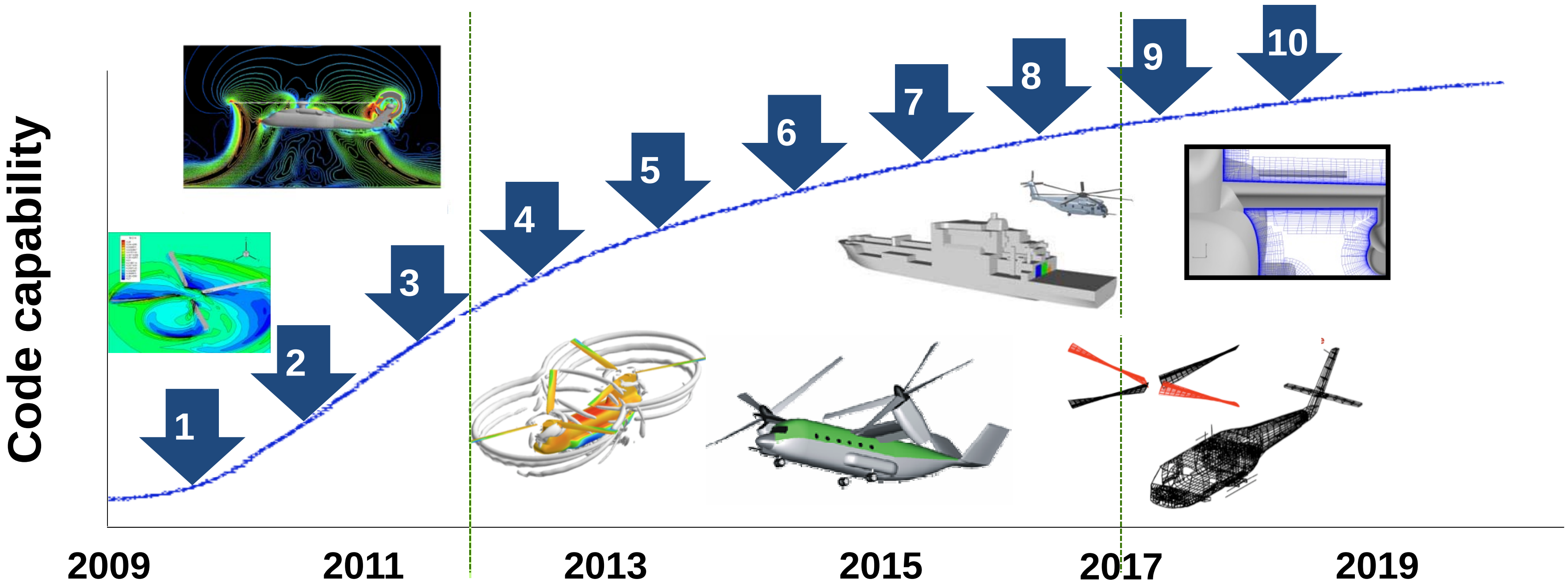








Helios CAPABILITY RELEASE SCHEDULE



1) Isolated rotor with CFD-CA Coupling; momentum disk
2) Fuselage+rotor free flight trim; maneuver; ground
3) Multiple rotors; propulsion; store sep
4) Strand solver, 3DFEM-rotor, multi-body dynamics, vtm
5) Multiple vehicles, hot, high, heavy, ship deck; time-spectral, high-fidelity engine model
6) Brownout; immersed boundary; 3DFEM-fuselage
7) Sea-state; icing; engine plume
8) Design Optimization; micro vehicles; acoustic module; improved models
9) Design Optimization; improved models
10) Design optimization; Improved models

FINAL OBSERVATIONS

- Careful review of defense acquisition engineering workforce processes and workflows has been used to identify capabilities that can be delivered by CBE and next generation computer resources to positively impact defense acquisition.
- Plans to deliver highest impact capabilities have been developed and are being implemented.
- Quickly evolving threats increasingly require quick (with known uncertainties) engineering responses. CBE and HPC provides a means of addressing this challenge in a scalable way.
- Greatest potential for long-term positive impact on defense acquisition?
  - **Early-phase workflows** (an ability to generate physics-based decision data in a timely way during conceptual design is paradigm changing)
- Greatest potential for immediate impact on warfighters?
  - **Sustainment-phase workflows** (e.g., flight clearance, modified/new configuration/loading certification, launch and recovery envelop generation, envelope expansion, mishap investigation, among many others).