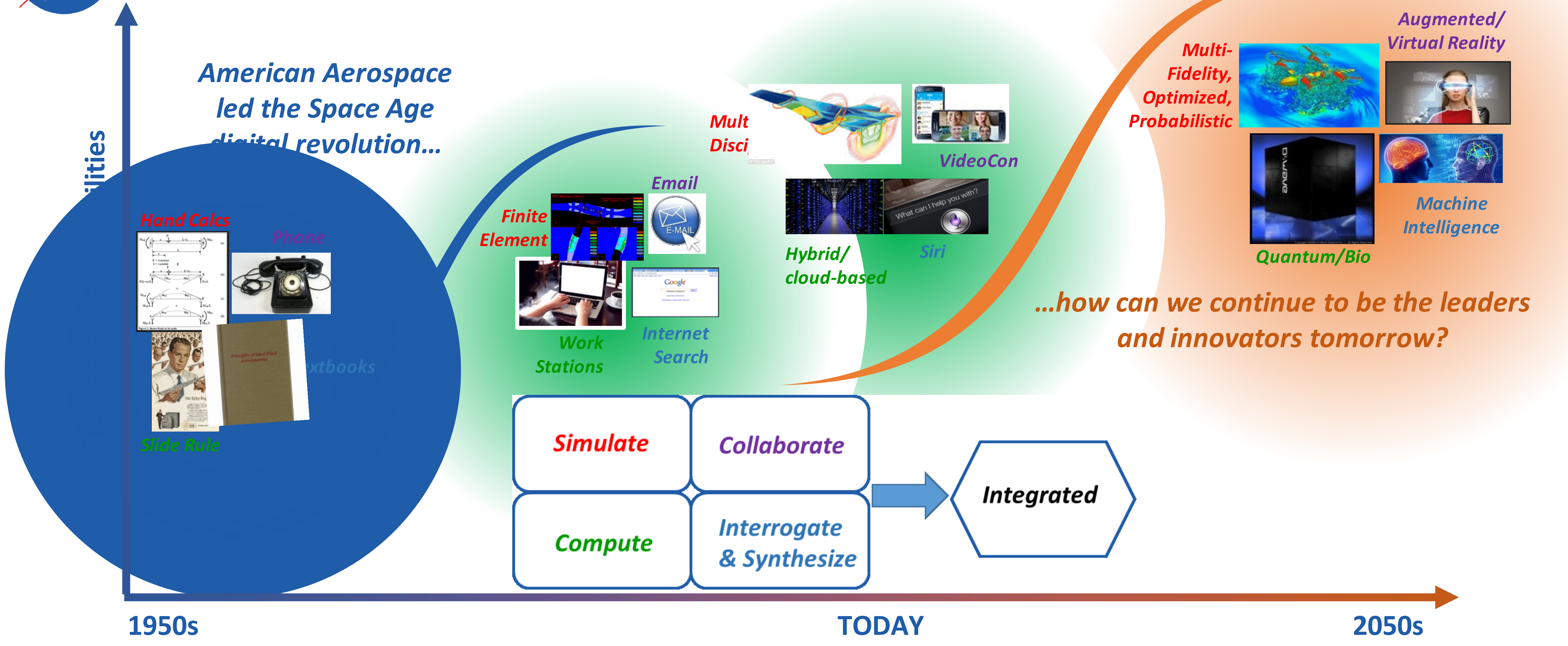
Comprehensive Digital Transformation
NASA Langley Research Center

A Revolution is dawning



What will this digital future enable for Aerospace?

- *Enable data-driven decisions in project and institutional management* via **probabilistic confidence** and **integrated risk assessments**
- *Integrate multi-disciplinary (physics and programmatic), multi-fidelity predictions* to design and develop a **increasingly diverse set of complex missions**
- *Fuse ground test, flight test demonstrations, theory, computational and operational data* to **optimize performance and enable the design and production of radical new vehicle concepts**
- **Increase affordability/agility/safety of missions** through *vehicle/infrastructure self-awareness, reconfiguration and adaptive mission management*
- Constantly *mine and synthesize world knowledge from numerous data sources in real time* to **create new knowledge, ideas**
- **Global collaboration** via *well-integrated geographically dispersed teams*, tapping best talent anywhere
- And more we haven't even thought of…

