Air Force Evolution to Open Avionics

- HPEC 2010 Workshop -

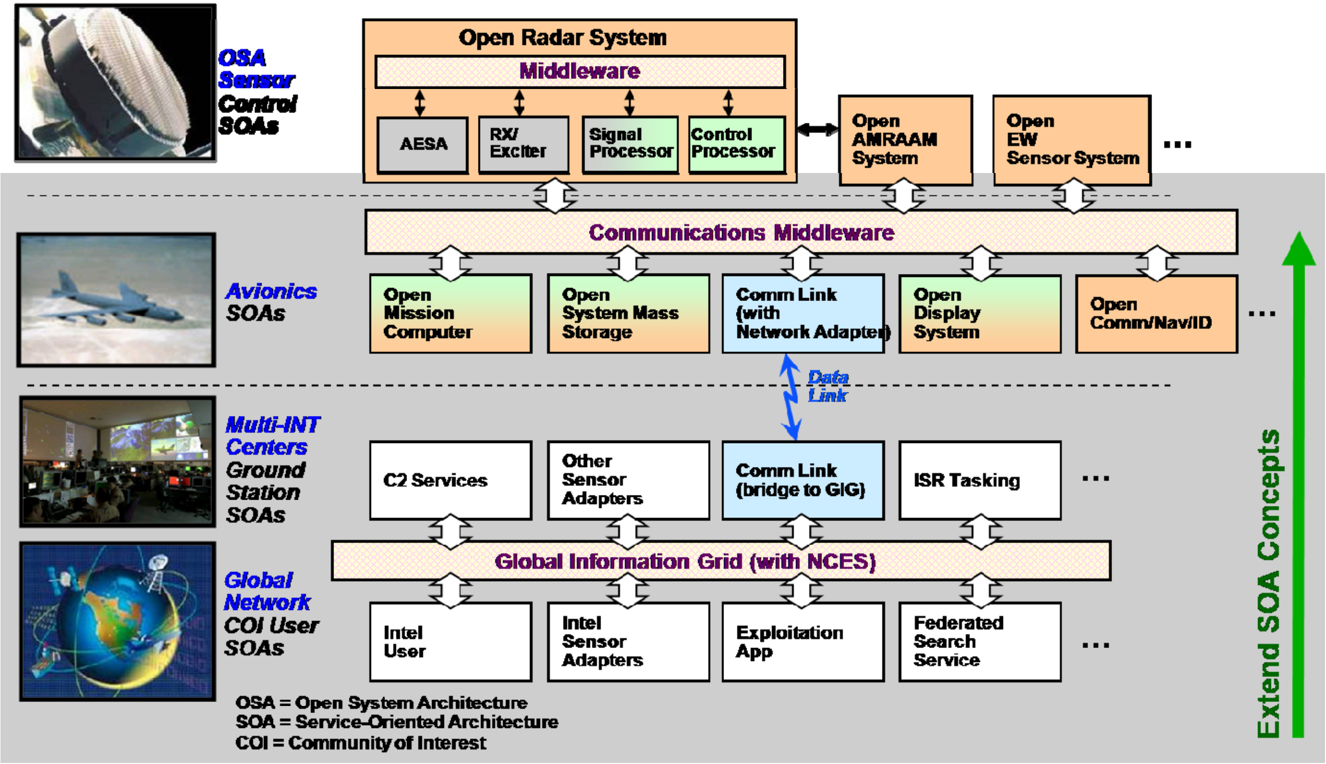
Robert Bond

16 September 2010

Outline

- Open Architecture Vision for the Air Force
  - Layered architecture
  - Technologies
- Air Force Avionics Architectures
  - F22 Raptor case study
  - Architecture evolution
- Open Avionics
  - Key open avionics concepts
  - Architectures and testbeds
- Acquisition in an Open Architecture Context
  - Leverage and adapt
  - “Open” acquisition
- Conclusion

