InfoSymbioticSystems/DDDAS

and Large-Scale-Big-Data & Large-Scale-Big-Computing for Smart Systems

CFD2030 Workshop

AIAA/SciTech

January 6-7, 2018

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Director AFOSR

Integrity ★ Service ★ Excellence

QUO VADIMUS
Timely Confluence across 4 axes
New Opportunities

AF Motivation; applies to broader drivers - other DOD, civilian/etc

New Capabilities through

DDDAS-Dynamic Data Driven Applications Systems

- Unifying High-End with Real-Time/Data-Acquisition&Control

Large-Scale-Big-Data (Large-Scale-Dynamic-Data)

- "Big Data" + Ubiquitous Sensing&Control (2^{nd} Wave of big-data)

Large-Scale-Big-Computing

- From the exa-scale to the sensor-scale/controller-scale

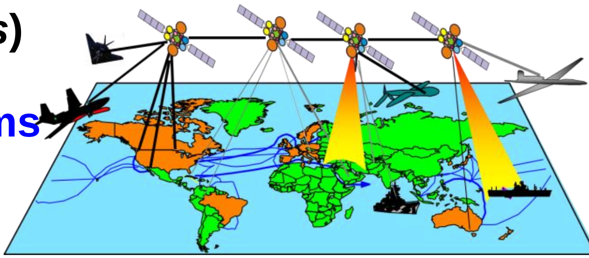
Multi-core Technologies

- Will be driven by sensor/controller and mobile devices

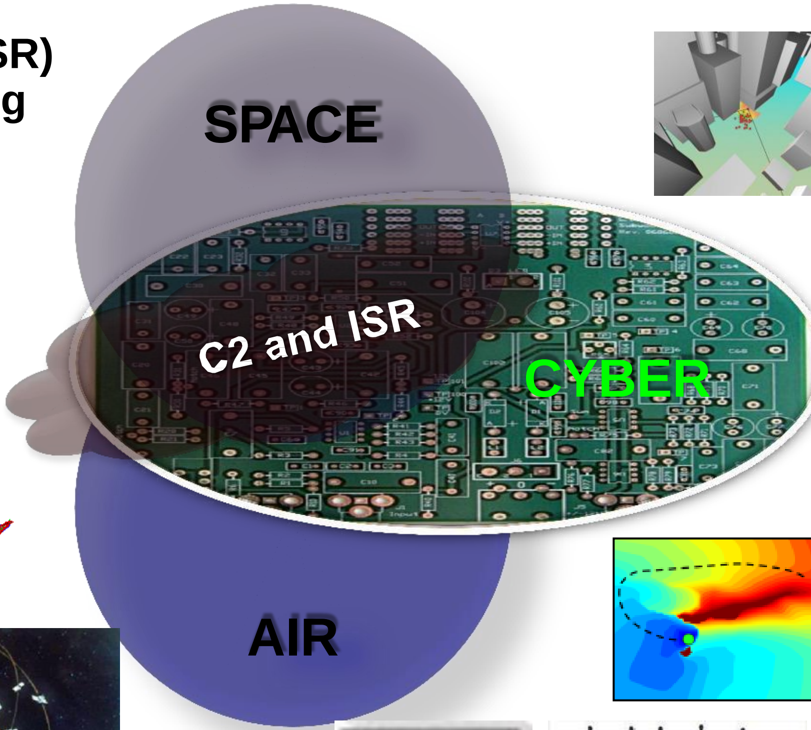
Timeliness&Opportunities - Examples

AF S&T Horizons – 10, 20, … 40 yrs + beyond

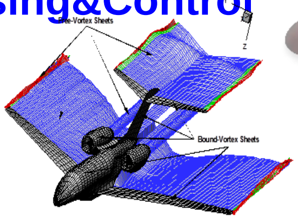
Technology Horizons
- Inherently Intrusion-Resilient Cyber Networks (*and Systems*)
- Trusted, Highly-Autonomous Decision-Making Systems
- Fractionated, Composable, Survivable, Autonomous Systems
- Hyper-Precision Aerial Delivery in Difficult Environments



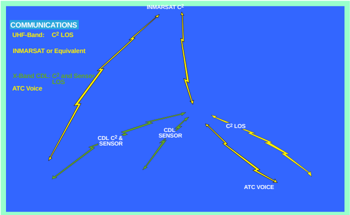
Global Horizons
- Command & Control (C2); IntellSurveilRecon (ISR)
- C2&ISR "targeted as center of gravity threatening integrated and resilient global operations"

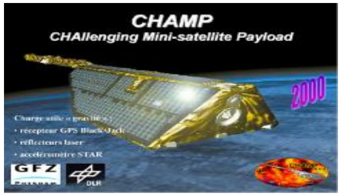


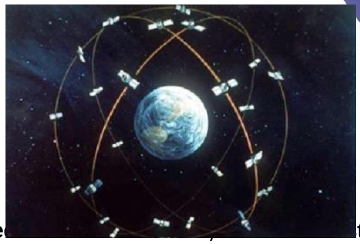
Autonomy Horizons
- Mission/Scenario Planning & Decision Making
- VHM, Fault /Failure Detection, Replanning
- SituationalAwareness, Multi-Sensing&Control



… (other) Horizons…
– *Energy Horizons*
– *Beyond Horizons*







Research for New Air Force Capabilities

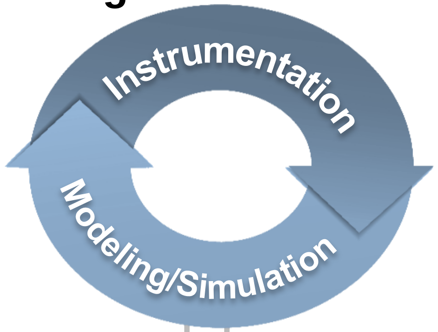
"excellence in science and transformative capabilities for the Air Force"

PROBLEM: Increasingly we deal with systems-of-systems and systems/environments that are

complex | heterogeneous | multimodal | multiscale | dynamic

INVESTMENT STRATEGY

Pursue excellence in science through disciplinary and multidisciplinary research, to develop new methods for end-to-end systems capabilities, applied to key Air Force challenges for transformative impact to the Air Force

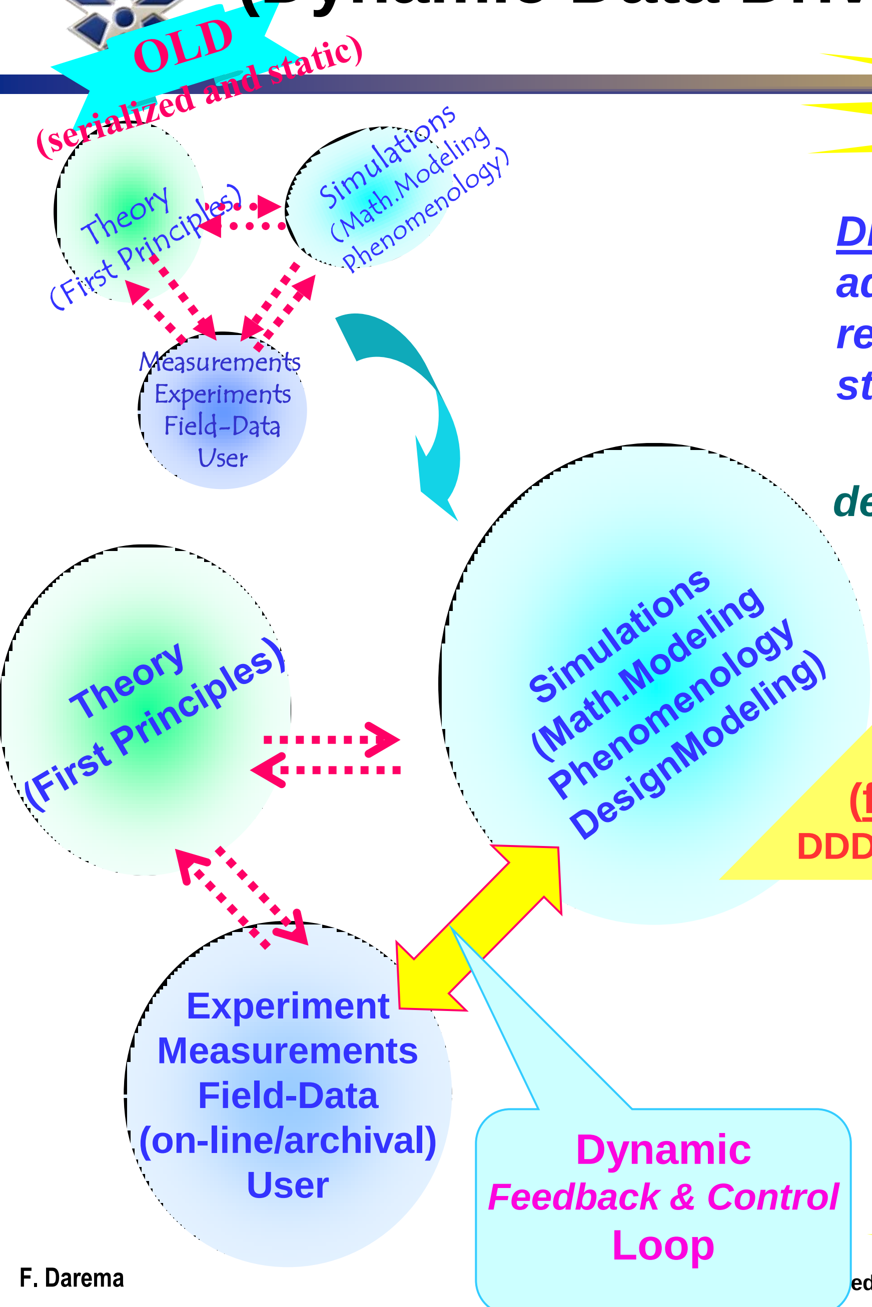


NEW METHODS - Paradigm Changing

- **enable more accurate and faster modeling capabilities for analysis, prediction, & operational support**
- **enable decision support capabilities with the accuracy of full scale models**
- **support adaptive multimodal instrumentation and fault tolerance in instruments/sensors failures**
- **exploit ubiquitous embedded sensing & control for new test & evaluation methods**

AF CAPABILITY: understand, design, manage & optimize systems-of-systems across life-cycle

The DDDAS Paradigm
(Dynamic Data Driven Applications Systems)



InfoSymbiotic Systems

***DDDAS**: ability to dynamically incorporate additional data into an executing application, and in reverse, ability of an application to dynamically steer the measurement(instrumentation) processes*

"revolutionary" concept enabling design, build, manage, understand complex systems

Dynamic Integration of
Computation & Measurements/Data
Unification of
Computing Platforms & Sensors/Instruments
(from the High-End to the Real-Time,to the PDA)
DDDAS – architecting & adaptive mngmnt of sensor systems

***Challenges*:**
Application Simulations Methods
Algorithmic Stability
Measurement/Instrumentation Methods
Computing Systems Software Support

Synergistic, Multidisciplinary Research

Advances in Capabilities through DDDAS and Fundamental Science and Technology

- **DDDAS: integration of application simulation/models with the application instrumentation components in a dynamic feed-back control loop**
  - ➢ **speedup of the simulation, by replacing computation with data in specific parts of the phase-space of the application**

    and/or
  - ➢ **augment model with actual data to improve accuracy of the model, improve analysis/prediction capabilities of application models**
  - ➢ **dynamically manage/schedule/architect heterogeneous resources, such as:**
    - **networks of heterogeneous sensors, or networks of heterogeneous controllers**
  - ➢ **enable ~decision-support capabilities w simulation-modeling accuracy**
- **unification from the high-end to the real-time data acquisition**
- **Increased Computat'n/Communic'n capabilities; ubiquitous heterogeneous sensing/control**

❖ **DDDAS is more powerful and broader paradigm than Cyber-Physical Systems**

DDDAS/InfoSymbiotics is the unifying paradigm

DDDAS for new capabilities for Air Force Emerging Technological Horizons and Beyond

- **Increasingly we deal with *systems-of-systems*, and *systems/environments* that are *complex, heterogeneous, multimodal, multiscale, dynamic***

- **Need methods and capabilities**
  - **not only for *understanding*, *and (optimizing) design…***

… but also manage/optimize systems' operational cycle, evolution, interoperability

→ DDDAS-based methods for across the life-cycle of systems

- **DDDAS – *beyond traditional modeling/simulation approaches and use***
  – beyond the traditional instrumentation approaches and use
- ***DDDAS enables:***
  - ***more accurate and faster modeling capabilities for analysis and prediction***
  - ***decision support capabilities with the accuracy of full scale models***
  - ***dynamic/adaptive and more efficient/effective management of heterogeneous resources; ability to compensate for instrumentation faults***

- **Program Investment Strategy**
  - **Select key AF areas & apply DDDAS for end-to-end systems capabilities**
  - **"*Excellence in Science and Transformative Impact to the Air Force*"**

Fundamental Challenges and Timeliness

- **Application modeling methods to support dynamic data inputs**
  - multi-modal, multi-scale, multi-fidelity models/simulations
    - dynamically invoke/select multiple scales/modalities/components
    - interfacing with measurement systems
- **Algorithms tolerant to perturbations from dynamic data inputs**
  - handling data uncertainties, uncertainty propagation, quantification
- **Measurements**
  - multiple modalities/fidelities, space/time distributed, data management
- **Systems Software methods supporting such dynamic environments**
  - dynamic/adaptive execution on heterogeneous/multi-hierarchical environments {from the high-end/mid-range to real-time platforms-- beyond Clouds(Grids) computation, communication, storage; programming models, run-time/OS, …}

Timeliness -- Confluence across 4 emerging

DDDAS-Dynamic Data Driven Applications Systems

- Unifying High-End with Real-Time/Data-Acquisition&Control

Large-Scale-Big-Data (Large-Scale-Dynamic-Data)

- "Big Data" + Ubiquitous Sensing&Control (2^{nd} Wave of big-data)

Large-Scale-Big-Computing

- From the exa-scale to the sensor-scale/controller-scale

Multi-core Technologies

- Will be driven by sensor/controller and mobile devices

Impact to Civilian Sector Areas of prior and present Multiagency DDDAS Efforts

- **Physical, Chemical, Biological, Engineering Systems**
  - Chemical pollution transport (atmosphere, aquatic, subsurface), ecological systems, molecular bionetworks, protein folding..
- **Medical and Health Systems**
  - MRI imaging, cancer treatment, seizure control
- **Environmental (prevention, mitigation, and response)**
  - Earthquakes, hurricanes, tornados, wildfires, floods, landslides, tsunamis, …
- **Critical Infrastructure systems**
  - Electric-powergrid ms, water supply systems, tra works and vehicles (air, ground, u
  - syst
  - Large-Scale Con ronments

"revolutionary" concept enabling to design, build, manage and understand complex systems

NSF/ENG Blue Ribbon Panel (Report 2006 – Tinsley Oden)

"DDDAS … key concept in many of the objectives set in Technology Horizons"

Dr. Werner Dahm, (former/recent) AF Chief Scientist

List of Projects/Papers/Workshops in www.cise.nsf.gov/dddas, www.1dddas.org

(+ DDDAS Conference Series - August2016, 2017,..)

