Computational Science and Engineering Software Development Challenges and Solutions

Dr. Douglass Post

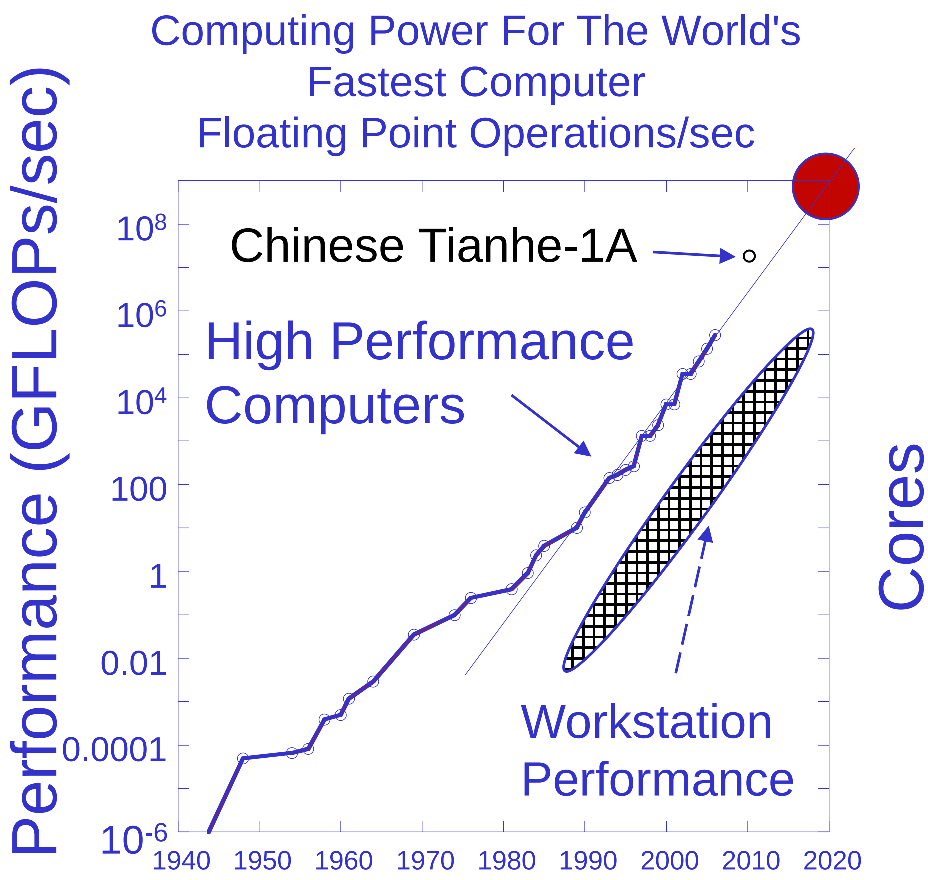
Chief Scientist and CREATE Program Manager

DoD High Performance Computing Modernization Program

HEC-IWG, 18 Aug 2011, Arlington, VA

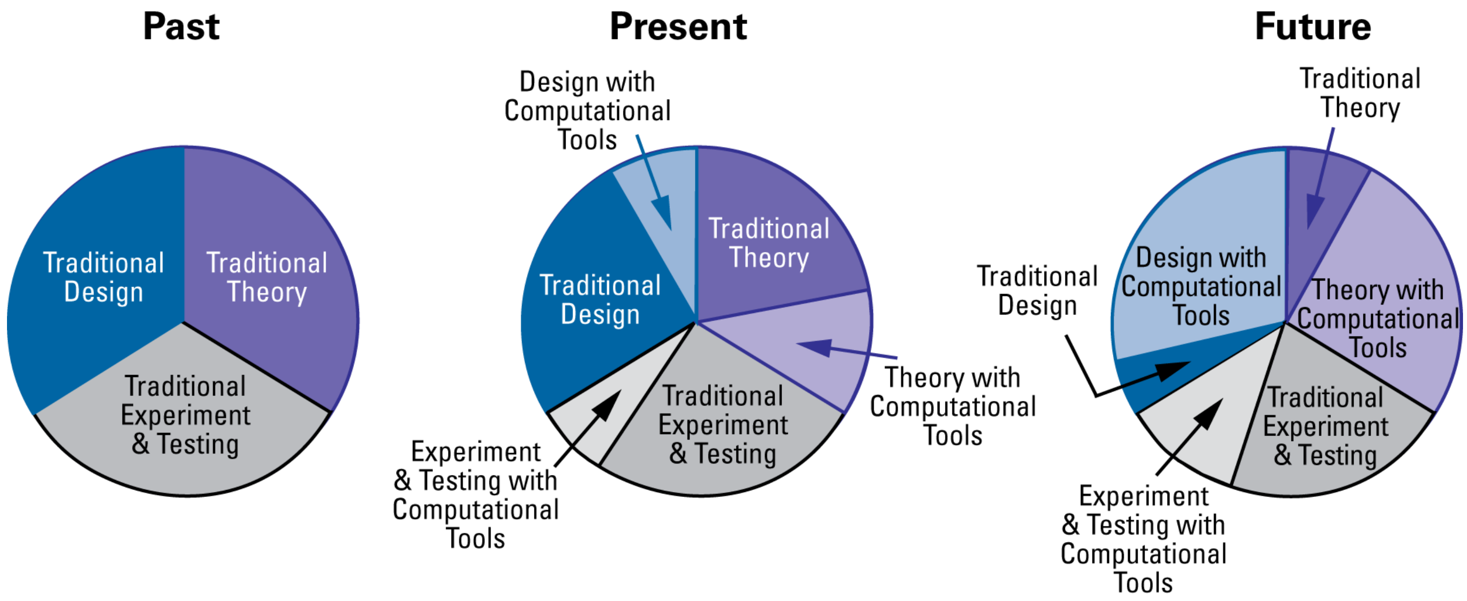
Enabling Technology

- **The 10^{15} increase in computer power enables codes to:**
  - **Utilize accurate solution methods**
  - **Include all the effects we know to be important**
  - **Model a complete system**
  - **Complete parameter surveys in hours rather than days to weeks to months**
- **In ~ 10 years, workstations will be as powerful as today's high performance computers**



Moore's "Law"

Computational Tools Are Becoming Widely Used In Science And Engineering



	Past	Present	Future
Theory	Pencils, paper; slide rules	New: symbolic math; computational solutions	New: Almost all computional
Experiments	Physical hardware; notebooks; chart recorders; polariod film, ...	New: computerized data collection & analysis; little V&V of computations; simple simulations & experimental design	New: Extensive V&V of computations; simulations are a part of experimental methodology
Eng. Design	Pencils, paper; slide rules	New: CAD-CAM; computational design analysis	New: Computational design & optimization

Computational Science And Engineering Has Five Major Elements.

Sponsors	Users	Codes	V&V	Computers & Networks
Sponsors provide mission and funding to solve their problems	Use tools to solve problems, do designs, make discoveries	More complicated models + larger programming challenges	Harder due to inclusion of more effects and more complicated models	Making progress but at cost of massive parallelism and processor complexity
	Users solve the sponsors' problem, provide impact!	**Greatest bottleneck**	Inadequate methods, need paradigm shift	Must reduce programming challenge

- **We need to develop a total capability to solve problems, not just build codes or computers.**

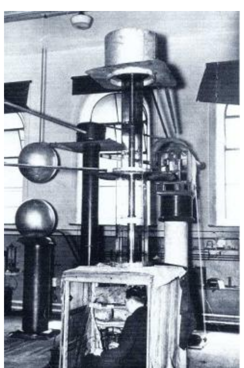
Reductionism and Emergence Why V&V is important!

- **Complex multi-physics and multi-scale codes include tens to hundreds of effects**
  - Reduce problem to its constituent elements
  - Answer depends on trade-off of many competing effects
- **Robert Laughlin* (Nobel Prize, 1999) and others point out: Solution of complex problems by calculating the trade-off the detailed effects (reductionist) is an NP incomplete problem**
- **We only solve problems when we can use a set of overarching or “emergent” principles (e.g. conservation laws, symmetry, thermodynamic principles,…)**
  - Example: hydrodynamics for water flow, not molecular dynamics
- **How can we ensure that our complex models correctly capture the relevant emergent principles?**
  - Validation is the best (only?) tool we have

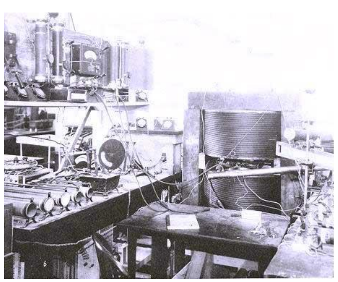
*R. Laughlin, *The Physical Basis of Computability, 2002, Computing in Science and Engineering,* ***4, 27-30.***

Computational Science And Engineering Is Making The Same Transition That Experimental Science Made In 1930 Through 1960.

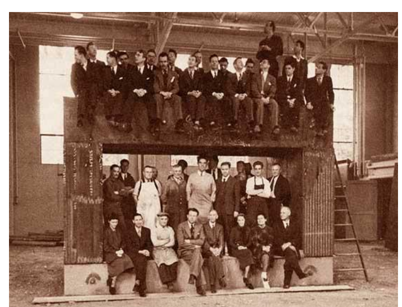
- **"Few-effect" codes developed by small teams (1 to 3 scientists) → "Many-effect" codes developed by larger multi-disciplinary distributed teams (10, 20 or more staff).**
- **Analogous experimental science transition made in 1930-1960 time frame**
- **Small-scale science: a few scientists at small laboratories → "big science" experiments with large, distributed teams and large facilities.**
- **"Big Science" experiments → greater attention to formality of processes, project management issues, and coordination than small-scale science.**
- **Experimentalists were better equipped than most computational scientists and they had more time to make the transition.**
  - Small scale experiments require much more interaction with the outside world than small-scale code development.
  - Experimentalists had ~20 years, while computational scientists are doing the transition much more quickly.