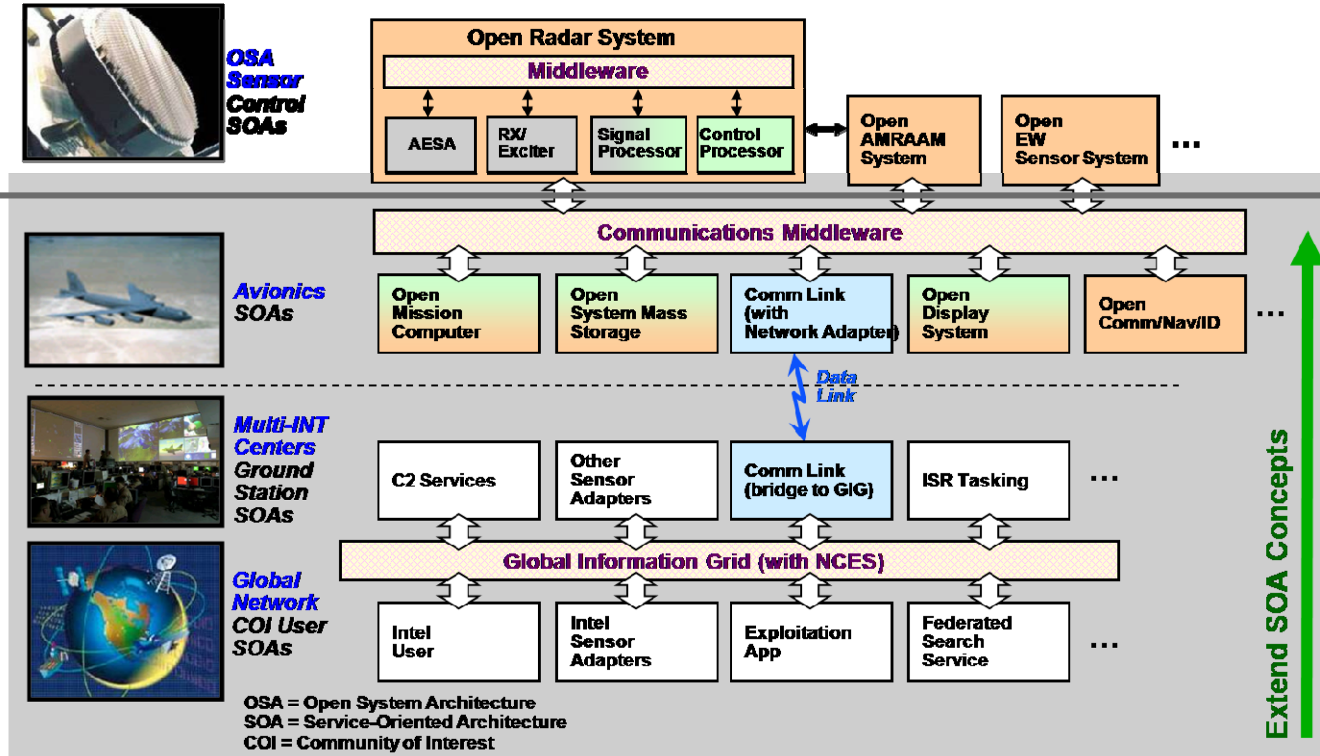
Air Force Layered Open Systems Architecture (OSA)



VISION: Air Force is developing an integrated (but loosely coupled) open-systems architectures spanning Air Force layered system-of-systems

Air Force
Layered Open Systems Architecture (OSA)

Open Sensors



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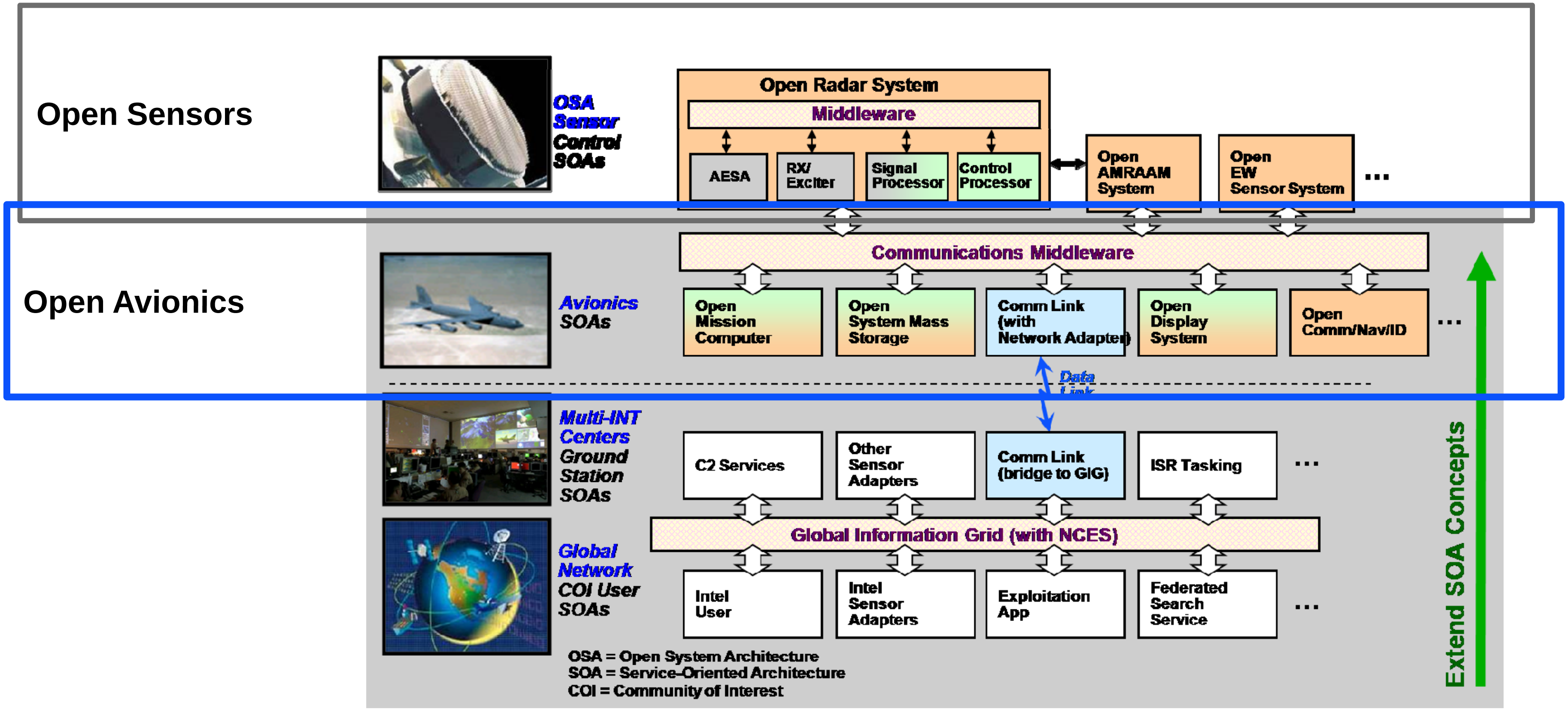
Layered Open Systems Architecture (OSA)