Impact of DDDAS in AirForce Systems

"from the nanoscale to the terra- and extra-terra-scale"

Materials modeling; Structural Health Monitoring – Environment Cognizant - Energy Efficiencies;
Autonomic Coordination of U(A/G)S Swarms;
Co-operative Sensing for Surveillance - Situational Awareness
Space Weather and Adverse Atmospheric Events;
CyberSecurity; Systems Software

Multidisciplinary Research

Drivers: advancing capabilities along the Key Areas identified in Technology Horizons, Autonomy Horizons, Energy Horizons, Global Horizons Reports

DDDAS … key concept in many of the objectives set in Technology Horizons

- Autonomous systems
- Autonomous reasoning and learning
- Resilient autonomy
- Complex adaptive systems
- V&V for complex adaptive systems
- Collaborative/cooperative control
- Autonomous mission planning
- Cold-atom INS
- Chip-scale atomic clocks
- Ad hoc networks
- Polymorphic networks
- Agile networks
- Laser communications
- Frequency-agile RF systems
- Spectral mutability
- Dynamic spectrum access
- Quantum key distribution
- Multi-scale simulation technologies
- Coupled multi-physics simulations
- Embedded diagnostics
- Decision support tools
- Automated software generation
- Sensor-based processing
- Behavior prediction and anticipation
- Cognitive modeling
- Cognitive performance augmentation
- Human-machine interfaces

Large-Scale-Big-Data

- **Emerging scientific and technological trends/advances**
  - *ever more complex applications – systems-of-systems*
  - increased emphasis in complex applications modeling
  - increasing computational capabilities
  - increasing bandwidths for streaming data
  - increasing sources of data

→ **Large Volumes of Data** (heterogeneous, distributed, multi-time-scales)

- **Sensors– Sensors EVERYWHERE…** *(data intensive Wave #2)*
  - *Swimming in sensors and drowning in data* - LtGen Deptula (2010)

Analogous experience from the past:

- *"The attack of the killer micros(microprocs)"* - Dr. Eugene Brooks, LLNL (early 90's)

about microprocessor-based high-end parallel systems

then seen as a problem – have now become an opportunity - advanced capabilities

Back to the present and looking to the future:

- *"Ubiquitous Sensing – the attack of the killer micro (sensors) – 2nd wave"*

Dr. Frederica … AFOSR (2011, LNCC)

challenge: … such resources

oppo… capabilities

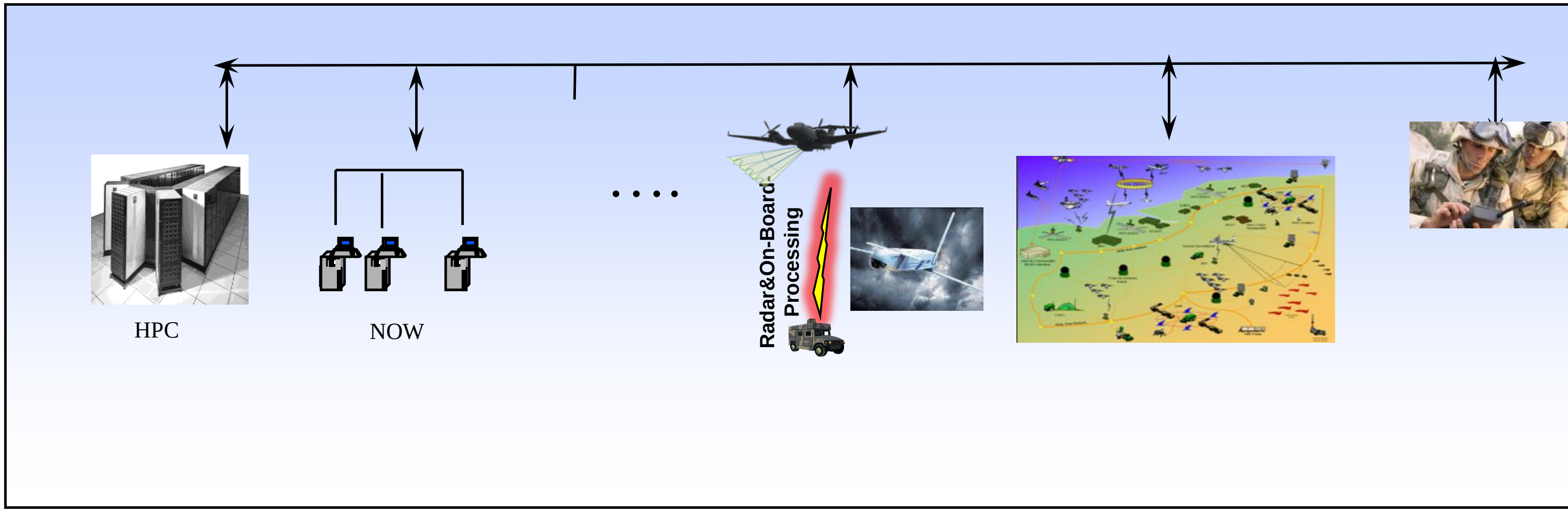
Ubiquitous Sensing
important component of BIG DATA -- Wave #2! -
→ Large-Scale-Big-Data

Integrated Information Processing Environments

from Data-Computation-Communication to Knowledge-Decision-Action

Multicores EVERYWHERE !!!

End-to-End Methods Across System Layers/Components



DDDAS - Integrated/Unified Application Platforms

Adaptable Computing and Data Systems Infrastructure spanning the high-end to real-time data-acquisition & contro… manifesting heterogeneous multilevel distribut… system architectures – softw…

Technological Advances for exascale … es

overlapping multicore needs – pow… t-tolerance

Large-Scale Big-Computing

Examples of Areas of DDDAS Impact to the AF

"from the nanoscale to the terra- and extra-terra-scale"

Materials modeling; Structural Health Monitoring – Environment Cognizant - Energy Efficiencies;
Co-operative Sensing for Surveillance - Situational Awareness;
Autonomic Coordination of U(A/G)S Swarms; Cognition
Space Weather and Adverse Atmospheric Events;
CyberSecurity; Systems Software

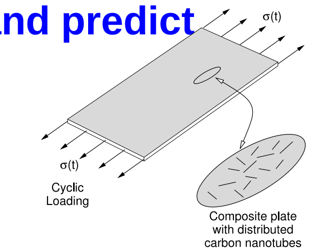
Development of a Stochastic Dynamic Data-Driven System for Prediction of Material Damage

J.T. Oden (PI), P. Bauman, E. Prudencio, S. Prudhomme, K. Ravi-Chandar - UTAustin

Goal: **Dynamic Detection and Control of Damage in Complex Composite Structures**

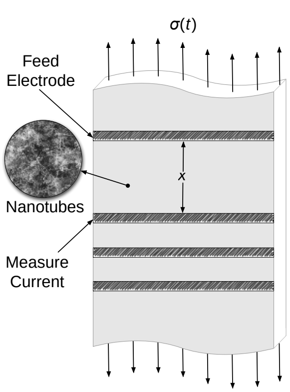
Results achieved:

- **Through DDAS new capabilities have been developed for prediction of material damage**
- **For example can predict on-set of damage before is observed experimentally and predict the evolution of the damage.**

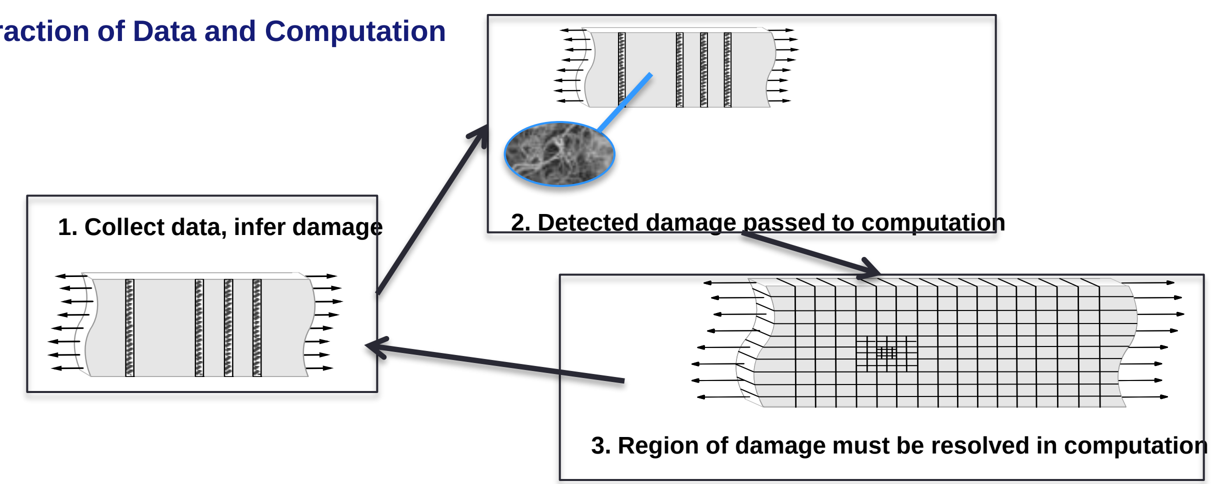


Methodology:

- **Dynamic Data: direct and indirect measurements of damage in materials**
- **Reliable predictive computational models: Finite element solution of continuum damage models**
- **Handling uncertainties: Bayesian framework for uncertainty quantification and Bayesian Model Plaucibilities to dynamically choose damage models based on evolving data; and**
- **Real Time Damage Monitorin**



Interaction of Data and Computation



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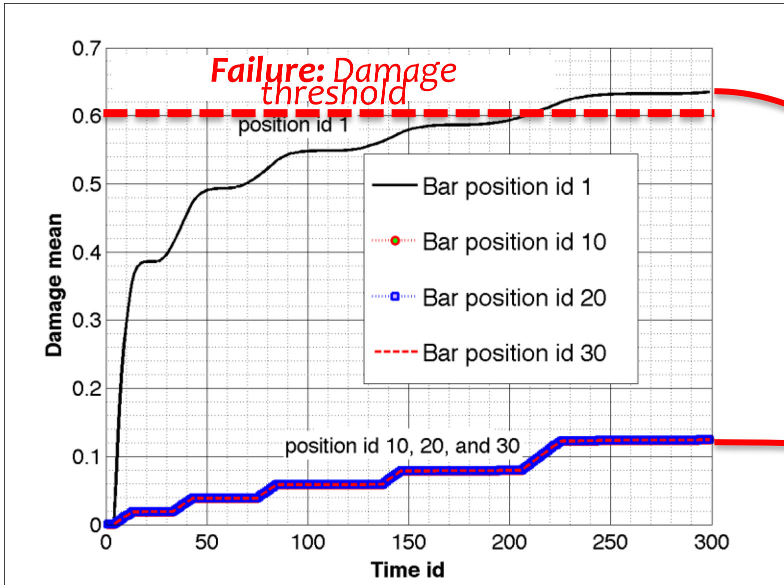
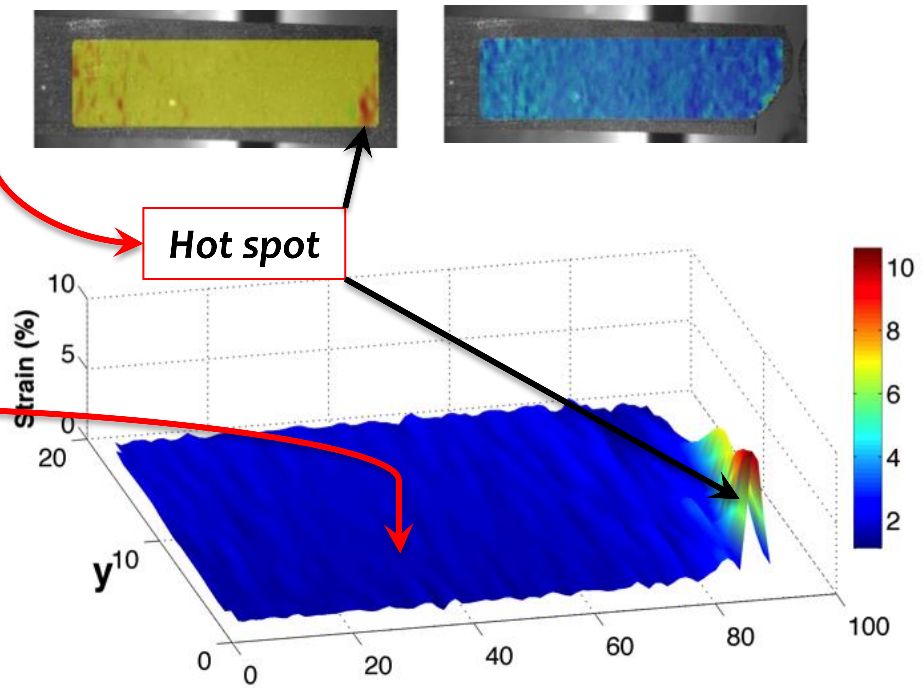
Prediction using Dynamic Data



Experimental Observation

2 (s) before failure *failure*



2 (s) before failure

Example Results:

- **Experimental Data: shows the spatial variation of strain 2(s) before the failure**
- **Prediction Using Dynamic Data: shows the computed evolution of the damage variable with time at various position**
- **“hot spot”: is the dangerous point leading to system failure**
- **From the test results the hot spot can be observed few second before failure**