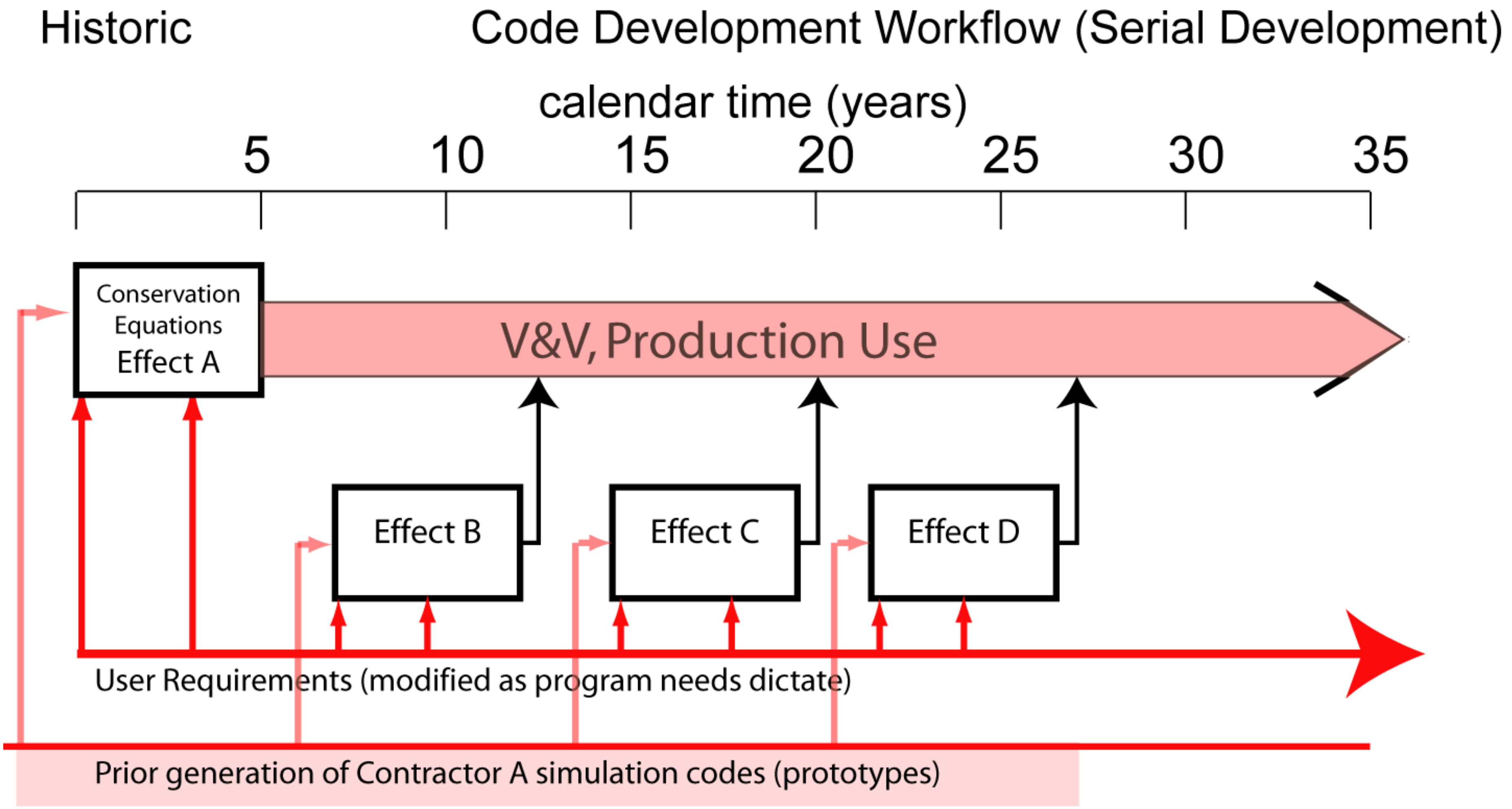
Early 1930's



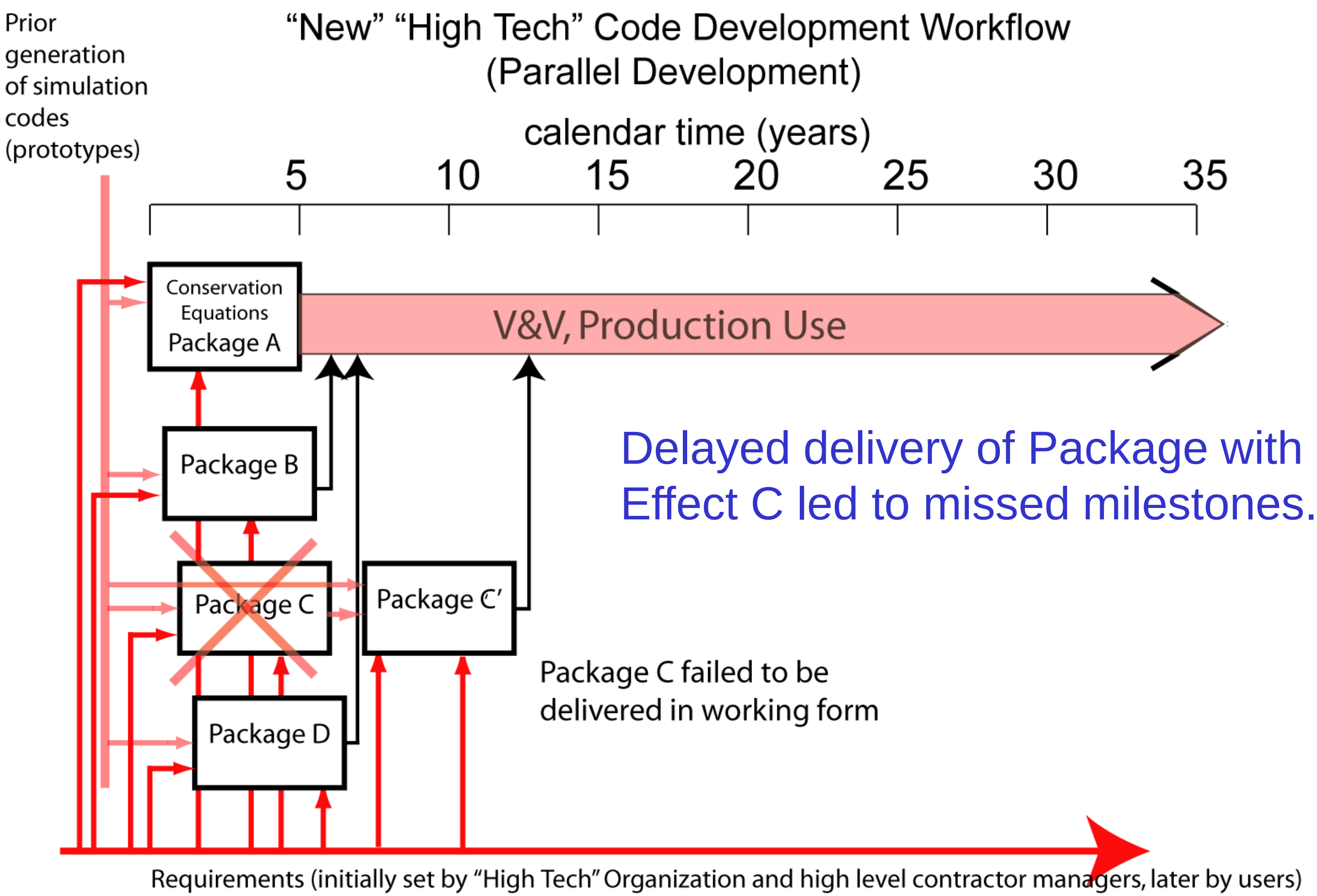
Late 1930's



Small Team Development of Application Codes Could Use Serial Development Workflows



Large Teams Required Parallel Development With No Contingency.

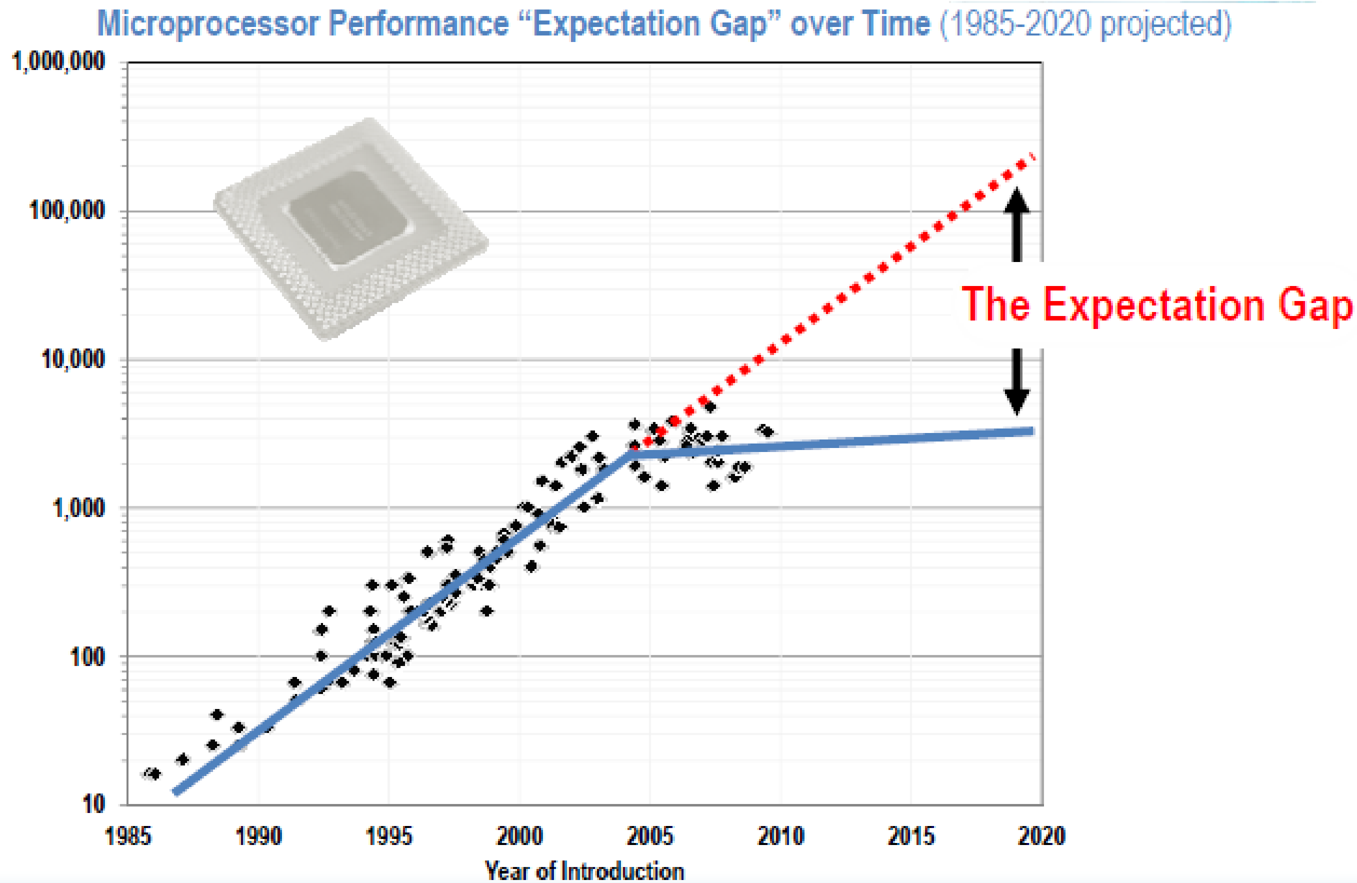


Delayed delivery of Package with Effect C led to missed milestones.

Distribution Statement A: Approved for public release; distribution is unlimited.

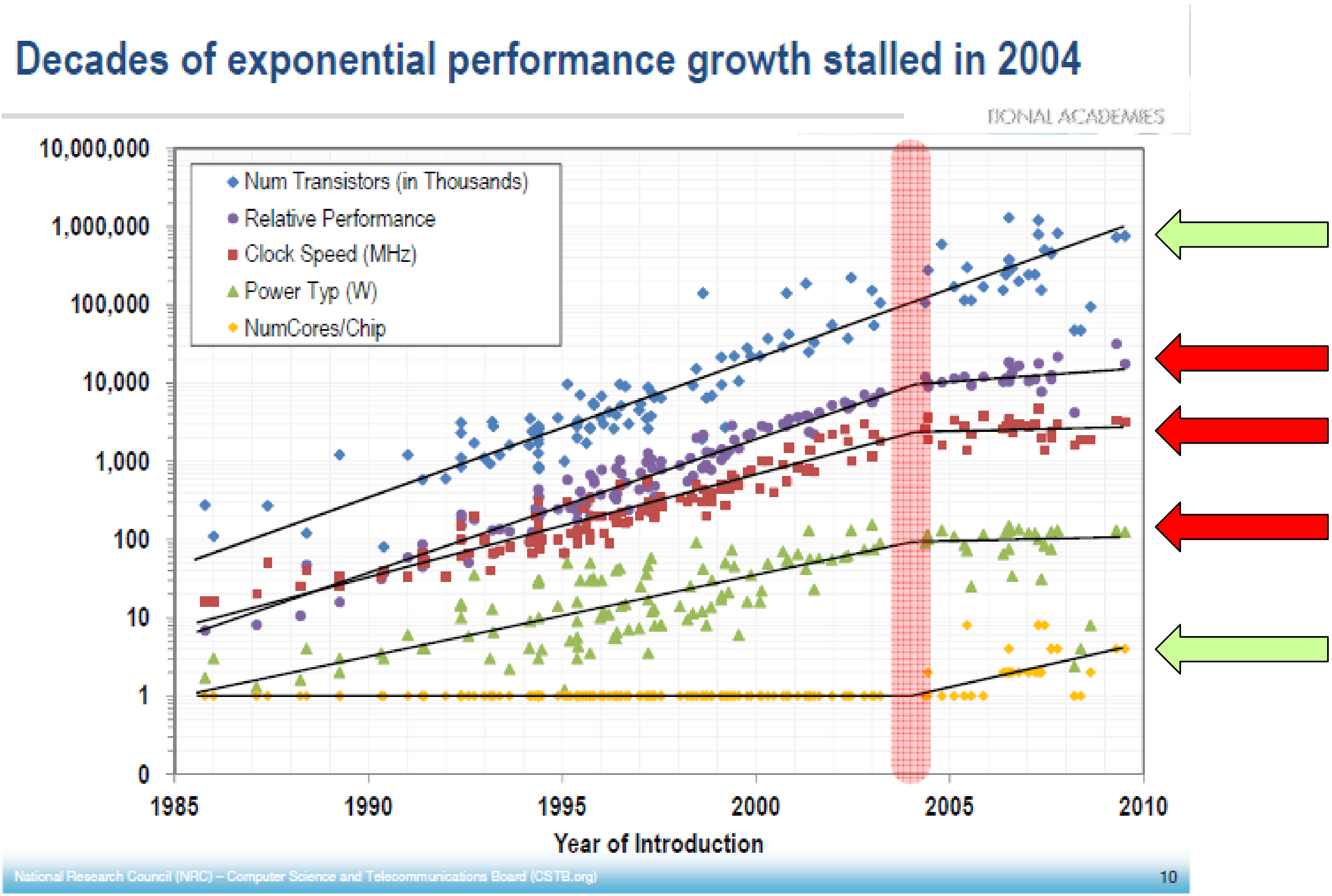
NRC: Computing is changing.

Processor Performance Plateaued about 2004



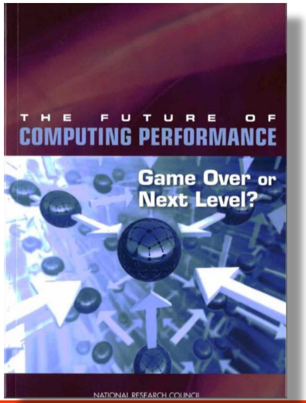
National Research Council (NRC) – Computer Science and Telecommunications Board (CSTB.org) 7

Clock Speed Growth Has Stalled But Not Transistor Density Growth



"What's it All About?"

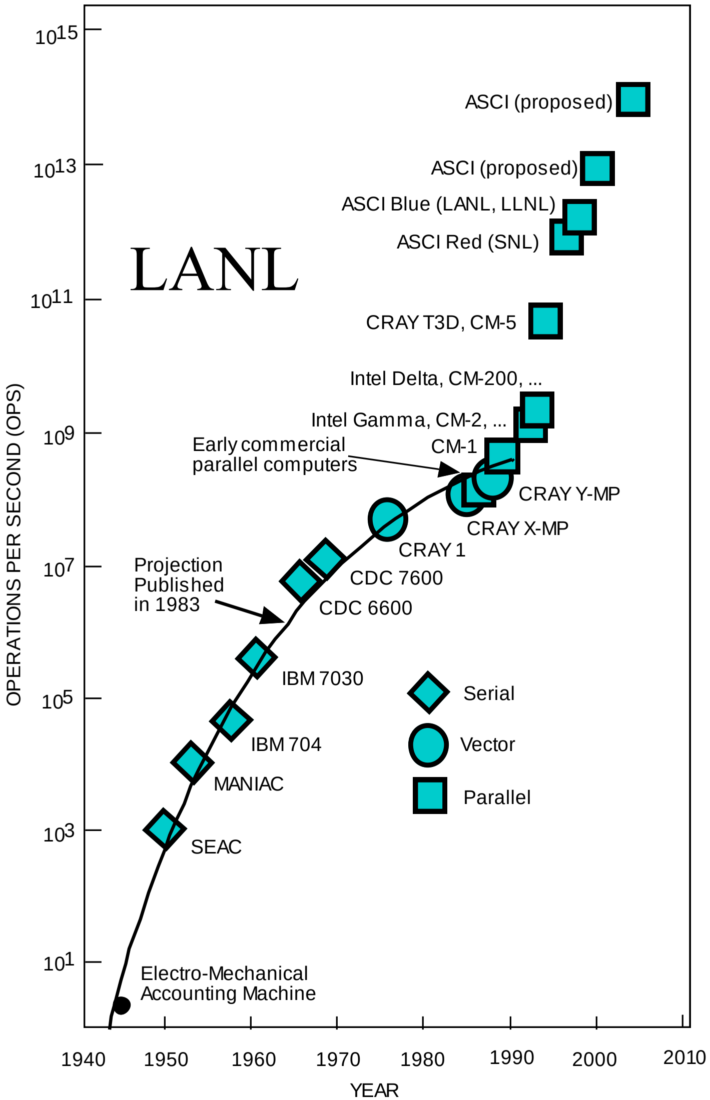
- Processor speed is stalled out at about 3GHz due to power and cooling limits
- However, feature size can still be reduced
- To get more performance, chip manufacturers are increasing the number and type of processors on a chip (multi-core)
- "Hail Mary Pass*" to Application Code developers: sequential → massively parallel (with heterogeneous processors)
- Many Science and Engineering applications: Completely sequential to moderately parallel (mostly data parallel)
- Community will need to invest in application software development and new software "stacks"
- Will require new algorithms and software engineers/computer scientists
- Requires the focus of the national HPC community
- **Will require explicit support of code development!**



