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*National Science Foundation
4th Annual Cyber-Physical Systems PI Meeting
Arlington, Virginia
October 17-18, 2013*

Cyber-Physical Systems Testbeds Panel
**Boeing Collaborative Systems
(Swarms) Laboratory**

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The Boeing Company

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Founded in 1916 in Puget Sound region of Washington state with a heritage that mirrors the history of flight. Aerospace pioneers now part of the Boeing enterprise include: North American Aviation, McDonnell Douglas, Rockwell International (space and defense business), Hughes Space & Communications, and Jeppesen.

Boeing Commercial Airplanes



Integrated Defense & Space Systems



Finding, creating, integrating and replicating technology solutions, processes, and leadership skills across the enterprise and the globe.

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**Boeing Central Research, Development and Innovation
organization creating the future of aerospace**

Presentation Overview

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- **Why a swarms lab?**
- **How has it been used?**
- **What is in the lab?**
- **How might it be useful as CPS testbed?**
- **Feedback & Questions**

Autonomous Collaborative Systems-- The Opportunity

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Cooperative automated systems can reduce the cost while also improving performance when compared to today's generally single-platform solutions-- whether it is in terms of goods moved, area searched, communication coverage, surveillance persistence, enemy suppressed, or environmental parameters monitored.

“complex/coupled systems”

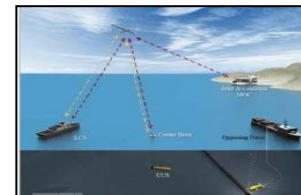
Large number of on/off-board sensors
Large number of interdependent decisions
Large number of failure modes

More-autonomous airplanes will interact intuitively and safely with future generation pilots and NextGen ground/space-based communication & control systems.



NextGen
Commercial

Autonomous multi-aircraft systems will perform defense & security by operating in teams and swarms to execute complex missions with minimal human supervision.



Defense &
Security

Air and ground vehicles will be on the internet-of-things performing search & rescue, environment monitoring, and agriculture services in teams with humans.



Civilian UAS

Heterogeneous mobile robot teams will autonomously perform complex assembly tasks without factory infrastructure.



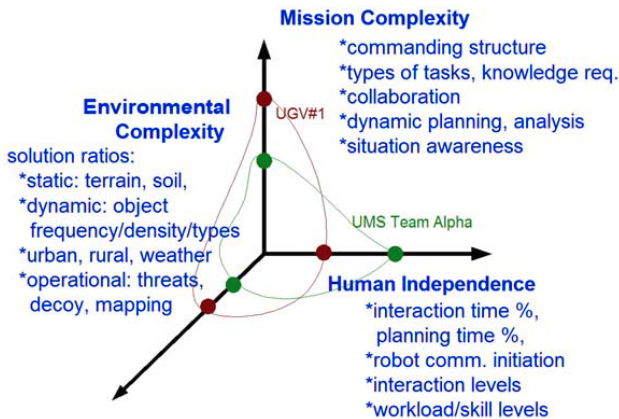
Automated
Assembly

Future aerospace systems will be more *autonomous* and *interact* with many other components (e.g. they are becoming complex/coupled systems)