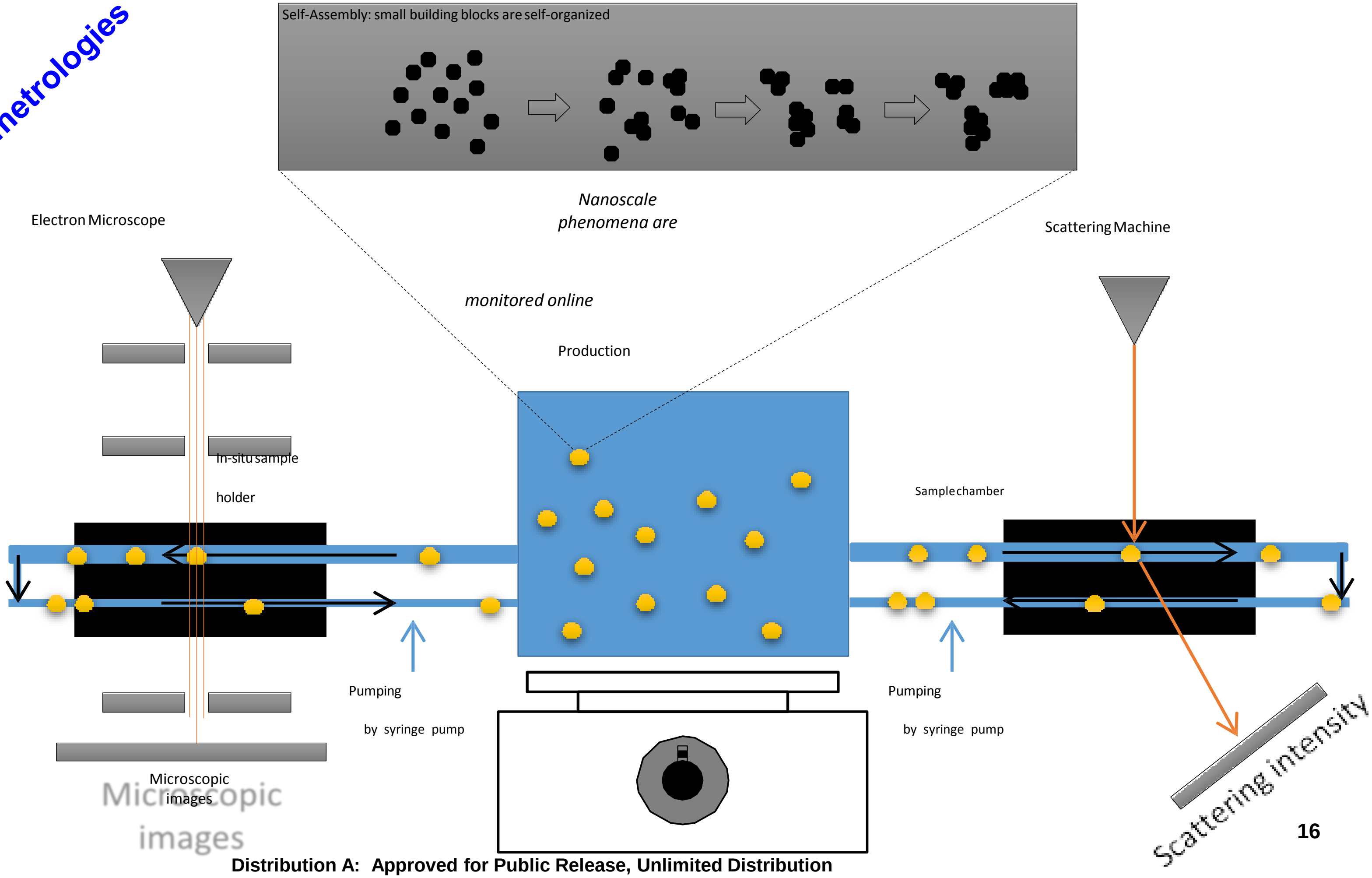
Dynamic, Data-Driven Modeling of Nanoparticle Self-Assembly Processes

Team: Ding, Park, Huang, Liu, Zhang

Many applications require nanoparticle products of precisely controlled sizes and shapes, because the functionalities of the nanoparticles are determined by their sizes and shapes.

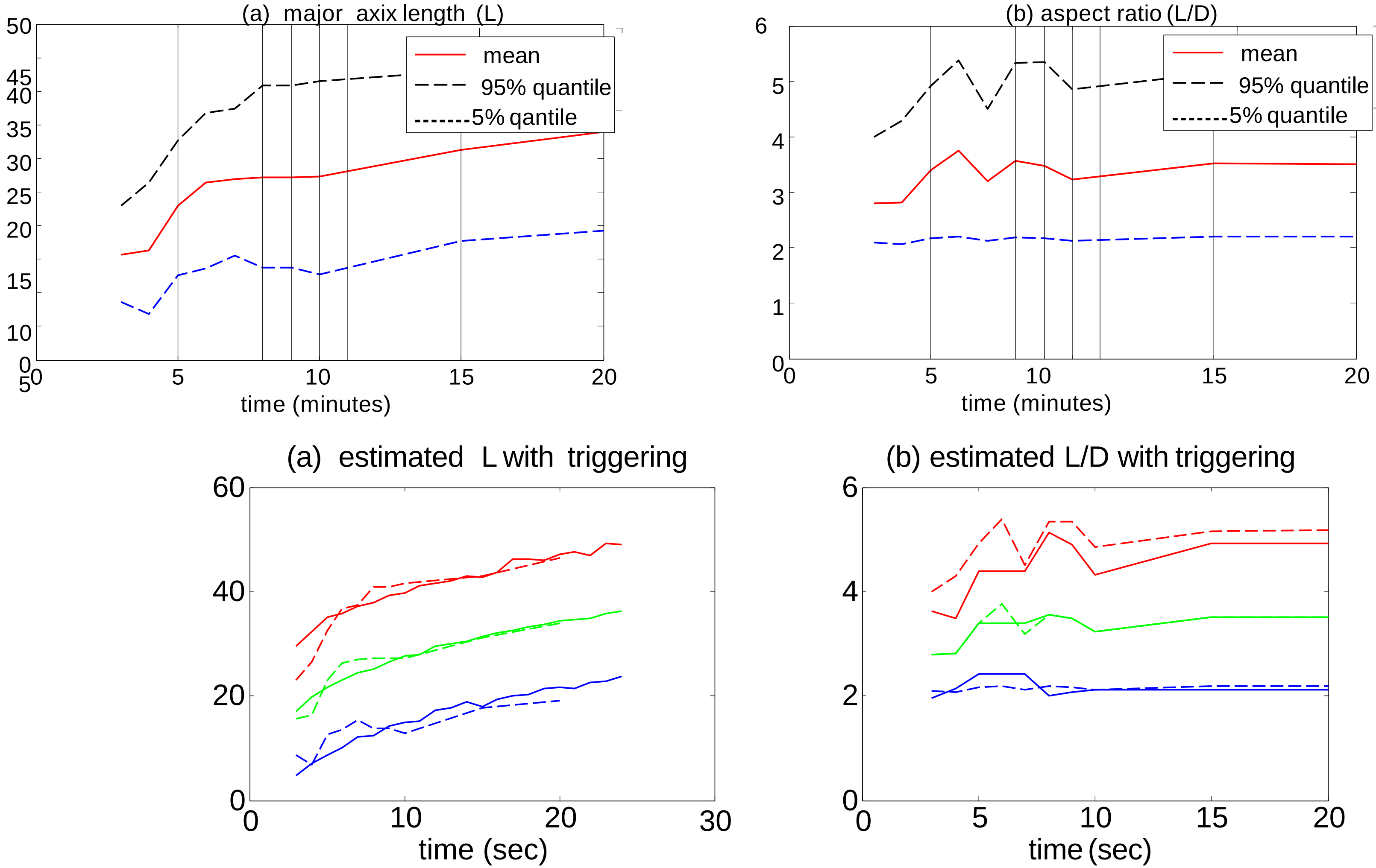
- **Nanoparticles as propellants of satellites and space craft propulsion;**
- **Nanocomposites with special mechanical and electrical properties;**
- **Photovoltaic catalyst for solar cell; and Sensing toxic biological weapons**

Combining multiscale metrologies



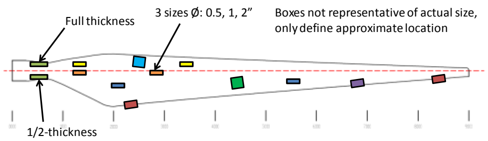
Controlled TEM Triggering

TEM triggering process initiated after t = 5 mins, controlled per the (DDDAS-based) approach. Additional TEM operations are triggered (DDDAS model driven) in between 5 and 20 minutes.



Y. Bazilevs, A.L. Marsden, F. Lanza di Scalea, A. Majumdar, and M. Tatineni (UCSD)

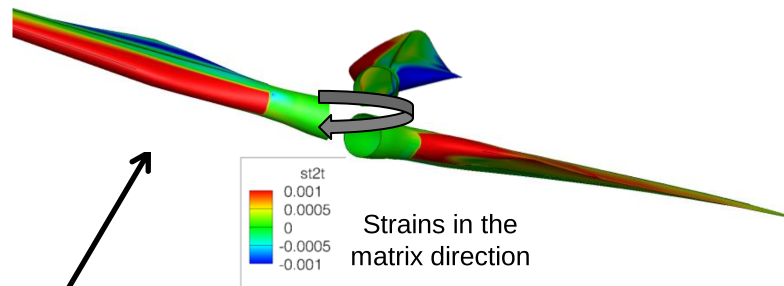
DDAS Loop for Detected In-plane Waviness



SENSOR DATA/ MEASUREMENTS

Request for additional or refined sensor data

IGA SIMULATION



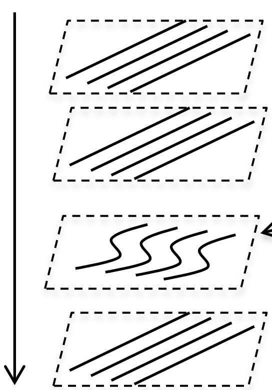
Strains in the matrix direction

Defect detection, geometry and type

Input for analysis, data for mesh refinement based on error indicators

IGA MESHING AND PREPROCESSING

Through-thickness homogenization



Ply 1

Ply 2

…

Ply i - Wavy

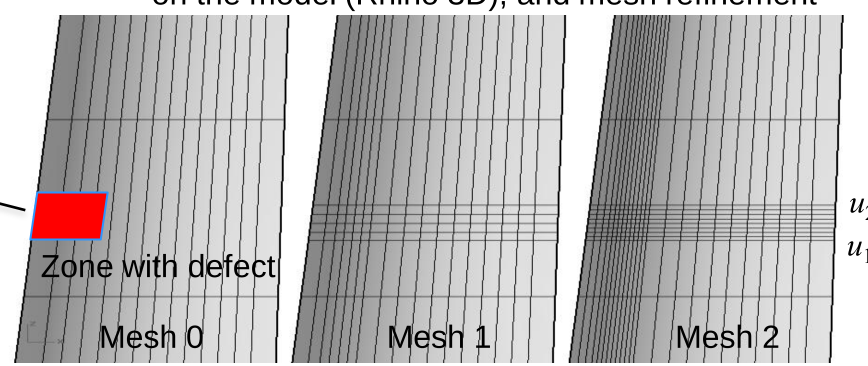
…

Ply N

Parametric description of fiber waviness

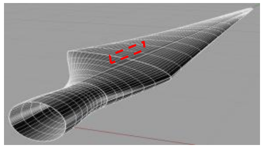
$$\bar{\theta} + \theta_{dev} \sin(2\pi \frac{u - u_1}{u_2 - u_1})$$

Waviness zone and ply identification on the model (Rhino 3D), and mesh refinement

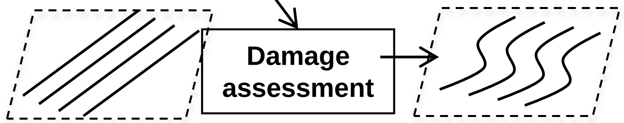


Computational Workflow Diagram

SHM



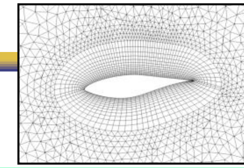
Sensor data

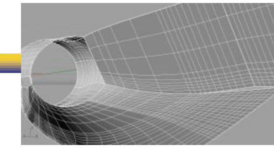


Original composite fiber direction

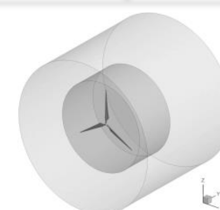
New composite fiber direction

Damage assessment code:
(in house code for sensor data processing and conversion)
Desktop/Single node on HPC cluster
Passive sensors: ~sec - mins
Active sensors: ~mins - hours



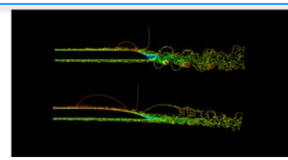


Grid generation code:
Rhino 3D (structural geometry & mesh),
ANSA (fluid mesh),
ParMETIS (decomposition)
Desktop/Large memory HPC node
Structural (re)mesh: ~secs
Fluid mesh (existing template): ~mins
Parallel decomposition: ~mins



FSI code:
Parallel scalable MPI code:
Structural simulation w/ IGA
(adaptive SHM ~mins; can speed-up)
Fluid simulation + FEM FSI coupling
~hours on multicore HPC system
(can speed-up w thin-layer approx'n)

Output:
blade deflection,
vibration freq
…



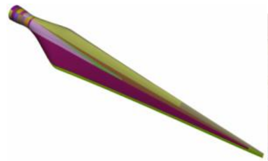
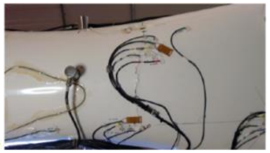
Sensitivity analysis, optimization, control codes:
Ensemble runs (launched in parallel)
using stochastic collocation method,
& surrogate management framework
~hours – day on multicore HPC system
Scalable at each step w/ multiple
simultaneous FSI runs

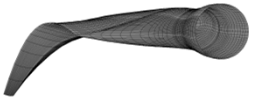
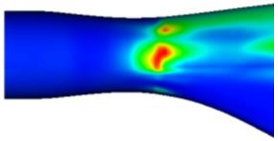
Normal operation
or
feedback to adjust operation

Advanced Simulation, Optimization, and Health Monitoring of Large Scale Structural Systems

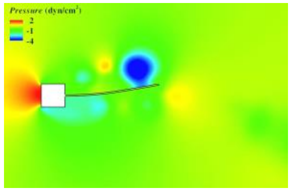
Y. Bazilevs, A.L. Marsden, F. Lanza di Scalea, A. Majumdar, and M. Tatineni (UCSD)

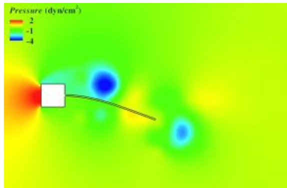
Fatigue damage prediction for full-scale structure in a lab setting