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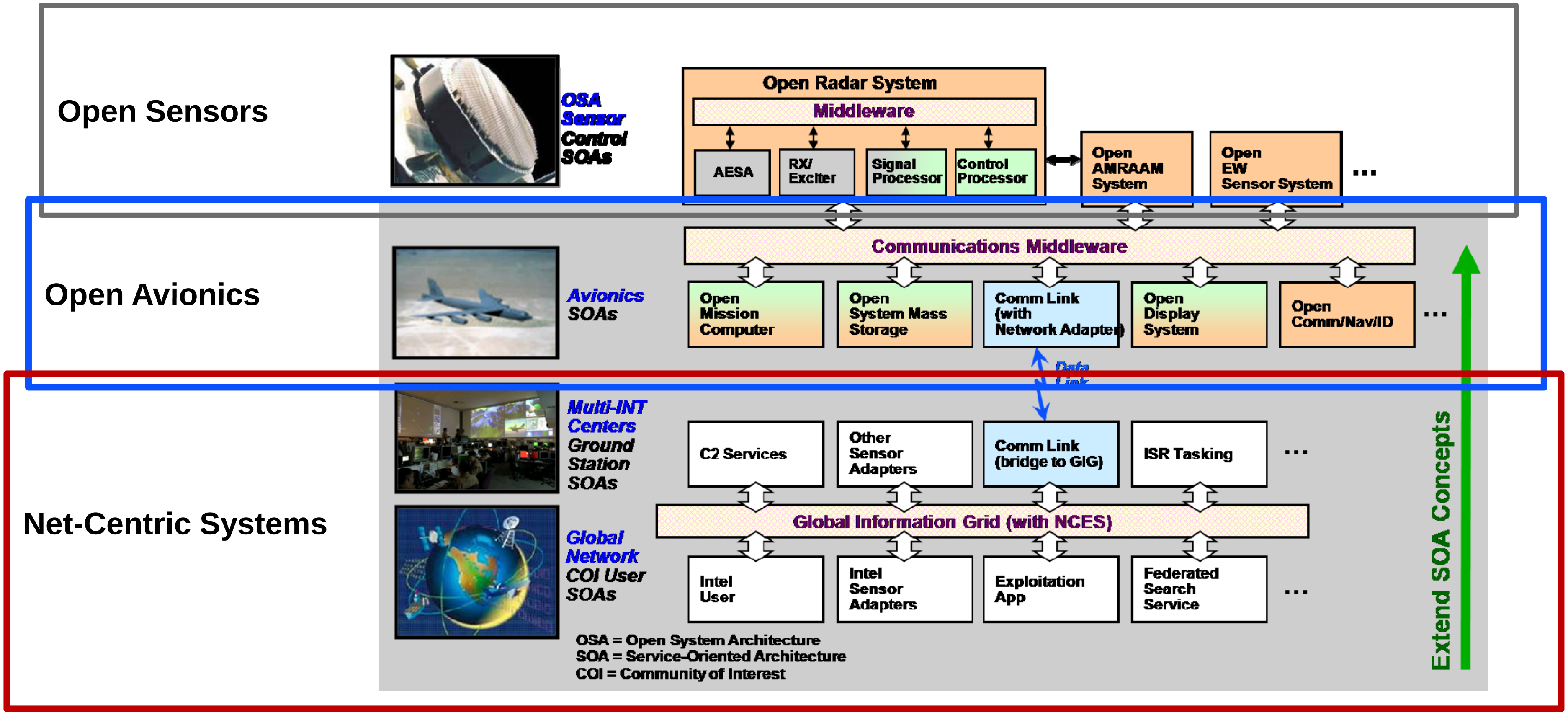