Autonomous Collaborative Systems-- The Challenge

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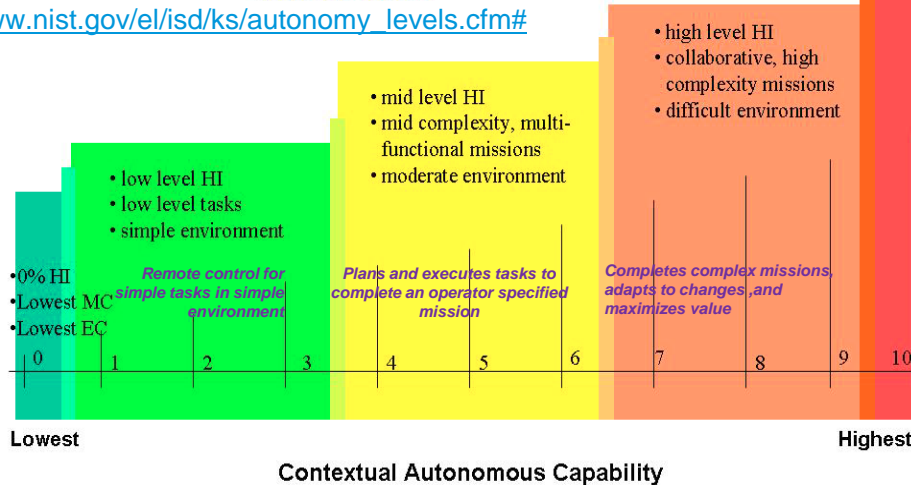
Autonomous cooperative systems can reduce operational costs and improve performance. However, development can difficult and risky.



http://www.nist.gov/el/isd/ks/autonomy_levels.cfm#

Accommodating increasing system complexity is very difficult.

- approaching 100 HI
- highest complexity, all missions
- extreme environment



Automating coupled systems without degrading safety, mission assurance, and security is very difficult.



<http://www.nts.gov/investigations>

Examples from today's "simple" systems warn of challenges ahead...

Challenge 1: Hybrid Systems Health-adaptive Framework and Control Theory

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Common Technology Supports Many Multi-vehicle Autonomous System Applications

Core Autonomy Technology

- Automated tasking & sequencing
- Cooperative control algorithms
- Health-adaptive architectures
- Automated & adaptive mission management
- Automated asset assignment
- Multi-vehicle trajectory planning
- Automated de-confliction & collision avoidance
- Safety & emergency behaviors
- Automated fleet operations & sustainment actions
- Carefree human control and interaction
- V&V by design
- ...

