Aerospace Cyber Physical Systems
— Challenges in Commercial Aviation

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Aerospace Cyber Physical Systems

The Digital Airplane

- Airlines & Aircraft Operators
- Airframe Manufacturers
- Onboard Equipment Suppliers
- Air Traffic Management
- Airports
- Flight Deck Crew
- Cabin Crew & Ground Personnel
- MRO
- Federal Agencies
- Passengers

Airplane in Factory

Airplane in Operation

Airplane in Air Traffic System
Cyber Physical Systems in Aerospace Manufacturing

42 Acres Factory: fit 75 NFL football fields
911 NBA basketball courts, or a few billion pop cans
Example: 777 Moving Assembly Line

(8) Fwd/Aft “S&I Crawlers”
(1) “Mid-Mover” for FBJ
(2) Airplane “Tugs”
(1) Data historian and visualization system
Typical IT ↔ SCADA Isolation Scheme

- **Users**
- **Datacenters**
- **Network & Security Management**
  - Complexity:
    - Duplicate wiring
    - VLAN Mgmt
    - Config Mgmt

- **IT Intranet**
- **Global Internet**
- **SCADA Network**
  - **Plant Worker**
  - **ICS Domain 1**
  - **ICS Domain 2**

- Cost
- Errors

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“Ideal” ICS ↔ IT Shared Network

- Users
- Datacenters
- Network & Security Management
- Global Internet
- IT Intranet “Backhaul”

ICS Domain 1
ICS Domain 2

IT/ICS Network
- Incompatibility
- Poor Security

Cost
Risk
SCADAnet Architecture

Untrusted IT Intranet “Backhaul”

Backhaul Connectivity
- Any link type: Ethernet, Cell, WiFi, WiMax, SatCom, etc.
- Authentication if needed

Transparency
- Existing ICS protocols
- Layer 2 VPLS
Enclave Architecture

- **ICS Ops Center**
- **Field DCS'**
- **Untrusted IT Intranet**
- **IP over Backhaul**
- **Ethernet**

**Isolated Logical Enclave**

**ICS DPI Firewall**

**Overlay Gateway**

**ICS PEP**

**IT Network Client**

**Isolation Boundary**
Airplane in Factory Challenges

- **How do we...**
  - Utilize commodity IT networks for SCADA connectivity?
  - Protect our manufacturing controls equipment?
  - Create a clear division of responsibility?
  - Create a solution that scales well?

- **Cross – industry commonality...**
  - Not unique to Boeing, nor to manufacturing in general
  - Equally applicable to
    - Oil/Gas industry (platforms, pipelines, refineries)
    - Energy sector (generation, transmission, distribution)
    - Automotive manufacturing
    - Chemical sector
  - Interoperability: combining forces with vendor and user communities to standardize solutions in this space
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Airplane in Operations

Tight integration within aircraft, and between aircraft and off-board systems
Smart Airplane Needs Wireless Sensor Technologies

- Current sensors impose extensive wiring and power requirements that limit their use.
- Breakthrough technologies in wireless sensing and actuation required in order to realize major benefits:
  - Extremely low energy or energy harvesting sensors
  - Highly efficient sensor communication and networking
  - Highly reliable
  - Cyber Security
Smart Airplane Onboard Software (OSW)

- **Development and certification**
  - 787 Certified by FAA & EASA in 2011
  - Integration of SW from dozens of suppliers
  - Up to O(20 million) source lines of OSW code
  - Cost trend shifting away from traditional aero/propulsion and structures to systems and OSW
  - SW verification leading systems cost (supporting FAA flight certification)

- **OSW critical for functions**
  - Flight control & navigation
  - Passenger entertainment
  - Passenger cabin lighting
  - Dimmable window tint control
  - Control of the bidet in passenger lavatory

- **Flight control function**
  - Allows for optimizing wing camber in flight
  - Fully augmented authority in all three axes
Software Distribution and Applications
Airplane, Manufacturers, Airline, and Airport/Internet Interfaces
Data Analytics for Smart Airplane Operations

- Volume and variety of data collected on smart aircraft and by ground operations growing exponentially
  - Maintenance messages / Fault codes
  - Quick Access Recorder (QAR) of flight and system parameters
  - Maintenance action logs / test results / shop data
  - Real-time data and real-time information management for decision making
- Data analytics enables proactive response to improve aircraft operations
Cyber security requirements for e-Enabled airplanes addressed during certification

Anti-Tamper avionics hardware and software

Industry/government collaboration will be essential in addressing the cyber threat to aviation
Airplane in Operations Challenges

- **Communication and network**: signal processing, wireless performance, worldwide interoperability for aeronautical networks, and aircraft interfaces to the Internet

- **Onboard Software**: efficient verification and validation, secure distribution for end-to-end processes, life-cycle cyber-physical scale

- **Airplane health, control, and prognostics**: sensor networks/fusion, data analytics, information management, systems-of-systems for sharing critical real-time data, assured timely end-to-end information exchange, distributed cooperation and coordination for efficient and optimized decision making

- **Human-automation interface**: visualization, human-in-the-loop modeling and simulation, cyber security, close coupling of networking with aircraft controls and air traffic systems
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NextGen uses "cyber," i.e., networking, software, computing, to tightly weave taxing, takeoffs, enroute flight paths, and landings.
Cyber-Physical Interactions in NextGen

Examples

Control and coordination for flight safety and efficiency

In-flight coordination

Coordination for airborne sensing and action webs

Control and coordination for separation assurance and hazard avoidance

Flight Operations Centers

Aircraft

Airspace

ANSP

Air Navigation Service Providers
Operations Enabled With ADS-B

Reduced-Separation in Non-Radar Airspace

Merging andSpacing, Surface Operations, and Closely-Spaced Parallel Approaches

In-Trail Procedures

Blocking Aircraft

ITP Aircraft

Standard Longitudinal Separation Requirement
Continuous Descent Approaches

Features

- Low power – less noise, fewer emissions
- Timing predictability – better flow management
- Punctuality, final savings – lower overhead and fuel costs
A Near-Term Example – Tailored Arrivals

Tailored arrivals are CDAs, or near-CDAs, flown on 4D paths that are shaped for local constraints and timed for merging traffic.
CPS Challenges in Air Traffic System

- NextGen systems must function with a variety of legacy aircraft and operational procedures
- Worldwide interoperability
- Advances in human-automation interfaces are needed to increase airport capacity, efficiency, and airplane/airspace safety
- NextGen requirements (2012 Congressional Mandate) for Unmanned Systems operating in national airspace
Summary

- Manufacturing supervisory control and data acquisition networks enable automation and integration with IT systems

- Airplane operations employ CPS on a grand scale

- NextGen is a Cyber-Physical System-of-Systems (CPSS) challenge that requires tight integration to increase overall system capacity, efficiency, safety and security.

CPS investments cross multiple technology domains/industries, and require national-level critical mass to achieve required performance and affordability.