VISION: Air Force is developing an integrated (but loosely coupled) open-systems architectures spanning Air Force layered system-of-systems

Technology Drivers
- Embedded Systems -

Embedded System — Distributed System — Networked System-of-Systems

Component Attribute	Airborne Radar	Avionics	Ground Station	GIG
Throughput	~ 1 TOPS	~ 10 GFLOPS	~1s GFLOPS	< 1 GFLOPS
Form-factor	10 GOPS/W	> 100 MFLOPS/W	10s MFLOPS/W	10s MFLOPS/W
Data Rate	~500 GB/s	~ 100 GB/s	~ 10GB/s	< 10GB/s
Latency	~ mSecs	~ 100 mSecs	~ secs	> secs

Note that *embedded military systems* have challenges that set them apart from distributed and networked systems, but…

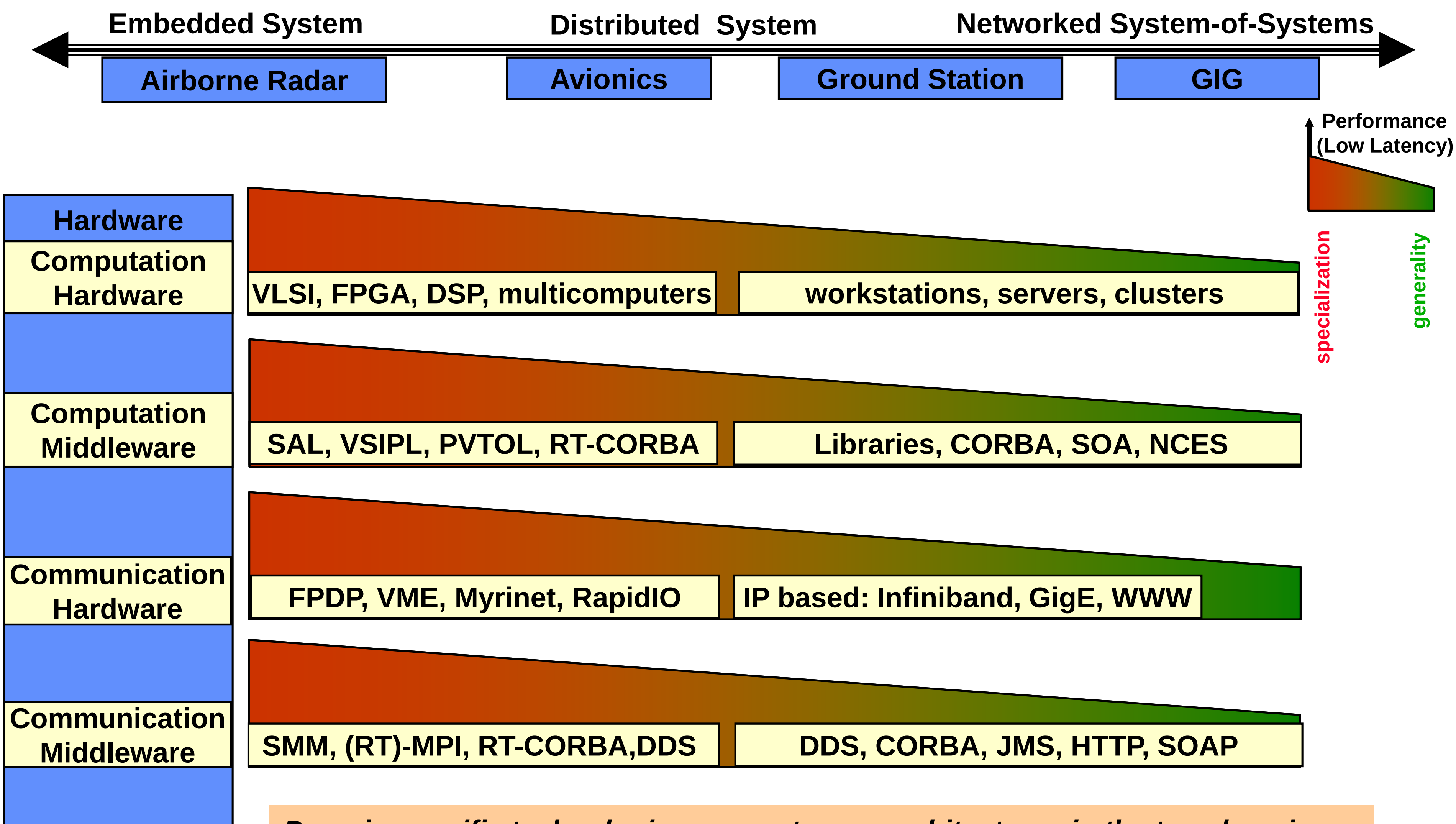
Technology Drivers
- System-of-systems -

