Aerospace Cyber Physical Systems
— *Challenges in Commercial Aviation*

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Boeing Research and Technology

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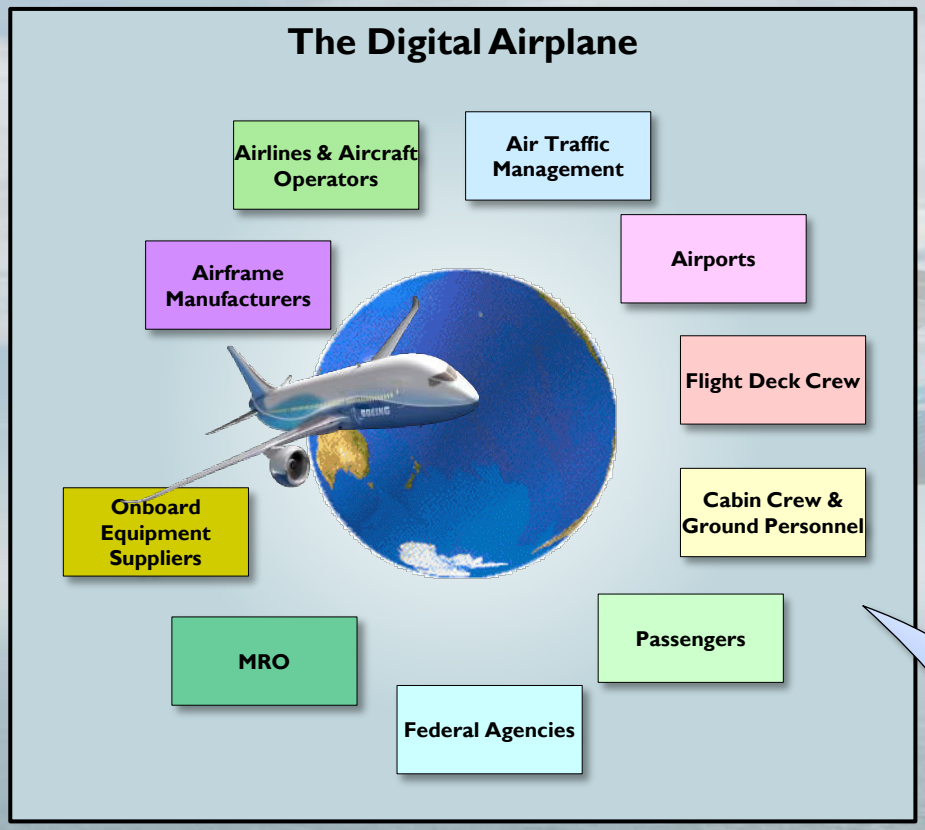
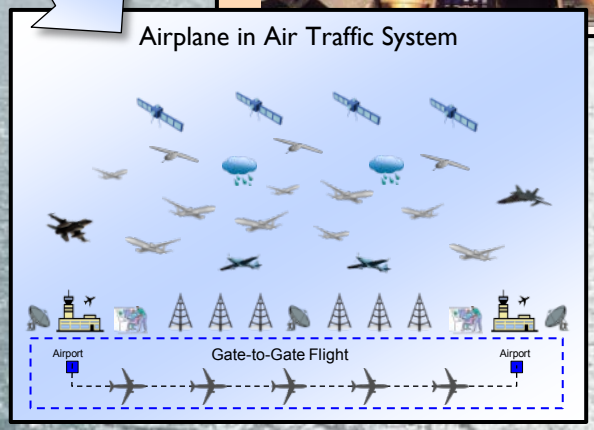
Aerospace Cyber Physical Systems





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Cyber Physical Systems in Aerospace Manufacturing

42 Acres Factory: *fit* 75 NFL *football fields*
911 NBA basketball courts, or a few billion pop cans

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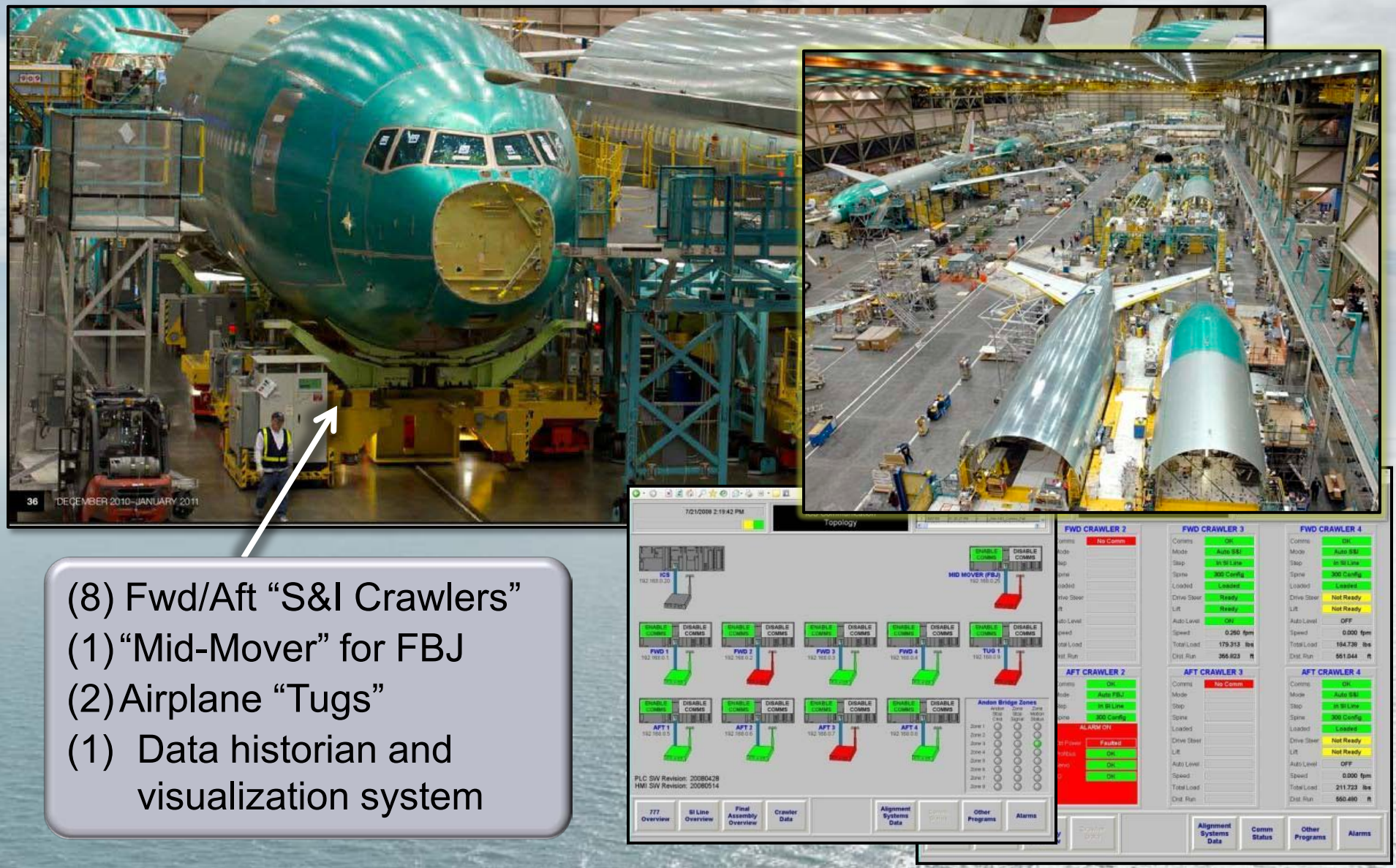
Example: 777 Moving Assembly Line