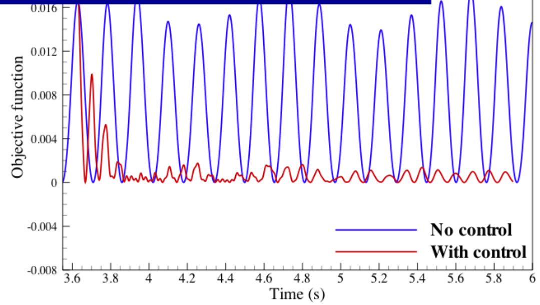




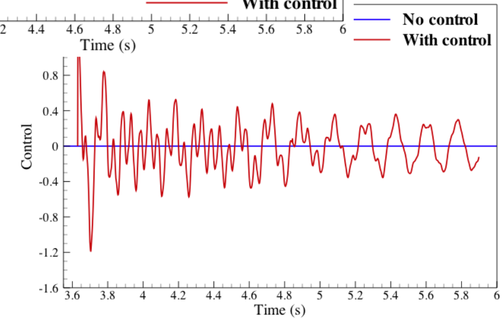



Adjoint-Based Control for FSI

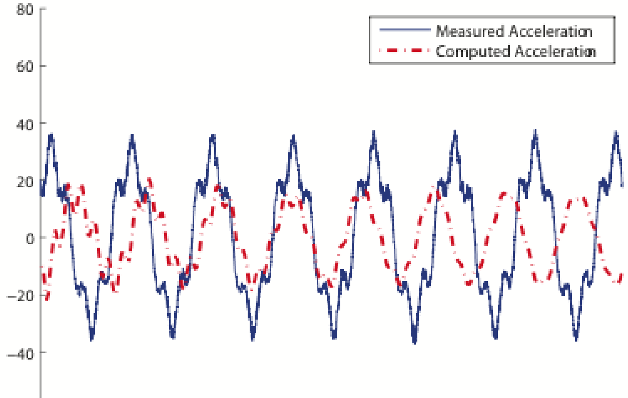




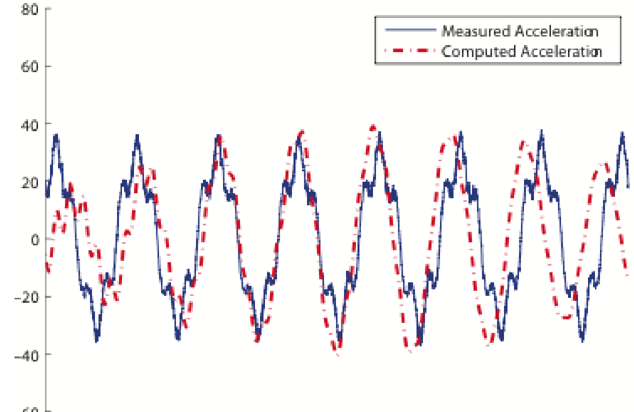




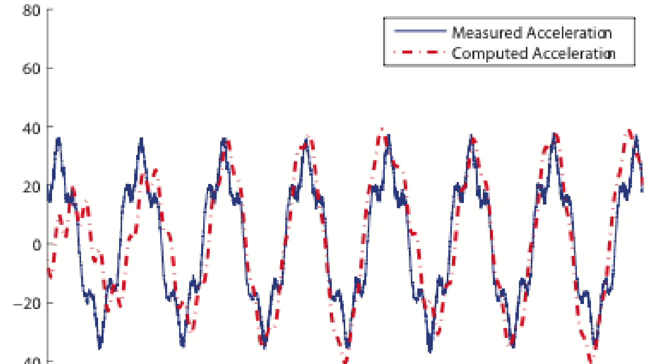
Acceleration



(a) No DDDAS



(b) With DDDAS



(c) Further calibration

Advanced Simulation, Optimization, and Health Monitoring of Large Scale Structural Systems

Y. Bazilevs, A.L. Marsden, F. Lanza di Scalea, A. Majumdar, and M. Tatineni (UCSD)

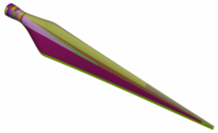
Using the DDDAS paradigm the project has developed :

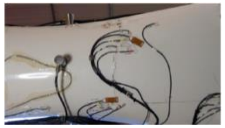
- new **multiscale** laminated-composite **fatigue damage model** data-based dynamic calibration
- new algorithm for numerical **fatigue testing and failure prediction** for laminated composite structures driven by dynamic accelerometer data
- new formulation and algorithm for **adjoint-based control** in coupled **fluid-structure interaction**
- new software based on **isogeometric analysis** for modeling **complex geometry** and material layout, including measured defects, for large-scale composite structures

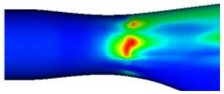
Results:

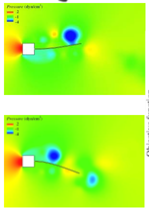
- new capability to dynamically update advanced fatigue damage models in full-scale structural simulations with the goal to predict the remaining fatigue life of a structure

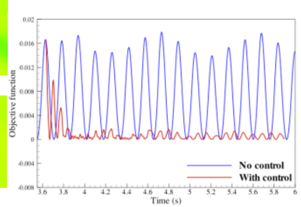
Fatigue damage prediction for full-scale structure in a lab setting

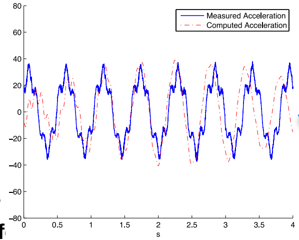




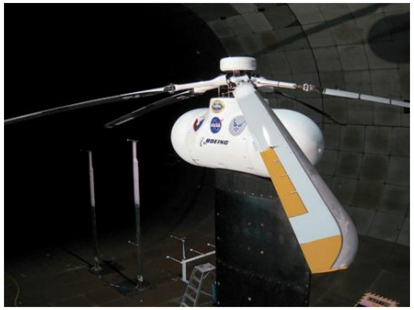








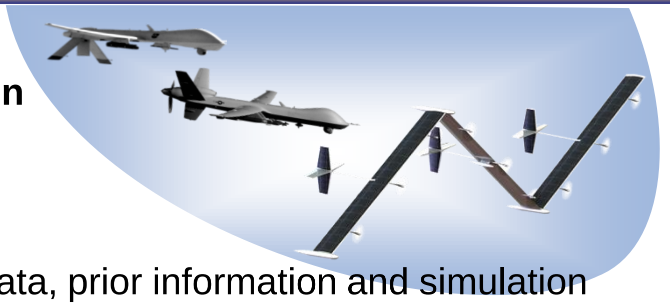
Prediction of fatigue damage in real operating conditions…



… and sheltering of structures from excessive damage

Dynamic Data-Driven Methods for Self-Aware Aerospace Vehicles

D Allaire, L Mainini, F Ulker, M Lecerf, H Li, K Willcox (MIT); G Biros, O Ghattas (UT Austin);
J Chambers, R Cowlagi, D Kordonowy (Aurora)



A self-aware aerospace vehicle; dynamically adapt to perform mission cognizant of itself and its surroundings and responding intelligently.

Approach and objectives

- **infer** vehicle health and state through dynamic integration of sensed data, prior information and simulation models
- **predict** flight limits through updated estimates using adaptive simulation models
- **re-plan** mission with updated flight limits and health-awareness based on sensed environmental data

Research Goal: multifidelity framework using DDAS paradigm

- draws on multiple modeling options and data sources to evolve models, sensing strategies, and predictions
- dynamic data inform online adaptation of structural damage models and reduced-order models
- dynamic guidance of sensing strategies
- dynamic, online multifidelity structural response models&sensor-data, for predictions w sufficient confidence

Results: dynamic health-aware mission re-planning with quantifiable benefits in reliability, maneuverability and survivability.

Methodologies

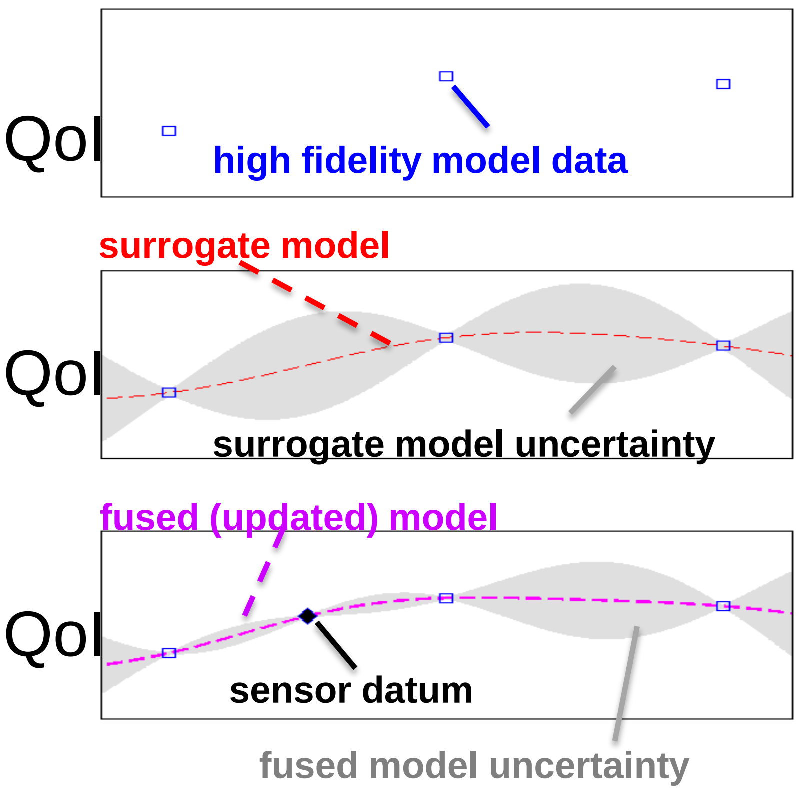
- statistical inference for dynamic vehicle state estimation, using machine learning and reduced-order modeling
- adaptive reduced-order models for vehicle flight limit prediction using dynamic data
- on-line management of multi-fidelity models and sensor data, using variance-based sensitivity analysis
- quantify the reliability, maneuverability and survivability benefits of a self-aware UAV

Dynamic Data-Driven Methods for Self-Aware Aerospace Vehicles

D. Allaire, K. Willcox (MIT); G. Biros, O. Ghattas (UT Austin); J. Chambers, D. Kordonowy (Aurora)

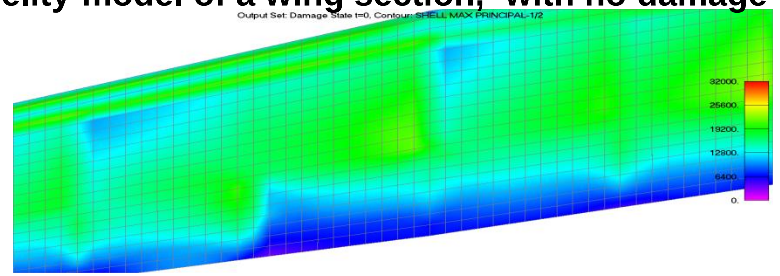
Data Incorporation Examples

Surrogate Models

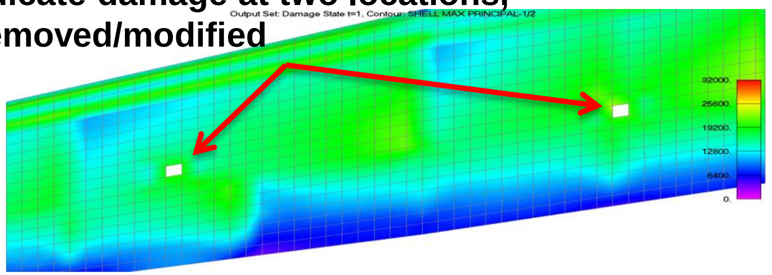


Structural Damage Models

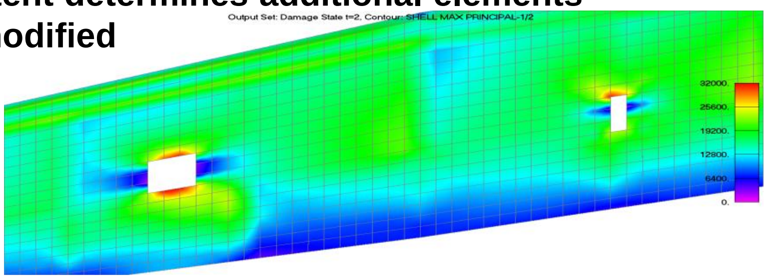
Medium-fidelity model of a wing section, with no damage



Sensors indicate damage at two locations, elements removed/modified



Damage extent determines additional elements Removed/modified



Dynamic Data-Driven Methods for Self-Aware Aerospace Vehicles

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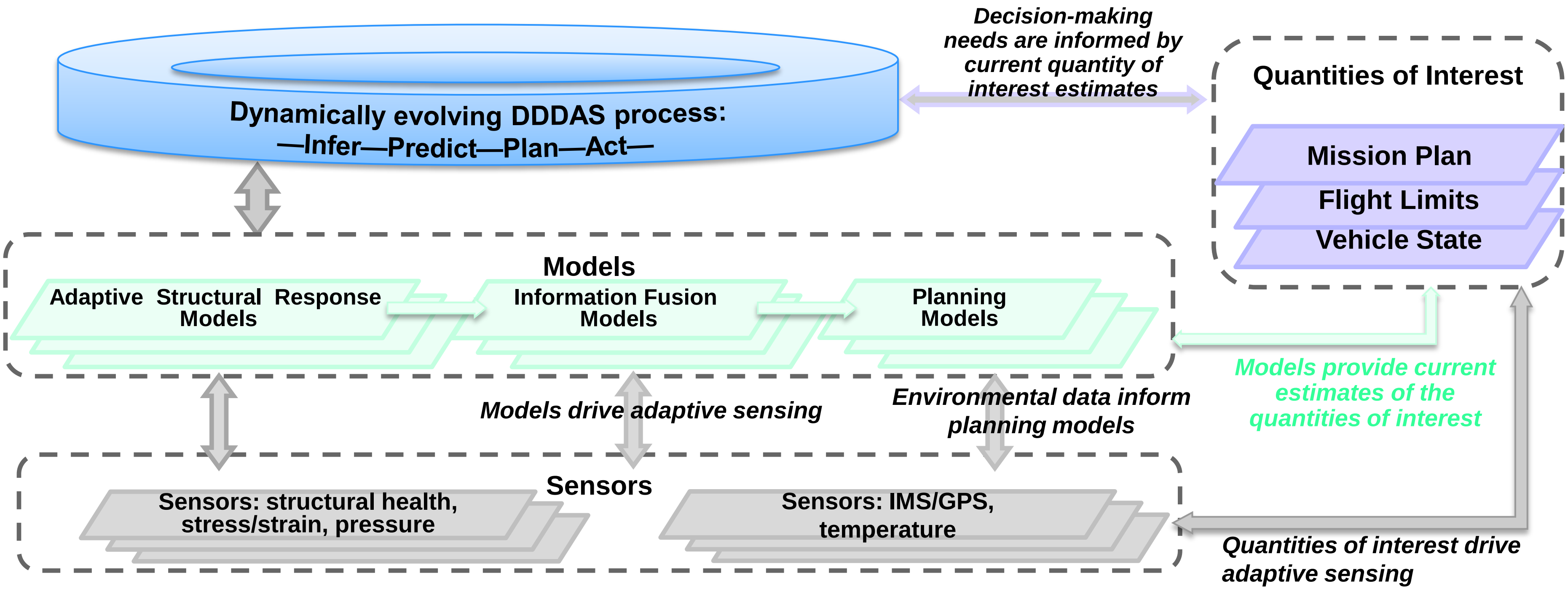

INFERENCE

- Confident estimation of vehicle state in offline phase, time-sensitive estimation of vehicle state in online phase
- Onboard damage model updated using sensed structural data/state
- Efficient algorithms scale well on GPU and manycore architectures

PREDICTION

- Update estimates of flight limits via adaptive reduced-order models
- Progressively fuse higher fidelity information with current information as more time and resources become available
- Sensitivity analysis for dynamic online management of multifidelity models & sensors for vehicle state & flight limit

PLANNING

Dynamic environmental data inform online adaption of reduced-order models for mission planning