Embedded System ← Distributed System → Networked System-of-Systems

System Attribute	Airborne Radar	Avionics	Ground Station	GIG
Application Complexity	~10s modes	~100s functions	100s modules	100s Programs
# Components	<10 subsys	10s subsys	100s subsys	1000s nodes
Configurability	Static (design)	redundancy	User select	Dynamic topologies, users, content/use
Data Complexity	arrays	structures	databases	databases web content (semantic)

…distributed and networked **military system have their own set of challenges that set them apart from embedded systems; and *avionics* have elements of both domains.**

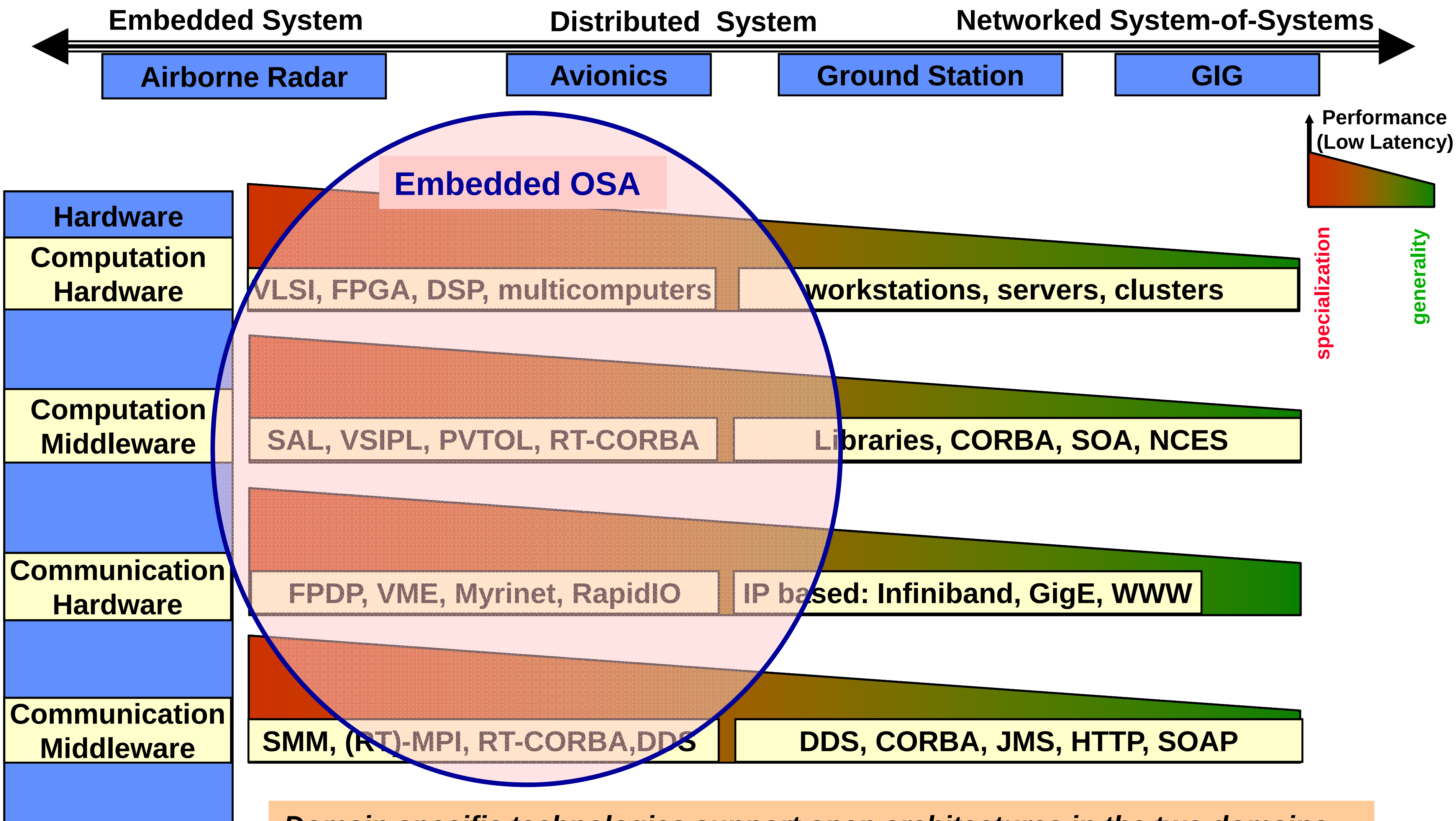
Open Systems Technologies



Domain specific technologies support open architectures in the two domains

SOA = Service Oriented Architecture
OSA = Open System Architecture

Open Systems Technologies



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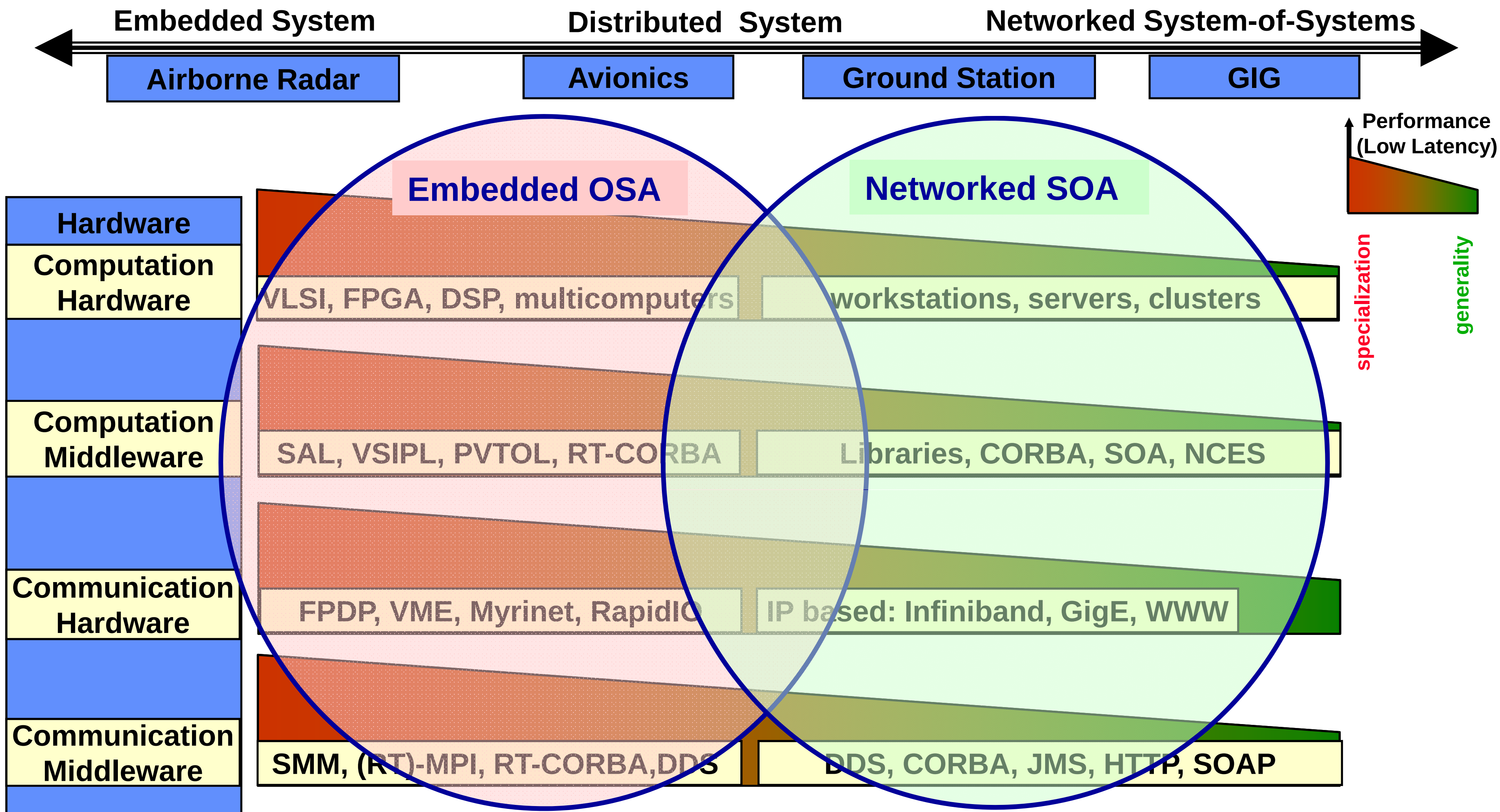