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

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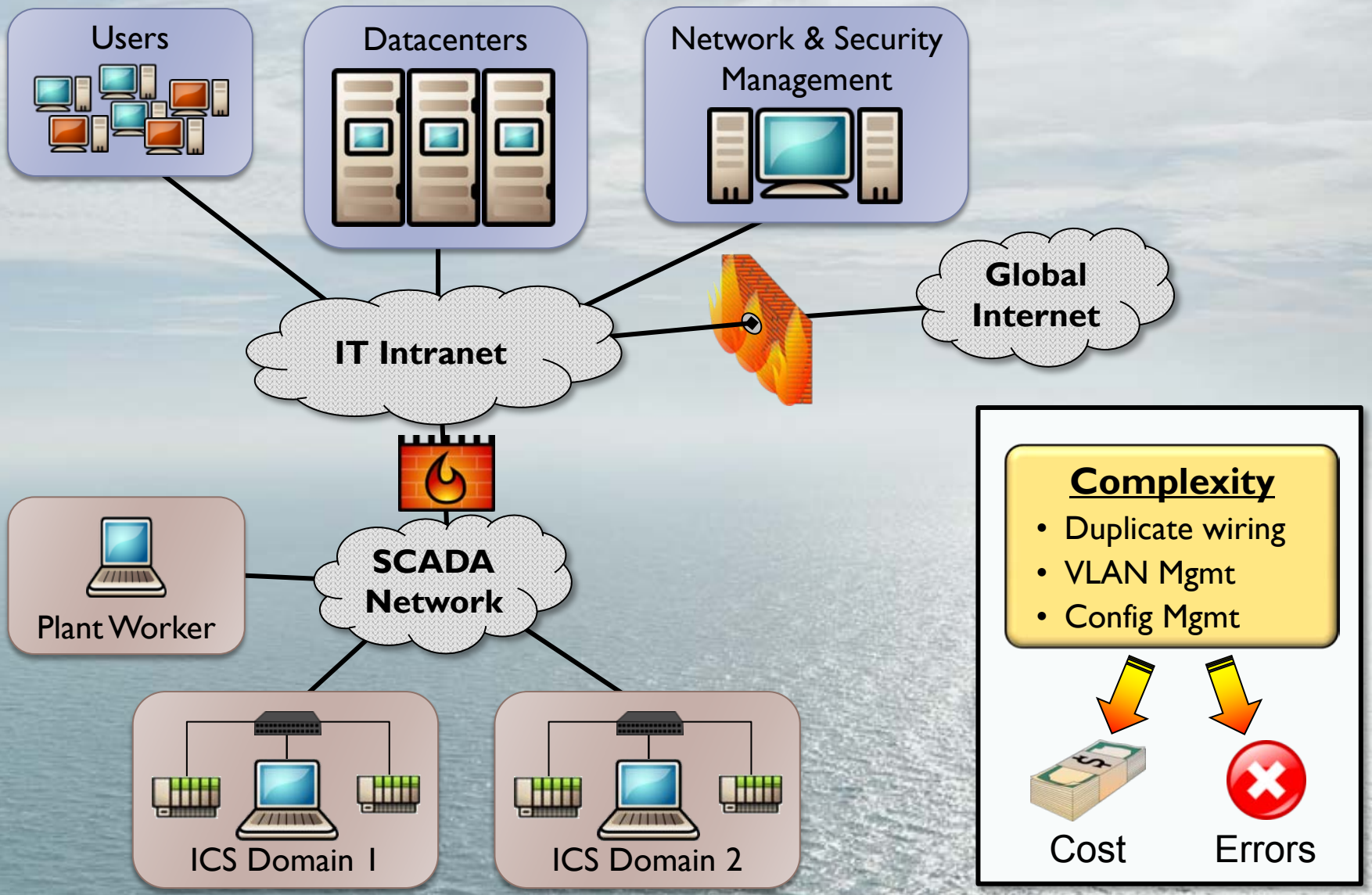
Typical IT ⇔ SCADA Isolation Scheme



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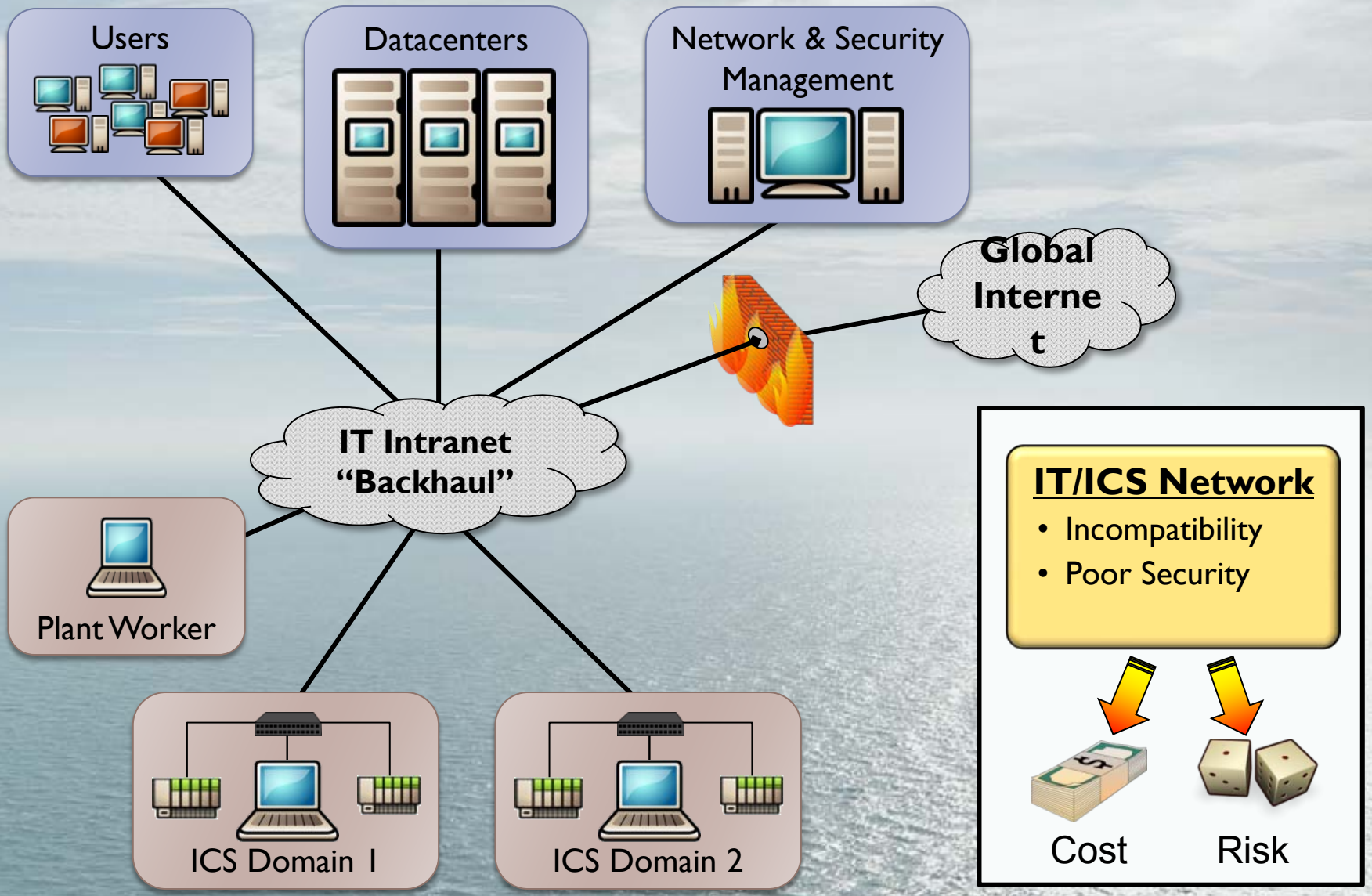
“Ideal” ICS ⇔ IT Shared Network



