Cyber Physical Systems in Aerospace – Challenges and Opportunities

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June 16, 2011

Boeing is a Key CPS Stakeholder

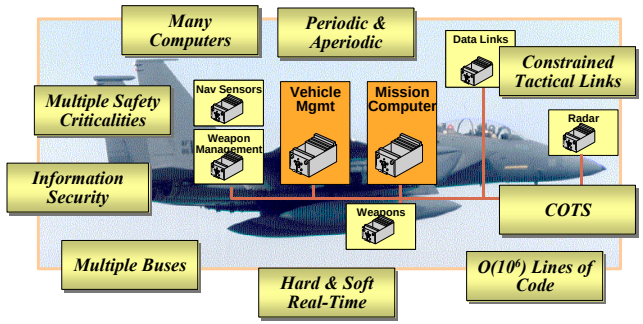
Figure 1

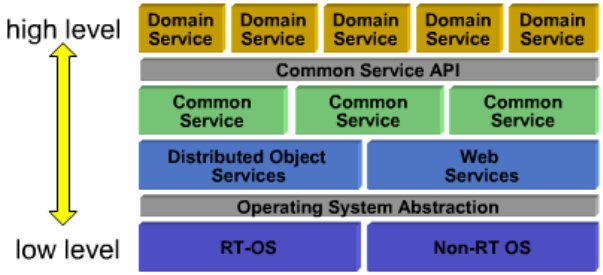
- **The Boeing Company is working a rich set of application areas that are benefiting from CPS research**
  - **Air (military and commercial)**
  - **Space (high-reliability applications)**
  - **Land (networking land elements)**
- **Applications involve multiple, networked CPS systems**
  - **Safety-critical aspects**
  - **Security**
  - **Need for predictability in face of dynamic environments**
- **Aircraft platforms**
  - **Commercial**
    - **Stringent certification and V&V processes and standards**
  - **Military**
    - **Piloted and autonomous vehicles**
    - **Support all services**
    - **Unmanned vehicles in NAS**
    - **Varying levels of V&V requirements**

Aerospace Systems are Increasingly CPS-Intensive

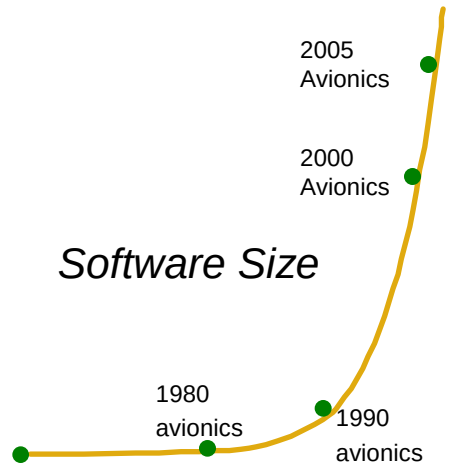
Figure 2

- **Aerospace systems for today and beyond**
  - **New capabilities**
  - **Agile behavior in highly dynamic operating environments**
  - **Operation in a SoS Network**





Networked SoS Architecture for Army



- ***Avionics S/W challenges – 100M – >1B* SLOC***
- ***Software Intensive Systems***
- ***Multiple levels of criticality***

Source: IBM Global Innovation Outlook 2006.

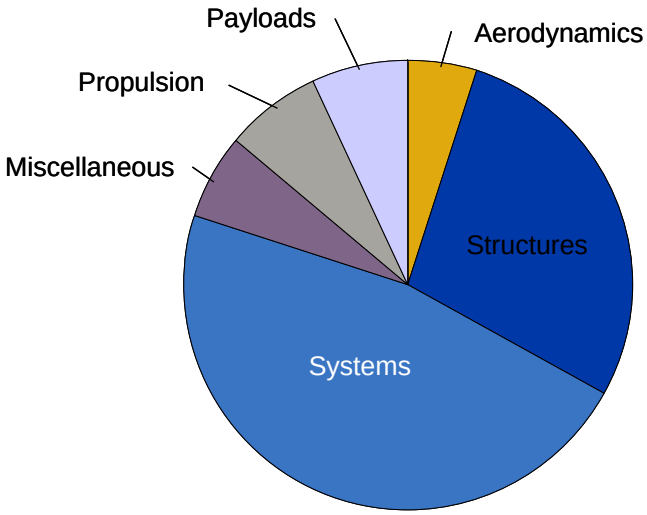
Importance of CPS Software to Aerospace Systems