Multifidelity planning approaches using reduced-order models

Quantification of reliability, maneuverability, survivability

Dynamic Data-Driven Methods for Self-Aware Aerospace Vehicles

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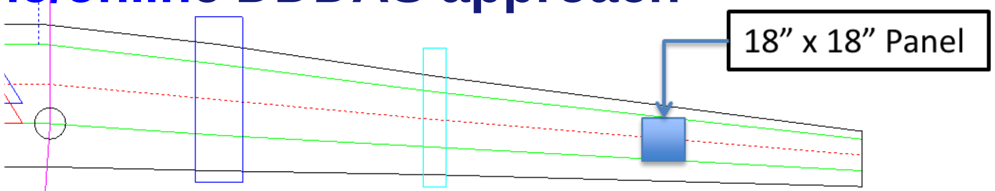
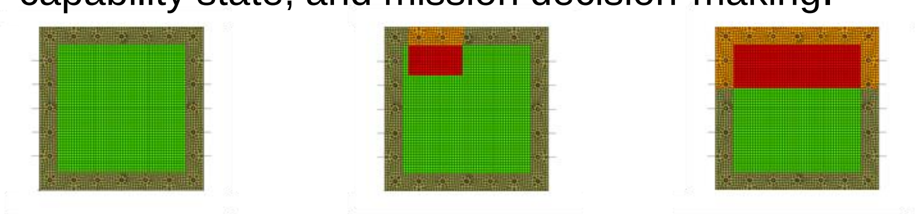
J Chambers, R Cowlagi, D Kordonowy (Aurora)

An offline/online DDDAS approach

- **Test case: composite panel on a UAV**



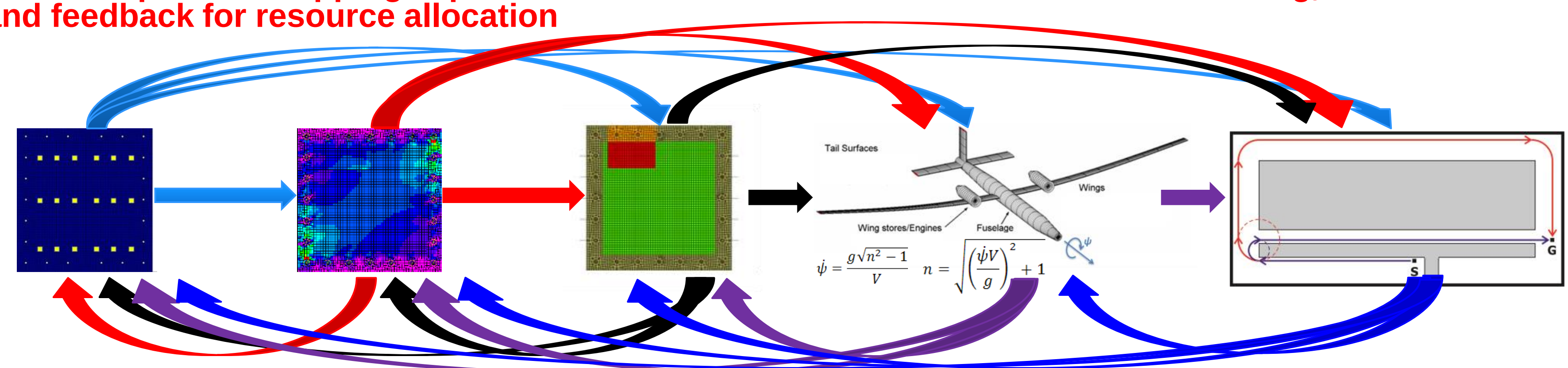
- **Offline:** develop libraries of panel strain information, under different load/damage scenarios under uncertainty. Develop data-driven reduced-order models to map from sensed strain to damage state, capability state, and mission decision-making.



Example damage scenarios caused by ply delamination. Red and orange indicate delamination sites.

- **Online**: information management strategy for dynamic sensor and model-based data acquisition, damage and capability state updates, and dynamic mission re-planning.

Arrows represent mapping capabilities from sensor data to mission decision-making, and feedback for resource allocation



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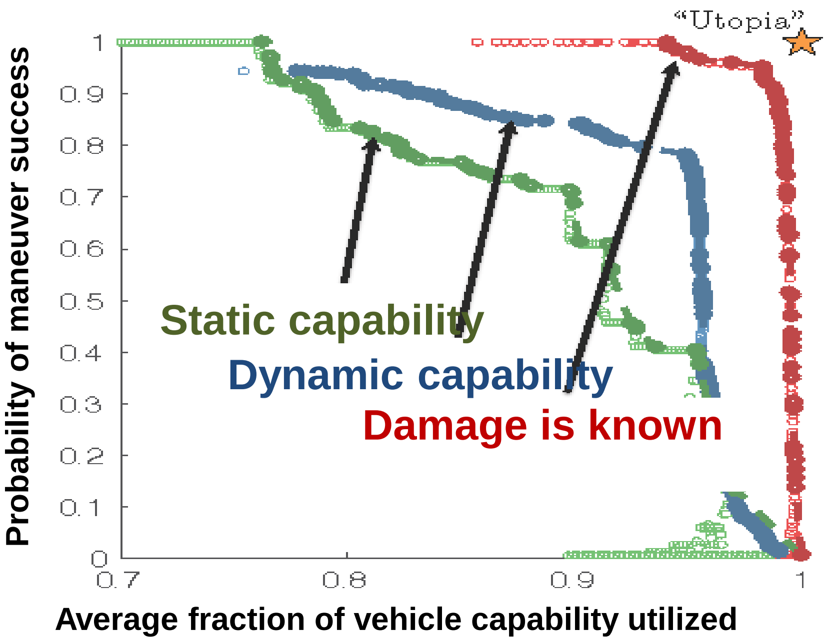
Dynamic Data-Driven Methods for Self-Aware Aerospace Vehicles

D Allaire, L Mainini, F Ulker, M Lecerf, H Li, K Willcox (MIT); G Biros, O Ghattas (UT Austin); J Chambers, R Cowlagi, D Kordonowy (Aurora)

Trade-off curves for evasive maneuver flight scenario decision strategies



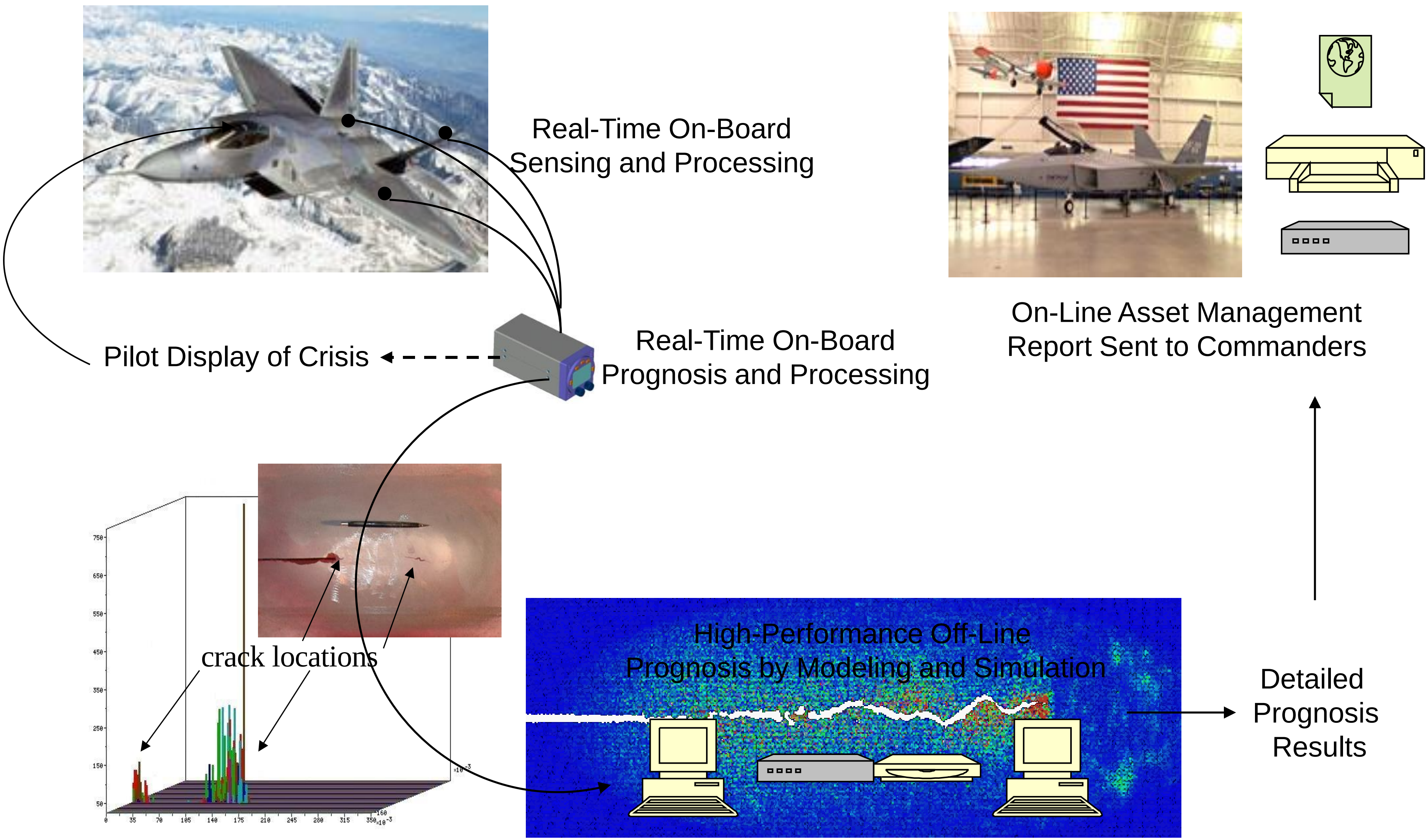
Using the dynamic data through the DDDAS approach increases both vehicle utilization and probability of maneuver success

Highlights of improvements achieved in this project:

- **High-fidelity offline evaluation takes ~5-10 seconds per maneuver per damage case. To evaluate a flight envelope over 100 damage cases and 50 maneuvers takes ~7-14hrs**
- **Online classification using the damage library takes ~100-300 microseconds The DDDAS method yields a speed up of a factor of ~50,000-100,000**
- **Decision support for maneuver**
- **Work transitioned to Aurora Flight Sciences**