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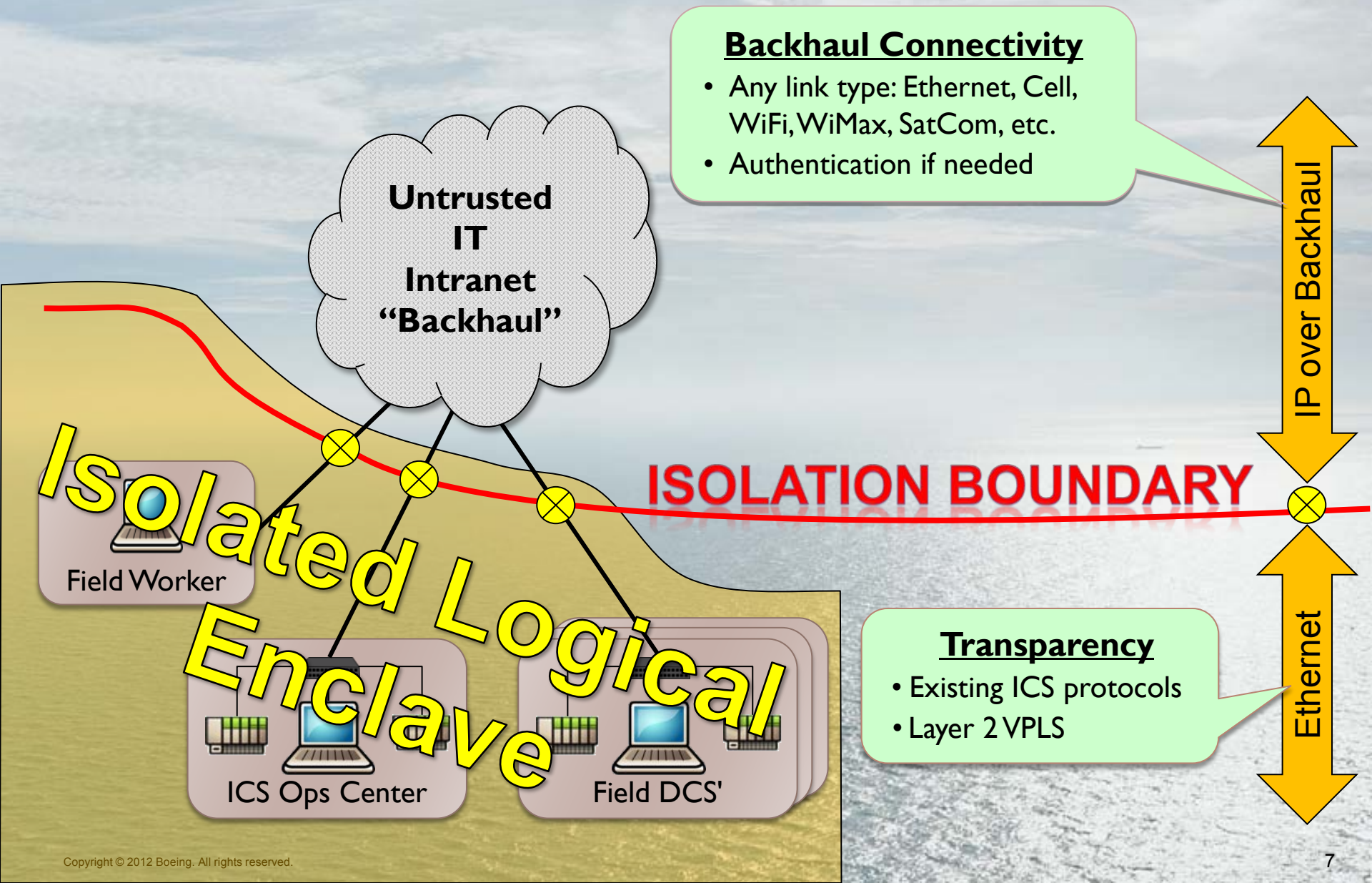
SCADAnet Architecture



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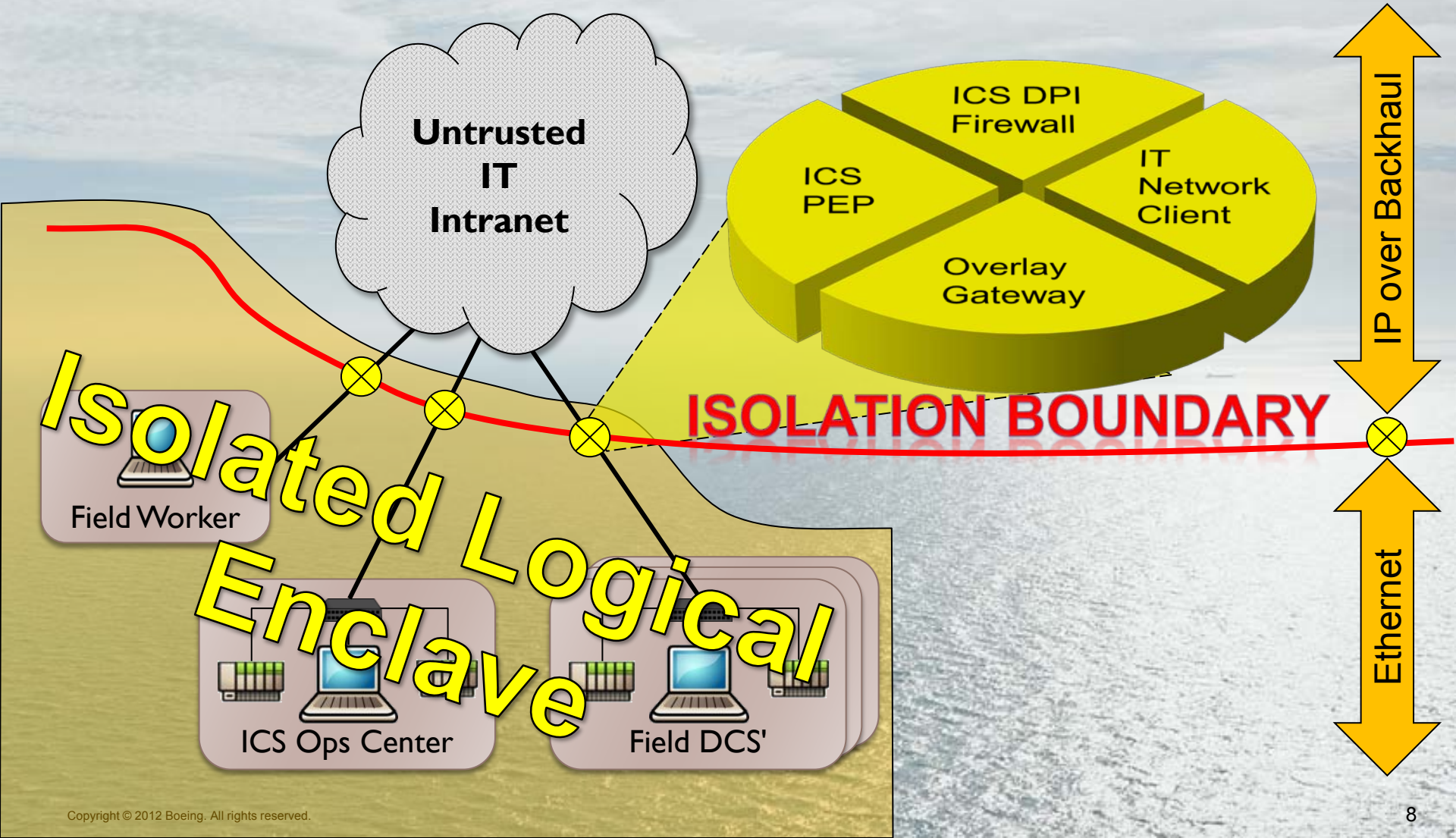
Enclave Architecture



