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# Industrial Challenges in Composition of Embedded Systems

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# Who We Are

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*NCO Thrust*

- The Boeing Company, working a rich set of application areas that will benefit from research focused on composition of real-time embedded systems
  - Air (manned and unmanned, commercial and military)
  - Space (ultra high-reliability applications)
  - Land (e.g., Future Combat Systems)
- Complexity of emerging system challenges is outstripping our capability to affordably develop and compose the next-generation of real-time embedded systems
- Virtually all new developments are focused on component based systems
  - All can benefit from additional research
  - Most are highly dynamic and require some level of “dependable” performance
- Aircraft platforms
  - Commercial
    - Primarily safety challenges
  - Military
    - Security and Safety challenges
    - Multi-service
    - Piloted and autonomous aircraft
    - Production and research customers

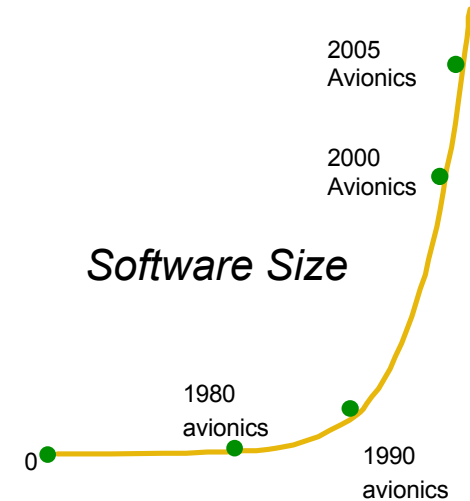
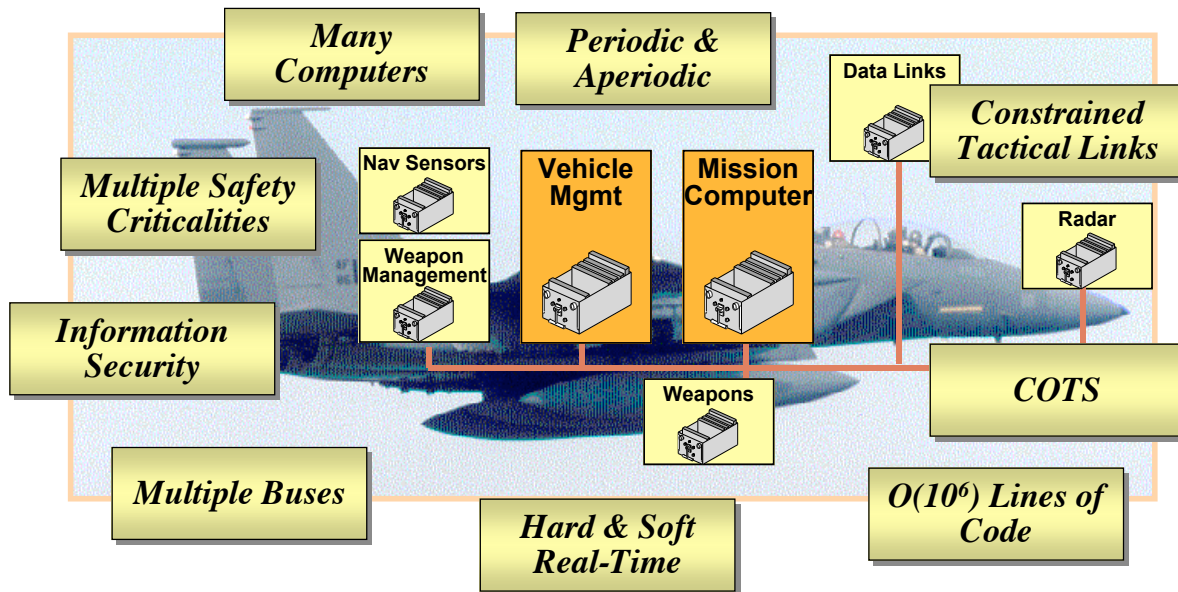


# Embedded Systems Technology Challenges

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- **Operational Complexity of Large-scale Embedded Systems Is Growing Exponentially**
  - **New capabilities:** autonomous UAVs, Mixed Initiative, broadband aircraft networking,
  - **Extended capabilities:** real-time mission replanning...
  - **Highly dynamic operating environments**
  - **Operation in a SoS Network**



- **Avionics S/W challenges**
- **Networking challenges**
- **Information Management challenges**
- **Application challenges**
- **Verification, Validation and Certification challenges**
- **Software Engineering challenges**
- **Commercial vs military domain**

# Typical Mission Computing Legacy Characteristics

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System size of 10 – 30M not unknown