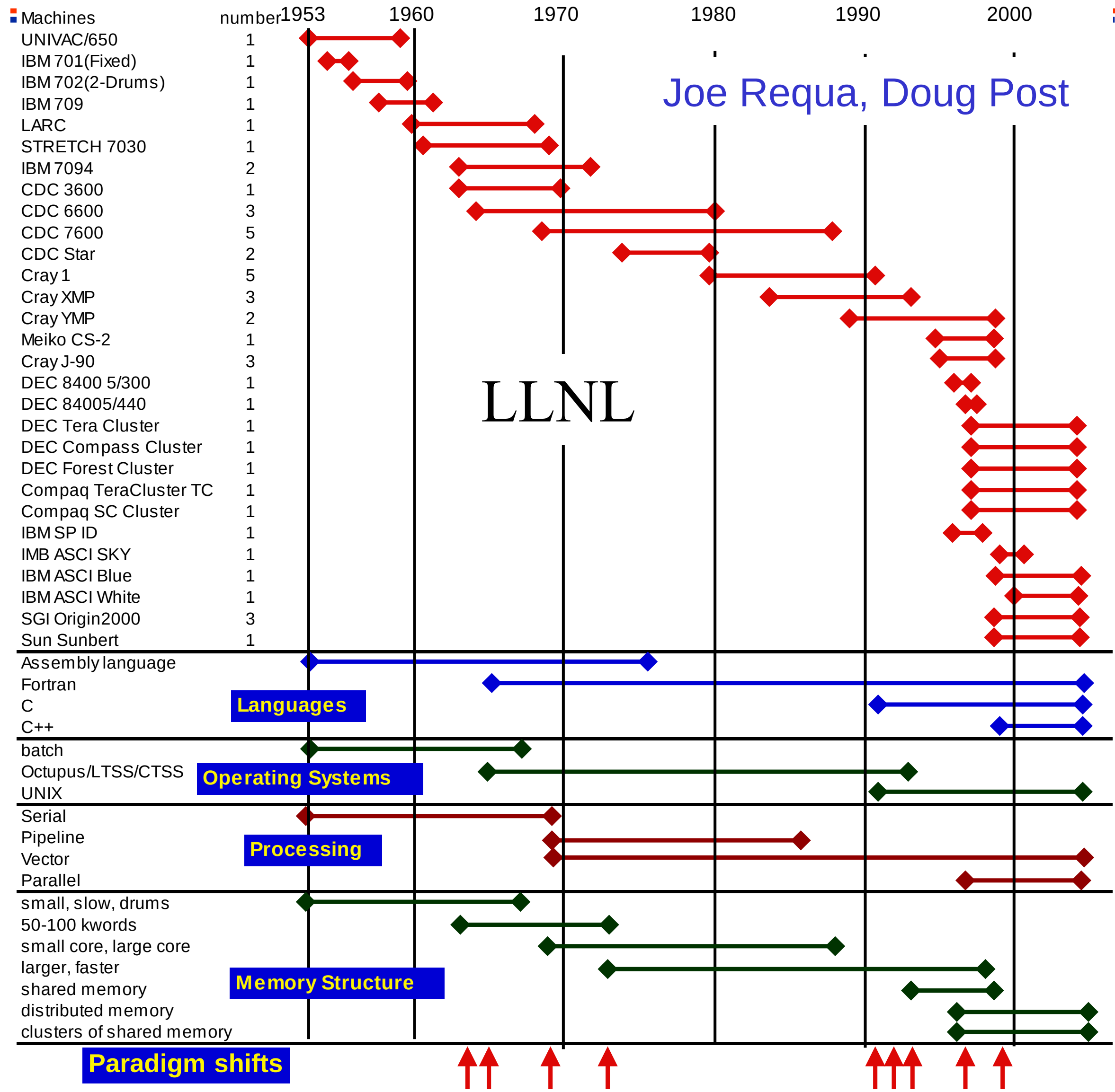
*D. Patterson, *The trouble with Multi-core, 2010, Spectrum, IEEE,* ***47, p7.***

History: Computer Paradigm Shifts at LLNL and LANL Led to Significant Code Extinctions