Figure 3

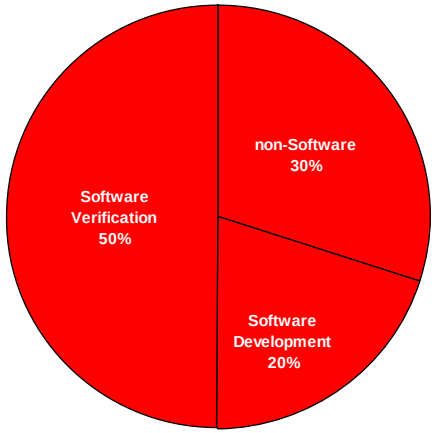
- **Aerospace systems cost trend is shifting away from traditional structures, aero and propulsion to software and systems. Trend will accelerate after 787 (1st largely composite airplane)**

- **Software verification is becoming one of the leading components of system cost – supporting FAA flight certification**

- **Verification will become even larger challenge as systems become more highly integrated**



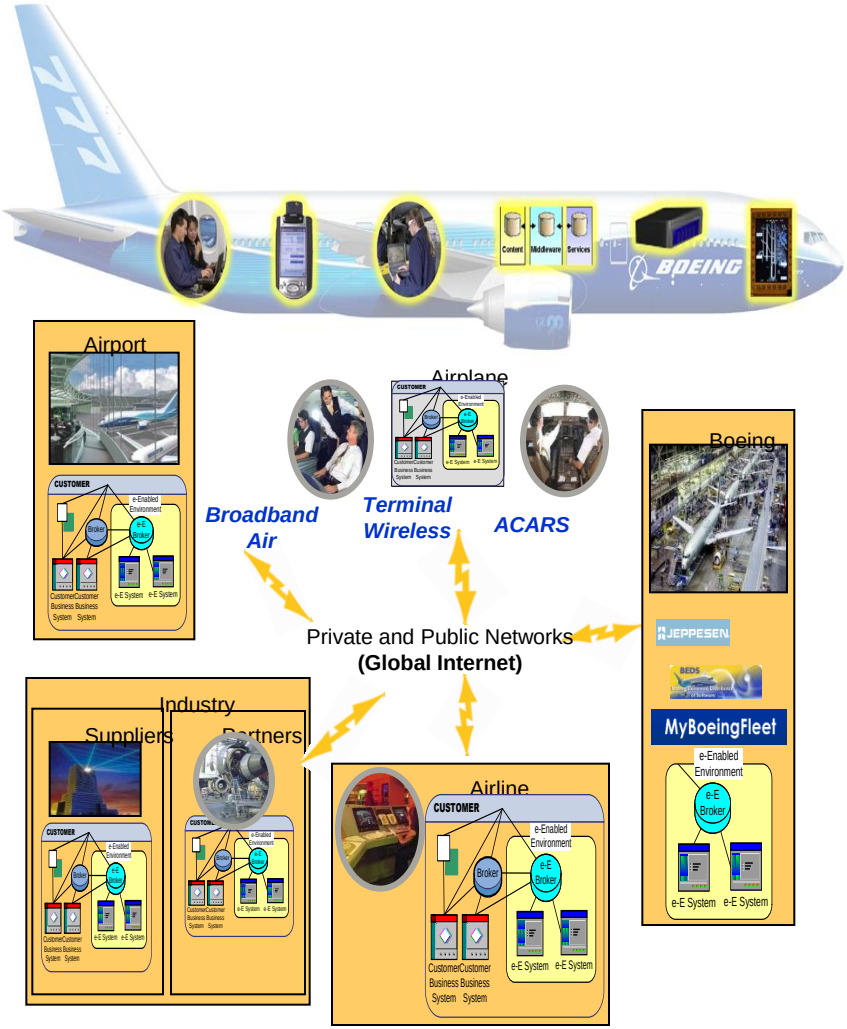
Typical Recent Commercial Aircraft Cost Distribution