Everything is connected; connectivity is required to survive

~~Preserve~~ Grow America's Competitive Advantage in Aerospace

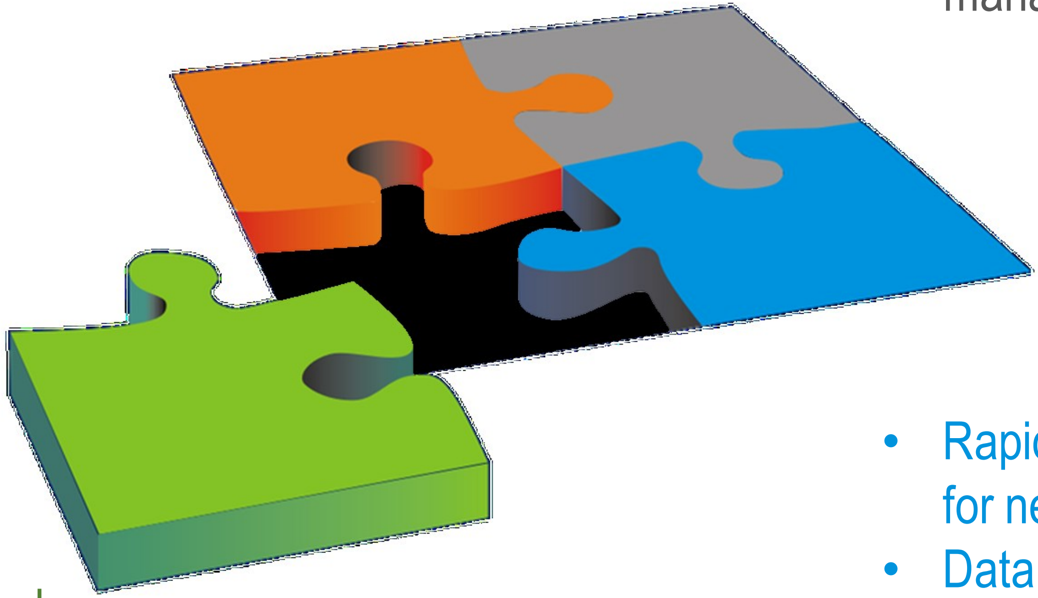
CDT Core Functional Areas

Modeling and Simulation

- Integrated analysis and design of complex systems
- Facilitate improved physics-based discipline tools
- Optimally combine testing and M&S

Advanced Information Technology

- Open, secure collaboration for synergy
- Networks handle burgeoning data
- Data governance, architecture, and management