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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

IETF ISA TRUSTED COMPUTING GROUP THE Open GROUP

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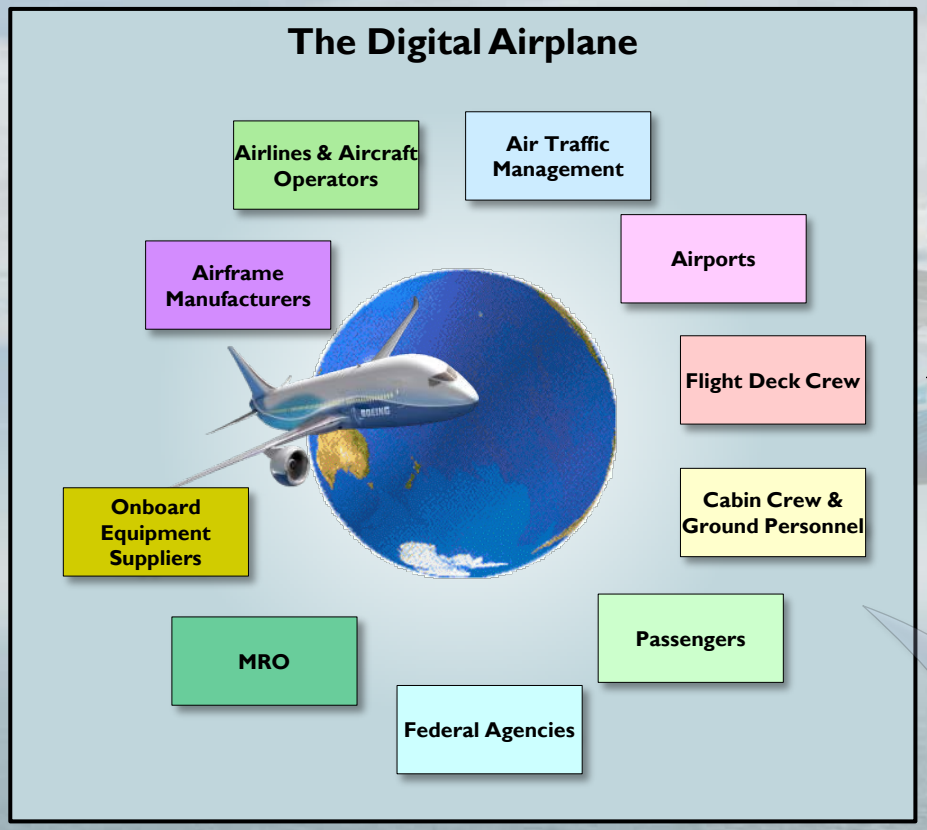
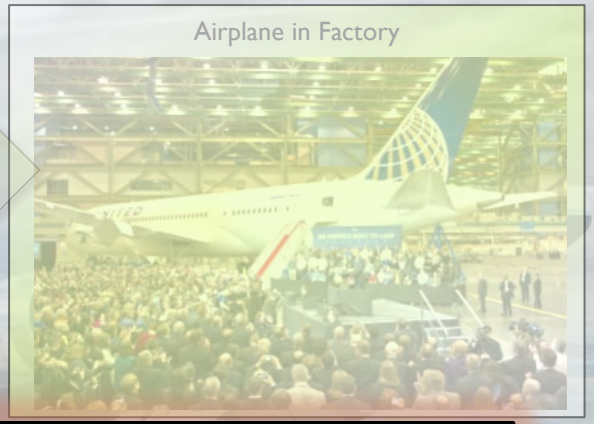
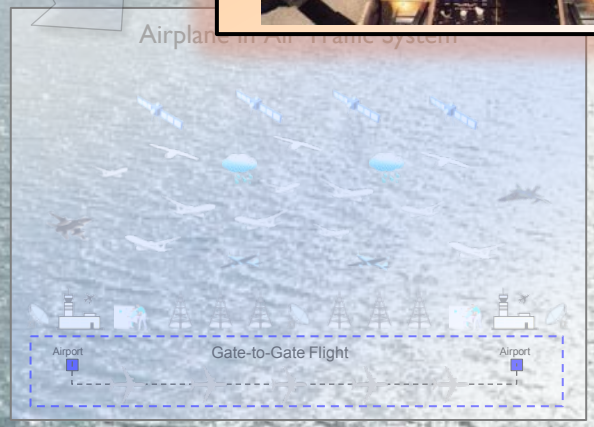
Aerospace Cyber Physical Systems