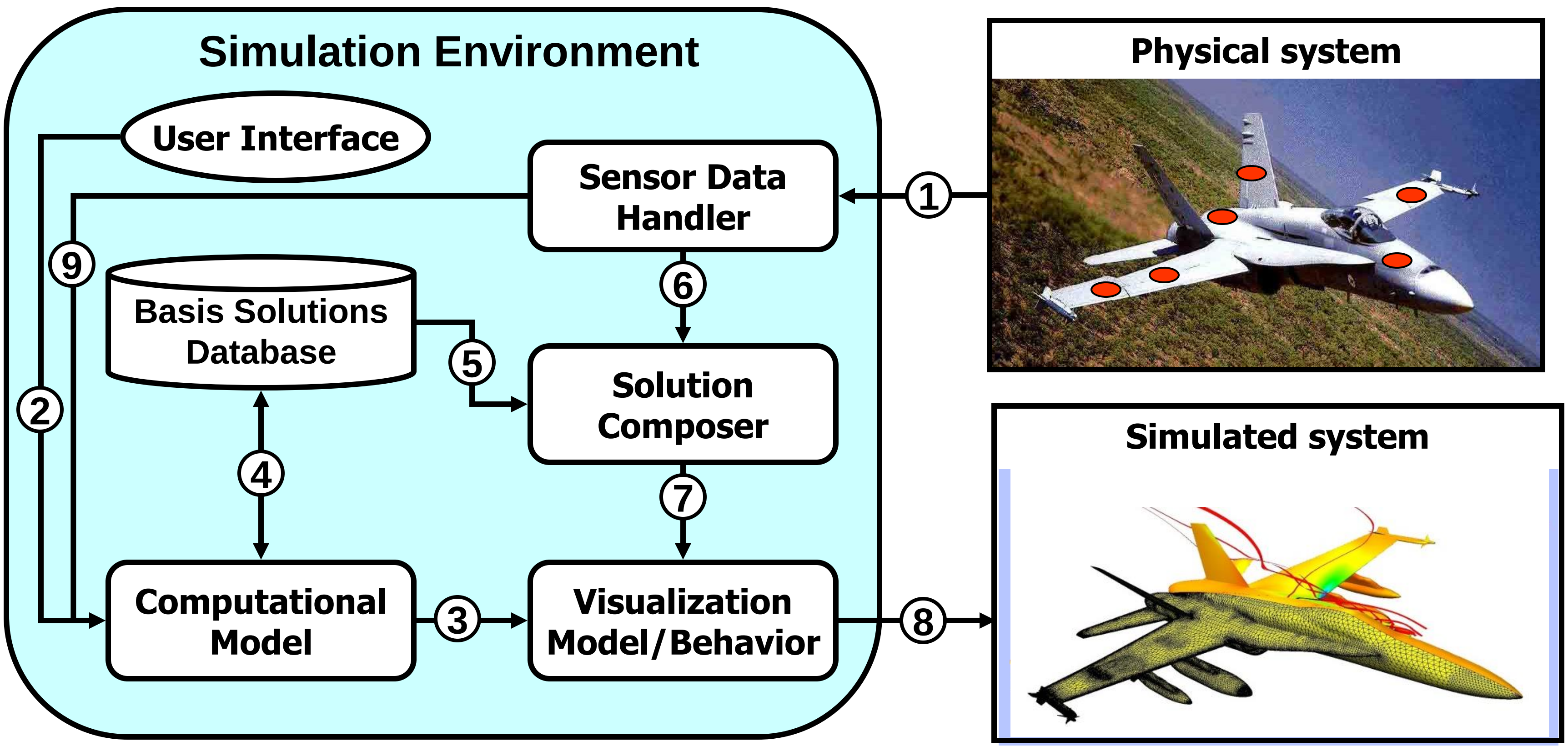
PROGNOSIS

Slides Courtesy C. Farhat



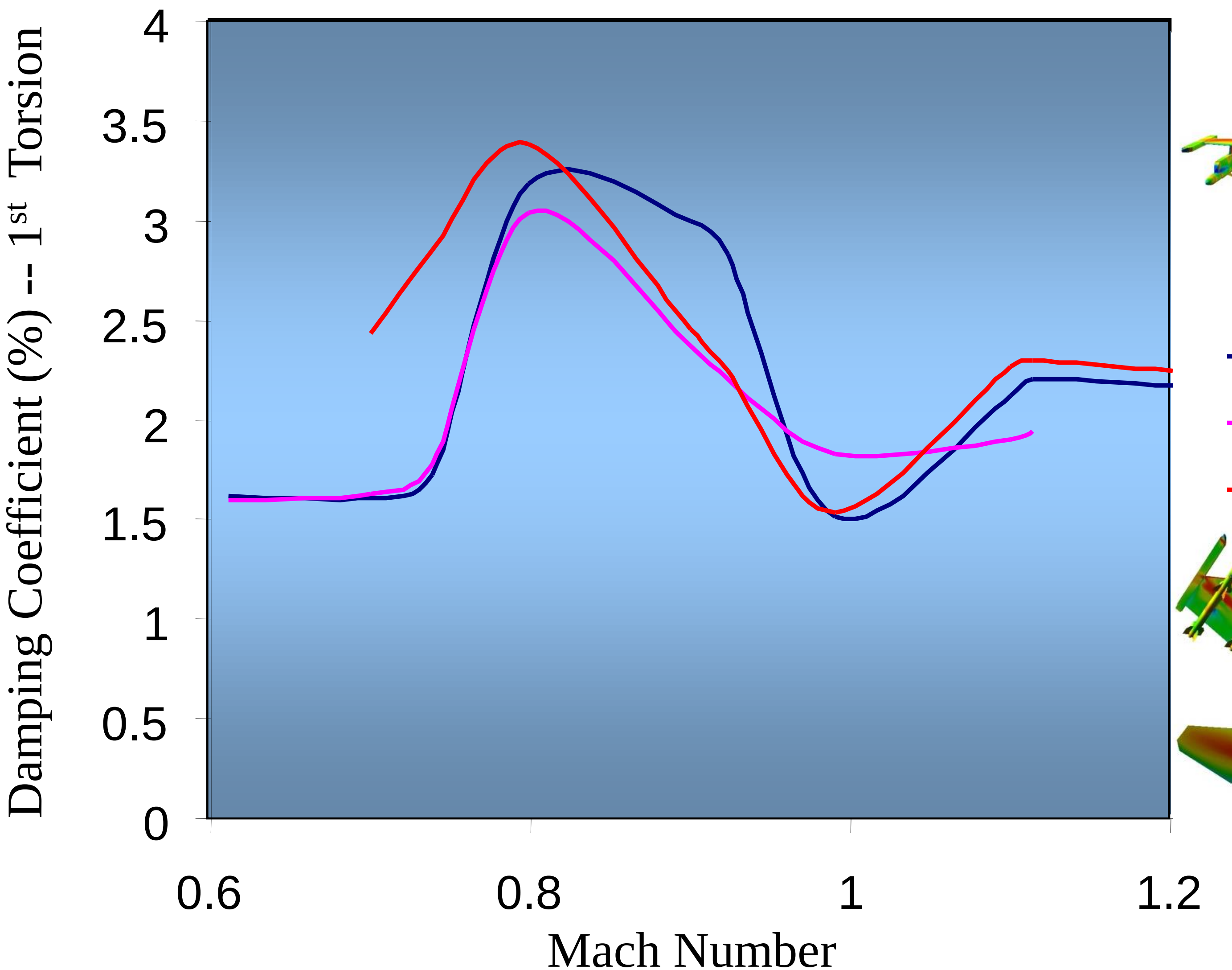
Real-Time Support for *supersonic/hypersonic multiphysics simulation*-based paltform management: Flutter, Temperature & Softening of Skin Material Degradation etc.

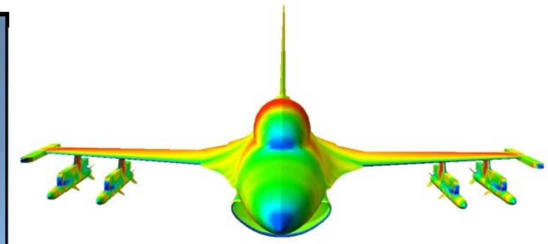
Slides Courtesy C. Farhat

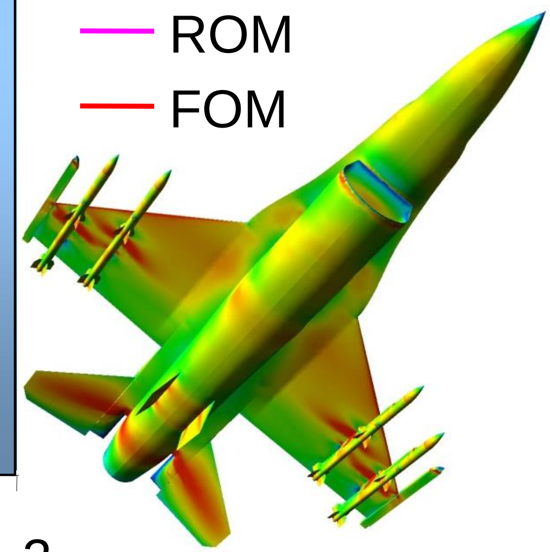


VALIDATION

Slides Courtesy C. Farhat



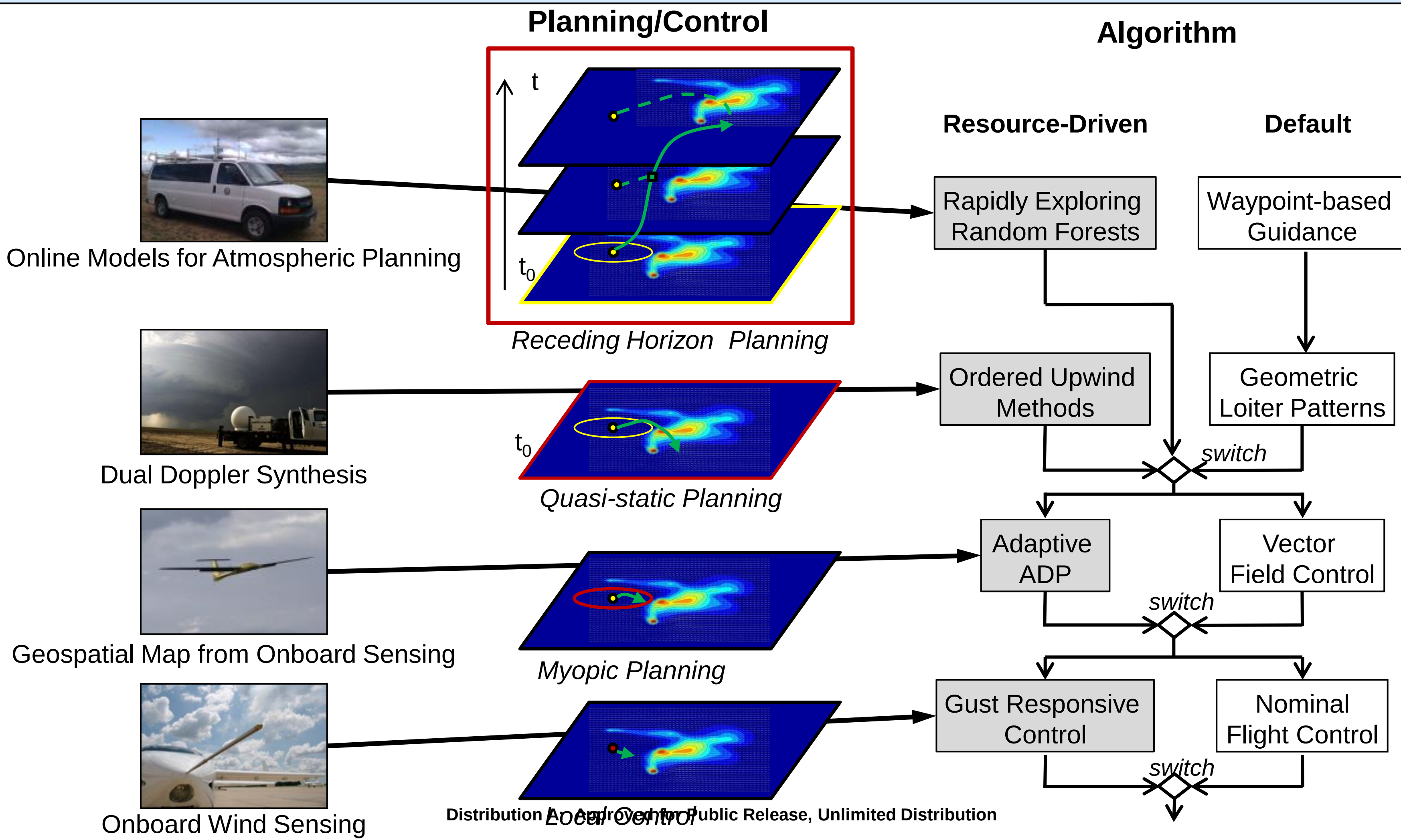




Energy-Aware Aerial Systems for Persistent Sampling and Surveillance

E. W. Frew, Brian Argrow- U of Colorado-Boulder; Adam Houston – U of Nebraska-Lincoln)
Chris Weiss - Texas Tech University

Energy efficient flight planning through dynamically integrated multilevel models and information sources
local aircraft energy and wind states; spatio-temporal wind fields;
dual-Doppler synthesis of regional winds; on-line models for atmospheric planning.



Energy-Aware Aerial Systems for Persistent Sampling and Surveillance

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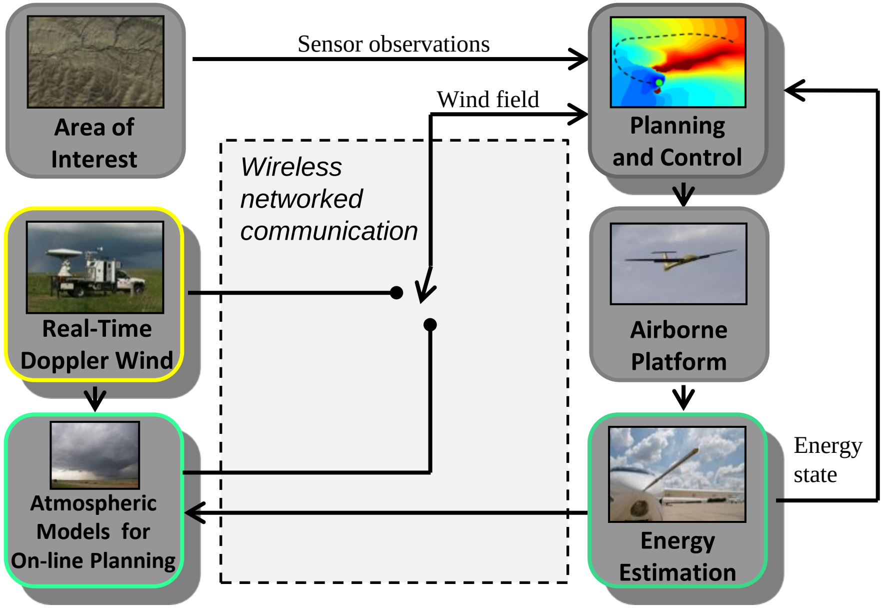


This effort will develop, assess, and deliver new Air Force capabilities in the form of energy-aware, airborne, dynamic data-driven application systems (EA-DDDAS) that can perform persistent sampling and surveillance in complex atmospheric conditions.

Features of the EA-DDDAS span the four key DDDAS technology frontiers

•Decision-making over different **application modeling layers** that include

- local aircraft energy and wind states
- spatio-temporal wind fields
- dual-Doppler synthesis of regional winds
- on-line models for atmospheric planning.

•**Mathematical algorithms** that provide high degree of autonomy with control loops closed over multiple spatial and temporal scales.

•New **measurement systems and methods** whereby disparate information sources are assimilated by online models; mobile sensors are targeted to relevant measurements in real time; and data processing rates are throttled in response to computation resource availability.

•Net-centric middleware **systems software** that connects multiple systems with computation and control resources dispersed over wireless communication networks.

Dynamic Modality Switching Aided Object Tracking using an Adaptive Sensor

Matthew Hoffman , Anthony Vodacek (RIT)

- Create capabilities to ***enhance persistent aerial vehicle tracking in complex environments where single imaging modality is insufficient, and full spectral imaging yields inordinate amounts of data***
- **Approach and objectives**
  - *Use the DDDAS framework to allow the tracker to dynamically control the sensor to specify modality and location of data collection and this data to reduce uncertainty in target location*
  - *Develop algorithms to optimize the use of small amounts of hyperspectral data and evaluate performance in simulated scenes using realistic noise and a moving platform*
  - *Begin development of real data testing scenes*
- **Methodology**
  - Tracker leverages DOTCODE framework from previous AFOSR funding
  - Simulation study leverages existing Digital Imaging and Remote Sensing Image Generation (DIRSIG) scenes of a cluttered urban area
  - Real data collection leverages multispectral WASP Lite sensor at RIT

(left) Simulated DIRSIG image and (right) Google maps image of same area

Multispectral Wasp Lite scene with moving vehicles

Dynamic Modality Switching Aided Object Tracking using an Adaptive Sensor

Matthew Hoffman , Anthony Vodacek (RIT)

- **Object tracking** through particle filtering approach – uses **Gaussian Sum Filter** (GSM needed to handle noise in observing turning vehicles – uses an ensemble of vehicle models)
- **New adaptive image processing methods** for **both the targets and the background**

Introduced new cascaded target detection, combining:

Target Detection/ Background Modeling
- NDVI vegetation detection
- Nonlinear SVM roads classifier
- Spectral matching to target
- Linear SVM/HoG vehicle classifier

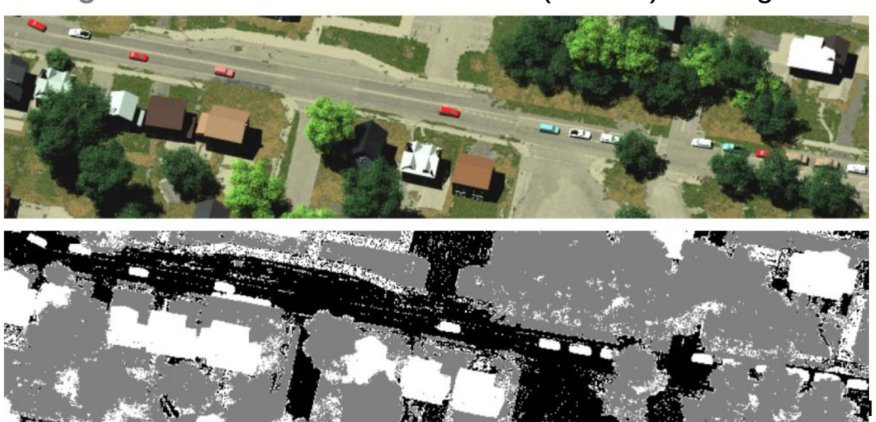
Data Acquisition & Filtering
- MHT Data Association
- Gaussian Sum Filer

Target Movement Model
- Adaptive, multi-model ensemble

Sensor Control & Data Acquisition
- Modality Selection
- Region of interest determination

Processing
- SIFT Keypoint Registration
- Homography Estimation

Vegetation and **road** classification (bottom) of image



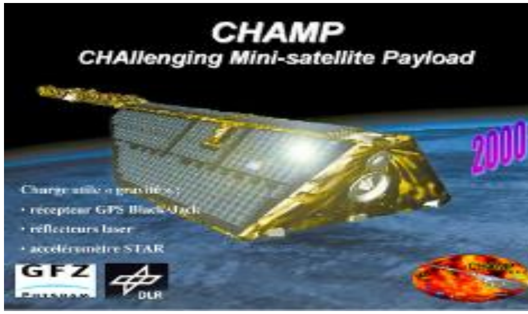
Object tracking through targeted feature matching

Transformative Advances in DDDAS with Application to Space Weather Modeling

Dennis Bernstein (PI), Amy Cohn, James Cutler, Aaron Ridley – U of Michigan

Scientific Motivation

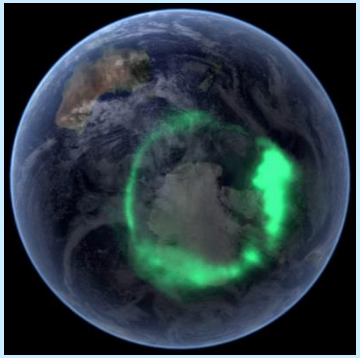
– Unknown changes to the atmospheric density degrade the accuracy of GPS and impede the ability to track space objects