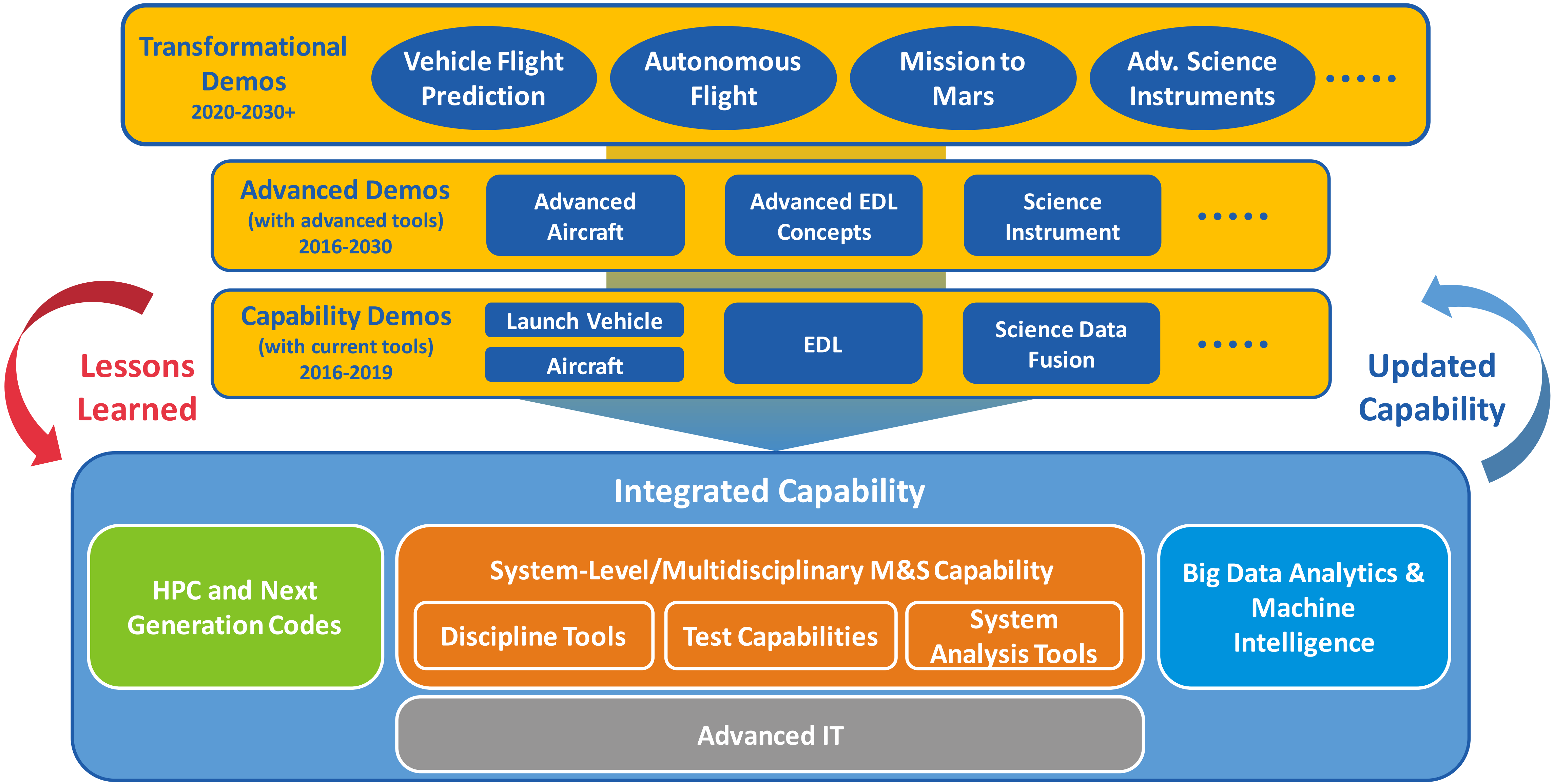
High Performance Computing

- Next generation software development
- Rapid Compute power for M&S and BDA&MI
- Architecture for real-time analysis and design

Big Data Analytics and Machine Intelligence

- Rapid synthesis of global scientific info. for new insights
- Data intensive scientific discoveries for advanced designs
- Virtual Experts: Human-machine symbiosis

Virtual Analysis and Design of Aerospace Systems and Science Instruments



CDT Vision: 2035 Virtual Capabilities

Vehicle Flight Prediction	Enable real-time simulated testing of entire aircraft/spacecraft 2035 Goal: 5X Testing Bang / Buck
Vehicle Digital Twin	High-fidelity lifecycle simulation of as-built system 2035 Goal: ½ Maintenance; 10X Vehicle Life
Materials By Design	Rapidly optimize multifunctional material system performance 2035 Goal: Entirely New Capability; 10X Speed-up to New Material
Airspace Simulation	Large-scale, live, virtual, constructive simulation of airspace architecture 2035 Goal: Accelerate insertion of new technologies to the NAS
Virtual Entry, Descent & Landing	High-fidelity simulation of mission from atmospheric entry to landing 2035 Goal: 100X Current Fidelity; All Systems
Coupled Earth System Data & Models	Link LaRC data with Agency, national and worldwide models 2035 Goal: Entirely New Capability; Mitigate Climate Effects

M&S Vision: Mod-Sim and Systems Analysis Capabilities

Goal: Enable new capabilities; improve fidelity; 5X testing bang/buck by 2035
Enable real-time simulation of complete systems, systems innovation and optimization, accelerate new technology insertion, reduce margins, decrease risk

- **2015** Single Physics, Limited Predictive Capability
- **2020** Coupling Frameworks
- **2025** System Interaction Quantification
- **2030** Risk-Based Decisions
- **2035** Manage Entire Lifecycle

Disciplinary Modeling & Simulation

Systems Biology Models
Predictive Multi-Scale Simulation
Similitude-Based Certification
Adaptive Algorithms for Flight Control
Wall-Resolved LES
Predictive Multi-Physics Simulation
Hybrid RANS-LES
Materials Design