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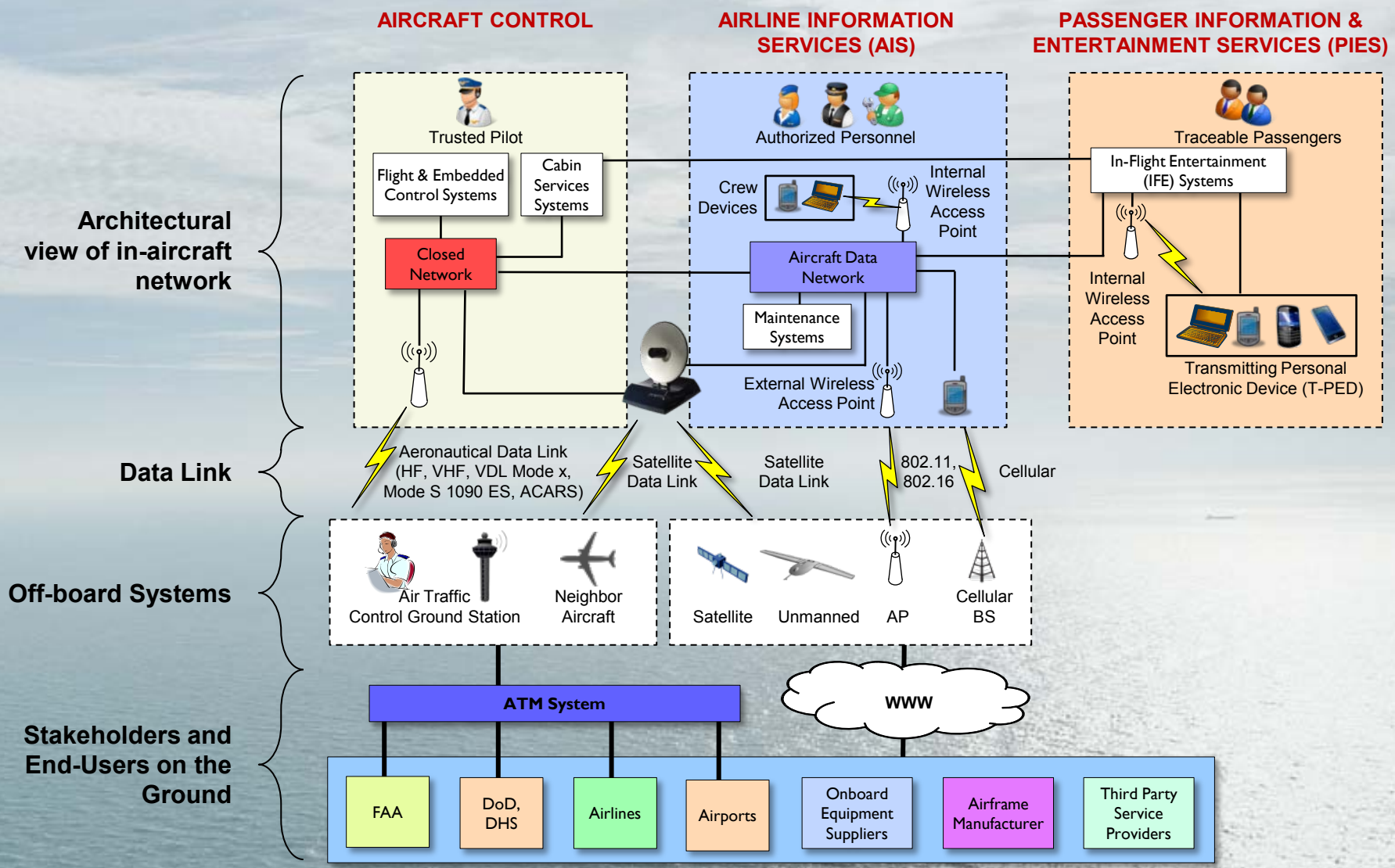
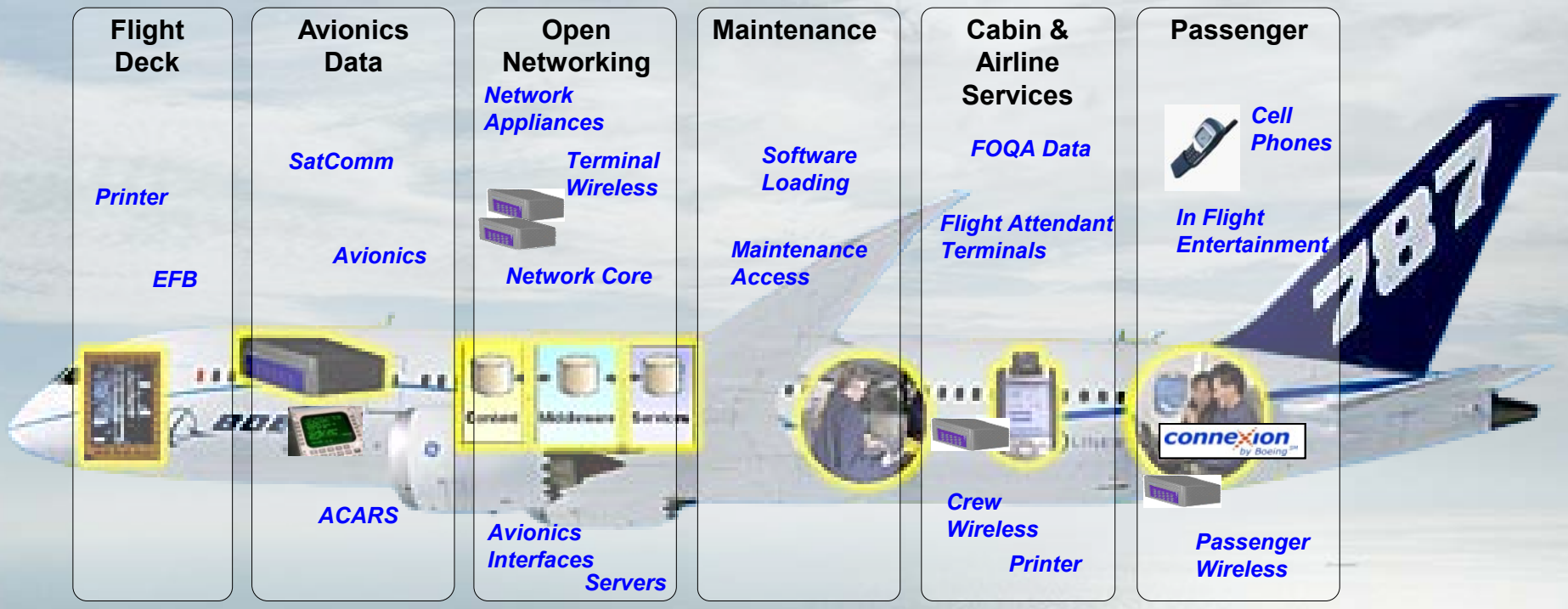
Airplane in Operations



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

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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

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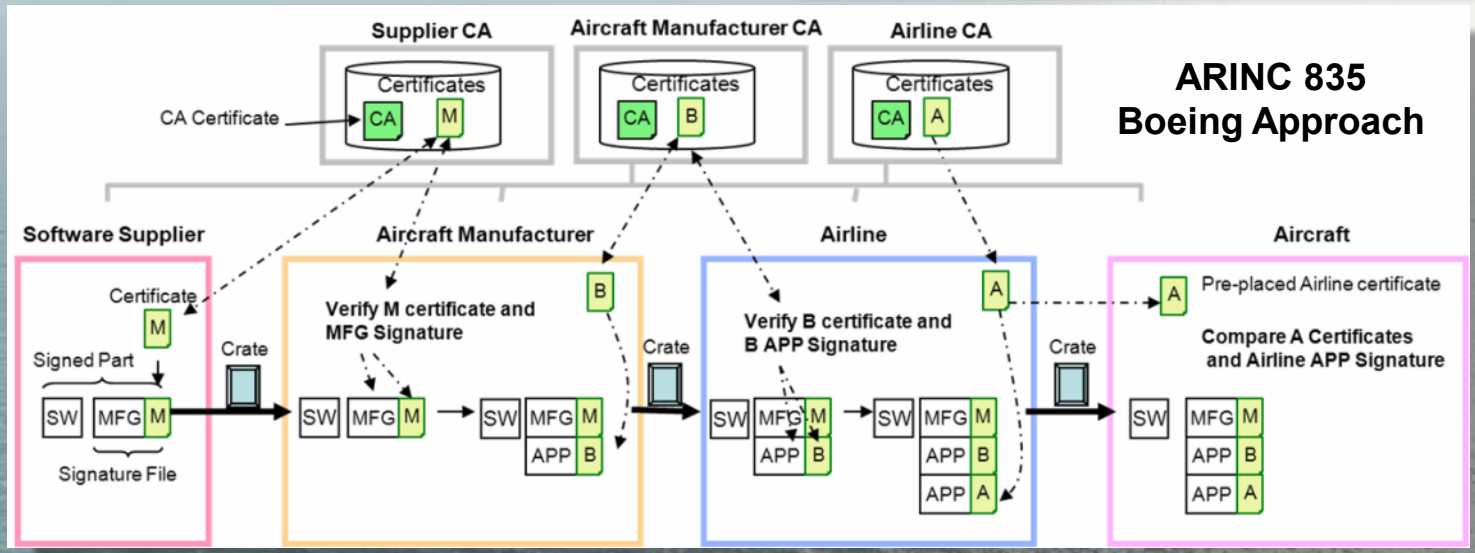
Software Distribution and Applications