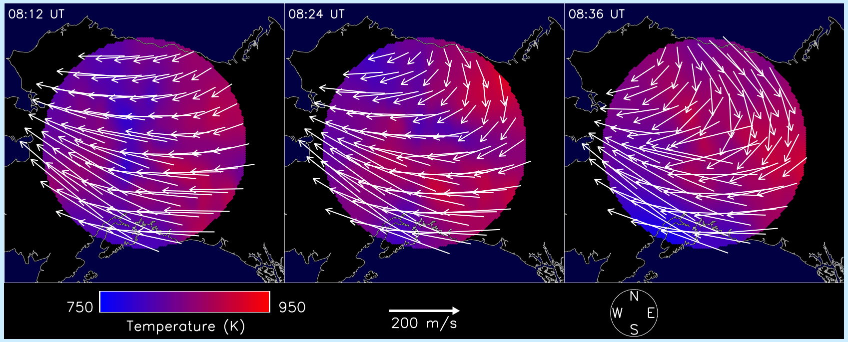
Project Scope and Objectives

– Apply DDDAS concepts and methods to space weather monitoring
– Key goals are input estimation and model refinement to facilitate higher-accuracy data assimilation
– Input reconstruction is used to estimate atmospheric drivers that determine the evolution of the ionosphere-thermosphere
– Model refinement is used to improve the accuracy of atmospheric models
– DDDAS supported by space physics modeling and mission planning and analysis
– DDDAS-based accurate prediction of important quantities: NO, Neutral Density, PhotoElectron Heating, Eddy Diffusion Coefficient Estimate

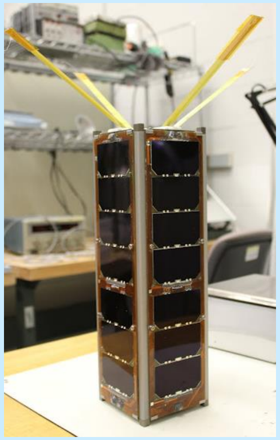
Space Debris



Auroral Heating



Wind Field Estimation



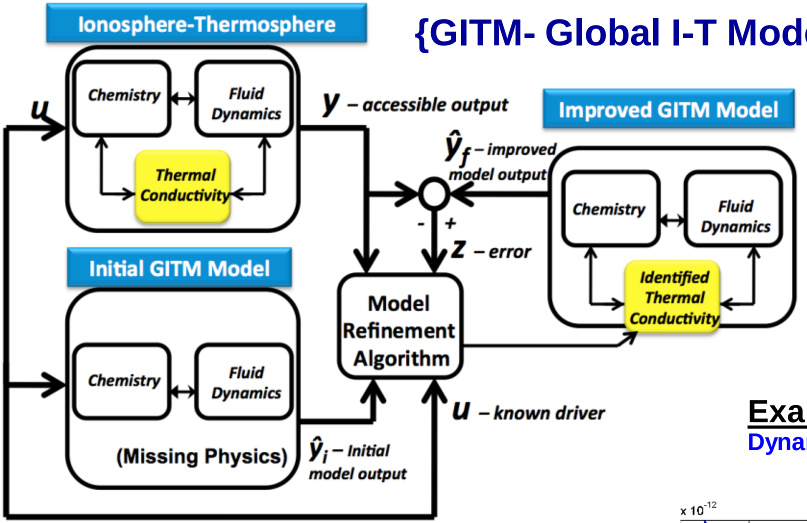
RAX-2 CubeSat

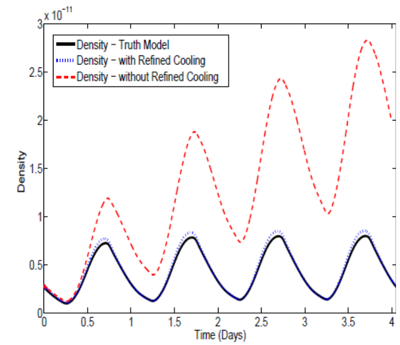
Transformative Advances in DDDAS with Application to Space Weather Modeling

Dennis Bernstein (PI), Amy Cohn, James Cutler, Aaron Ridley – U of Michigan

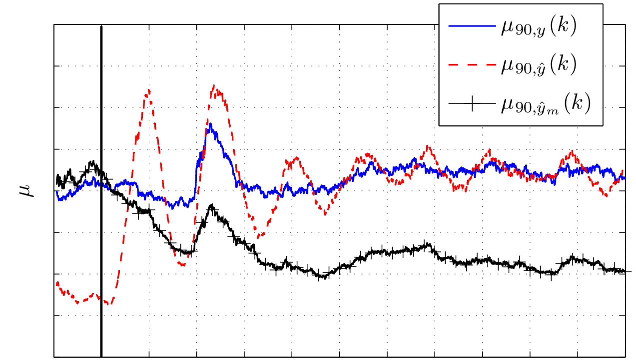
DDDAS Approach: *Model Refinement to Enable Enhanced Data Assimilation*

{GITM- Global I-T Model}

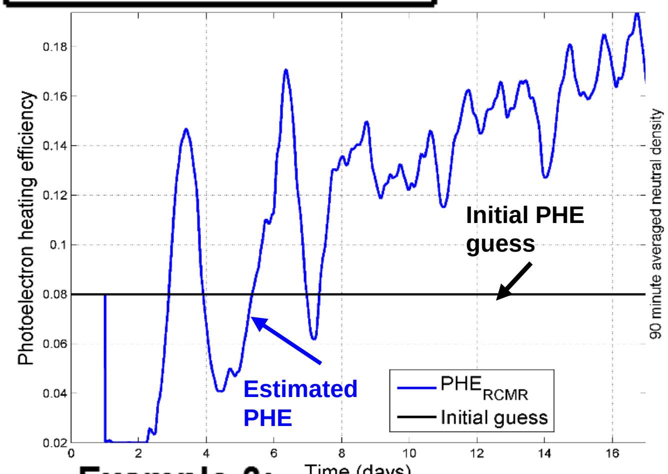




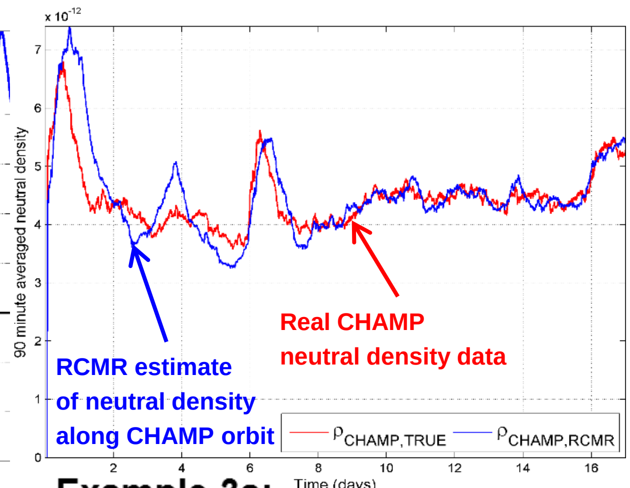
Example 1:
Dynamic estimation of Nitrous-Oxide Density



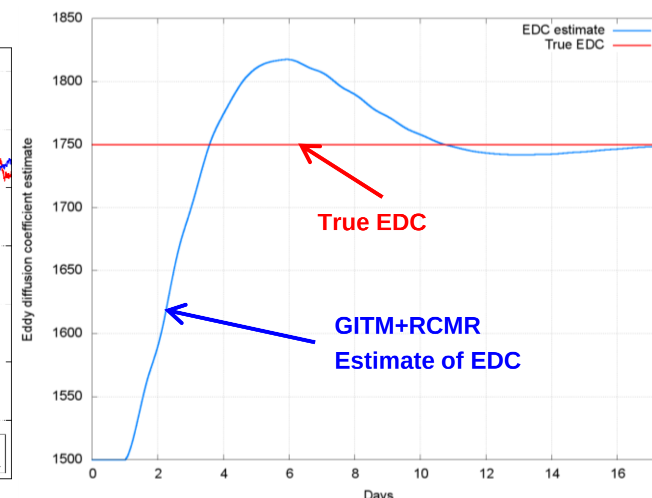
Example 2: Neutral Density



Example 3:
Dynamic estimation of Photoelectron Heating Efficiency using neutral density



Example 3a:
Dynamic estimation of Photoelectron Heating Efficiency using neutral density



Example 4:
Dynamic estimation of Eddy Diffusion Coefficient using total electron content

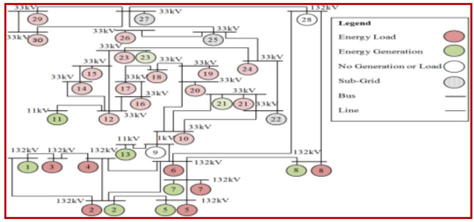
Real-time Assessment and Control of Electric-Microgrids
(YIP – Project)

Nurcin Celik, University of Miami

Motivation: predict/mitigate power outage (case study: effects in an AF Base)

- *How should a real-time diagnosis and forensics analysis be performed automatically?*
- *Did it occur because of an accidental failure or malicious and possibly ongoing attack?*
- *A wide spread disturbance or just a localized outage of a few minutes?*
- *How should the AFB microgrid respond to this abnormality (or catastrophe)?*
- *What actions should be taken to secure the AFB power supply?*

→ **quick responsive and corrective actions via autonomous control**



Approach:

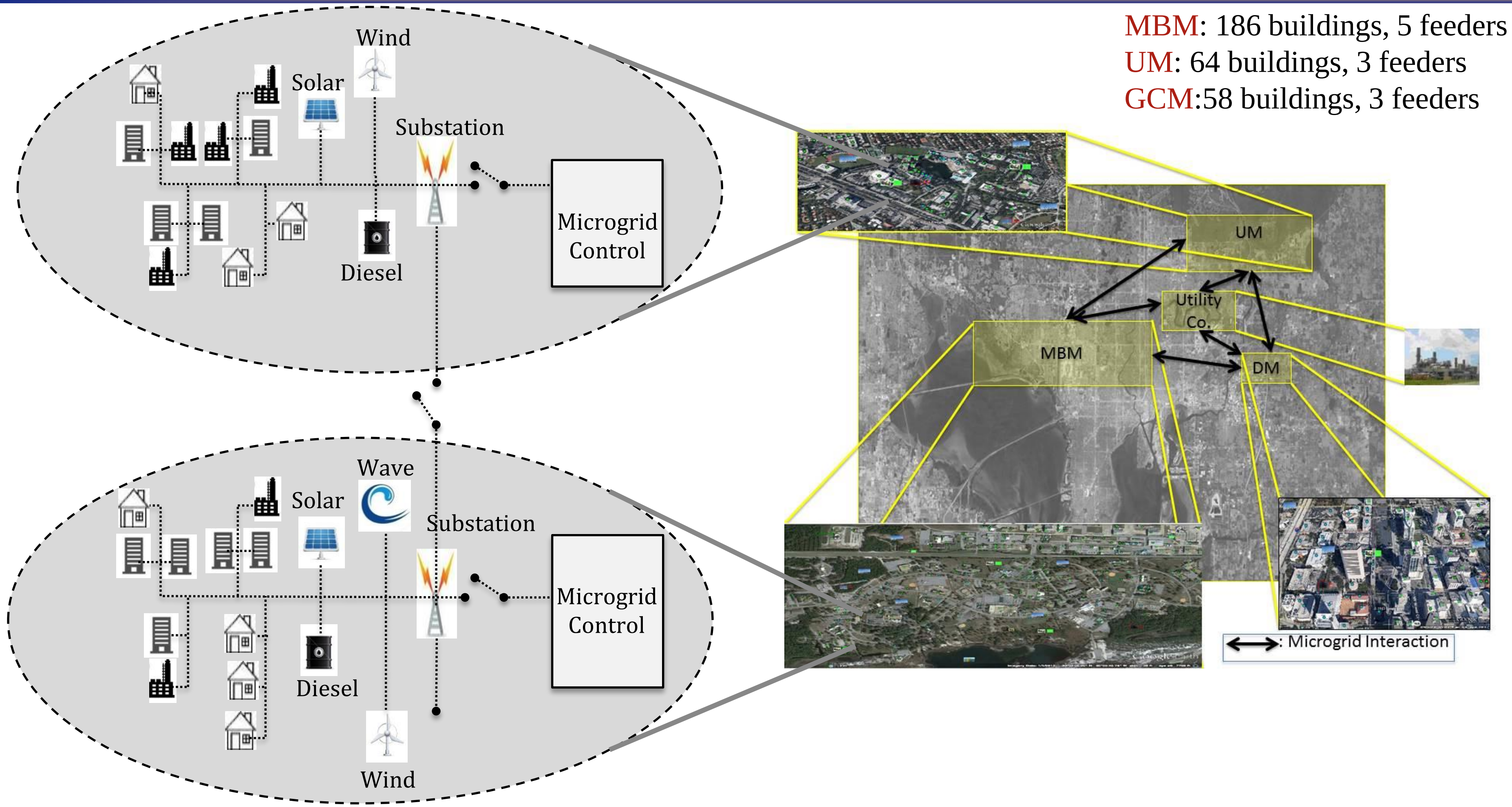
→ *Dynamic Data Driven Adaptive Multi-scale Simulations framework (DDDAMS)*

- *new algorithms and instrumentation methods for RT data acquisition and timely control*

Challenges:

- Large number of variables, nonlinearities and uncertainties
- Intense and time-critical information exchange
- High processing requirements for massive information loads
- Synchronization between the distributed sensor and decision networks

Real-time Assessment and Control of Electric-Microgrids
(YIP – Project)
Nurcin Celik, University of Miami



- **To ensure that primary electrical needs are satisfied while total cost is minimized**
- **To maintain MGs' stability and security by**
  - **Meeting requested demands within each individual MG**
  - **Searching for neighboring MGs for back-up**

Experiments on Self-Healing Microgrids

The proposed DDDAMS approach is tested on MGs that do not share energy in the following cases:

- **Scenario A:** A major hurricane completely wipes out power to GCM for 48 hrs
- **Scenario B:** A terrorist attack within the borders of UM forces MBM to isolate from the local utility for 2 hrs until the threat is cleared (damage on UM link will require 6 hrs to repair)