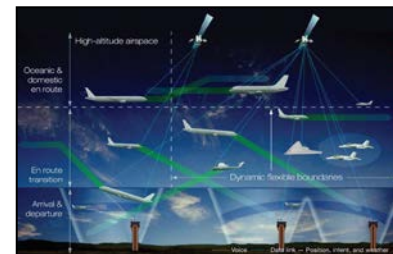
Applications



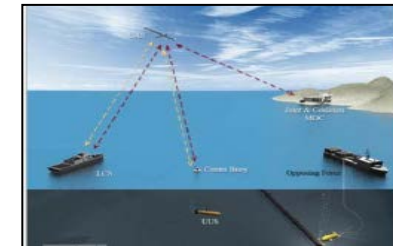
Factory
Automated
Assembly



Civilian UAS
Applications



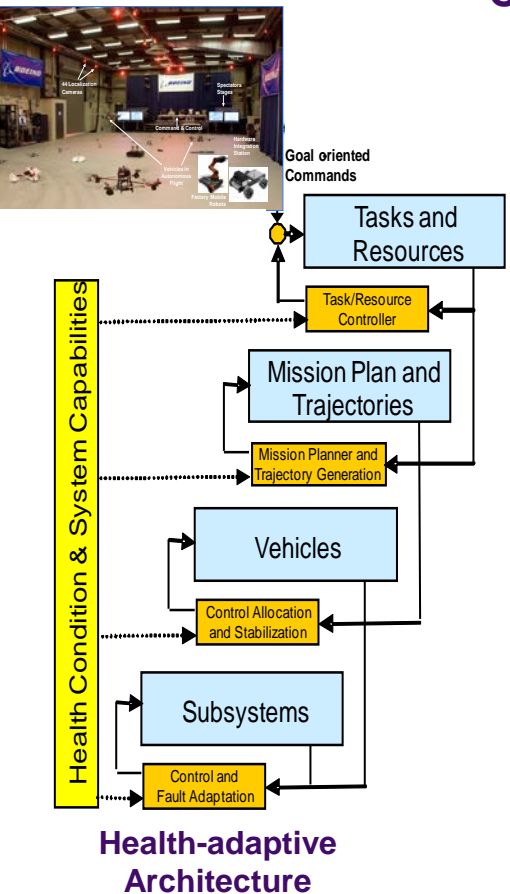
NextGen
Commercial



Defense UAS
Applications

Health-Adaptive Autonomous Multi-vehicle Systems

technology reuse to reduce development time & cost

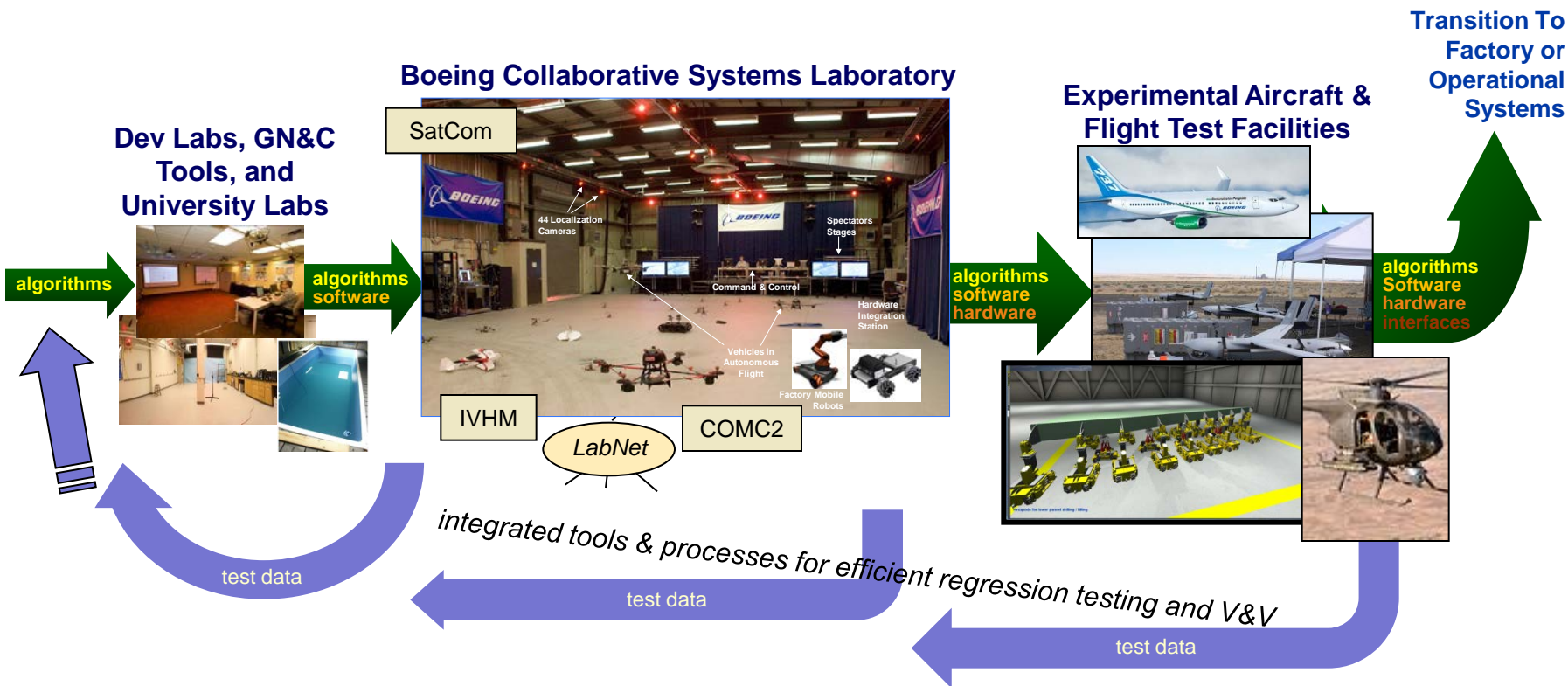


Health-adaptive Architecture

Challenge 2: Integrated Hybrid Systems Rapid-Prototyping, Experimentation, and V&V