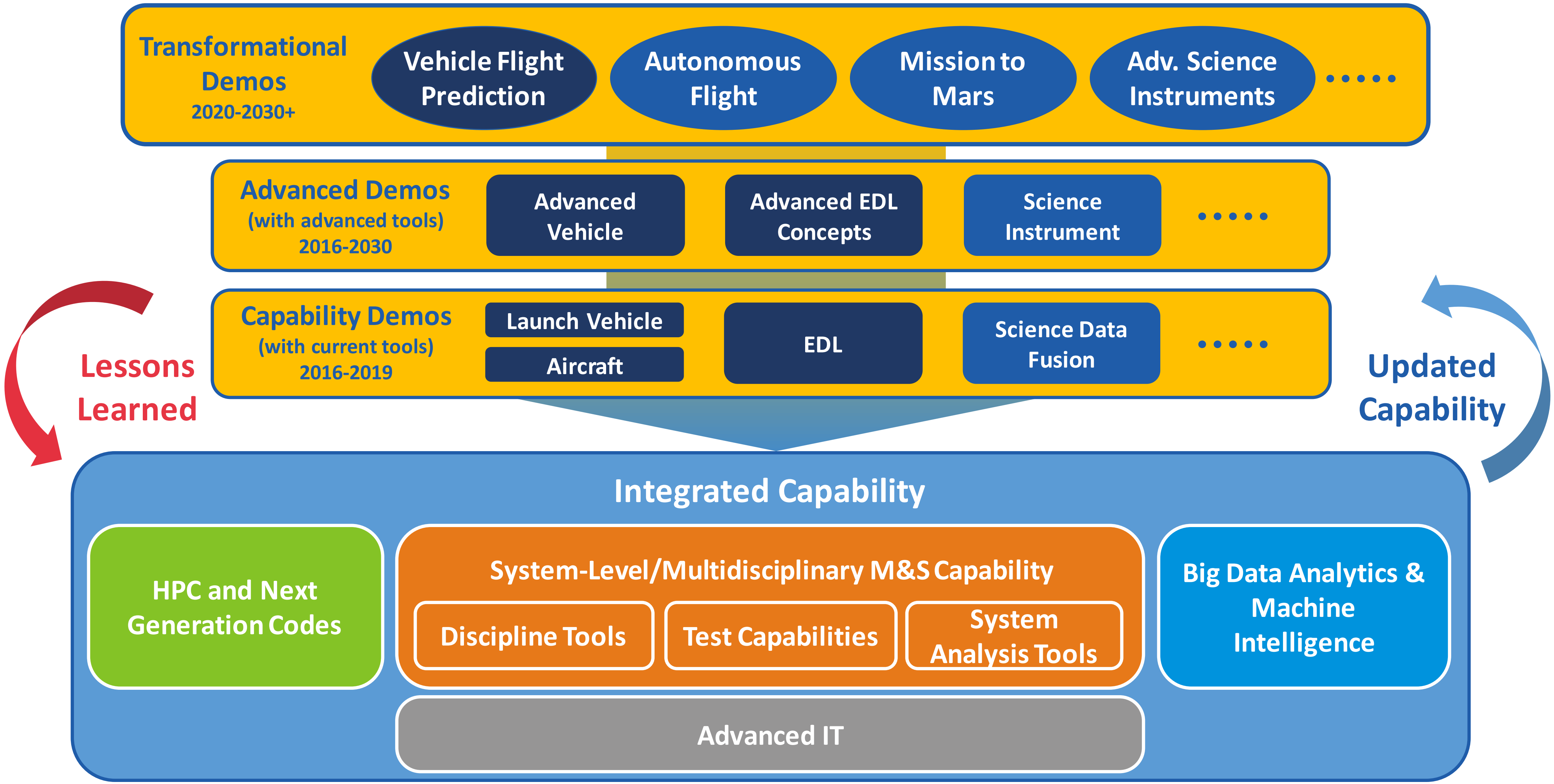
DoE, V&V, UQ, NDA

Probabilistic Design
Optimized Experiment-Simulation Integration
Reliable Error Prediction
Virtual Digital Certification
Uncertainty Minimization

Interdisciplinary Mod-Sim and Systems-of-Systems

Interface Development Prototyping Team
Active Control of Structural Response
SHM-THM Integration
Near-Real Time Simulation of Flight Vehicle Performance
Model-Based Systems Engineering
UQ Enabled MDAO

Vehicle Flight Prediction



Vehicle Flight Prediction

Transformational Demos
2020-2030+

- Vehicle Flight Prediction
- Autonomous Flight
- Mission to Mars
- Adv. Science Instruments
- • • • • •

Advanced Demos
(with advanced tools)
2016-2030

- Advanced Vehicle
- Advanced EDL Concepts
- Science Instrument
- • • • • •

Capability Demos
(with current tools)
2016-2019

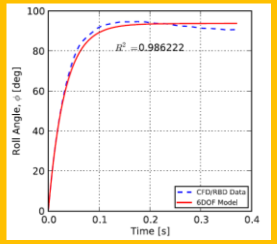
- Launch Vehicle
- Aircraft
- EDL
- Science Data Fusion
- • • • • •

Lessons Learned

Updated Capability

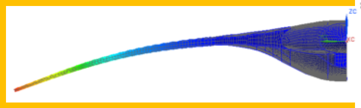
Flight Prediction Workshop

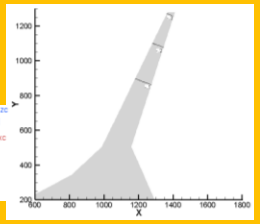
Launch Vehicle
Launch Vehicle Trajectory Simulation with Integrated CFD Aerodynamic Prediction