Airplane, Manufacturers, Airline, and Airport/Internet Interfaces



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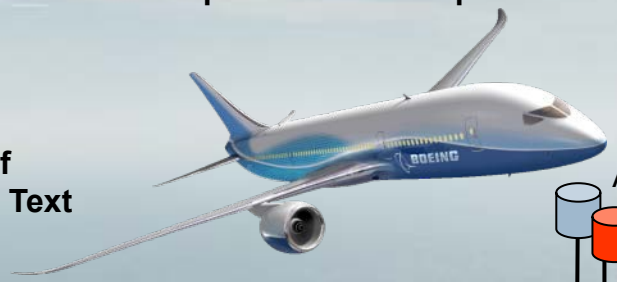
Data Analytics for Smart Airplane Operations

- 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



Mining of Maintenance Text

Reliability Analysis

ACMS
CMC
QAR

Maintenance data

ARMS
MMMS

Metrics / Evaluation

Airplane Health Management

Fault & Msg Tracking

Prognostics

Monitoring

AHM Tool Real-time Decision aid

ARMS / ISDP
In-Service Data Program

MSG-3
Maintenance Steering Group

CMMP
Centrally Managed Maintenance Program

Monitoring

Prediction

Analysis

ACMS: Aircraft Condition Monitoring System
CMC: Central Maintenance Computer
QAR: Quick Access Recorder
ARMS: Airworthiness, Reliability, Maintainability, Safety
MMMS: Maintenance Messages Management System

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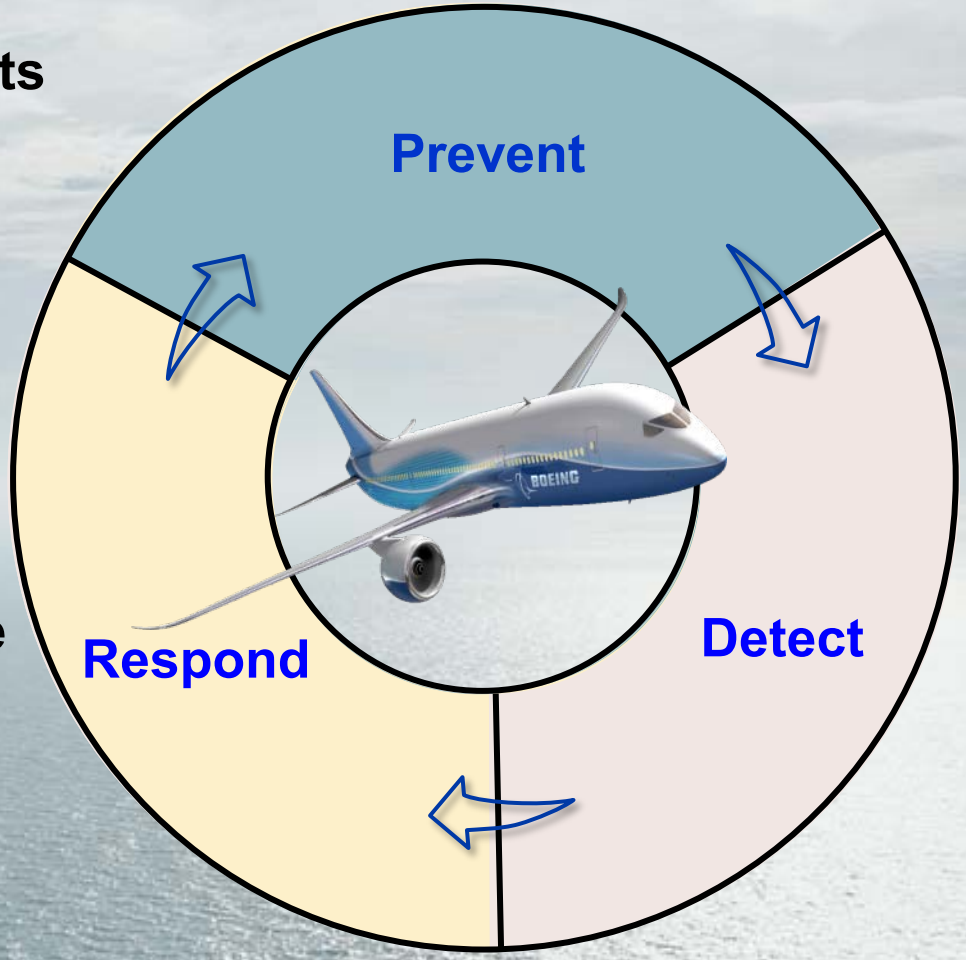
Information Assurance & Cyber Security Challenges

- 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



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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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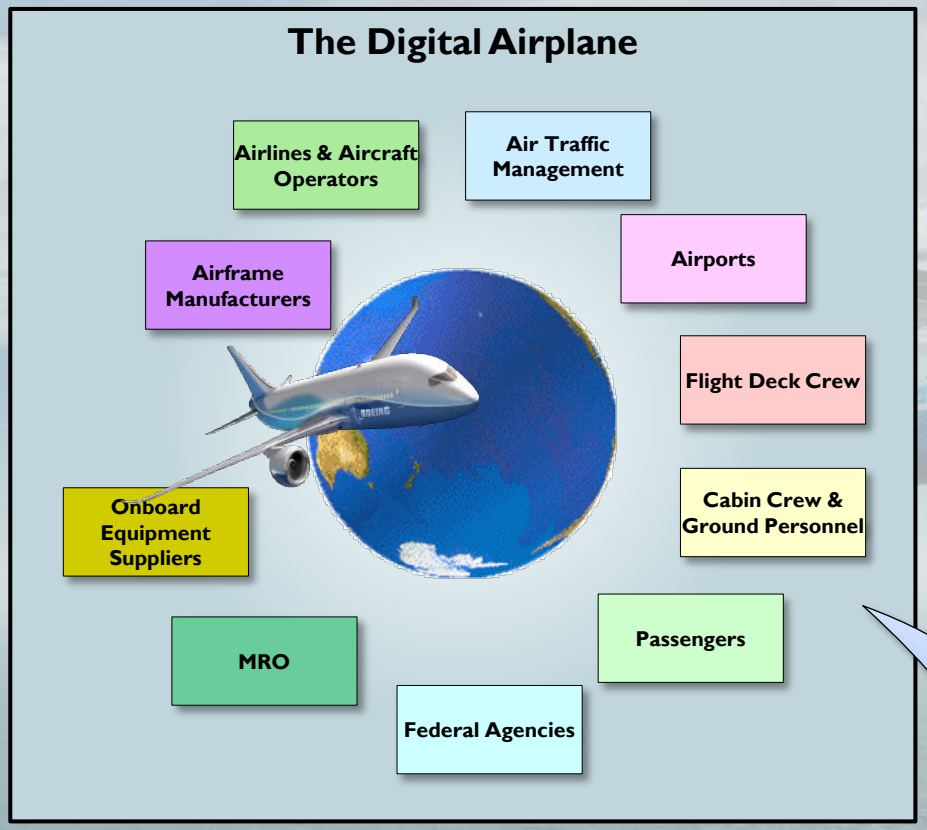
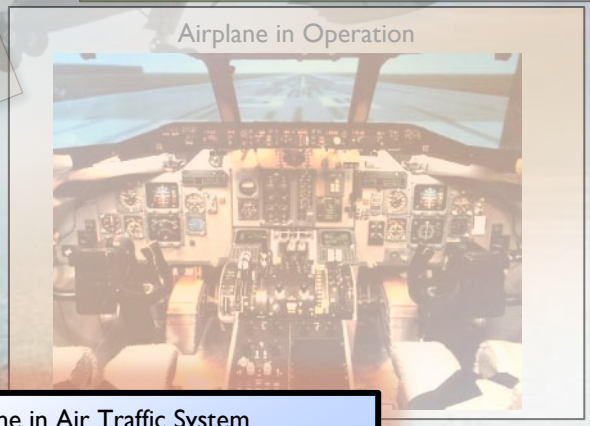
Aerospace Cyber Physical Systems