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*Seamless laboratory infrastructure and common hw/sw integration architecture for **earlier technology assessment, faster conops prototyping, and lower risk transition.***



Collaborative Systems Lab Applications

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A common basis of control technology is re-used across multiple domains

Harbor / City
Boarder Patrol



<http://libraryphoto.cr.usgs.gov>

Environmental
Monitoring



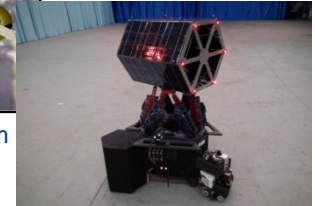
Fire
Management



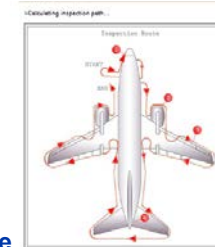
Space
Applications



Small Satellite Program
F6 Fractionated Space



Mobile
Automated
Assembly



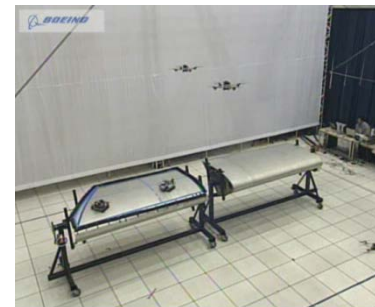
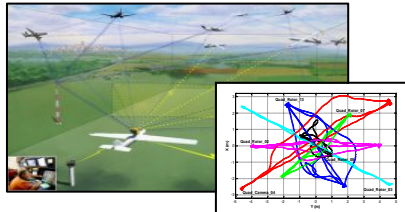
Airplane
Inspection

- Trajectory software
- Sensor coverage
- Health-adaptive architecture
- Heterogeneous Vehicle Collaboration
- Collision avoidance software

Security
Applications

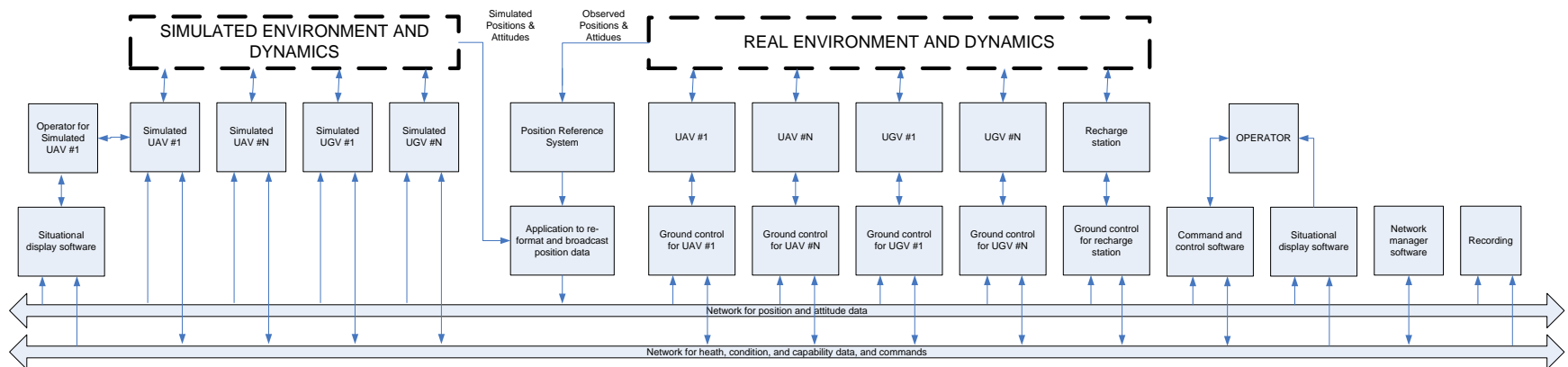
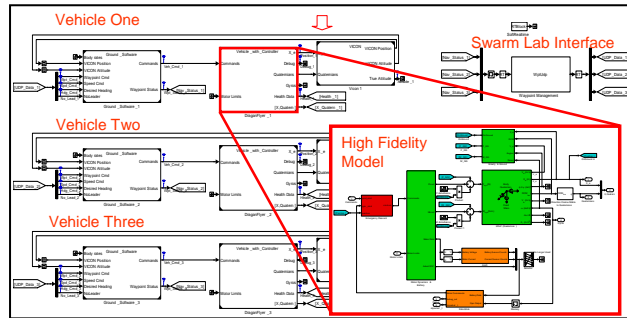
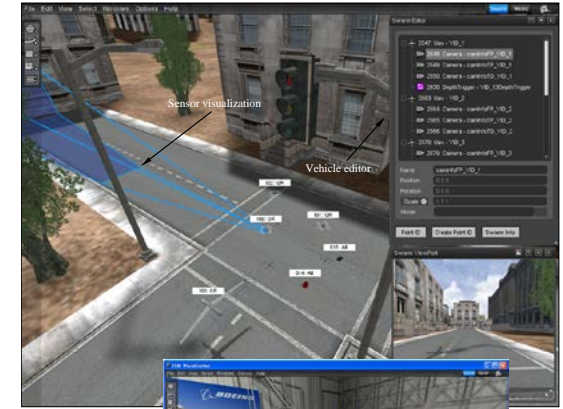
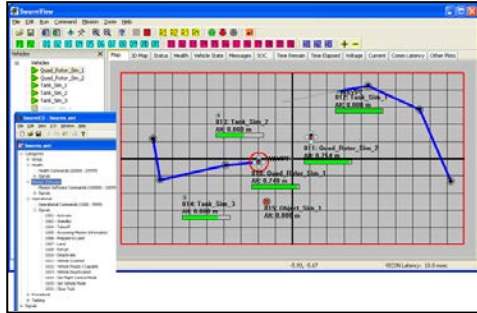