Commercial Aerospace Environment of Tomorrow

Figure 4

- **Worldwide commercial aircraft environment**
  - **A complex network of systems, processes, & people**
  - **Evolved independently over decades**
- **This industry is now undergoing a major paradigm shift**
  - **Explosion of Information Technology (IT)**
  - **Increasing costs and passenger demands**
- **Evolving toward a Network Enabled Environment**
  - **To improve efficiency & reduce cost**
  - **Still in its infancy for Commercial airplanes**

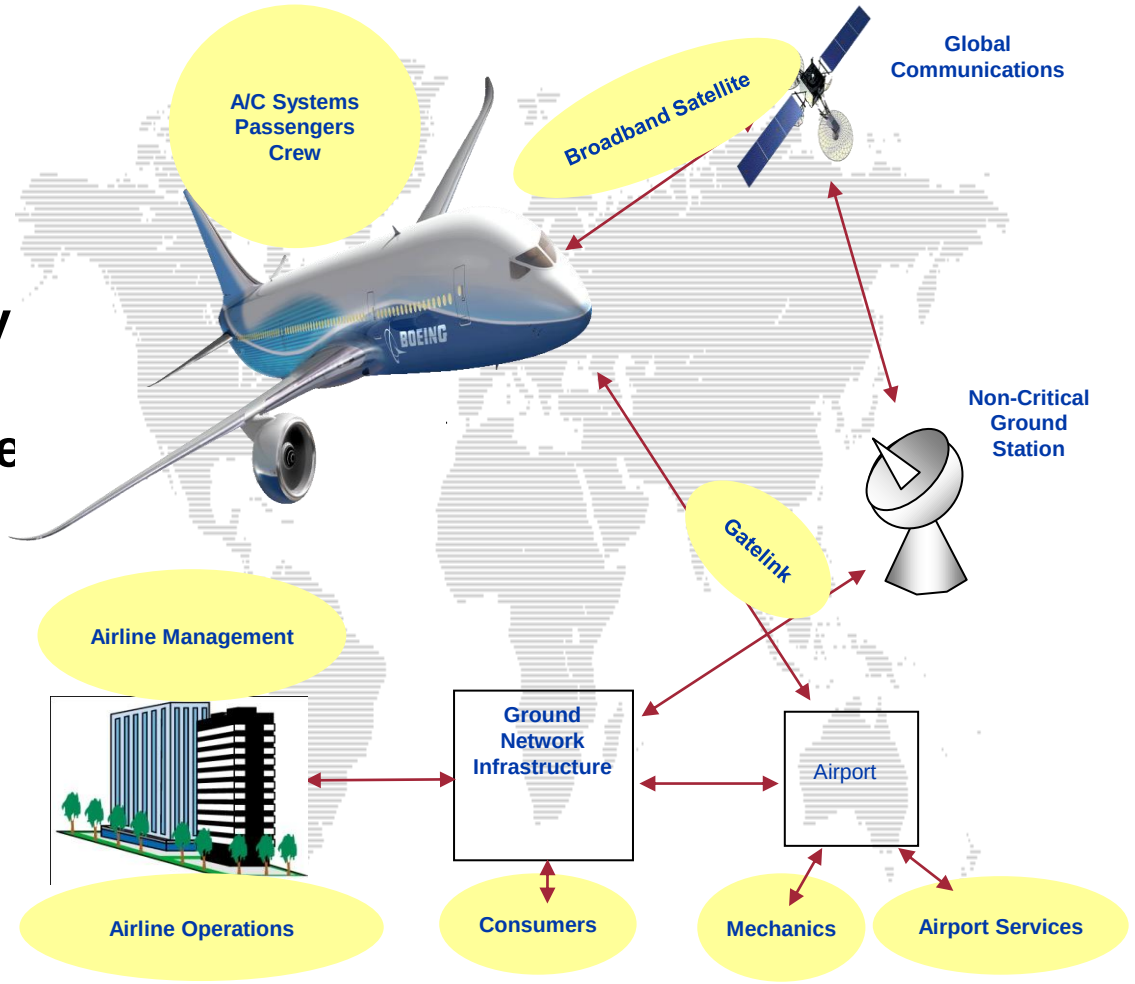


Commercial Aviation Challenges and Opportunities

Figure 5

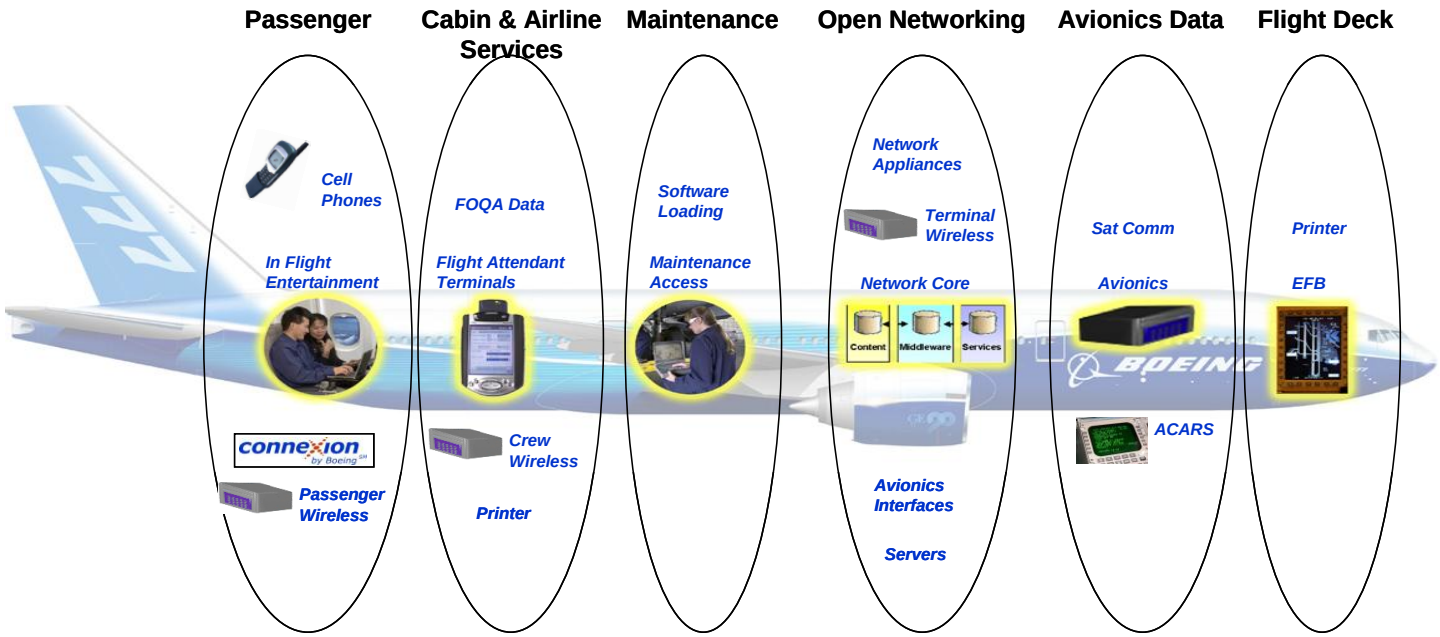
Integrated Network infrastructure can be divided into 5 groups:

1. Onboard Connectivity
2. Offboard Connectivity
3. Network Interoperability Technologies
4. Information Architecture
5. Information Management (Post processing)



CPS Needs in Wireless Sensor Technologies

Figure 6



- **Current sensors impose extensive wiring and power requirements that limit their use**
- **Breakthrough technologies in wireless sensing and actuation required**
  - **Extremely low energy or energy harvesting sensors**
  - **Highly efficient sensor communication**
  - **Highly reliable and secure**
  - **Spectrum compliant, globally**