- **10-100 Hz Update Rates**
- **Up To 10-100 Processors**
- **~1M Lines of Code**
  - **$O(10^3)$  Components**
- **Proprietary Hardware**
  - **Slow CPU, small memory**
  - **Fast I/O**
- **Test-Based Verification**
- **Mil-Std Assembly Language**
- **Highly Optimized For Throughput and Memory**
- **Functional Architectures**
  - **Flowchart designs**
- **Frequently No Maintained Requirements or Design**
  - **Ad-hoc models used by algorithm developers**
- **Hardcoded Hardware Specific Single System Designs**
- **Isolated Use Of**
  - **Multi-processing**
  - **Schedulability analysis**
    - **Frequently overly pessimistic to be used**

David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

# Typical Vehicle Management Legacy Characteristics

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## *Additional Characteristics*

- **80/160 Hz Update Rates**
- **Single CPU System/  
Quad Redundant**
- **Dual/Quad Redundant  
Sensors and Actuators**
- **<100K Lines of Code**
- **Extensive Built-In-Test**
  - **>50% of code**
- **Extensive Testing**
  - **Very conservative  
development culture**
  - **>50% of effort**
- **Control System Models  
Carefully Developed And  
Used**
  - **Matlab/MatrixX with  
auto code generation**

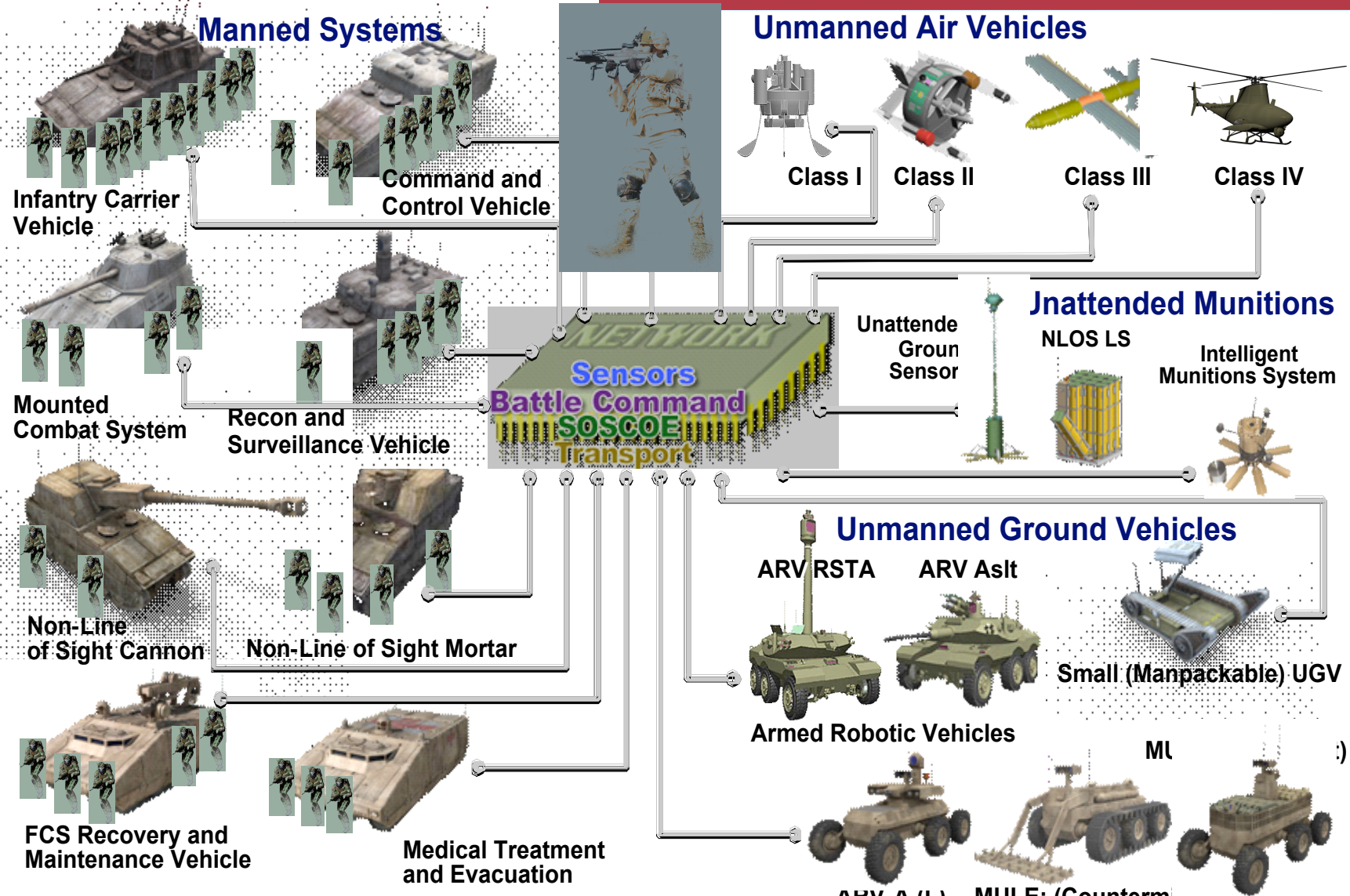
David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