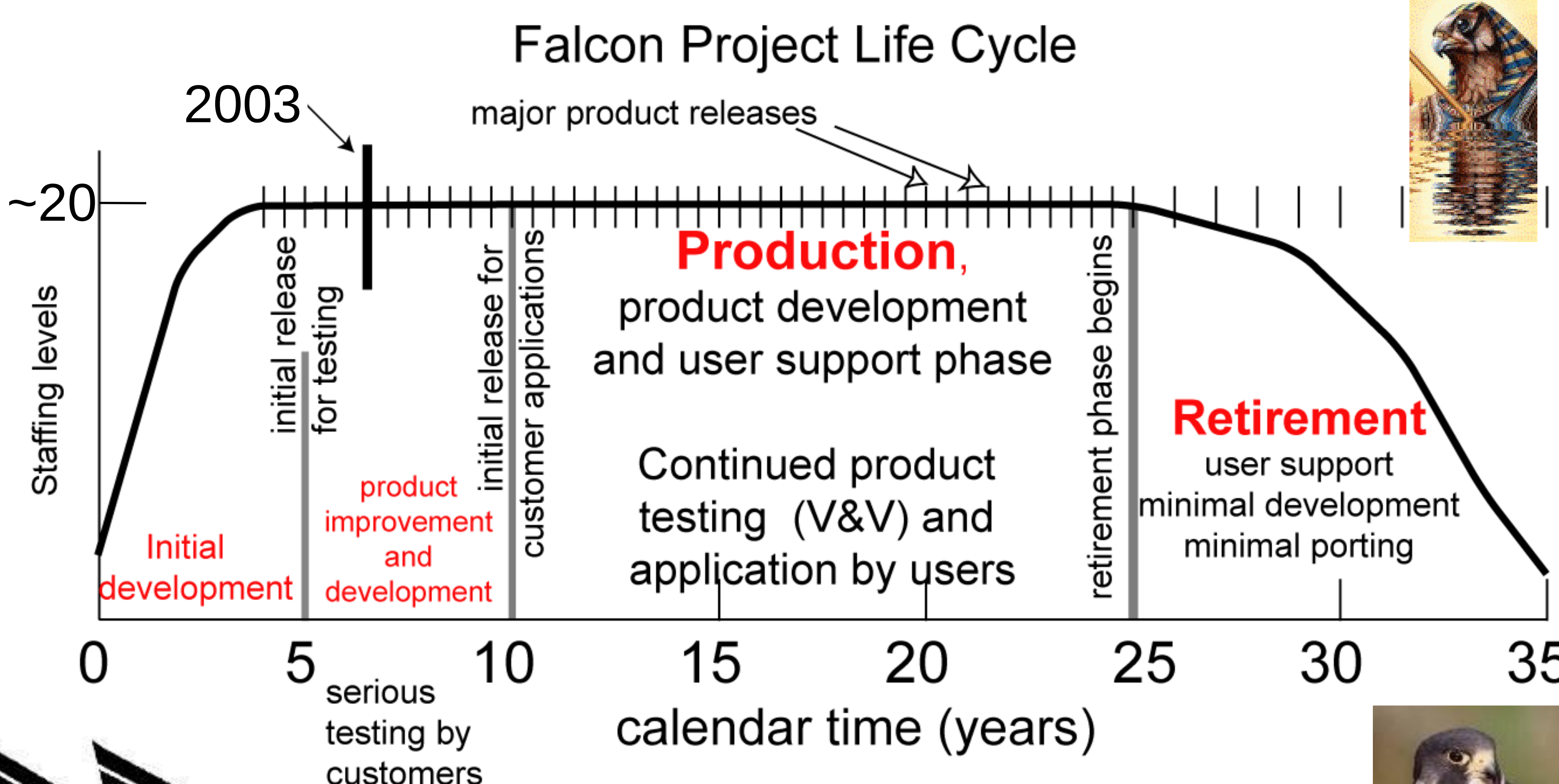
Post and Cook, 2000



—James Mercer-Smith

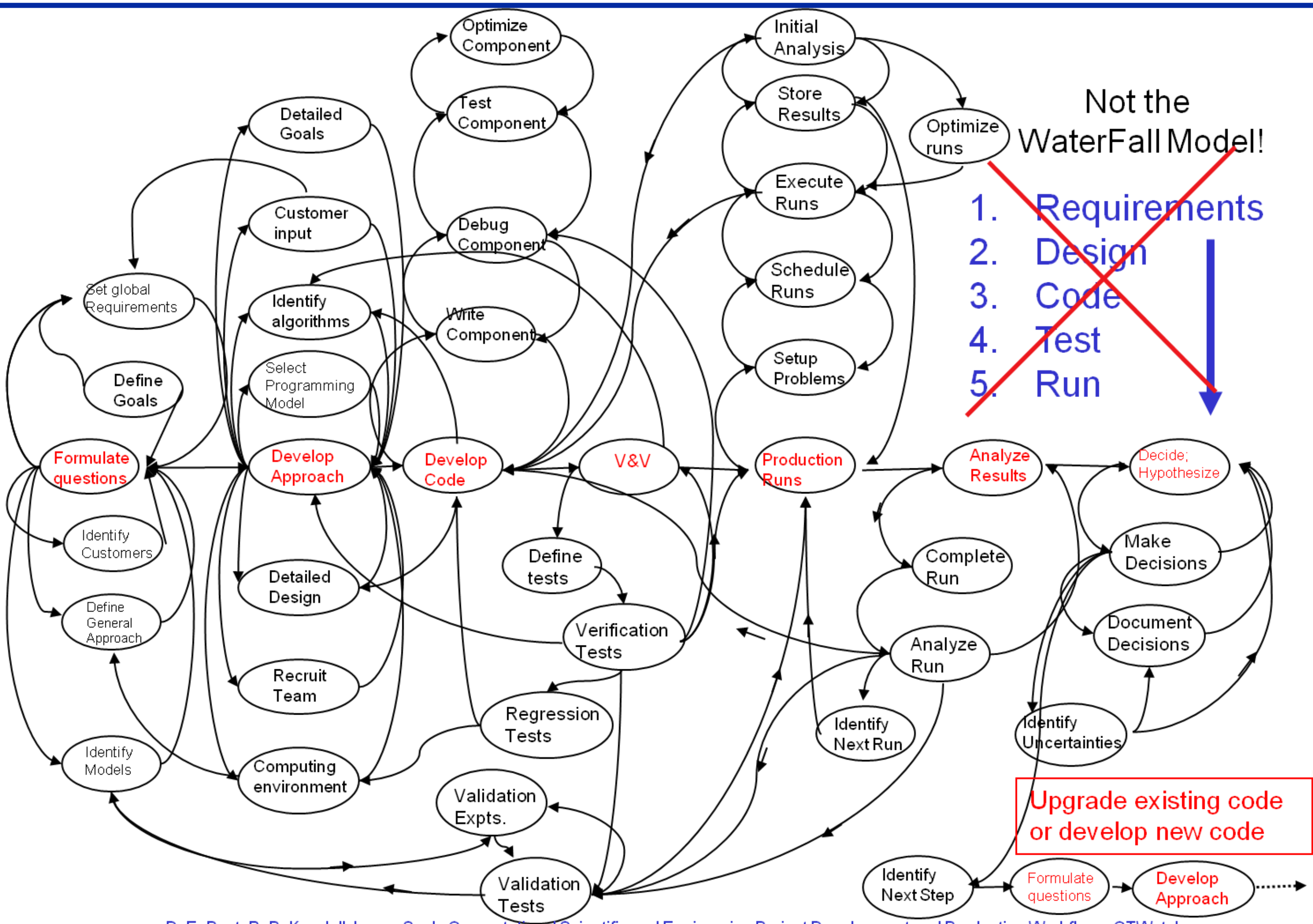


Developing Complex Codes Takes A Large Team A Long Time



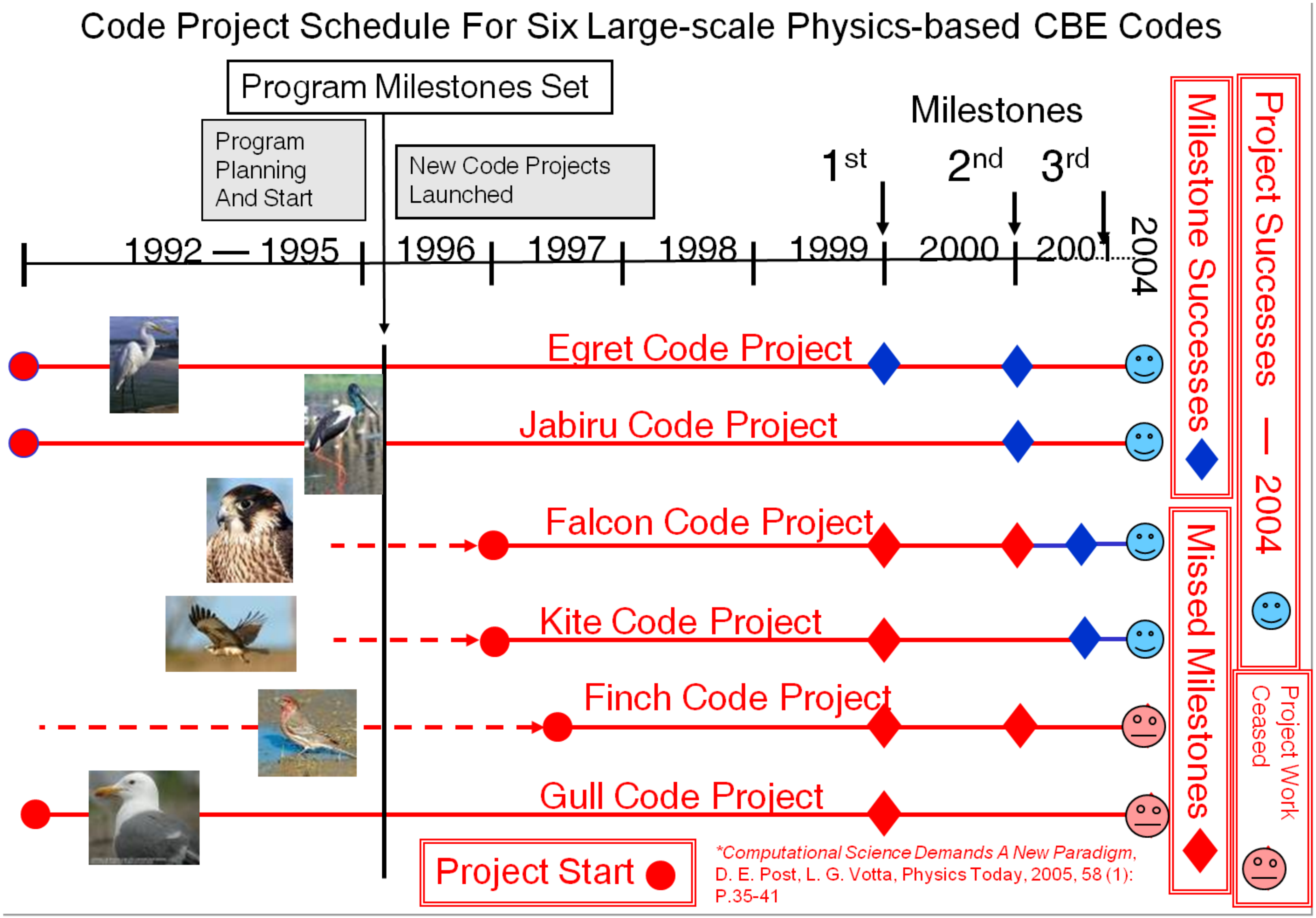
From: D. Post, R. Kendall and E. Whitney, “Case Study of the Falcon Code Project”, Proceedings of the Workshop on Software Engineering for High Performance Computing, International Conference on Software Engineering, May 15, 2005, St. Louis, Missouri.

Development of Science-Based Software is a Complex Process!



—D. E. Post, R. P. Kendall, Large-Scale Computational Scientific and Engineering Project Development and Production Workflows, CTWatch (2006), vol.2-4B, pp68-76.

Development of Science-Based Software is Risky!



What Do We Do?

- **Bottom line: Too expensive, too long and too risky.**
  - **We have to do better, but how?**
- **Study the past and identify the “lessons learned”**
- **Study the present challenges and assess what is needed to overcome them**
- **Implement the lessons learned in light of the changing environment and challenges**
- **Continually assess what works and what doesn’t**
- **Given the scale of the challenges, explicitly fund code development by multi-disciplinary teams for sufficiently long to develop and implement complex codes**
- **Provide supportive development and production environments**

Lessons Learned Are The Way Forward!!!

- **4 stages of design maturity for a methodology to mature—Henry Petroski—*Design Paradigms, 1994, Cambridge Press.***
- **Suspension bridges—case studies of failures (and successes) were essential for reaching reliability and credibility**
- **It's The Scientific Method!**

Tacoma Narrows Bridge buckled and fell 4 months after construction!

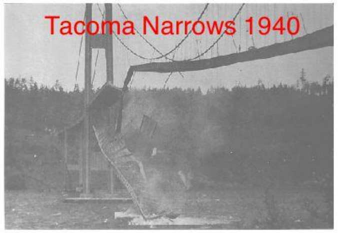
- Case studies conducted after each crash.
- Lessons learned identified and adopted by community
- Computational Science is at stage 3

time

1

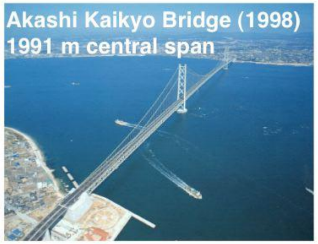
2

3



Lessons Learned
Case Studies

4



Case Studies of 6 Federal Agency Projects Identified *"Lessons Learned*"*

The Successful projects emphasized these and the unsuccessful projects didn't!

- **Conservative approach - Minimize Risks!**
  - Building on successful code development history and prototypes
  - Solid science and computational mathematics is the most important element
  - The use of proven Software Engineering rather than new Computer Science
    - Don't let the code project become a Computer Science research project!
- **Sound Software Project Management - Plan and Organize the Work!**
  - Highly competent and motivated people in a good multi-disciplinary team
  - Development of the team
  - Software Project Management: Run the code project like a project
  - Determine the Schedule and resources from the requirements
  - Identify, manage and mitigate risks
  - Focus on the customer
    - For code teams and for stakeholder support
  - Software Quality Engineering: Best Practices rather than Processes
- **Verification and Validation – Correct Results are Essential!**
  - Need for improved V&V methods became very apparent

Software Project Management and Quality Engineering Practices for Complex, Coupled MultiPhysics, Massively Parallel Computational Simulations*, D. E. Post and R. P. Kendall, The International Journal of High Performance Computing Applications, **18(2004), pp. 399-416

Example: Computational Research and Engineering Acquisition Tools and Environments (CREATE) Program

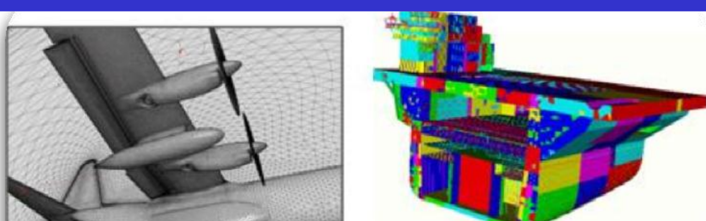
- **CREATE is a DoD program to develop and deploy multiphysics-based software for engineering design and analysis of:**
- **Air Vehicles (AV)**
  - Aerodynamics, structures, propulsion, control, concept design…
- **Ships**
  - Shock vulnerability, hydrodynamics, concept design
- **Radio Frequency (RF) Antennas**
  - RF Antenna electromagnetics and integration with platforms
- **Mesh and Geometry (MG) Generation**
  - Rapid generation of mesh and geometry representations

CREATE tools support all stages of acquisition from rapid early stage design to full life-cycle sustainment


Design concept


Seakeeping and resistance

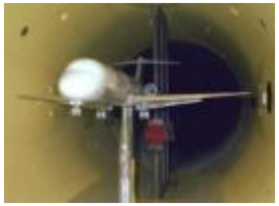

Shock vulnerability


Aircraft and aircraft carrier meshes


Military platforms with antennas

Present Product Development Process
Iterated Design → Build → Test Cycles



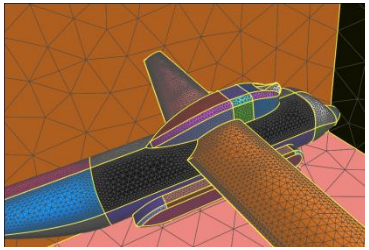
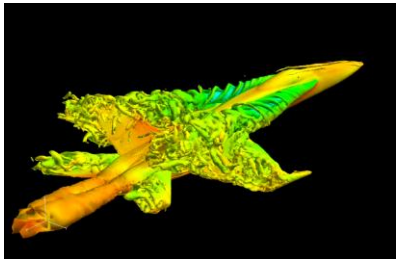

Requirements → Design → Build Physical Product → Test Physical Product → Manufacture, Sustain, and Modify

(Many) Design iterations

- **Long time to market**
  - Requires many lengthy and expensive design/build/test iteration loops
- **Process converges slowly**
  - Process is rigid, not responsive to new requirements
  - Design flaws discovered late in process leading to rework
  - Systems Integration happens late in process

MultiPhysics-Based Performance Analysis Increases Productivity for Complex Systems



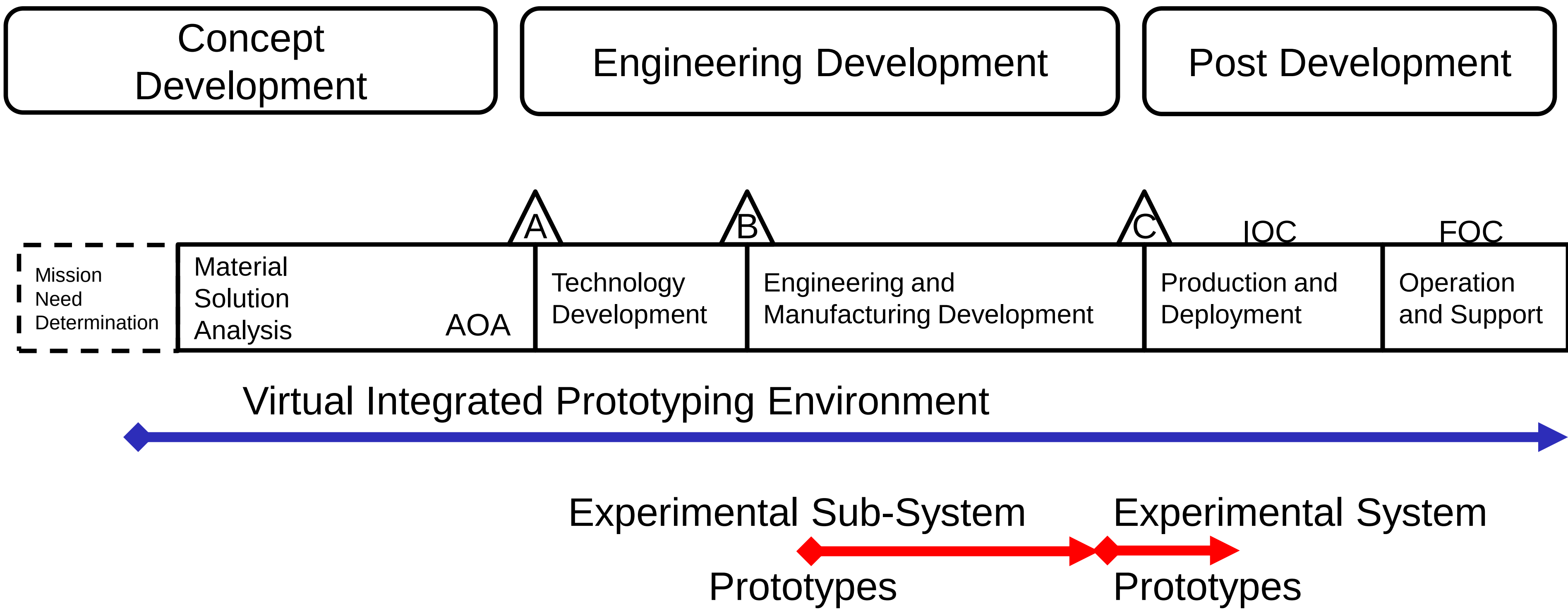

Requirements → Design on Computer → Build Mesh → Analyze Performance → Ground-based and Flight Tests

(Many) Design iterations

Manufacture, Sustain, and Modify

- **Reduced design and development time**
  - Highly scalable computational performance analysis of virtual prototypes reduces the need to test real prototypes
- **Process converges much faster**
  - Process is flexible, very responsive to new requirements
  - Design flaws early in process reducing rework
  - Systems Integration happens at every step of the process

Performance Analysis of Virtual Prototypes Is the Key



- Replace “rule of thumb” extrapolations of existing designs with physics-based designs
- Inject physics into design early and all through the process!

CREATE Is a Multi-Service, Multi-institutional Program: Strong Teams

HPCMP Executing Agent
HPCMP Director

Official HPCMP Advisory Panel

CREATE Program

Ships Project
NSWC-Carderock

- NAVYRANS
  NSWC-Carderock,
- Integrated Hydro Design Environment
  NSWC-Carderock
- Navy Enhanced Sierra Mechanics
  NSWC-Carderock
- Rapid Design
  NAVSEA 05D

Air Vehicles Project
NAVAIR, Patuxent River

- Kestrel
  Eglin AFB
- Shadow-Ops
  NAVAIR, Patuxent River
- Helios
  Army, Ames
- DaVinci
  ASC & AFRL
- Firebolt
  AEDC