Multi-Disciplined CPS Research Agenda is Required

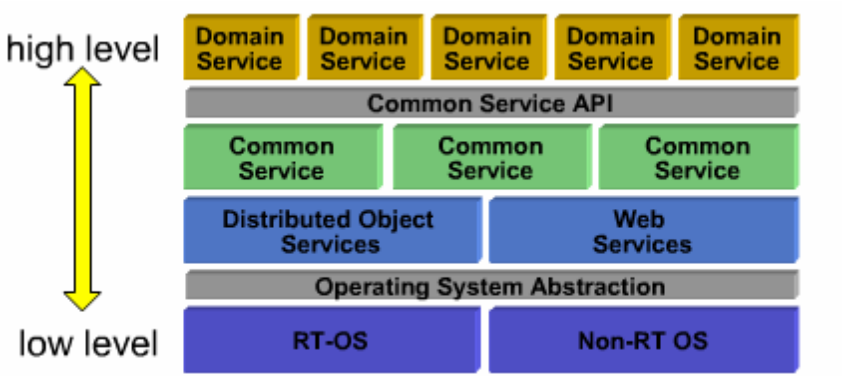
Figure 7

- **Advances in technologies such as model-based development tools, methods, and validation environments to build systems rapidly and affordably**

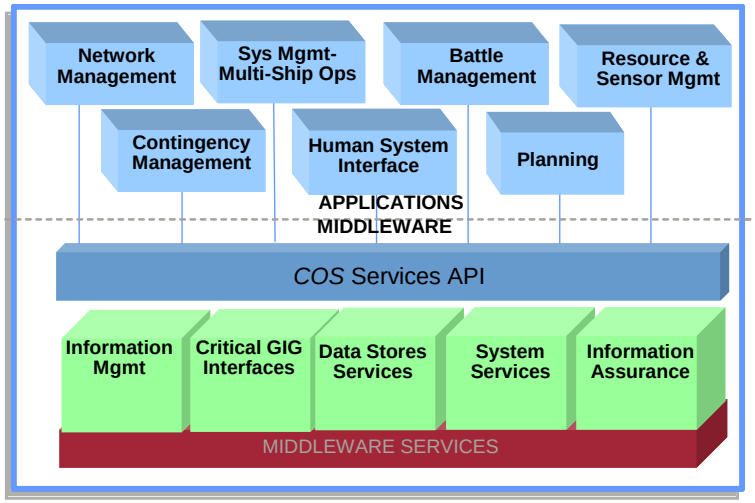
- **Product focused technologies including software reuse, architectures, real-time theory, languages, and product line architectures to achieve system affordability by recouping investment across multiple system developments.**