# Networked System of Systems Example:

FCS 18 Integrated Systems + Network + Soldier



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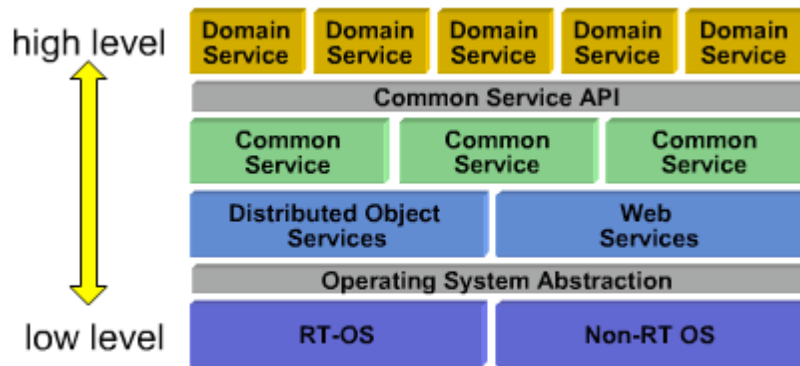
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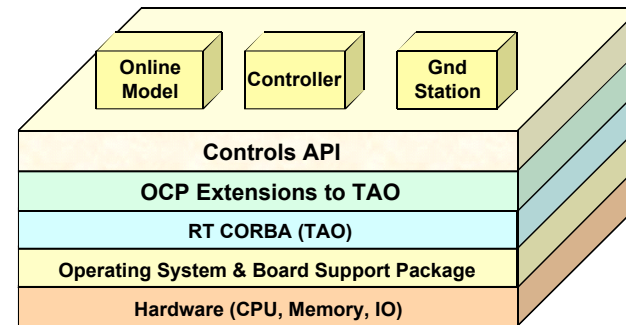
# Boeing Leverages Middleware Based Architectures to provide Hardware and Operating System Independence

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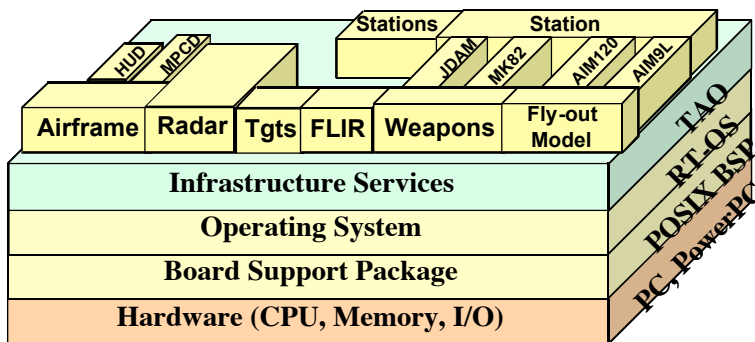
NCO Thrust