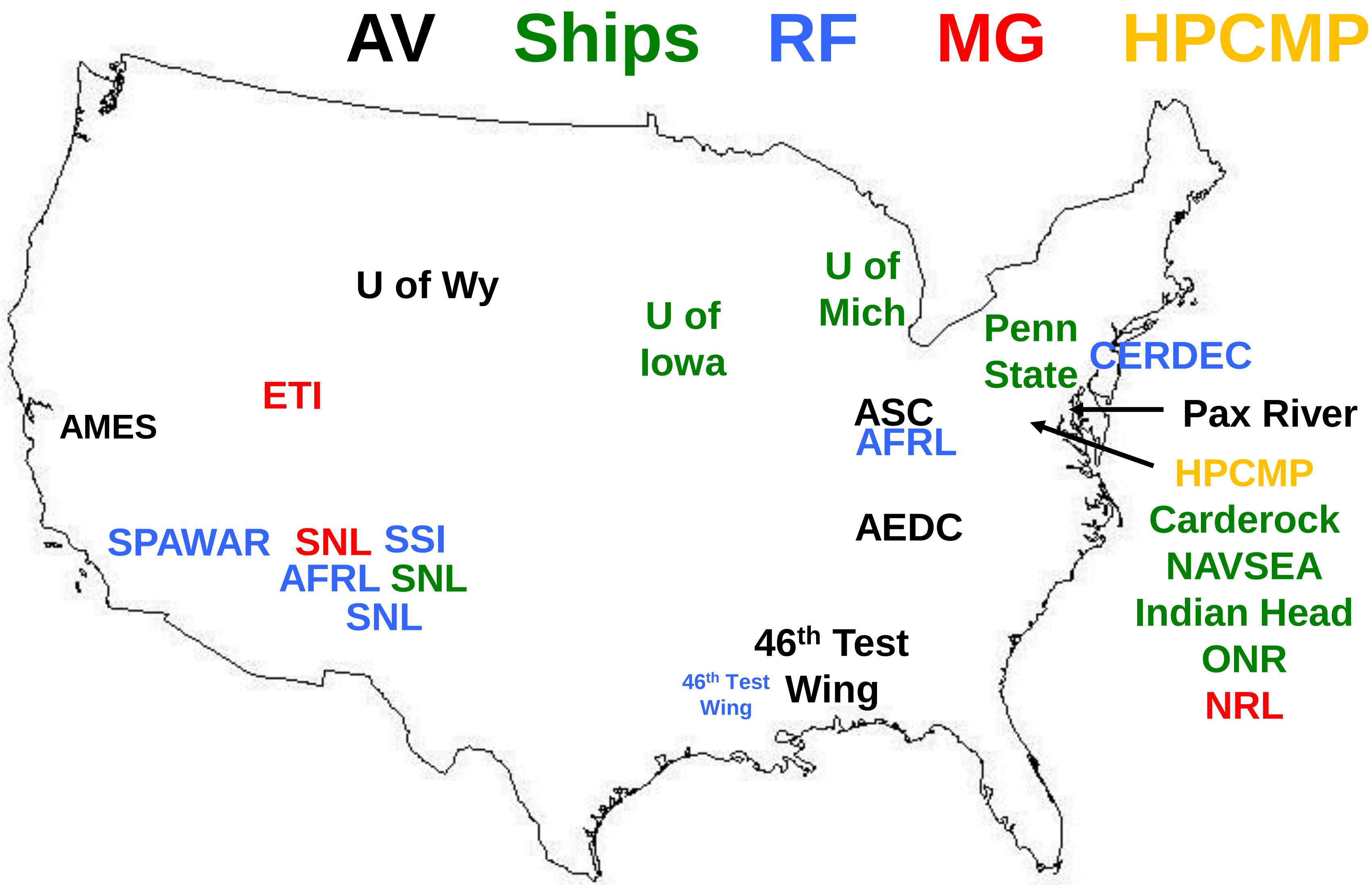
RF Antennas Project
AFRL, WPAFB

- SENTRI-core
  AFRL, WPAFB
- SENTRI-V&V
  AFRL, KAFB

Mesh & Geometry Project
NRL

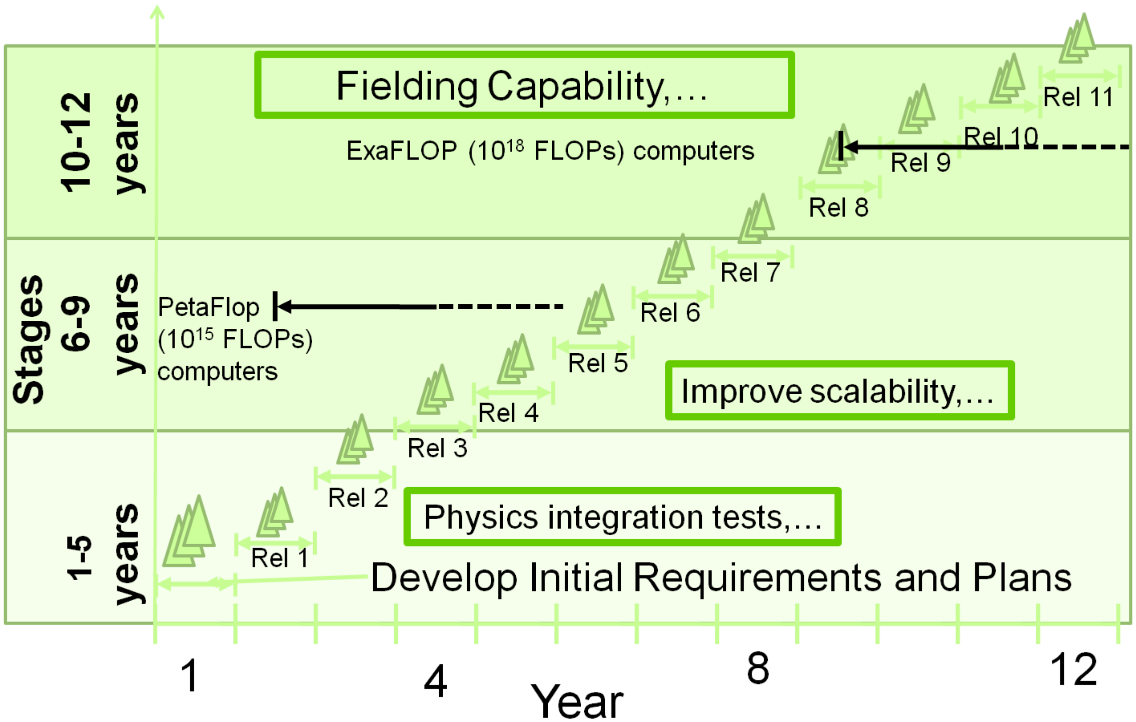
Capstone

CREATE is a Distributed Set of Teams at DoD Engineering Centers

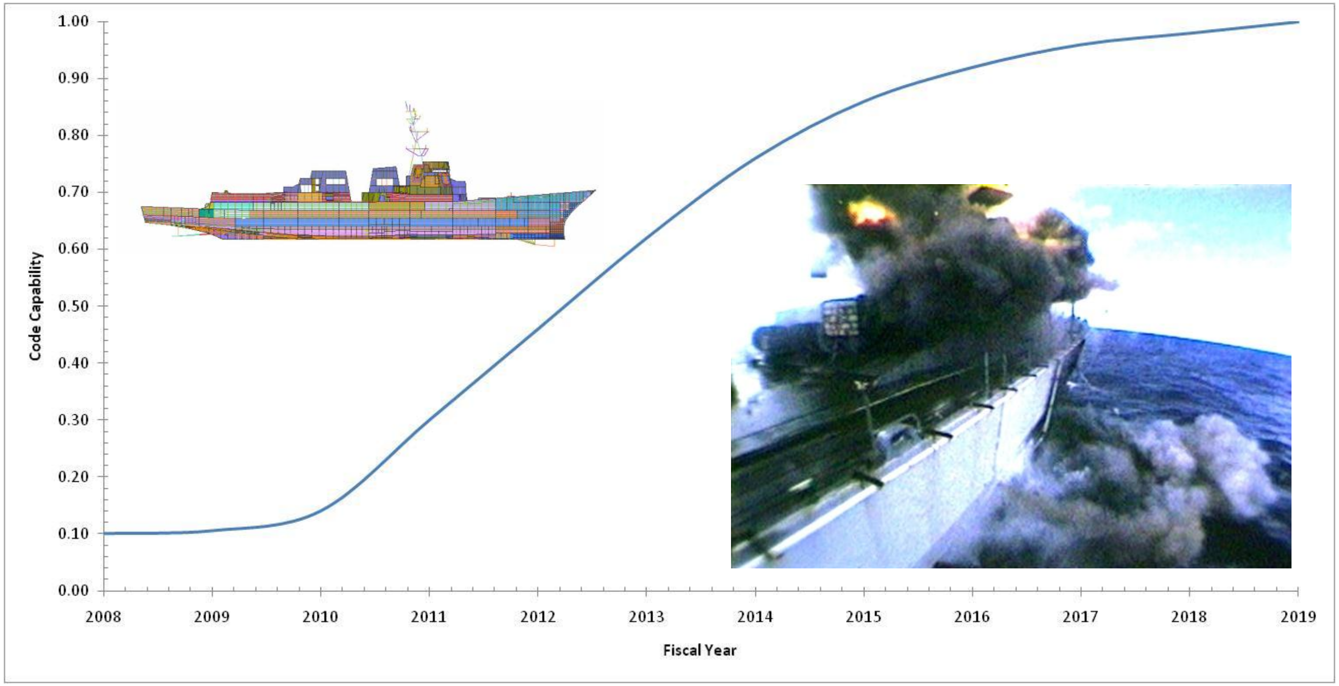


The CREATE Approach

- **Software built by government-led teams—the business model**
- **Annual releases of each product following a three-phase roadmap**
  - Increased capability annually
  - Extensive beta-tests of each release
  - Rigorous V&V process
  - Improved scalability for massively parallel computers
  - Improved usability
  - Responsive to evolving requirements
  - Gates for transition from one phase to the next



Long term roadmap is important
Example: NESM 12 Year Roadmap



- FY-08 => Planning, Start UC I
- FY-09 => UC I Development
- FY-10 => UC I Improvement
- FY-11 => UC I Production
- FY-12 => UC II Improvement
- FY-13 => UC II Production
- FY-14 => UC III Production
- FY-15 => UC IV Development
- FY-16 => UC IV Improvement
- FY-17 => UC IV Production
- FY-18 => UC V Production
- FY-19 => UC VI Production

Navy Enhanced Sierra Mechanics—Ship Shock Analysis

- **NESM Development Plan & Requirements Based On Six (6) Use Cases**
  - **UC I => Ship Response To Standoff UNDEX Where Structure Remains Predominantly Elastic (minimal damage)-FY10-11**
  - **UC II => Ship Response to UNDEX Causing Moderate Structural Damage-FY11-12**
  - **UC III => Ship Response To UNDEX Causing Severe Structural Damage (including SURFEX)**
  - **UC IV => Ship Response To AIREX Causing Moderate Structural Damage**
  - **UC V => Ship Response To AIREX Causing Severe Structural Damage**
  - **UC VI => Ship Response To Unconventional Weapon Attacks**
- **Use Case I capability completed in FY2011**
- **NESM selected by Navy as M&S tool for the Full Ship Shock Trial for the new CVN-78 aircraft carrier**

Software Engineering Focused on Producing High Quality Engineering Software Tools

- **Goal: maintainable, extensible, portable, reliable, high quality, and long life cycle software**
- **Software engineering practices designed for technical software**
- **Agile development methods (e.g. SCRUM)**
- **Extensive documentation**
  - Development plans; Technical, Developer, & User Manuals; Test Plan…(+ training, tutorials, sample input and output,…)
- **V&V is a key priority**
  - Verification at every level
  - Extensive Validation (large potential role for defense industry)
  - Extensive Beta testing (a key opportunity for defense industry input)
- **User support**

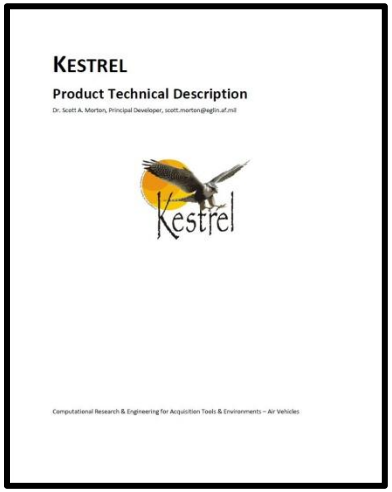
Kestrel SE Docs

KESTREL

Acquisition Program Baseline (ABP) - 2011

Dr. Scott A. Morton, Principal Developer, scott.morton@eglin.af.mil

Computational Research & Engineering for Acquisition Tools & Environments – Air Vehicles



KESTREL

Product Technical Description

Dr. Scott A. Morton, Principal Developer, scott.morton@eglin.af.mil

Computational Research & Engineering for Acquisition Tools & Environments – Air Vehicles

Kestrel v3.0 PSDP

KESTREL v3.0

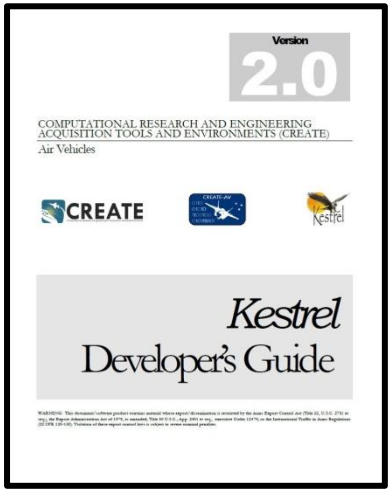
Project Software Development Plan (PSDP)

Dr. Scott A. Morton, Principal Developer, scott.morton@eglin.af.mil

Computational Research & Engineering for Acquisition Tools & Environments – Air Vehicles

And CREATE-AV Requirements

1



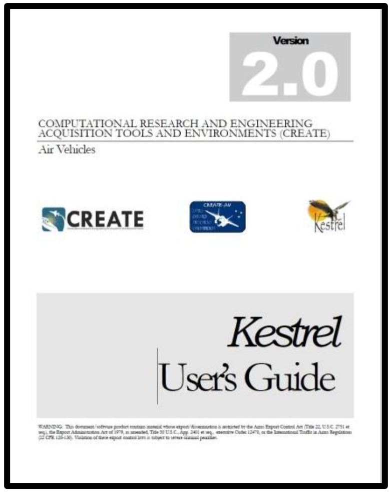
Version 2.0

COMPUTATIONAL RESEARCH AND ENGINEERING ACQUISITION TOOLS AND ENVIRONMENTS (CREATE)

Air Vehicles

Kestrel

Developer's Guide



Version 2.0

COMPUTATIONAL RESEARCH AND ENGINEERING ACQUISITION TOOLS AND ENVIRONMENTS (CREATE)

Air Vehicles

Kestrel

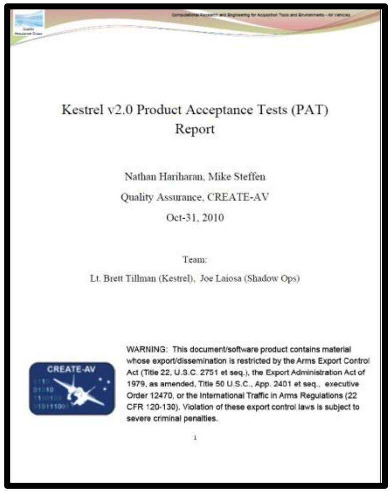
User's Guide

Kestrel

Product Acceptance Testing 2010

Nathan Hariharan

6 July 2010



Kestrel v2.0 Product Acceptance Tests (PAT) Report

Nathan Hariharan, Mike Steffen

Quality Assurance, CREATE-AV

Oct-31, 2010

Team:

Lt. Brett Tillman (Kestrel), Joe Laiosa (Shadow Ops)

WARNING: This document/software product contains material whose export/dissemination is restricted by the Arms Export Control Act (Title 22, U.S.C. 2751 et seq.), the Export Administration Act of 1979, as amended, Title 50 U.S.C., App. 2401 et seq., executive Order 12470, or the International Traffic in Arms Regulations (22 CFR 120-130). Violation of these export control laws is subject to severe criminal penalties.