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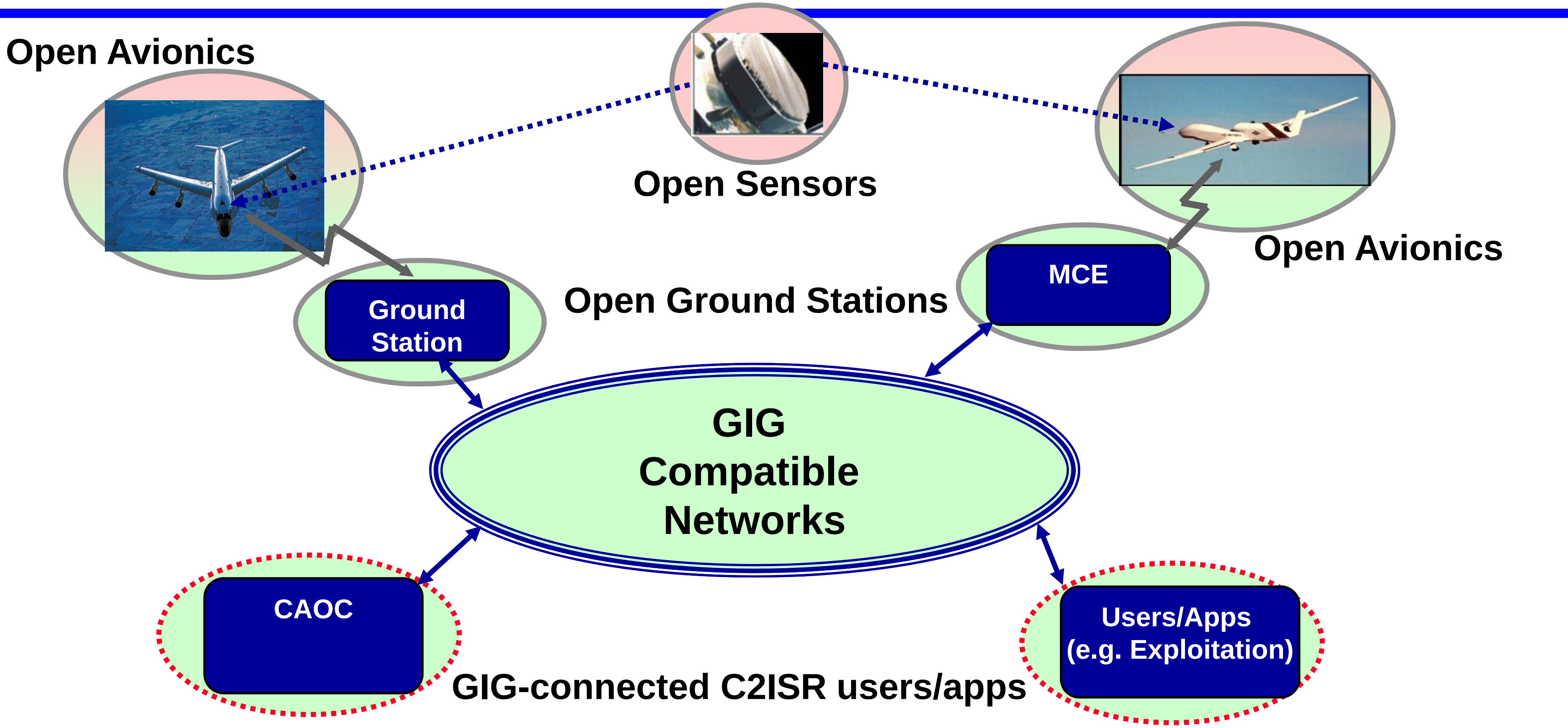
Open Architecture Thrusts



Sensors → Embedded OSA
Avionics → OSA and SOA blend — Leverage best of both
Ground Stations → Networked SOA
GIG Users/Apps → Networked SOA

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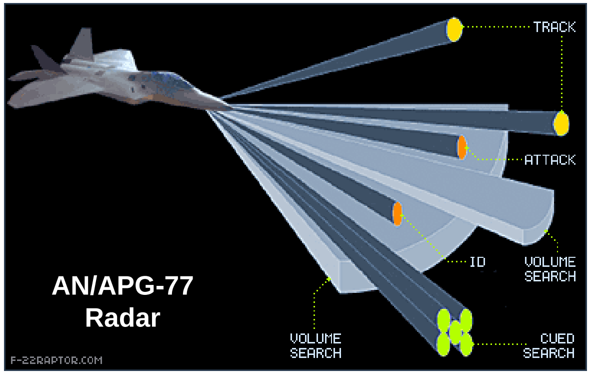
F-22 Raptor