FCS SOSCOE Architecture



Open Control Platform for Autonomous Systems



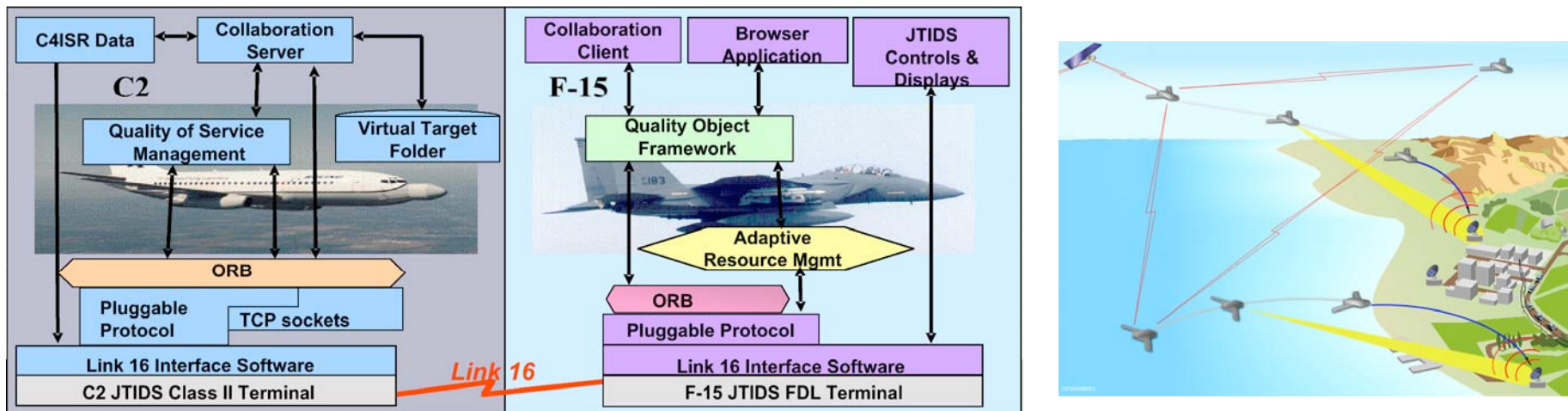
Bold Stroke Product Line Architecture (F/A-18, F-15, T-45)



# Avionics Software Challenges: Dynamic System Behavior

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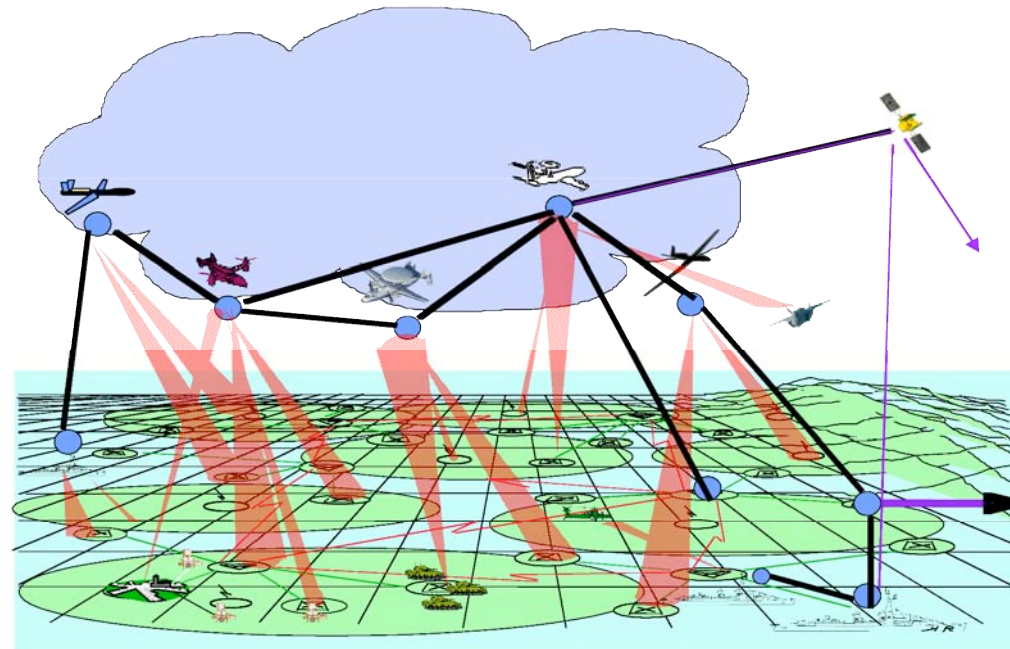
- **New applications require dynamic behaviors**
  - Mixture of hard and soft real-time tasks
  - Active resource management and dynamic scheduling
  - Mode changes with component configuration changes
  - Dynamic changes to system membership
    - Swarms
    - NCO
    - Power conservation
- **Current component/system models favor static systems**
  - CCM
  - OCP
- **Must meet Embedded/Real-Time constraints in a dynamic setting**
  - Need to handle during system execution things that were typically dealt with “out of band” at startup

# Networking Challenges

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- **Smart routers**
  - Help deal with massive amounts of data
- **QoS in “open” networks**
  - Latencies
  - Predictability
  - Guaranteed delivery
- **Bandwidth**
  - Wireless
  - Mobile
  - Satellite
  - Airborne
- **Heterogeneous/federated networks**
- **Inherently unreliable networks**
- **Networked systems ranging from Motes upwards**