1

CREATE is Guided by Senior Science and Technology Leaders From the Services

HPCMP Executing Agent
Cray Henry (Director)

CREATE Program
Douglass Post, IPA (PM)

Luanne Handley-Blair (Dep PM)

Official HPCMP Advisory Panel

Ships
Myles Hurwitz, IPA (PM)
Robert Keane (con.)

Board of Directors

- ***RADM Thomas Eccles, NAVSEA Chief Engineer**
- Dr. Walter Jones, SES, Executive Director, ONR
- Mr. C.F. Snyder, SES, 33Technical Director, NSWC, Carderock Division
- Mr. Glen Sturtevant, Director, S&T, PEO, SHIPS
- Mr. Cray Henry, Director, HPCMP

Air Vehicles
Robert Meakin, IPA (PM)
Chris Atwood (Dep)

Board of Directors

- ***Dr. Ed Kraft, ST, Chief Technologist, AEDC/CZ**
- Samuel T Crews, U.S. Army Aviation and Missile Research, Development, and Engineering Center
- Mr. Richard Gilpin, Director, AIR-4.3 NAVAIR
- Mr. Tom Rudowsky, Director, NAVAIR), (IBST)
- Dr. Michael Scully, ST, Aeroflightdynamics Directorate (AMRDEC), U.S. Army RDECOM
- Mr. Cray Henry, Director, HPCMP

RF Antennas
John D'Angelo (PM)

Board of Directors

- *Mr. Dennis DeCarlo, Chief Antenna Systems Engineer, NAVAIR
- Dr. Keefe Coburn, ARL
- Dr. Charles Macon, AFRL/RYS
- Dr. Mark Kragalott, NRL
- Dr. Robert Peterkin, ST, Chief Scientist, AFRL Directed Energy Directorate
- Mr. Cray Henry, Director, HPCMP

MG
Saikat Dey (PM)

Board of Directors

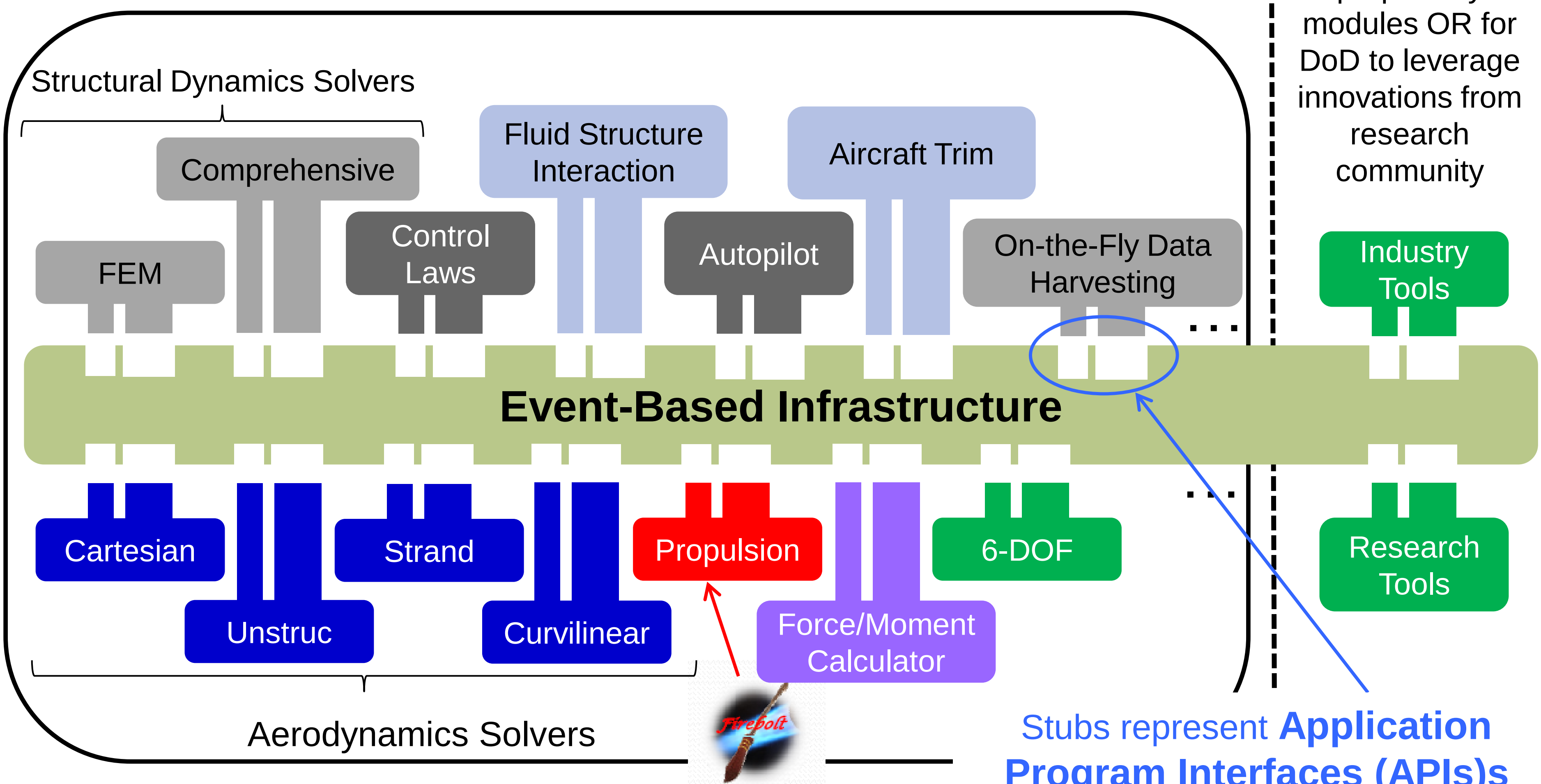
- ***Dr. Robert Meakin, PM CREATE Air Vehicles**
- Mr. Myles Hurwitz, CREATE Ships Project Manager
- Dr. Sudip Sodanjh, Computational Engineering Leader, SNL
- Dr. John D'Angelo, CREATE RF Antenna Project Manager
- Mr. Cray Henry, Director, HPCMP

*Board of Director Chairs

CREATE-AV Developed An Architecture to Facilitate Multi-physics Integration

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

APIs available for use by industry for proprietary modules OR for DoD to leverage innovations from research community



Distribution Statement A: Approved for public release; distribution is unlimited.

Early Success
Rapid Deployment of EP-3E

- **Shadow-Ops: CREATE staff use computational tools to support acquisition programs → provide experience and establish connections and value**
- **Performed CFD analysis of impact of electronic countermeasure pod for EP-3E flight clearance–Not sufficient time for conventional process (flight tests)**
  - Eliminated construction cost of wind tunnel model and tests and need for contractor flying quality report.
  - Provided aircraft flying qualities characteristics within required time frame.
  - Provided data required to issue flight clearance in time for direct deployment.
- **Reduced overall program cost and time**
- **Only 1 flying qualities flight test required – Saving between 3–4 flight tests**
- **System was deployed in the forward theatre in less than four months instead of twelve**

DEPARTMENT OF THE NAVY
PROGRAM EXECUTIVE OFFICER
AIR ASW, ASSAULT AND SPECIAL MISSION PROGRAMS
47123 BUSE ROAD, BUILDING 2272, SUITE 162
PATUXENT RIVER MD 20670-1547

IN REPLY REFER TO

May 15, 2008

Dr. Robert Meakin
CREATE-AV Program Manager
HPCMPO
10501 Furnace Road
Lorton, VA 22079

Dear Dr. Meakin:

SUBJECT: HPC CREATE-AV EP-3E CFD SUPPORT FOR FLYING QUALITIES ASSESSMENT AND CERTIFICATION

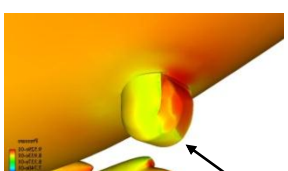
I wish to extend my thanks for the support your program, CREATE-AV, provided recently to certify the airworthiness of a new modification to the EP-3E aircraft. The computational support supplied by the Shadow Ops team provided the required computational data to the NAVAIR Flight Dynamics Branch to help issue a safe-for-flight clearance, from a flying qualities perspective, without the need of a costly, time consuming wind tunnel test. This accelerated the database development on the order of months and saved the program office hundreds of thousands of dollars. In addition, the data and subsequent flying qualities analysis, performed by Flight Dynamics Engineer, Ms. Ryan Fitzgerald, was sufficient to limit the flight test program to only one flight. This further reduced flight test time by several weeks, saving the program tens of thousands of dollars and allowing the EP-3E program to deploy this capability in the forward theater in support of the Global War on Terror (GWOT).

The creation of the Shadow Ops area of the overall CREATE-AV program is ideally suited to support DOD acquisition programs. It is an excellent venue to develop a working relationship between the computational engineering community and existing DOD aircraft programs. We are looking forward for future projects, and seeing how we can improve upon this process even further.

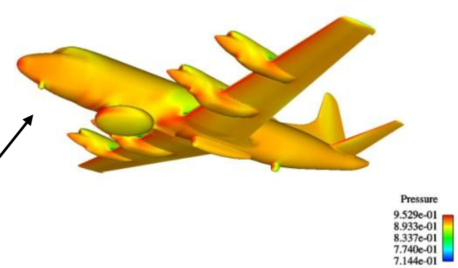
Sincerely,

LCDR Ryan Batchelor
EP-3E/Special Mission Class Desk, PMA-290E
22347 Cedar Point Rd
Bldg 2185, Floor 3, Room 3190-B1
Patuxent River, MD 20670
301-757-5684

POC: Ms. Ryan Fitzgerald, FQ Engineer NAVAIR 4.3.2.5



New Forward Component



Distribution Statement A: Approved for public release; distribution is unlimited.

CREATE –
Four Projects, Ten Products

- **Air Vehicles—CREATE AV**
  - **DaVinci -** Rapid conceptual design
  - **Kestrel -** High-fidelity, full vehicle, multi-physics analysis tool for fixed-wing aircraft
  - **Helios -** High-fidelity, full vehicle, multi-physics analysis tool for rotary-wing aircraft
  - **Firebolt -** Module for propulsion systems in fixed and rotary-wing air vehicles
- **Ships—CREATE Ships**
  - **RDI -** Rapid Design and Synthesis Capability
  - **NESM -** Ship Shock & Damage-prediction of shock and damage effects
  - **NAVYFOAM -** Ship Hydrodynamics-predict hydrodynamic performance
  - **IHDE -** Environment to facilitate access to Naval design tools
- **RF Antenna—CREATE RF**
  - **SENTRI -** Electromagnetics antenna design integrated with platforms
- **Meshing and Geometry—CREATE MG**
  - **Capstone -** Components for generating geometries and meshes

CREATE Has Established a Cadence for Annual Releases

- **8 products were released in FY2010, plan second releases in FY2011**
- **2 new conceptual design products (AV: DaVinci and Ships: RDI) planned for first releases in FY2011**
- **CREATE Connecting with user community (~ 300 people have used CREATE products at least once)**
  - Have established and are testing a user support process
- **Outreach to industry through NDIA and other avenues very successful**
  - CREATE March 8 Briefing to 60 defense industry engineering leaders was well received
  - NDIA holding a conference on Physics-Based Computational Engineering Tools Nov. 14-17, 2011 in Denver
- **Portal project with Maui DSCR launched in May, 2011**
- **Two highlights:**
  - NESM selected as the official modeling tool for the Full Ship Shock Trial of the Navy's new carrier, the CVN-78.
  - Helios demonstrated the ability to make highly accurate predictions of vortex shedding from rotorcraft tips—achieved the "Holy Grail" of rotorcraft modeling

Establishing Our Release Cadence

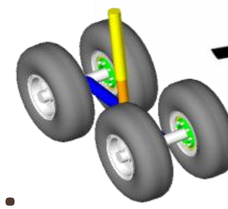
Fiscal Year	FY2010				FY2011				FY2012 (planned)			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4
AV-DaVinci								1			2	
AV-Firebolt			1					2				3
AV-Helios		1				2				3		
AV-Kestrel		1				2				3		
MG-Capstone				1				2				3
RF-SENTRI	1	1.5						2				3
Ships-IHDE	1				2				3			
NavyFoam				1				2				3
Ships-NESM	0.1						1				1.1	
Ships-RDI								1				2

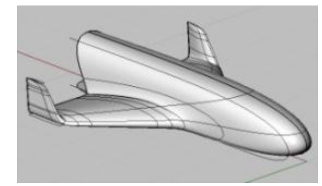
- **Release date is defined as the start of beta testing → code features have been defined, developed and alpha tested.**

DaVinci 1.0 Initial Capabilities—Planned For First Release in 3rd Quarter FY2011

Deliver foundational conceptual design capability to:

- enable creation of parametric, associative engineering models
- of fixed and rotary wing aircraft
- from pre-engineered components (e.g., airfoils, 3-D wing surface, rotor, fuselage, engines)
- resulting in mesh-able, NURBS-based surface geometry



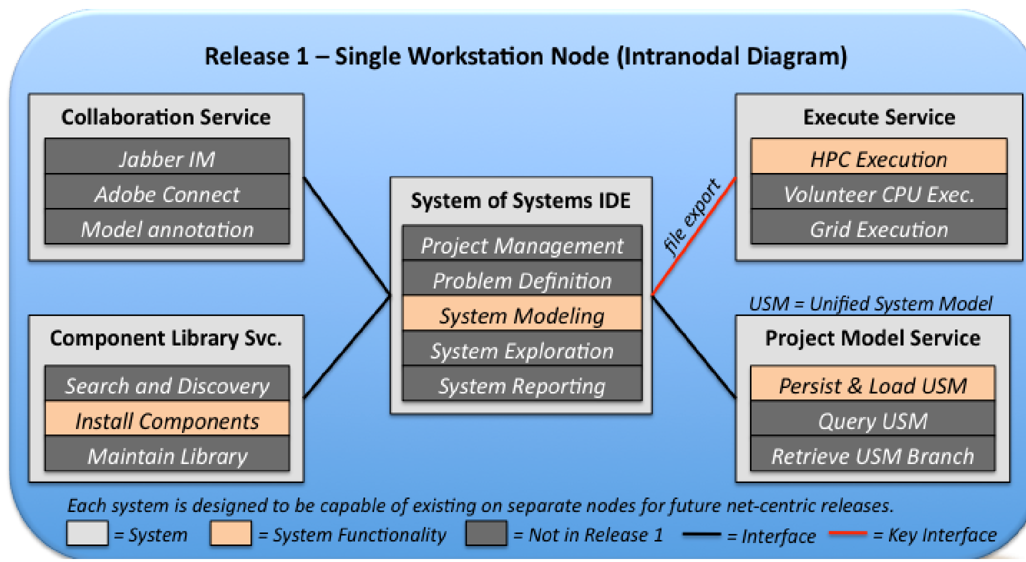


Build capability on an agile infrastructure allowing:

- rapid model development and
- seamless transition from conceptual design to preliminary/detailed level analysis (e.g., Kestrel/ Firebolt and Helios/ Firebolt products)

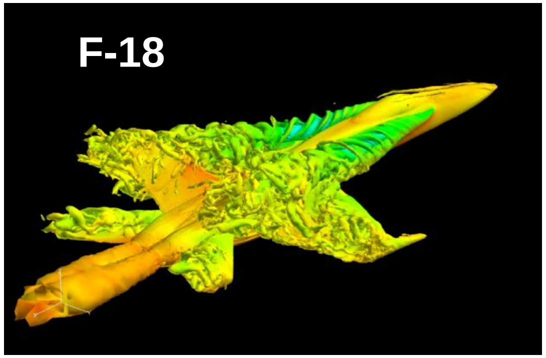
Kestrel

Helios

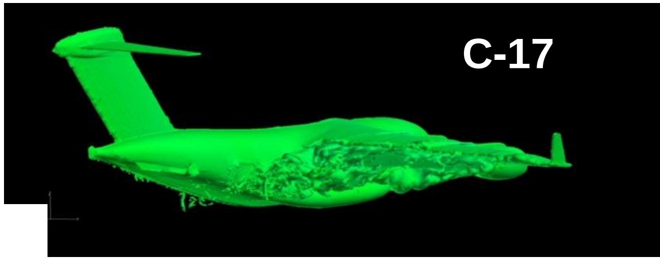


Kestrel v2.0 Has Many New Capabilities

- **Kestrel new capabilities include:**
  - Static Rigid Aircraft
  - Rigid Single Body Prescribed Motion
  - Aeroelastic Aircraft
  - Control Surface Motion
  - 6DoF Predictive Motion
  - Prescribed Aircraft with Control Surface Motion
  - 6DoF Aircraft Motion with Control Surface Motion
  - Prescribed Aeroelastic Aircraft Motion
  - 6DoF Aeroelastic Aircraft Motion

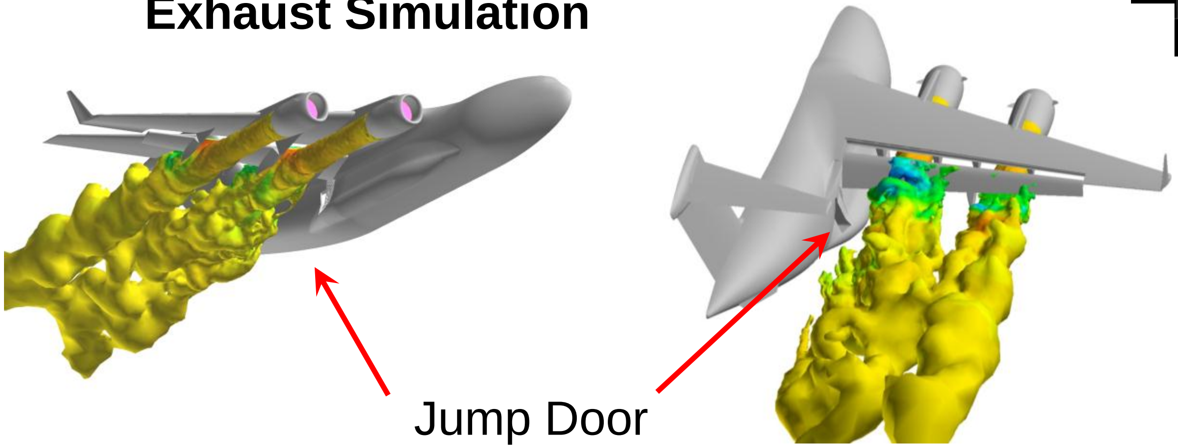


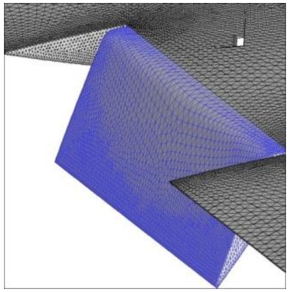
Vortex induced Tail Buffet



Unsteady Aerodynamics

Kestrel 3.0 (Firebolt enabled) C-17 Exhaust Simulation

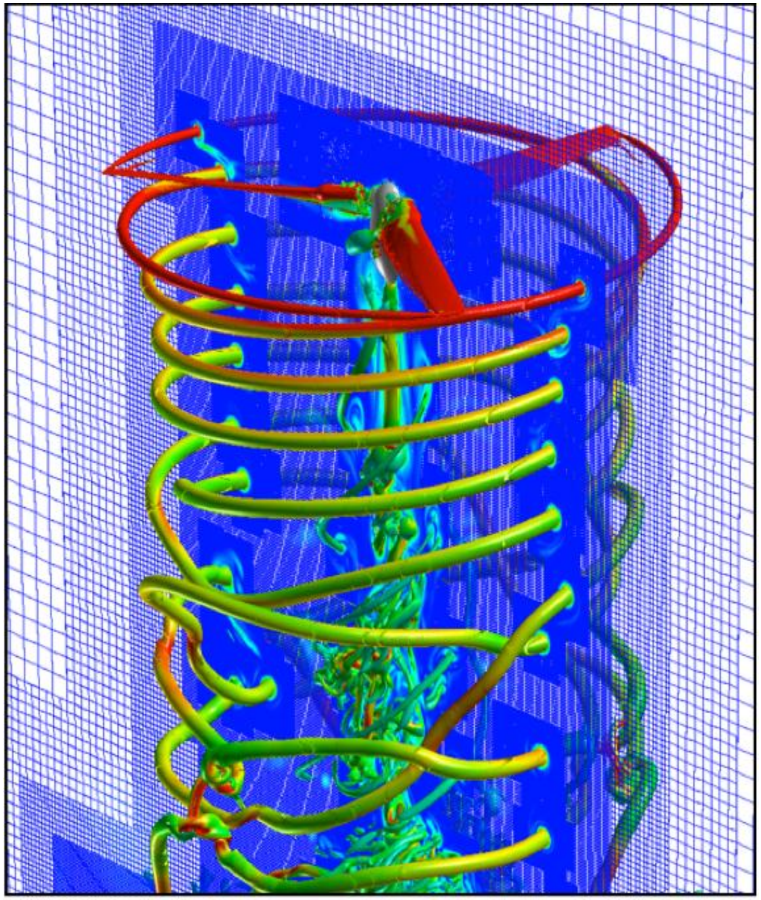




Control Surfaces

HI-ARMS/CREATE FY011 Software Release
Helios v2.0 “Shasta”

- **Beta release completed**
- **New Capabilities**
  - **Rotor-fuselage configuration**
  - **Prescribed maneuver with tight coupling**
  - **Active rotors with flaps/slats**
  - **Store separation with prescribed missile motion**
- **Additional Capability Enhancements**
  - **Arbitrary shaft angles**
  - **Multi-bladed rotors**
  - **Momentum disk model in Helios mode**
- **New Functionalities**
  - **Automated off-body mesh refinement**
  - **Load balancing module for improved scalability**
  - **Generalization of interfaces**
- **Additional Functional Enhancements**
  - **Improved physical models in the off-body solver**
  - **Additional solver and physical model options in NSU3D**
  - **Improved robustness and efficiency of Pundit**
  - **Parallelization of fluid structure interface**

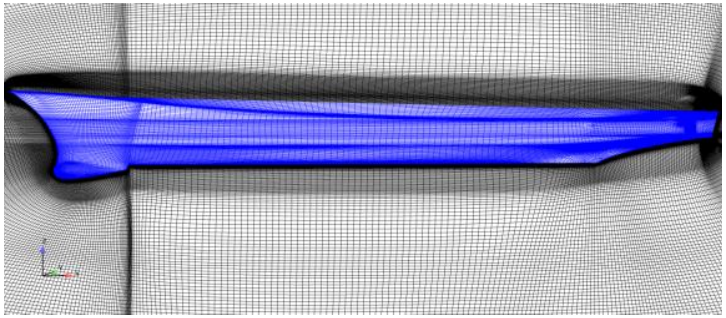


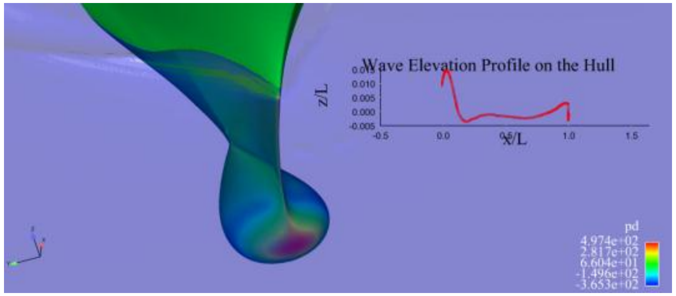
Firebolt v1.0 Capabilities

- **Developed methodology for creating engine modules from existing 0D models**
  - ATEST (AEDC Developed)
  - NPSS (NASA Developed)
  - OEM customer decks
  - Flat Engine (General tabular engine input for steady state or transient simulations)
- **Created coupling interface for CREATE-AV CFD codes**
  - Engine transient time step advancement controlled by the KIE
  - CFD code coupling through inflow and outflow boundary conditions
  - 0D interface data clipping and filtering to assure numerical robustness
- **User interface for *Firebolt* v1.0 through KUI**

NavyFoam Completed its First Three Use Cases

- FY2010—completed assessment of OpenFoam, developed capability for 3 use cases
  - Resistance Related
    - UCR1 (FY10): Hull with fixed ship sinkage and trim (no movement of ship, applicable to submarines)
    - UCR2 (FY10): Hull with computed sinkage and trim: 2 degree of freedom ship motion capability
  - Powering Related
    - UCP1 (FY10): Body force model for propulsor (simple model without propeller details)





- GridPro Structured Mesh (6 Million hexa cells with wall function spacing)

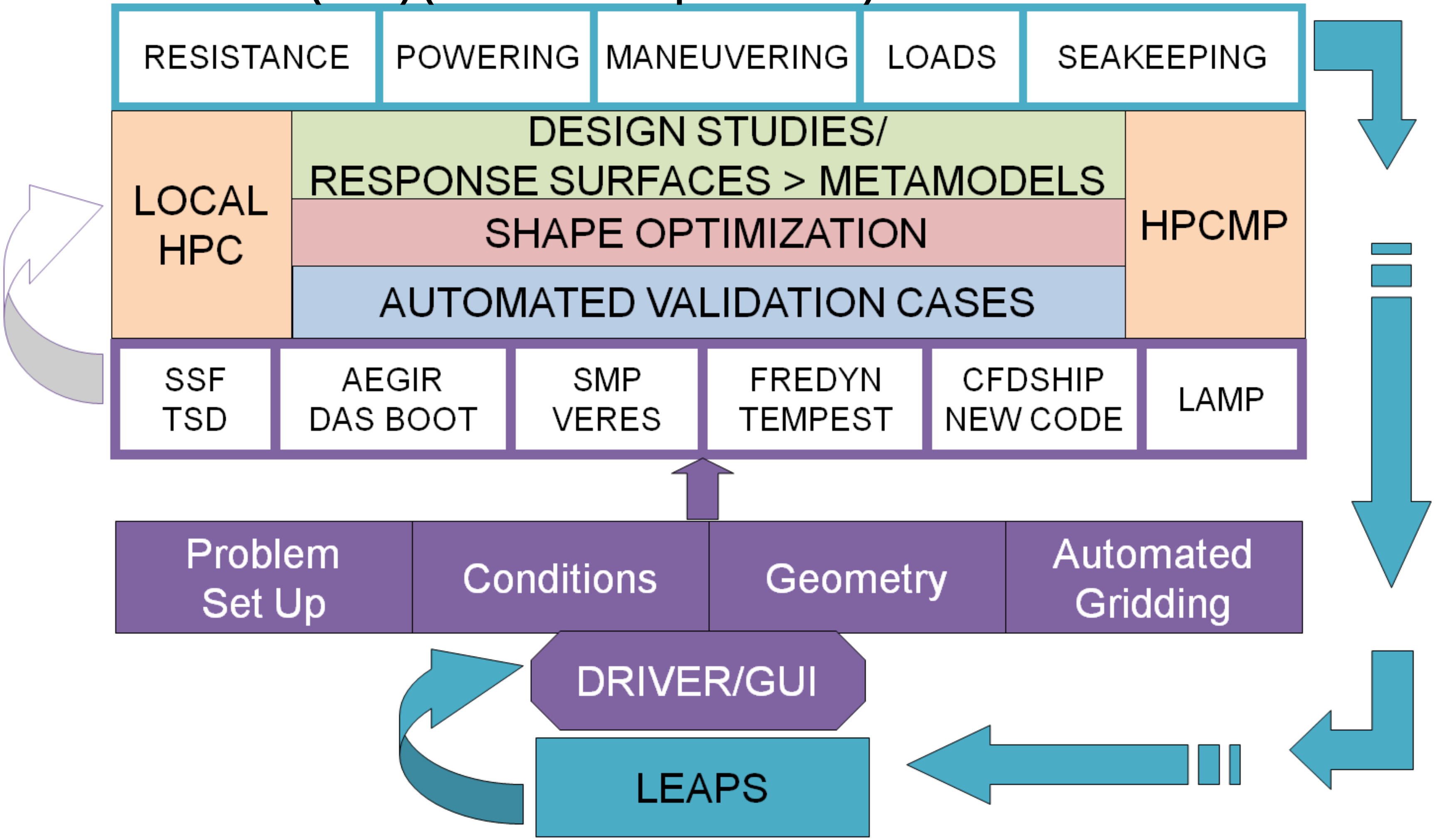
- Need structured or hex dominated grids for the free surface interface prediction