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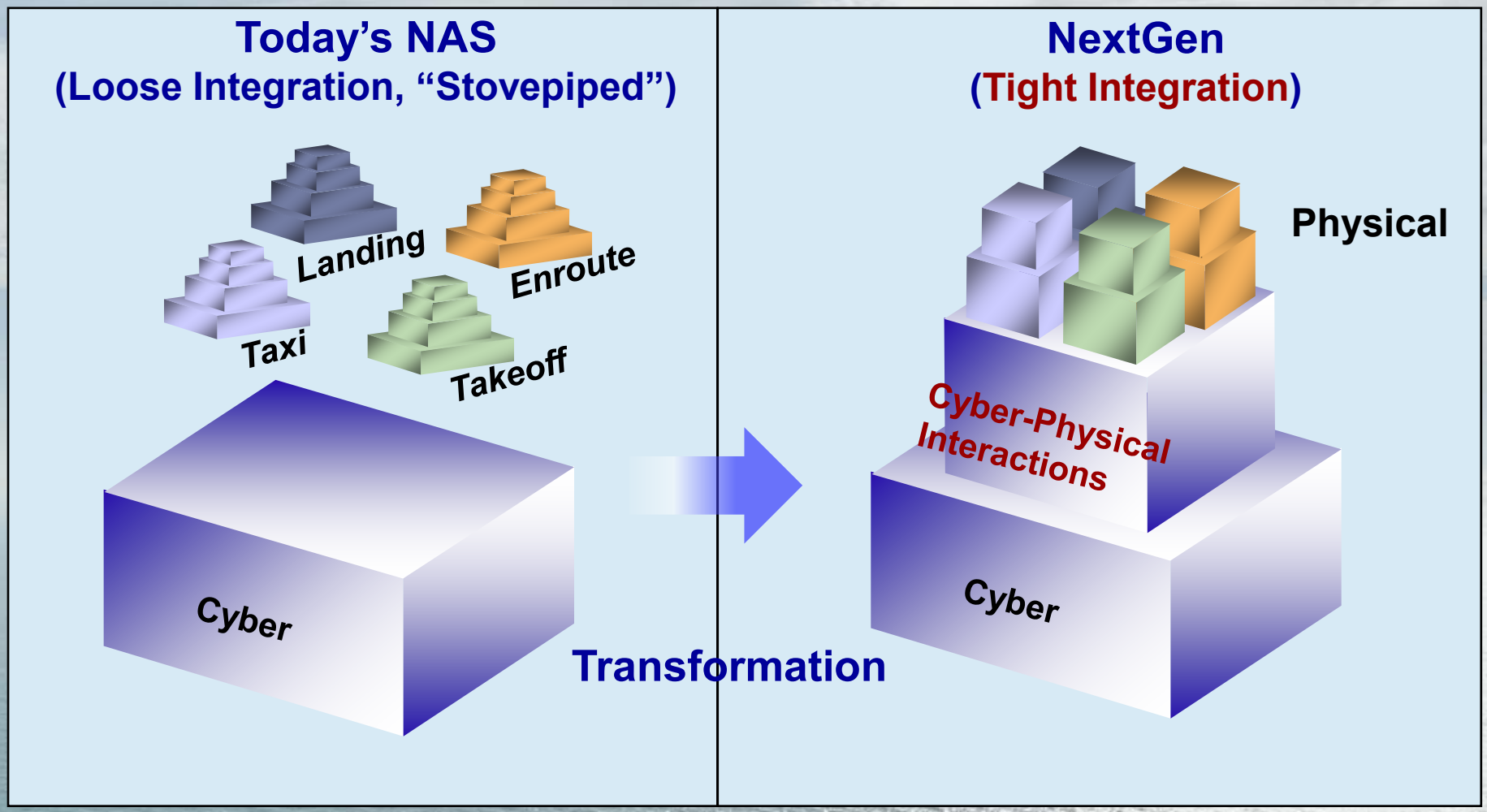
NextGen is a Large-Scale CPSS



NextGen uses "cyber," i.e., networking, software, computing, to tightly weave taxing, takeoffs, enroute flight paths, and landings

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Cyber-Physical Interactions in NextGen

Examples

Aircraft

Coordination for airborne sensing and action webs

Airspace

Control and coordination for flight safety and efficiency

Control and coordination for separation assurance and hazard avoidance

FOC

In-flight coordination

ANSP

Flight Operations Centers

Air Navigation Service Providers

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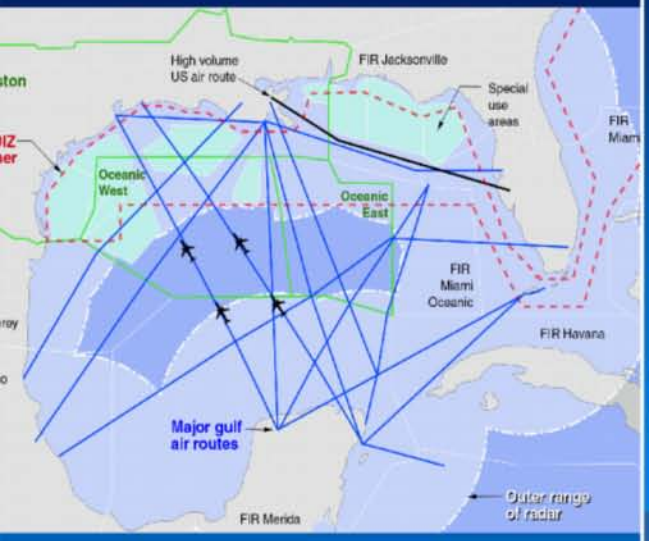
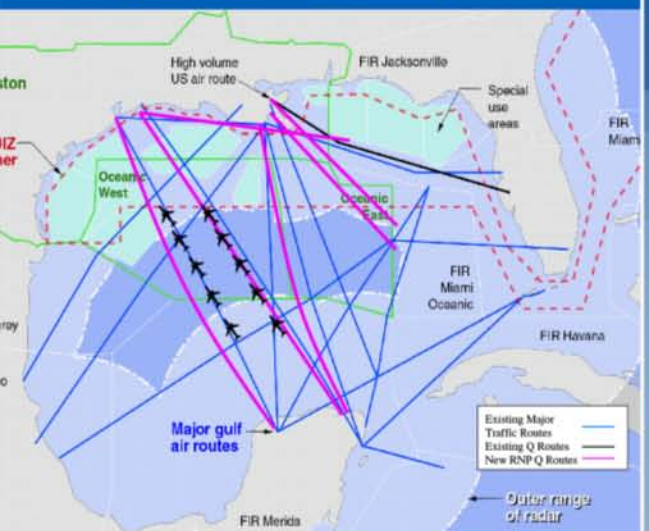
Operations Enabled With ADS-B