EDL
Randomized Martian Atmosphere

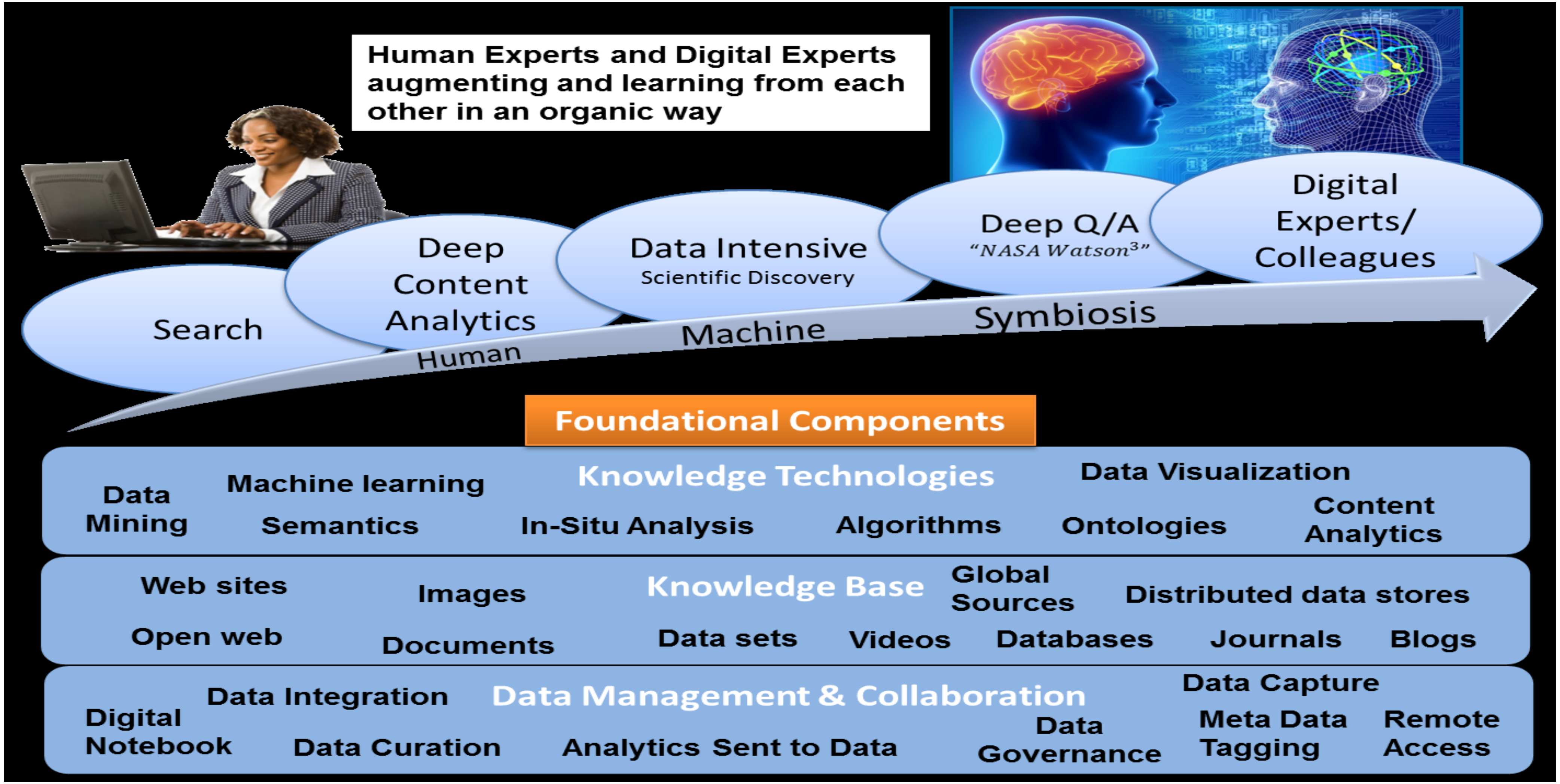
Aircraft
Flexible Vehicle Dynamic Stability Determination using CFD





BDA & MI Vision: Virtual Research and Design Partner

Enable NASA employees to achieve greater scientific discoveries and systems innovations



Deep Content Analytics – Knowledge Assistants

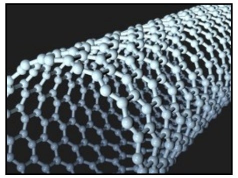
Deep Content Analytics: Obtaining insights, identifying trends, aiding in discovery, and finding answers to specific questions by mining and synthesizing global knowledge from scholarly, web, and multimedia content – ***Cognitive Computing.*** *Using Watson Technologies by IBM*

Watson Content Analytics (WCA)

- Digest and Analyze thousands of articles without reading
- Identify trends, connections and experts quickly
- Positive feedback; WCA as center wide capability is in the works

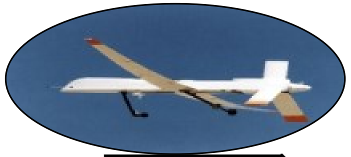
Carbon Nanotubes Research

Analysis of ~ 130,000 articles from a 20-year time span



Autonomous Flight Research

Analysis of 4,000 articles integrating scholarly and web content



Space Radiation Research

Analysis of ~200,000 articles of research related to the Human Research Program

Human Machine Teaming, Uncertainty Quantification, and Vehicle Design are being worked

Watson Pilot and Aerospace Innovation Advisors: Proof of Concepts

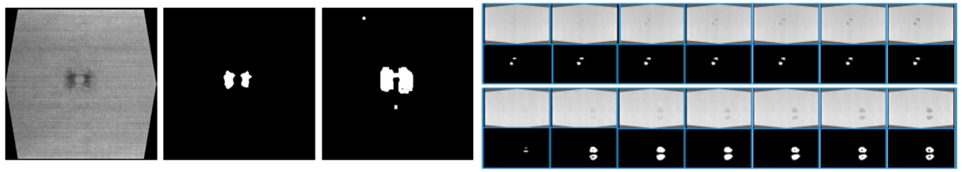
- Generates leads to hard questions and provide evidence for new paths
- Based on Watson Discovery Advisor that is being used in medicine/pharma
- Evaluation of cognitive computing in aerospace domains

Data Intensive Scientific Discovery – Data Assistants

*Deriving new insights, correlations, and discoveries from diverse experimental and computational data sets – **The Fourth Paradigm***