Rapid Design Integration (RDI) Will Support Three Use Cases in FY2011

Use Cases	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15	FY 16	FY 17	FY 18	FY 19
	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs	Number of Ship Designs
ASSET Synthesis	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
Hullform Transformation		1	100+	100+	100+	100+	100+	100+	100+	100+
Hullform Generation				1	100+	100+	100+	100+	100+	100+
Hullform - Intact and Damaged Stability	1	1	1	100+	100+	100+	100+	100+	100+	100+
Hullform - Resistance Analysis	1	1	1	1	1	100+	100+	100+	100+	100+
Hullform - Maneuvering Analysis					1	100+	100+	100+	100+	100+
Hullform - Seakeeping Analysis		1	1	1	1	100+	100+	100+	100+	100+
Hullform - Structural Analysis					1	1	1	1	1	1
Arrangement - Internal Compartments (Outside in)					1	100+	100+	100+	100+	100+
Arrangement - Component Placement						1	1	100+	100+	100+
Arrangement - Routing of Distributed Systems							1	1	100+	100+
Arrangement - Internal Compartments (Inside out)									1	100+

Integrated Hydrodynamics Design Environment

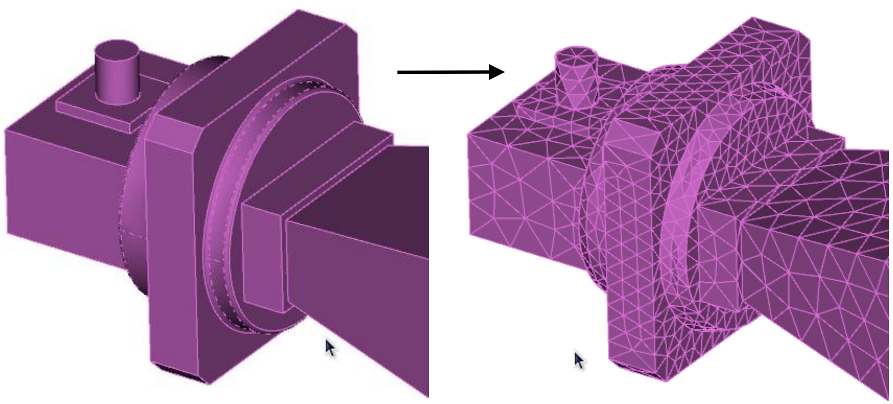
IHDE achieved Use Cases I and II in UCR2 FY11): Bare hull with the Boundary Element Method (BEM) (no slender ship limitation)



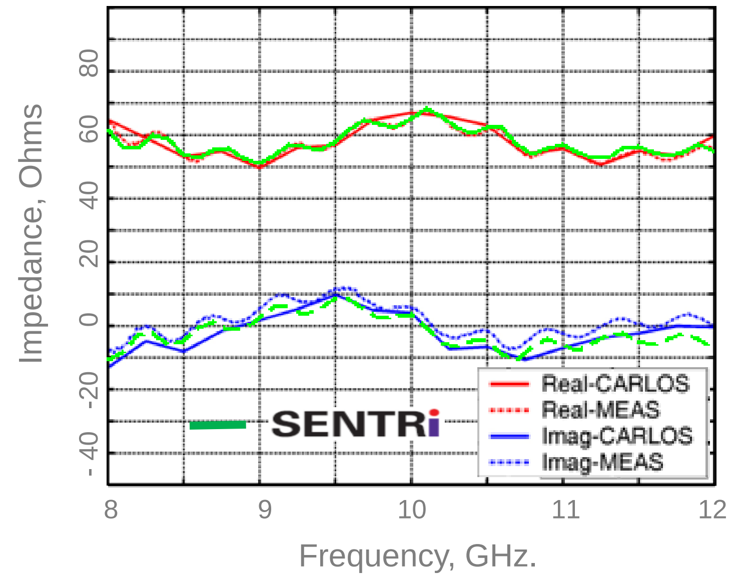
CREATE RF Developed Basic Computational Electromagnetics Capability

Detailed mechanical CAD model EMCC pyramidal horn (1/2).

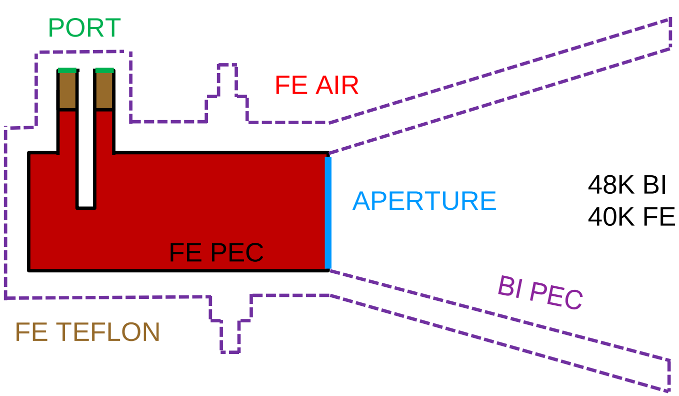
Composited surfaces in CUBIT to de-feature the fillets on the coupler.



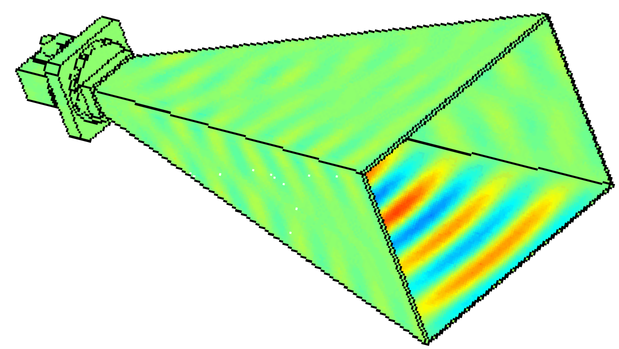
Good agreement on Z_{in}.



Hid the feed region behind BI.



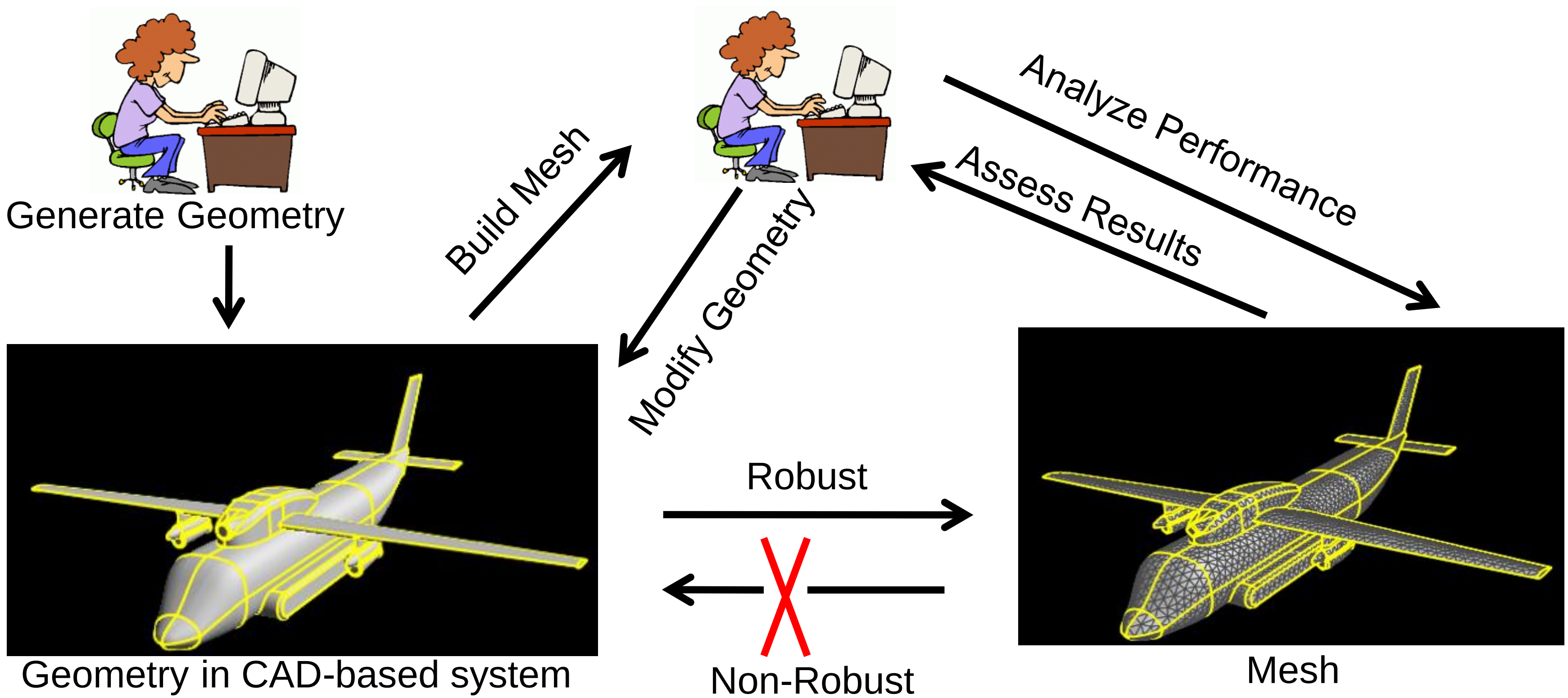
48K BI unknowns
40K FE unknowns



Required ACA to solve. Good speedup vs. CARLOS. (22min vs. 11hr*)

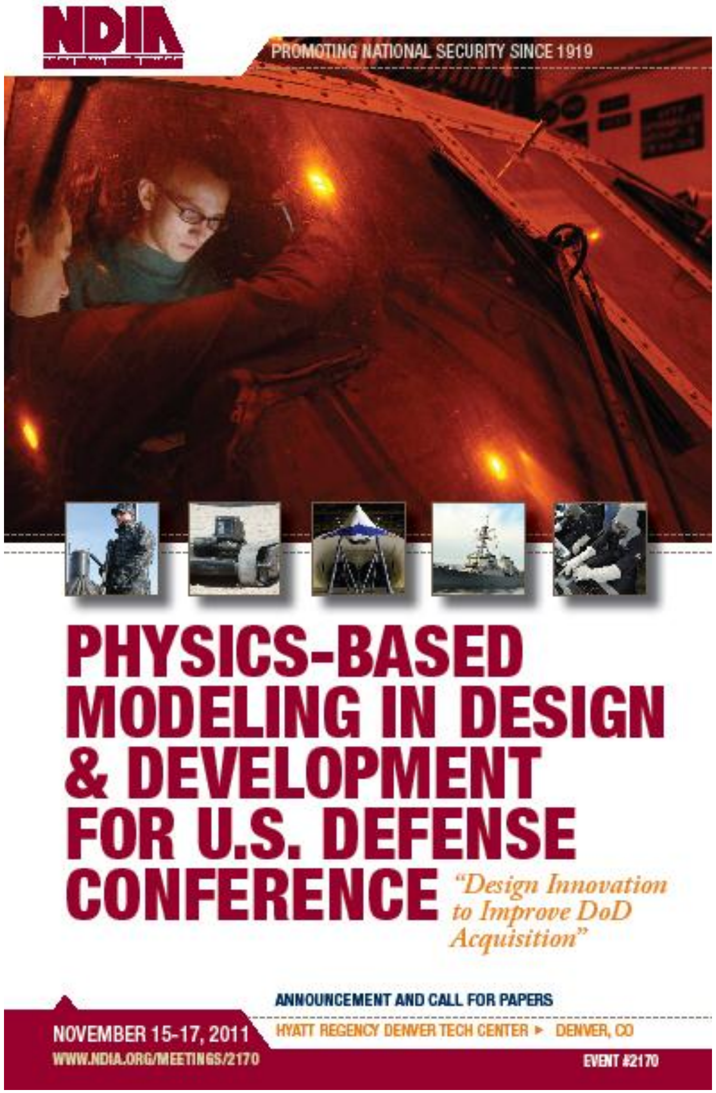
CAPSTONE Is Geometry-Centric, Not Mesh-Based!

- **Designed around a <u>full-featured boundary-representation geometric model;</u> mesh is dependent on geometry, not the other way around**
  - Enables associative and robust persistence of attributes when mesh changes
- **Functionally consistent with, and interfaces to, leading CAD-representations (CAD-neutral)**
- **Build analysis-suitable geometry from scratch (no need to 'repair/clean' geometry)**
  - Enables automation of Design Iteration and shape-based optimization



Market to Customers: NIDA is Assuming a Leadership Role In Support of Physics-based Modeling

- 4 day conference Nov. 14-17
- Monday: Tutorials and Tool Seminars
- Tuesday: Plenary talks
- Wednesday: Parallel Sessions
- Thursday: Parallel Sessions
- Parallel Session authors need to submit abstracts (300-500 words)
- Tutorials and Tool Seminars must submit proposals
- Abstracts and Proposals due June 30, 2011
- Detailed information will be available at www.ndia.org/meetings/2170/Pages/default.aspx



NRC Study "Future of Computing Performance" Recommendations Need HPC Community Focus

Summary of Recommendations

TIONAL ACADEMIES

Invest in:

1. Algorithms to exploit parallel processing
2. Programming methods to enable efficient use of parallel systems
3. Long-term efforts on rethinking of the canonical computing "stack"
4. Parallel architectures driven by applications
   - enhancements of chip multiprocessor systems
   - data-parallel architectures
   - application-specific architectures
   - radically different approaches
5. Make computer systems more power efficient
6. Cooperation & innovation of open interfaces for parallel programming
7. Tools and methods to transform legacy apps to parallel systems
8. Increased emphasis on parallelism in computer science education

Summary

- **Computational Science and Engineering is a uniquely powerful problem solving methodology**
- **But, like all other technical methodologies, it is complex, challenging, and is taking a long time to mature**
- **Progress will require learning from the past, assessing the present, and planning for the future**