Demand Satisfaction

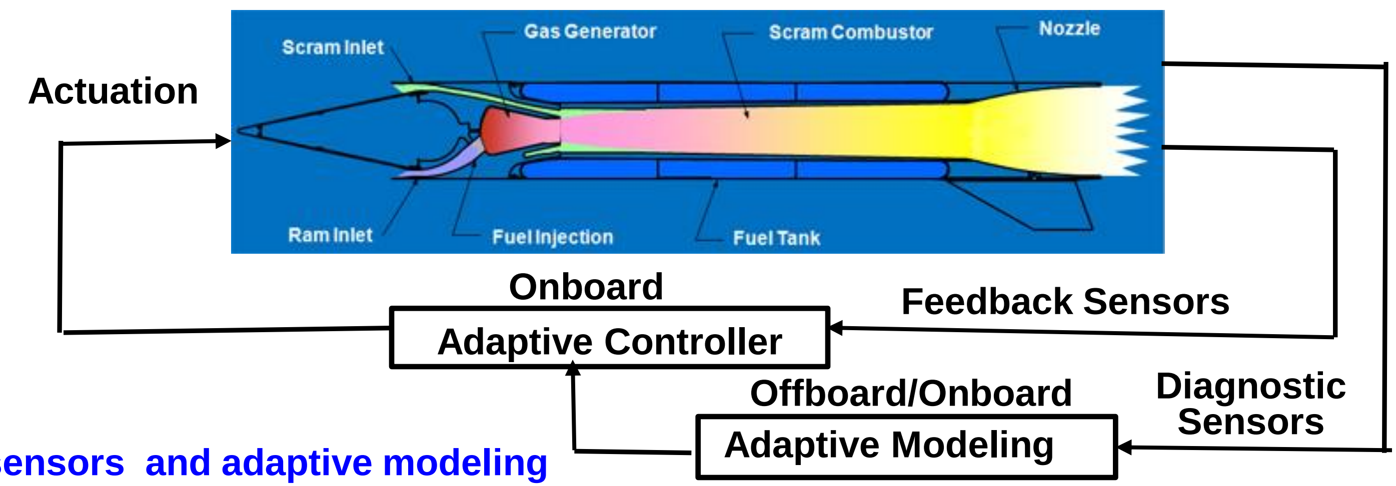
	Scenario	MBM Loads			UM Loads			GCM Loads		
		Cr	Pr	NCr	Cr	Pr	NCr	Cr	Pr	NCr
No Sharing	A	100%	100%	100%	100	100%	100%	46%	0%	0%
	B	97.6%	79%	66.4%	45.2%	4%	0%	100%	100%	100%
Sharing	A	100%	100%	95.7%	100%	93.2%	27.9%	100%	0%	0%
	B	98.6%	94%	66.4%	97%	41.1%	6%	99%	52.1%	26%

Cr: Critical Pr: Priority NCr: Non-critical

An example of other possible future scope of work
Estimation and Control of Highly Inaccessible Dynamics in Complex Systems

- **Major challenges for understanding, characterization, performance optimization, adaptive control in real-world natural&engineered systems and their applications are due to a combination of:**
  - **high degree of non-linearity; very high dimensionality of the parameter space;**
  - **epistemic and aleatoric uncertainty; and hard constraints on states and control inputs**
- **Examples include: turbulent flows for complex and adaptive aircraft configurations; combustion in jet engines and scramjets; instabilities in structures; and programmable metamaterials (e.g. solitons/breathers; quantum information devices)**
- **Measurements are difficult to attain, and models alone do not afford the fidelity needed, in highly unstable (&inaccessible) regions**
- **Dynamic Data-Driven Application Systems (DDDAS) based methods**
  - **combine estimation and control techniques with real-time computation and data**
  - **dynamically couple an executing model with the instrumentation, allow targeted collection of data and compensate for data sparsity in the measurement or the solution phase space**

Highly Complex System (Scramjet)



DDDAS uses diagnostic sensors and adaptive modeling to provide crucial information for controller adaptation

Examples of Sci&Tech Highlights
of Outcomes/Results/Achievements through DDDAS

Materials modeling - Structural Health Monitoring

- Demonstrated that DDDAS-based materials modeling can model regions of instabilities leading to exploitation of new properties in materials
- Have demonstrated that DDDAS models can predict the onset of damage prior to being detected experimentally

Self -Cognizant and Environment -Cognizant UAS Mission Planning

- Demonstrated that DDDAS methods allow decision support in real-time with accuracy of large scale simulation – e.g.: DDDAS method yields a speed up of a factor of ~50,000-100,000 - online classification using the damage library takes ~100-300 microseconds.

Algorithmic Advances in UQ

- Demonstrated effectiveness of PCQ in a broader class of systems than gPC; developing further improved UQ methods based on the DDDAS paradigm

Improved sensing approaches

- Demonstrated that intelligent deployment of mobile sensors provides improved efficiencies – e.g. one mobile sensor (DDDAS model driven) vs 7 stationary sensors

Cybersecurity

- Demonstrated theoretical basis for resilient software security.

Summary and QUO Vadimous

Key strategies and directions

- Transformational Research - Dynamic Data-Driven methods for Adaptive, Agile, Autonomic systems; end-to-end capabilities
- Responsive to AF needs, Transformational Impact to the AF and other sectors
- Impact to civilian sector applications

Expansion Opportunities

- Expanding interactions with AFRL, ONR/NRL, ARO/ARL
- Expanding collaborations and leverage other Agencies' efforts
- Expanding international collaborations
- Expanding/leveraging industry partnerships

(1998- … precursor Next Generation Software Program)
SystemsSoftware – Runtime Compiler – Dynamic Composition – Performance Engineering

(2000 -Through NGS/ITR Program)
Pingali, Adaptive Software for Field-Driven Simulations

(2001 -Through ITR Program)
Biegler – Real-Time Optimization for Data Assimilation and Control of Large Scale Dynamic Simulations
Car – Novel Scalable Simulation Techniques for Chemistry, Materials Science and Biology
Knight – Data Driven design Optimization in Engineering Using Concurrent Integrated Experiment and Simulation
Lonsdale – The Low Frequency Array (LOFAR) – A Digital Radio Telescope
McLaughlin – An Ensemble Approach for Data Assimilation in the Earth Sciences
Patrikalakis – Poseidon – Rapid Real-Time Interdisciplinary Ocean Forecasting: Adaptive Sampling and Adaptive Modeling in a Distributed Environment
Pierrehumbert- Flexible Environments for Grand-Challenge Climate Simulation
Wheeler- Data Intense Challenge: The Instrumented Oil Field of the Future

(2002 -Through ITR Program)
Carmichael – Development of a general Computational Framework for the Optimal Integration of Atmospheric Chemical Transport Models and Measurements Using Adjoints
Douglas-Ewing-Johnson – Predictive Contaminant Tracking Using Dynamic Data Driven Application Simulation (DDDAS) Techniques
Evans – A Framework for Environment-Aware Massively Distributed Computing
Farhat – A Data Driven Environment for Multi-physics Applications
Guibas – Representations and Algorithms for Deformable Objects
Karniadakis – Generalized Polynomial Chaos: Parallel Algorithms for Modeling and Propagating Uncertainty in Physical and Biological Systems
Oden – Computational Infrastructure for Reliable Computer Simulations
Trafalis – A Real Time Mining of Integrated Weather Data

(2003 -Through ITR Program)
Baden – Asynchronous Execution for Scalable Simulation in Cell Physiology
Chaturvedi– Synthetic Environment for Continuous Experimentation (Crisis Management Applications)
Droegemeier-Linked Environments for Atmospheric Discovery (LEAD)
Kumar – Data Mining and Exploration Middleware for Grid and Distributed Computing
Machiraju – A Framework for Discovery, Exploration and Analysis of Evolutionary Data (DEAS)
Mandel – DDDAS: Data Dynamic Simulation for Disaster Management (Fire Propagation)
Metaxas- Stochastic Multicue Tracking of Objects with Many Degrees of Freedom
Sameh – Building Structural Integrity
{Sensors Program: Seltzer – Hourglass: An Infrastructure for Sensor Networks}

(2004 -Through ITR Program)
Brogan – Simulation Transformation for Dynamic, Data-Driven Application Systems (DDDAS)
Baldridge – A Novel Grid Architecture Integrating Real-Time Data and Intervention During Image Guided Therapy
Floudas-In Silico De Novo Protein Design: A Dynamically Data Driven, (DDDAS), Computational and Experimental Framework
Grimshaw: Dependable Grids
Laidlaw: Computational simulation, modeling, and visualization for understanding unsteady bioflows
Metaxas – DDDAS - Advances in recognition and interpretation of human motion: An Integrated Approach to ASL Recognition
Wheeler: Data Driven Simulation of the Subsurface: Optimization and Uncertainty Estimation

(2005 DDDAS Multi-Agency Program – NSF/NIH/NOAA/AFOSR)
Ghattas - MIPS: A Real-Time Measurement-Inversion-Prediction-Steering Framework for Hazardous Events
How - Coordinated Control of Multiple Mobile Observing Platforms for Weather Forecast Improvement
Bernstein - Targeted Data Assimilation for Disturbance-Driven Systems: Space weather Forecasting
McLaughlin - Data Assimilation by Field Alignment
Leiserson - Planet-in-a-Bottle: A Numerical Fluid-Laboratory
Chryssostomidis - Multiscale Data-Driven POD-Based Prediction of the Ocean
Ntaimo - Dynamic Data Driven Integrated Simulation and Stochastic Optimization for Wildland Fire Containment
Allen - DynaCode: A General DDDAS Framework with Coast and Environment Modeling Applications
Douglas - Adaptive Data-Driven Sensor Configuration, Modeling, and Deployment for Oil, Chemical, and Biological Contamination near Coastal Facilities
Clark - Dynamic Sensor Networks - Enabling the Measurement, Modeling, and Prediction of Biophysical Change in a Landscape
Golubchik - A Generic Multi-scale Modeling Framework for Reactive Observing Systems
Williams - Real-Time Astronomy with a Rapid-Response Telescope Grid
Gilbert - Optimizing Signal and Image Processing in a Dynamic, Data-Driven Application System
Liang - SEP: Intergrating Multipath Measurements with Site Specific RF Propagation Simulations
Chen - SEP: Optimal interlaced distributed control and distributed measurement with networked mobile actuators and sensors
Oden - Dynamic Data-Driven System for Laser Treatment of Cancer
Rabitz - Development of a closed-loop identification machine for bionetworks (CLIMB) and its application to nucleotide metabolism
Fortes - Dynamic Data-Driven Brain-Machine Interfaces

McCalley - Auto-Steered Information-Decision Processes for Electric System Asset Management
Downar - Autonomic Interconnected Systems: The National Energy Infrastructure
Sauer- Data-Driven Power System Operations

Ball - Dynamic Real-Time Order Promising and Fulfillment for Global Make-to-Order Supply Chains
Thiele - Robustness and Performance in Data-Driven Revenue Management
Son - Dynamically-Integrated Production Planning and Operational Control for the Distributed Enterprise

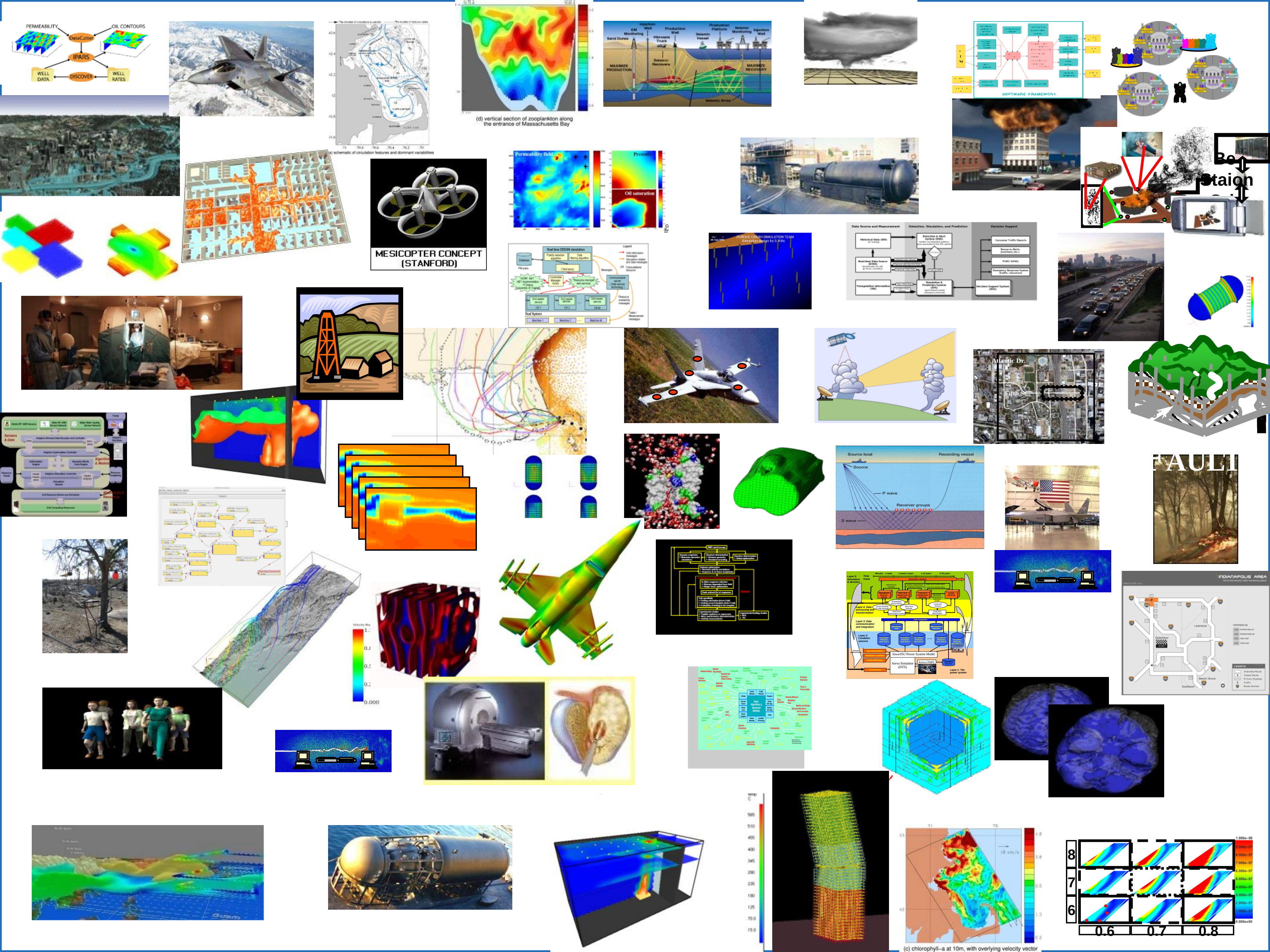
+ . . .

* projects, funded through other sources and "retargeted by the researchers to incorporate DDDAS"

* ICCS/DDDAS Workshop Series, yearly 2003 – todate
• other workshops organized by the community…

• 2 Workshop Reports in 2000 and in 2006, in www.cise.nsf.gov/dddas & www.dddas.org

* www.dddas.org (maintained by Prof. Craig Douglas)


PERMEABILITY
OIL CONTOURS
DataCutter
IPARS
WELL DATA
DISCOVER
WELL RATES
(a) schematic of circulation features and dominant variabilities
(d) vertical section of zooplankton along the entrance of Massachusetts Bay
SOFTWARE FRAMEWORK
Permeability field
Pressure
Oil saturation
MESICOPTER CONCEPT (STANFORD)
Real time DDDAS simulation
Legend
Atlantic Dr.
Fifth St.
Source boat
Recording vessel
Source
P wave
Receiver groups
S wave
INDIANAPOLIS AREA
(c) chlorophyll-a at 10m, with overlying velocity vector
8
7
6
0.6
0.7
0.8