Anomaly Detection in the Non-Destructive Evaluation images of Materials

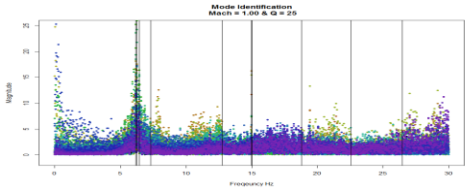
Automated algorithms for anomalies detection saving SME time and improving damage impact analysis



(a) (b) (c)

Predicting Flutter from Aeroelasticity Data

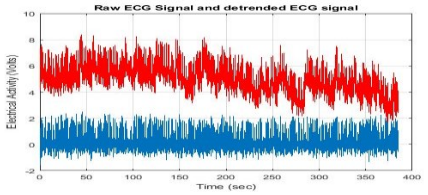
Help SMEs to accurately predict flutter onset using predictive models based on large experimental data sets



Semi-Span Super-Sonic Transport (S^4T) Model

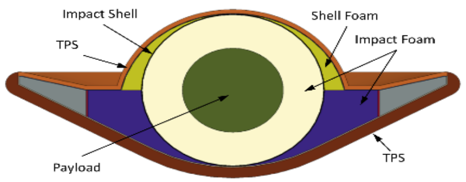
Pilot Cognitive State Monitoring

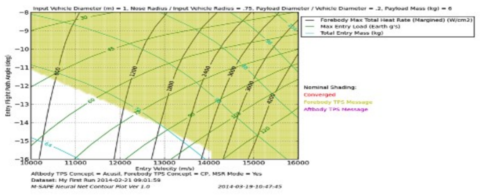
Predict Crew cognitive state using physiological data from flight simulations in different alertness modes to help improve Pilot training



Rapid Exploration of Aerospace Design

Provide a machine learning platform to help analyze modeling and simulation data quickly for design optimization





Use of machine learning and statistical techniques using MATLAB, R, Caffe, Python and C++........

Partnerships and User Education/Engagement

ODU – Machine Learning

Ga Tech – Machine Learning for Systems Design and Mod-Sim

MIT - Computer Science and Artificial Intelligence Lab

University of Michigan – Confluence of Mod-Sim, HPC & Big Data

IBM – Analytics and Cognitive Computing for Aerospace

Ames – Data Science and Machine Learning Team

NASA HQ – Big Data Group

Seminars; Courses; Workshops

Focus groups; Demonstrations

Web sites: Big Data ; Machine Learning; Knowledge Analytics

HPC Vision: HPC Community of Practice

Goal: Enable Rapid Scientific and Systems Level Computing
Enable real-time simulation of complete systems, systems innovation and optimization, accelerate new technology insertion, reduce design margins, decrease risk

2015
Multi-Core (CPU)

2023
Exa-Scale, Many Core (CPU+GPU/MIC)

2035
Beyond Moore's Law: Quantum Computing

Next-generation SW Development

Early access to Next-gen
DOE CORAL
Hybrid, heterogeneous

Co-design process

DNA computing

Beyond Moore's Law
Zeta-scale computing (10^{21})

Rapid Compute for M&S and BDA/MI

Frameworks, toolkits
Scalable math libraries

In-situ visualization and analysis

Neuromorphic
Predictive complex systems

Arch for Real-Time Analysis/Design

On-demand, tiered compute
NSF Bridges
Convergence of HPC/BDA

HPC in Labs, Add. Manufacturing

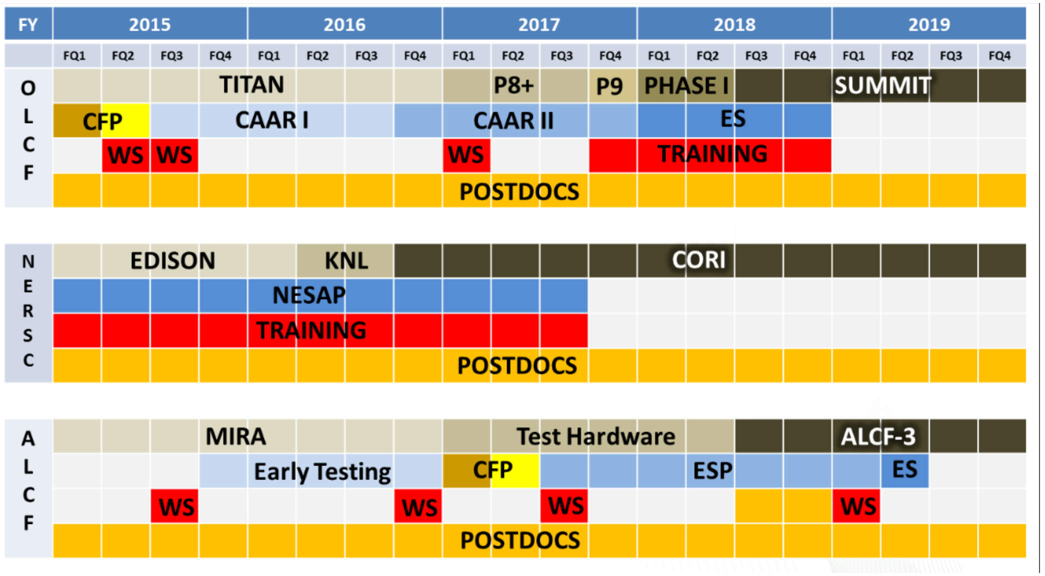
Collaborative environments

CDT High Performance Computing
- Next Generation Software Development

Build a critical mass (workforce, infrastructure) supporting a community of HPC practice