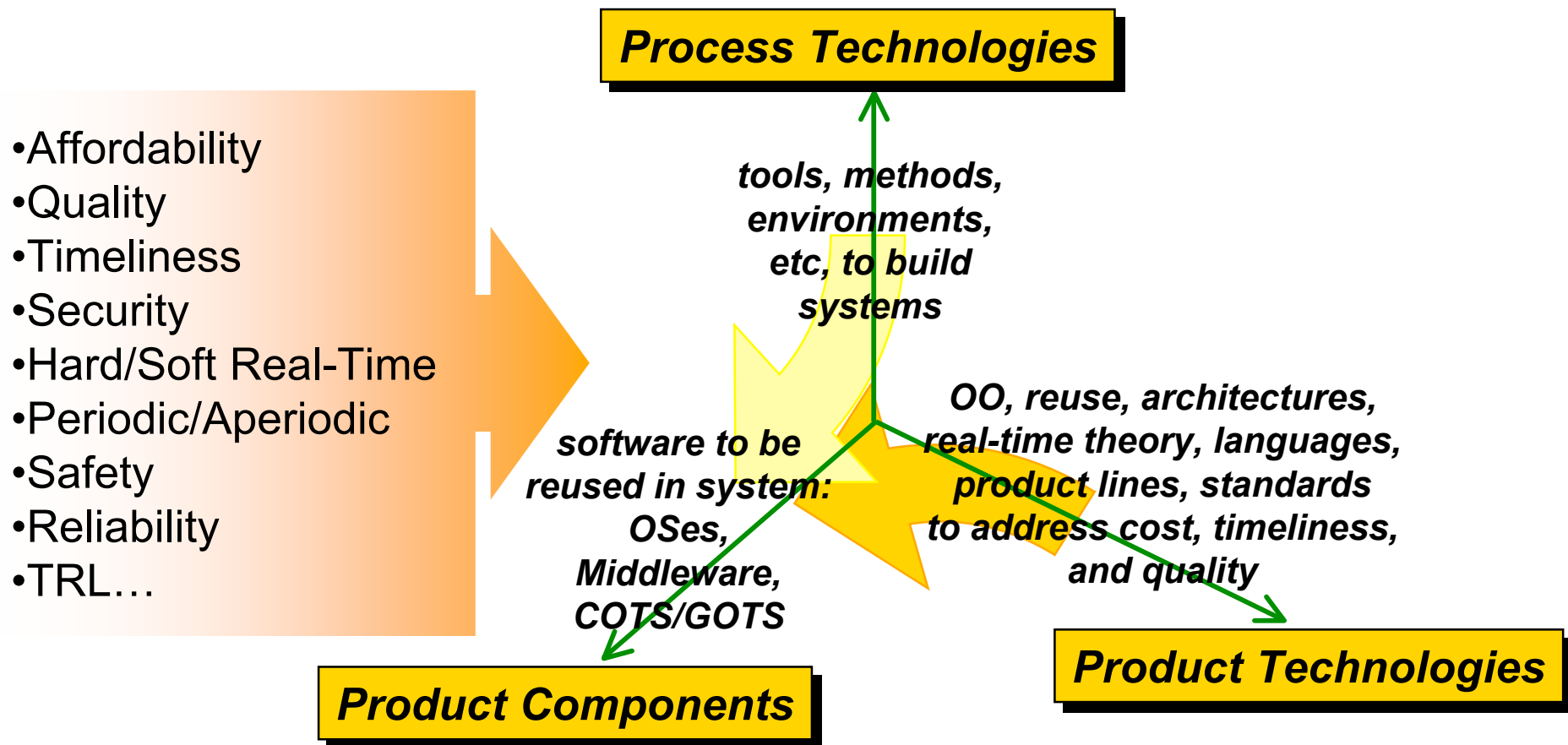


# Networked SOS IT Challenges (cont)

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## ***Multiple Competing Dimensions & Aspects Must Be Addressed, Balanced and Integrated***



# Process Technology Challenges

- **Design Technologies**
  - **Domain specific multi-view modeling & analysis**
    - Capture cross-cutting systemic concerns (deployment, composition, messaging, fault tolerance, etc.) in native architectural terms
  - **Integrated dynamic design space exploration & analysis**
    - e.g. traffic analysis, system loading, operational latencies, path tracing, safety/security non-interference, etc.
  - **Generative technologies for correct-by-construction synthesis**
    - Architectural abstractions, common pattern application, synthesized composition configuration, middleware integration, etc.
- **Verification & Validation Technologies**
  - **Flexible & reconfigurable SoS simulation & validation**
    - Tailorable to specific mission context
    - Composable in number and type of participants, topology, etc.
    - Integrating real and simulated/surrogate/synthesized elements
  - **Completeness in varying topologies & operational contexts**