Commercial
and UAS Ops in
NAS



Collaborative Systems Lab Example Elements (control, vehicles, hw, comm, hmi, virtual env, ...)

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Swarms Lab Overview (from 2009)

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CPS Testbed Using Collaborative Systems Lab Assets Linked To Industry Applications

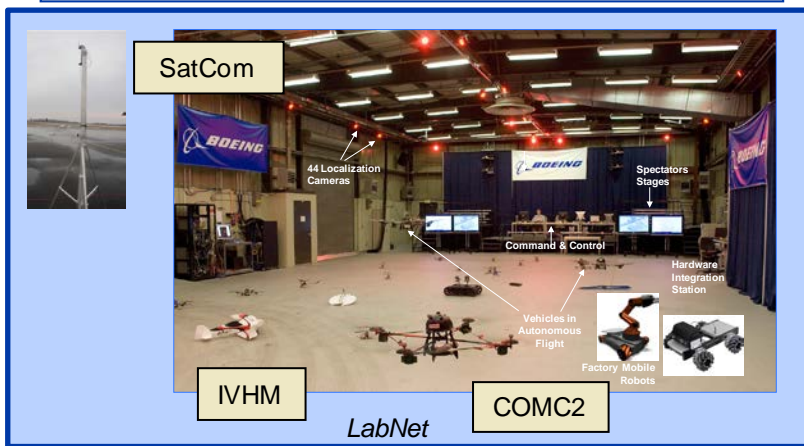
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Discover security issues earlier in the design phase by facilitating simultaneous analytic development and laboratory experimentation/prototyping using representative components.



Experimental investigation of CPS security

- multi-core, memory arch, networking chips
- comm links, I/O, and component security
- safety, privacy, and workload
- computing and sw fault tolerance
- component damage/degradation tolerance
- mixed criticality function assessment
- tasking/scheduling run-time optimization
- upset recovery robustness
- security protocol verification
- environment modeling/accommodation
- hacker vulnerability
- analytic and formal methods verification
- CSP security validation
- cross-domain reuse risk reduction
- other



Questions, Comments, and Discussion

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