Reduced-Separation in Non-Radar Airspace





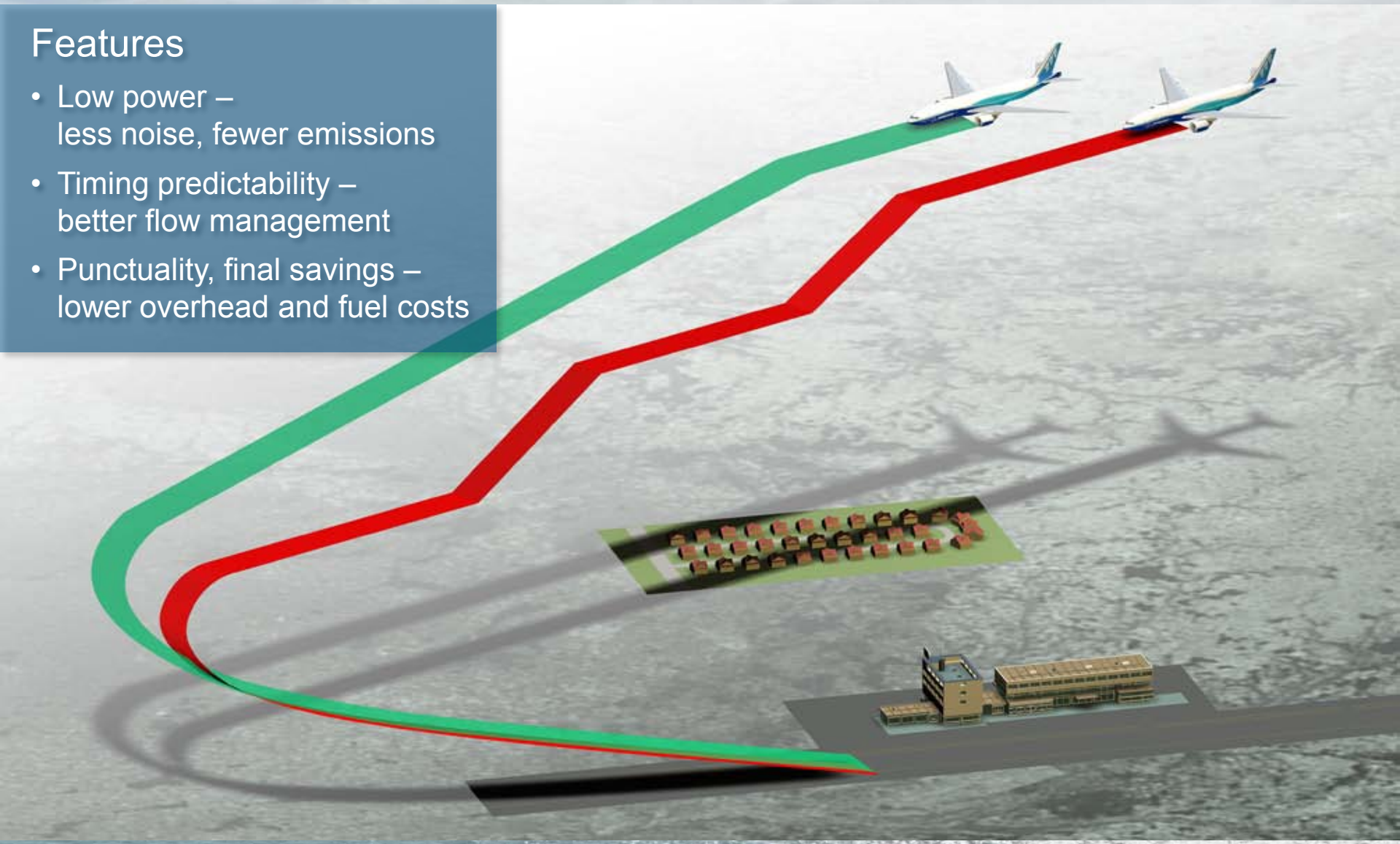
Merging and Spacing, Surface Operations, and Closely-Spaced Parallel Approaches

In-Trail Procedures

Continuous Descent Approaches

Features

- Low power –
  less noise, fewer emissions
- Timing predictability –
  better flow management
- Punctuality, final savings –
  lower overhead and fuel costs



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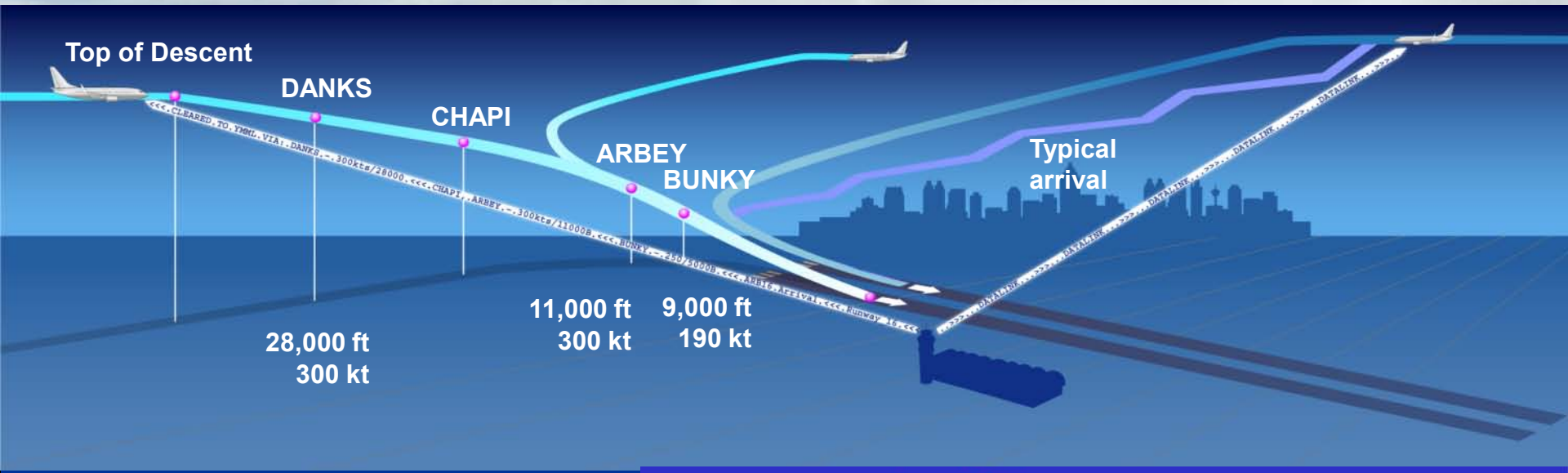
A Near-Term Example – Tailored Arrivals



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

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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

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