**Need Scalable technologies to design, analyze, verify and validate large Networked SoS.**

# Product Technology Challenges

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- **Product Line Architectures**
  - Contain product variability in heterogeneous security, criticality, timeliness & physical deployment concerns
- **Component models & patterns for uber-scale systems**
  - Enabling software variability across & within systems while addressing cross-cutting aspects
- **QoS / Resource Management**
  - Resource & behavioral adaptation to:
    - MANET topology, membership and capacity changes
      - Including local vs. coordinated networked behavioral tradeoffs
    - Intermittent communications availability (missed updates, dropped messages)
    - Changing mission context & commander's guidance
  - ... while maintaining
    - Information separation
    - Multiple degrees of timeliness and criticality
    - Concurrent mission activities (e.g. operational & training)
    - Limited/competing communications throughput
  - ... both at the system and SoS levels

Need ***Composable*** approaches to enable heterogeneous system variability while addressing changing resource availability.

# Product Technology Challenges (cont'd)

- **Information Management**
  - **Maintain coherent SoS situational awareness across possibly out-of-synch individual systems**
    - **Right information to the right user at the right time**
  - **Programming patterns, approaches and architectures for dealing with peer-to-peer ad hoc network communications**
- **Scheduling & Deployment**
  - **Hard, soft & non real-time, periodic & event-driven processing**
  - **Maintain optimal software deployment against changing user roles, mission context, systems modes and hardware availability**
- **Criticality**
  - **Intermixed safety critical, mission critical and non-critical processing**
    - **Deployment isolation, resource allocation, certification, etc.**
- **Information Assurance**
  - **Integrated IA architecture across GiG to the end-system user**
    - **Accounting for USI to multiple classification levels**

# Product Component Challenges

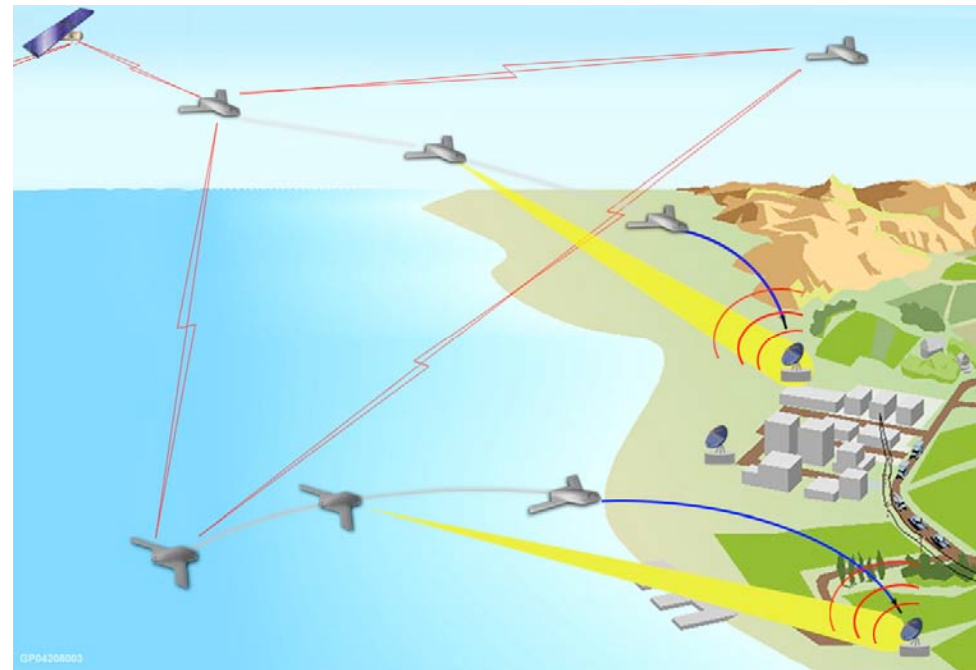
- **COTS Standards-based Network-centric SoS Middleware**
  - Composable from minimal safety certifiable profile to enterprise-level adaptive & reflective
  - Providing integrated network management for traffic flow reservation, priority negotiation and admission control
  - Supporting pushed & pulled, method-based & data-centric communications
  - Supporting static & dynamic peer-to-peer service discovery in a multi-network changing MANET topology
  - Optimized for limited network throughput
  - With reliable communications capabilities in support of safety critical operations
  - Tolerant of intermittent wireless comm failures
- **IA components**
  - High bandwidth trusted networking, cross domain and display components in support of tactical GiG to the soldier

# Multi-Entity Embedded System Challenges

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- **Dynamic replanning and response to uncertainty**
- **Resource and task allocation**
- **Mixed initiative operations**
  - Allocation of initiative to human operator or automata
- **Fault-Tolerance**
- **Heterogeneous platforms**