Product Line Architectures are Part of the Solution

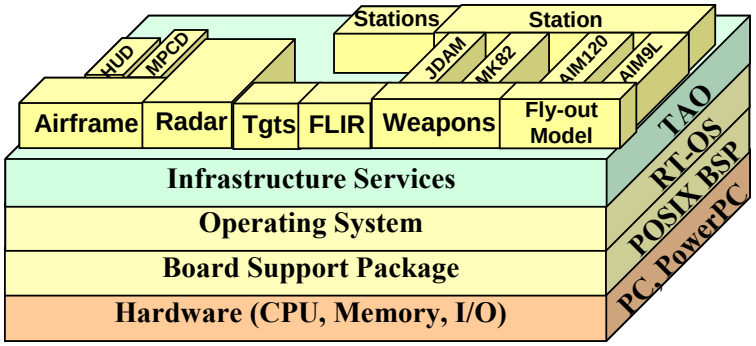
Figure 8



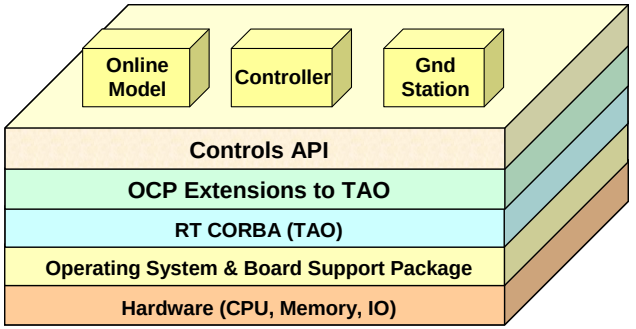
SOSCOE Architecture



J-UCAS Common Operating System



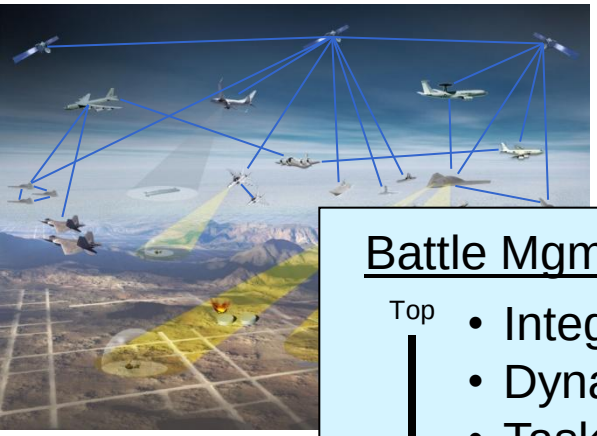
Bold Stroke Product Line Architecture
(F/A-18, F-15, T-45)



Open Control Platform for
Autonomous Systems

V&V Challenges for Autonomous C2

Figure 9



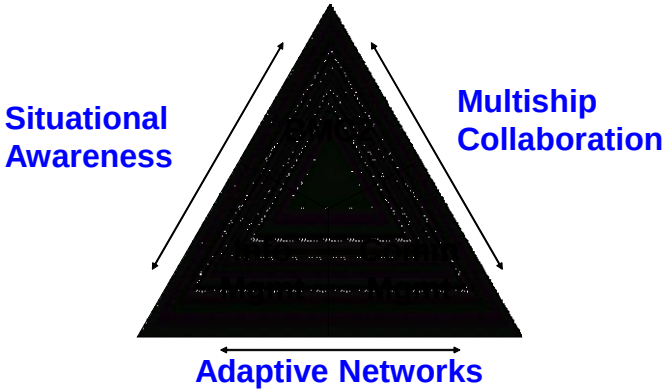
Hierarchical, distributed, optimal control of manned, semi-autonomous, and autonomous systems over wireless networks in adversarial environments

Battle Mgmt and C2

Top

Lowest Level

- Integrated Control of Distributed Assets
- Dynamic Resource Allocation
- Task Assignment, Scheduling, Route Planning
- Mission Execution and Monitoring
- Vehicle and Sensor Management (Outer Loop, Inner Loop)
- Subsystem Management



Challenges

SW Hierarchy, Complexity
Dynamic Environment, Not Predictable
Curse of Dimensionality
Appropriate Models and Simulations
Non-unique Behaviors

System Architecture Challenges

Figure 10

- **Mix of Centralized vs Distributed Processing Influenced by:**
  - **Communication Bandwidth / Quality of Service Requirements**
  - **Link Vulnerabilities**
  - **MLS Requirements**
  - **Equipment Capabilities (Legacy vs Advanced)**
- **Architecture / Algorithm Goals:**
  - **Service Oriented Architecture**
  - **Support Legacy & Advanced Platforms**
  - **Robust to Platforms Entering / Leaving Team**
  - **Adaptable to Communication Quality of Service / Degraded Comm**
- **Vision: Processing architecture adapts to mission and environment**

CPS Industrial Executive Board

Figure 11

- **Identify and formulate CPS scientific challenges across disciplines that have relevance to industry,**
- **Evaluate progress and impact in the scientific foundations, intellectual directions and societal impact**
- **Promote awareness of CPS within relevant government agencies, professional societies, and industrial partners.**
- **Evaluate progress in the CPS-VO operation, including infrastructure, collaborations, and education.**
- **Facilitate the awareness of the CPS community of industrial challenges cutting across multiple disciplines and foster coordination , cooperation, and transition of CPS technologies.**

Summary

- **Emerging cyber-physical systems will be highly complex, networked, highly reliable and secure.**
- **CPS investments cross multiple technology domains/industries and require national-level critical mass to achieve required performance and affordability, thus protecting national competitiveness**
  - **Corporate R&D dollars for CPS aren't enough**
- **A national research strategy in which long-term CPS technology needs are achieved by combined Government and Corporate investment is required**
  - **Vibrant industrial, academic, and Government collaboration is critical**