Application Readiness Strategy

Build workforce and expertise
- partner and leverage existing funding, expertise (DOE, DOD, NSF)
- assist with deep dive evaluation of codes
- provide HPC guidance: many-core options, types of parallelism, math libraries, etc.
- identify tools and assess emerging HW
- assess computational frameworks, toolkits, and standards
- address the diverse HPC requirements - both across the center and within disciplines.



This strategy enables the sharing of a common infrastructure and software design process supporting multiphysics (multi-scale, multi-fidelity).

Early Lessons Learned from DOE: Up to 1-2 persons 2 years required to port each (large) code from to many-core (Jaguar to Titan)—an unavoidable step required for the next generation regardless of the type of processors.

Partnering with OGAs (DOE, NSF) and HPC vendors is competitive and requires a high-level of HPC technical knowledge/skill and a sustained HPC infrastructure showing longevity.

CDT High Performance Computing
- Rapid Compute Power for M&S and BDA&MI

Ensures researchers have on-demand access to enough compute at the needed levels.

Key Activities

- **Evolutionary** architectures: Enable M&S and BDA/ML with rapid HPC compute power
- **Revolutionary** Architectures: Evaluate the applicability of quantum computing to LaRC project

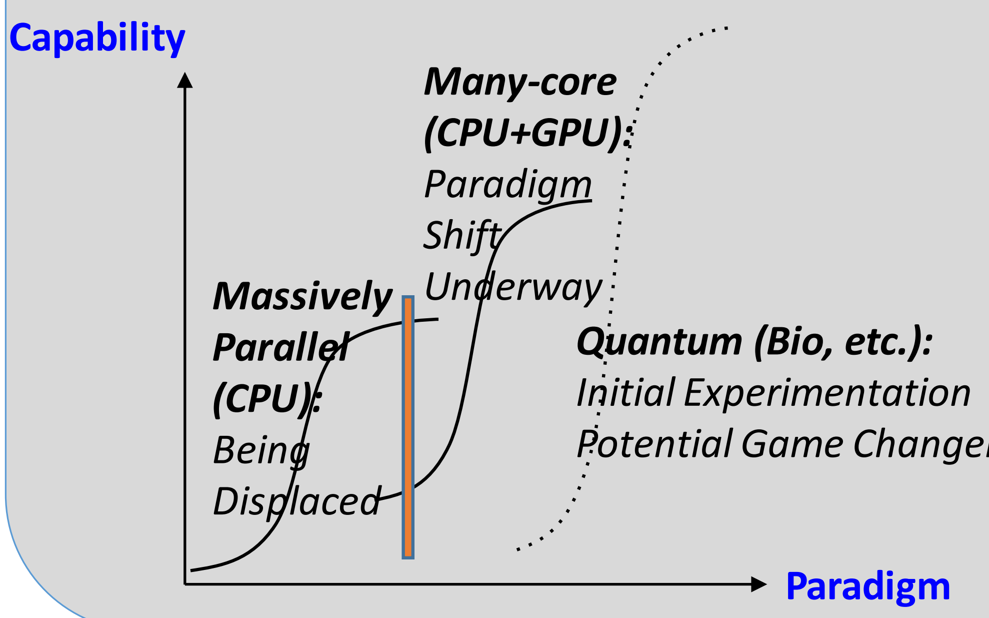
Technology and Capability Advancements

- Prepare for **Emerging Technologies** (HPC Paradigm shifts)
- Demonstrate rapid **compute power as alternate environments** for robustness, reliability, and stability of SMART NAS concepts, algorithms, and technologies. Precursor to HPC.

Specific use cases:

- **Quantum Computing** – Early exploratory projects in **carbon nanostructures on a quantum annealing platforms**. **Goal:** position LaRC to leverage HPC "Beyond Moore's Law" for NASA's unique problems.
- **SMART NAS** – adapting a SMART NAS component to run in the HPC Linux environment. **Goal: demonstrate added capabilities.**

Preparing for HPC Paradigm Shifts



CDT High Performance Computing
- Architecture for Real-time Analysis and Design

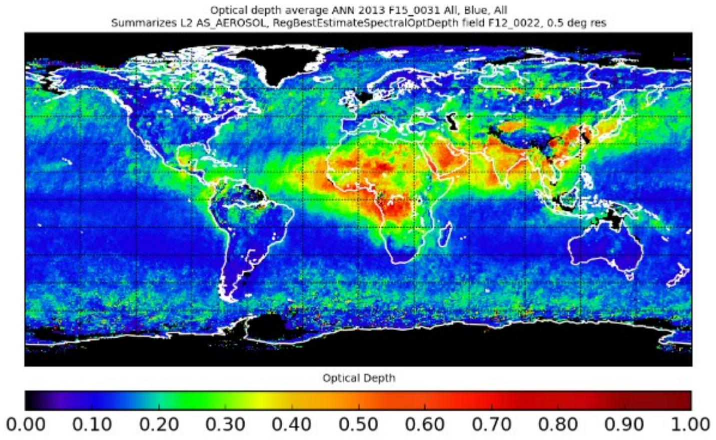
Enables the fusion of observational and experimental data with advanced simulation. The ability to dynamically (in situ) query and integrate high-fidelity simulation data with lower-fidelity data reduces overall risk in aerospace system design.