# Software Engineering Challenges

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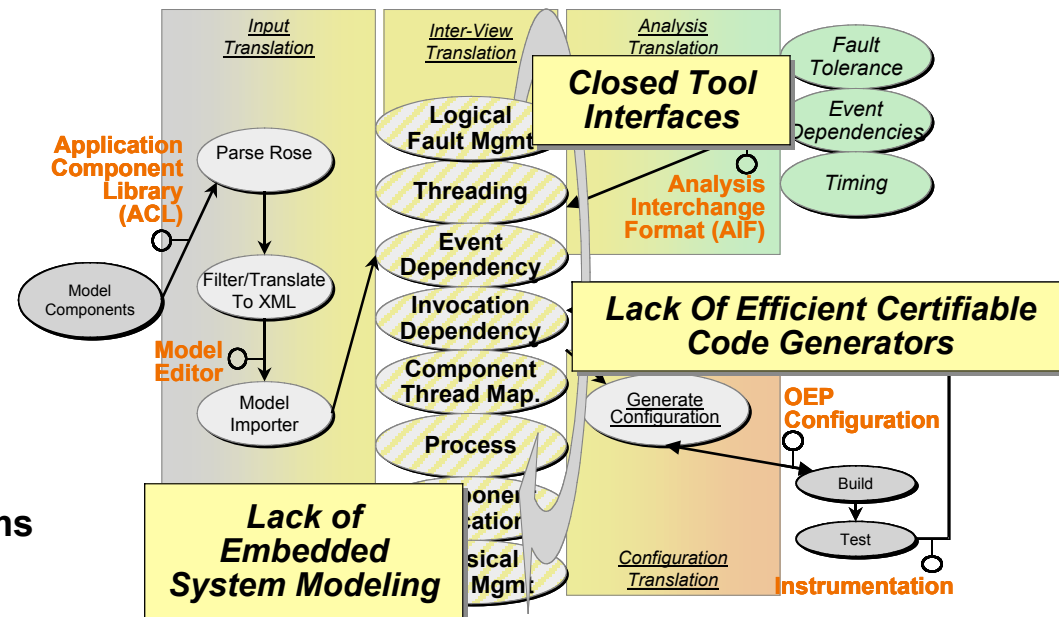
- Creating component models/development environments for “legacy” systems
  - May not always be able to select the component model first
    - \_ Have, instead, an existing infrastructure to create a component model and development environment for
    - \_ Define component model consistent with legacy platform
      - \_ Abstractions appropriate for
        - Component based development
        - Existing infrastructure
        - Functional and non-functional requirements
    - \_ Generate development environment
      - \_ Modeling tools
      - \_ Code generators
      - \_ Infrastructure adapters
      - \_ Testing/analysis tools
- Data collection
  - Analysis techniques require data that:
    - \_ Does not currently exist
    - \_ Frequently is difficult to obtain
    - \_ Too often impractical to create directly
  - Ex: timing and state transition data for legacy system/components

# Avionics Software Challenges: Integration

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- **Component/System integration is still hard**
  - The MoBIES problems are still out there
  - Component integration satisfying QoS
    - Real-time
    - Concurrency
    - Distribution
  - Constrained by
    - Large, distributed development teams
    - Product line based reuse
    - Legacy systems, platforms and processes
  - With Efficient/Effective
    - Performance analysis, prediction and testing
    - Testing and iterative development



# Verification, Validation and Certification Challenges

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- **V&V and Certification is expensive, and getting more expensive, for fielded systems**
- **Future advanced manned and un-manned systems may not fit naturally under current V&V and Certification regimes**
- **Need approaches for efficient V&V and Certification for emerging technologies for them to be deployable**
  - **Multi-entity Systems**
  - **Human interaction with Autonomy.**
  - **Fused Sensor Systems**
  - **Adaptive Systems that change with environmental stimulus**
  - **Mixed Criticality- Functions dependent on information of varying confidence**



# Program Composition of Embedded Systems (PCES) Program – Case Study in Unmanned Systems

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- **Challenge - Compose UAV embedded software to support dynamic behaviors with network centric connectivity to a mission commander on a tightly resource constrained system**
- **Development and composition from new UAV components executing on Product-line Reusable Scalable eMbedded (PRiSm) framework**
- **Demonstration as part of DARPA / ARMY / Air Force joint military exercise at White Sands Missile Range, New Mexico**
- **On-board Autonomy**
  - **Enabling Software technology for hosting autonomy on ScanEagle**
  - **C++ and Real-Time Java software platforms**
    - International award for Innovations in Use of Java
  - **On-board autonomy allowed UA to map it own path in response to high-level commands from a mission commander controlling multiple UA**

