A Revolution is dawning

American Aerospace led the Space Age digital revolution…

...how can we continue to be the leaders and innovators tomorrow?

1950s

1950s

TODAY

2050s

Simulate

Collaborate

Compute

Interrogate & Synthesize

Integrated

Multi-Fidelity, Optimized, Probabilistic

Augmented/Virtual Reality

Machine Intelligence

Quantum/Bio

Hybrid/cloud-based

Finite Element Work Stations

Email

Internet Search

VideoCon

Hand Cals

Phone

Slide Rule

Textbooks

American Aerospace led the Space Age digital revolution…
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…
CDT Core Functional Areas

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

Modeling and Simulation

- 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

- **Transformational Demos** 2020-2030+
  - Vehicle Flight Prediction
  - Autonomous Flight
  - Mission to Mars
  - Adv. Science Instruments

- **Advanced Demos** (with advanced tools) 2016-2030
  - Advanced Aircraft
  - Advanced EDL Concepts
  - Science Instrument

- **Capability Demos** (with current tools) 2016-2019
  - Launch Vehicle Aircraft
  - EDL
  - Science Data Fusion

- **Integrated Capability**
  - HPC and Next Generation Codes
  - System-Level/Multidisciplinary M&S Capability
    - Discipline Tools
    - Test Capabilities
    - System Analysis Tools
  - Big Data Analytics & Machine Intelligence
  - Advanced IT

- **Lessons Learned**

- **Updated Capability**
<table>
<thead>
<tr>
<th>CDT Vision: 2035 Virtual Capabilities</th>
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<tr>
<td><strong>Vehicle Flight Prediction</strong></td>
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<tr>
<td>Enable real-time simulated testing of entire aircraft/spacecraft</td>
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<tr>
<td>2035 Goal: 5X Testing Bang / Buck</td>
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<td><strong>Vehicle Digital Twin</strong></td>
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<td>High-fidelity lifecycle simulation of as-built system</td>
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<td>2035 Goal: ½ Maintenance; 10X Vehicle Life</td>
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<td><strong>Materials By Design</strong></td>
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<td>Rapidly optimize multifunctional material system performance</td>
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<tr>
<td>2035 Goal: Entirely New Capability; 10X Speed-up to New Material</td>
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<td><strong>Airspace Simulation</strong></td>
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<td>Large-scale, live, virtual, constructive simulation of airspace architecture</td>
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<td>2035 Goal: Accelerate insertion of new technologies to the NAS</td>
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<tr>
<td><strong>Virtual Entry, Descent &amp; Landing</strong></td>
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<td>High-fidelity simulation of mission from atmospheric entry to landing</td>
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<td>2035 Goal: 100X Current Fidelity; All Systems</td>
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<tr>
<td><strong>Coupled Earth System Data &amp; Models</strong></td>
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<tr>
<td>Link LaRC data with Agency, national and worldwide models</td>
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<tr>
<td>2035 Goal: Entirely New Capability; Mitigate Climate Effects</td>
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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
- Similitude-Based Certification
- Hybrid RANS-LES
- Adaptive Algorithms for Flight Control
- Wall-Resolved LES
- Materials Design
- Predictive Multi-Scale Simulation
- Predictive Multi-Physics Simulation

**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
- Model-Based Systems Engineering
- Active Control of Structural Response
- SHM-THM Integration
- UQ Enabled MDAO
- Near-Real Time Simulation of Flight Vehicle Performance
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
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Launch Vehicle
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System-Level/Multidisciplinary M&S Capability

Discipline Tools
Test Capabilities
System Analysis Tools

Advanced IT

Big Data Analytics & Machine Intelligence

Lessons Learned

Updated Capability
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Transformational Demos
2020-2030+

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Advanced Demos
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Advanced Vehicle

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Science Instrument

Capability Demos
(with current tools)
2016-2019

Launch Vehicle

EDL

Science Data Fusion

Launch Vehicle

Launch Vehicle Trajectory Simulation with Integrated CFD
Aerodynamic Prediction

EDL
Randomized Martian Atmosphere

Aircraft
Flexible Vehicle Dynamic Stability Determination using CFD

Lessons Learned

Flight Prediction Workshop

Updated Capability
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

Predicting Flutter from Aeroelasticity Data
Help SMEs to accurately predict flutter onset using predictive models based on large experimental data sets

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

- Early access to Next-gen DOE CORAL
- Hybrid, heterogeneous
- Next-generation SW Development
  - Co-design process
  - DNA computing
- Beyond Moore’s Law
  - Zeta-scale computing ($10^{21}$)
- Frameworks, toolkits
- Scalable math libraries
- Rapid Compute for M&S and BDA/MI
  - In-situ visualization and analysis
- Neuromorphic
  - Predictive complex systems
- On-demand, tiered compute
- NSF Bridges
- Convergence of HPC/BDA
- Arch for Real-Time Analysis/Design
  - HPC in Labs, Add. Manufacturing
- Collaborative environments
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.
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.
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.
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