Exascale (HPC) data produced by experiments and simulations are projected to rapidly outstrip our ability to explore and understand data.

- not only are scientific simulations forecasted to grow by many orders of magnitude, but
- current methods by which HPC systems are programmed and data are stored and extracted are not expected to survive to Exascale

CDT HPC proposes to **architecture and integrate data analytics with Exascale simulations.**

- the coordination and extraction of data from the rapid generation of (thousands of) simulations
- a much tighter coupling between data and simulation is critical, requiring new methods of fusing information from multiple sources (theory, experimental, simulation, and observation)
- there are opportunities for investments that can benefit both data-intensive science and Exascale computing



Science Data Processing – Leverage the convergence of HPC and BDA/ML to extract knowledge discovery over high speed networks.

CDT High Performance Computing – ODU Collaborations

Over the last two years, CDT HPC has established deep working relationships with several ODU professors and Chairs. Looking for more means of collaboration.

College of Sciences, Department of Mathematics & Statistics

Dr. Fang Hu. Aeroacoustics, HPC, GPU

College of Sciences, Computer Science Department

Dr. Desh Ranjan. Chair. Algorithmic Development

Dr. Mohammad Zubair. High Performance Computing

Dr. Nikos Chrisochoides. HPC, Parallel Mesh Generation

Batten College of Engineering & Technology Department of Modeling, Simulation and Visualization Engineering

Dr. Rick McKenzie. Chair

Dr. Masha Sosonkina. High Performance Computing, Xeon Phi

Advanced Information Technology Vision:

A vibrant foundation of connectivity, transparent information sharing, and global partnerships to create knowledge and enable innovation

2016
Advanced Knowledge Systems

2018
Integrated Partnering

2022
Grow a Global Digital Enterprise

2035
New Work Paradigm(s)

Global Pervasive Knowledge

NASA-Wide Information Sharing

Easy Sharing w/ Partners, Architectures for Integrated Analysis

Personalized Machine – Assisted Knowledge is Mainstream

Immersive and Augmented Collaboration

Integrated Collaboration
3D Augmented Reality

Human Interfaces,
Virtual Exploration

Full Immersion,
Virtual Citizen Exploration

Communications, Networks, Security, Storage

Constant Evolution and Paradigm Changes – Mobile Work from Anywhere, Advanced Networks, Cloud, Storage, New Security Threats, Unified Communications

Why Advanced IT?

- NASA missions are more complex and demanding than ever
  - *Obsolete IT creates mission drag*
  - *Advanced IT acts as a mission accelerator*
- NASA strategy to maximize partnerships implies collaboration, connectivity, and cutting-edge IT
  - *Partners expect easy, efficient collaboration & knowledge sharing with NASA*
  - *Partnerships enhanced via automated interfaces*
- Workforce Interviews & Mission Analysis:
  - *Make sharing, knowledge, information, and code easy across NASA & with partners*
  - *Establish security trust between NASA Centers*
  - *Enable huge Science file transfer 5-10x current speeds*
  - *Need modern tools which support fast-paced, agile work methods*
  - *Need the architecture to integrate emerging capabilities (M&S, Big Data, HPC, more)*
- 21st Century workforce expects 21st century tools
  - *NASA objective to attract & retain brightest minds*
  - *Lure of competitors' cutting edge IT*

The CDT Advanced IT thrust accelerates selected emerging IT for NASA strategic advantage

CDT Advanced IT in FY16

Secure Collaboration within and outside NASA

- Secure collaboration with internal and external partners (Google Apps, ExplorNet, Vidyo)
- Hyperwalls for Multi-center Aeronautics collaboration (Installed and in testing/training)
- Collaborative Problem Solving and Education – Collaboratory w/ C. Camarda (Pending legal resolution)
- Contribute to Agency collaboration thrust (Gathered and submitted robust LaRC inputs; ongoing)

Network Optimization and Network Trust

- NASA-wide network trust (opened / opening standard ports among all centers)
- Network optimization w/ ASDC (conducted successful proof of concept)

Integration Architecture for Digital Transformation

(in planning; in support of other CDT areas' initiatives, to include center MBSE team)

Other Areas of Work

- Training / education (Gartner Catalyst in Aug, etc.)
- Cloud (OCIO working this)
- Enhanced knowledge systems (Unfunded; potential FY17 start)

Green:	Proceeding per plan
Blue:	Dependent on others
Red:	Not resourced