Source: Boeing Press Release [www.boeing.com/news/releases/2005/q2/nr\\_050420o.html](http://www.boeing.com/news/releases/2005/q2/nr_050420o.html)

- **\*Public-release video\***

# Technical Progress and Tech Transition

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- **RT-Java middleware, event channels, and frameworks evaluated**
  - Demonstrating real-time performance in embedded avionics application
  - Hosted on relevant embedded hardware in relevant vehicle (ScanEagle)
  - Realizing small footprint designs
- **C++ PRiSm (Product-line Reusable Scalable Embedded) middleware exhibiting real-time performance**
  - Relevant hardware / relevant vehicle



Source: Boeing Public Release video for PCES demonstration

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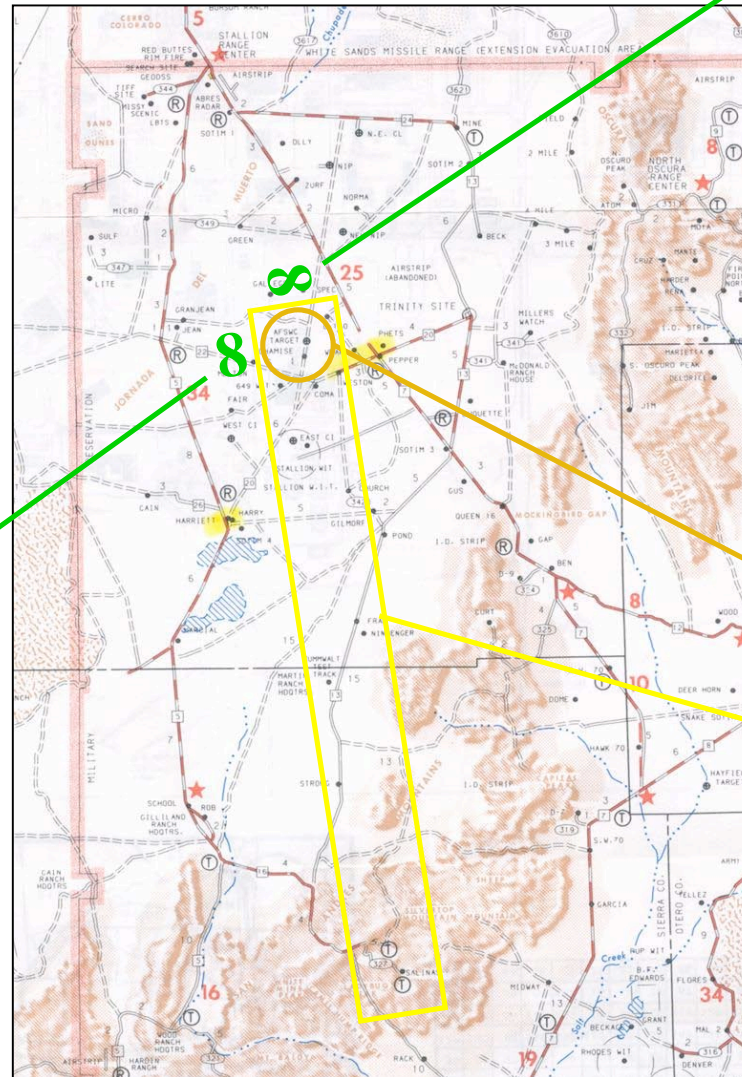
# Technical Progress and Tech Transition

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- PCES RT-Java and C++ applications implementing autonomous maneuvering in ScanEagle to support time-critical target recce and monitoring of surface target weapon strikes
- Infospace leverage in integrated capstone demonstration

Offset Stare maneuvering crosstrack of impact;



Offset Stare maneuvering downtrack of impact;

Stallion WIT, Missile Target

No-Fly Zone

Source: Boeing Public Release video for PCES Demonstration

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# Public Release Video

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# Summary – Pervasive Industrial Strength Challenges in Composition of Embedded Systems

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- **Dynamicism**
  - System of systems with changing participants
  - Changing modalities of individual systems
  - On-line code generation
- **Heterogeneity**
  - System of systems
  - Heterogeneous/federated networks
  - Heterogeneous collaborations
    - Ad hoc coalitions
  - COTS/GOTS components in an overall system
- **Fault Tolerance**
  - Unreliable networks
  - High confidence
  - Mission effectiveness in the presence of failures
  - IVHM
- **Scalability**
  - Massive data flows
  - Systems of many systems
  - Ever larger end systems
- **Certification and V & V**