- LO Stealth
- Supercruise (the ability to attain and sustain supersonic speeds w/o afterburners)
- Agility (maneuverability for shoot-to-kill)
- Advanced Avionics (integrated 4pi-steradian situation awareness)
- Supportability (by means of higher reliability and 2 level maintenance)



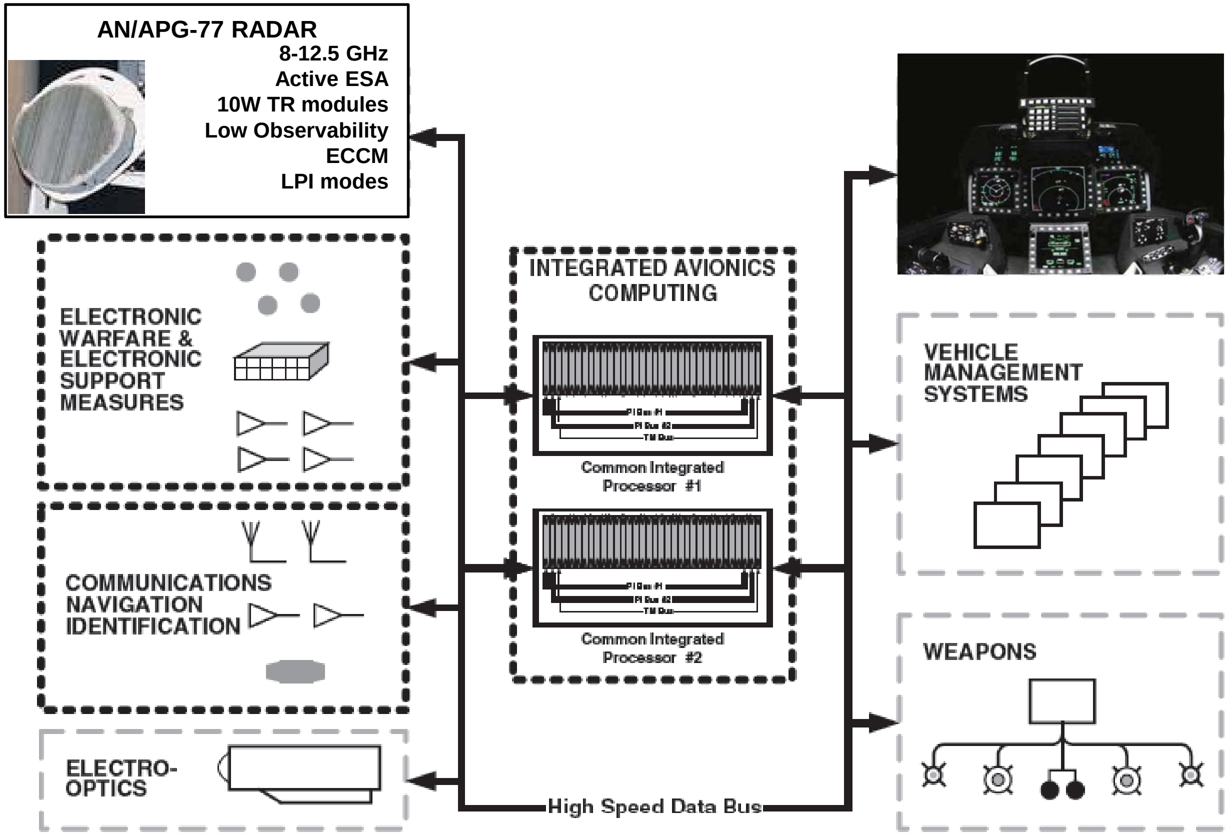
Source: http://www.f-22raptor.com/af_radar.php

Wing Area:	840 sq ft
Engine Thrust Class:	35,000 lb
Level Speed:	921 mph
Total Length:	62.08 ft
Wing Span:	44.5 ft
Horizontal Tail Span:	29ft
Tail Span:	18'10"
Total Height:	16.67ft
Track Width:	10.6ft
Engines:	Pratt & Whitney F-119
Max. Takeoff Weight:	60,000 lb (27,216 kg)
Max. External Stores:	5,000 lb (2,270 kg)
Weight Empty:	31,670 lb (14,365 kg)
Ceiling:	50,000 ft (15,240 m)
G Limit:	9+

The F-22 Raptor is the world's pre-eminent air dominance fighter

Source: http://www.f22fighter.com/

F-22 Avionics Architecture



Highly sophisticated *integrated avionics system architecture*

Source: Military Avionics Systems, I. Moir and A. Seabridge
2006 John Wiley & Sons, Ltd

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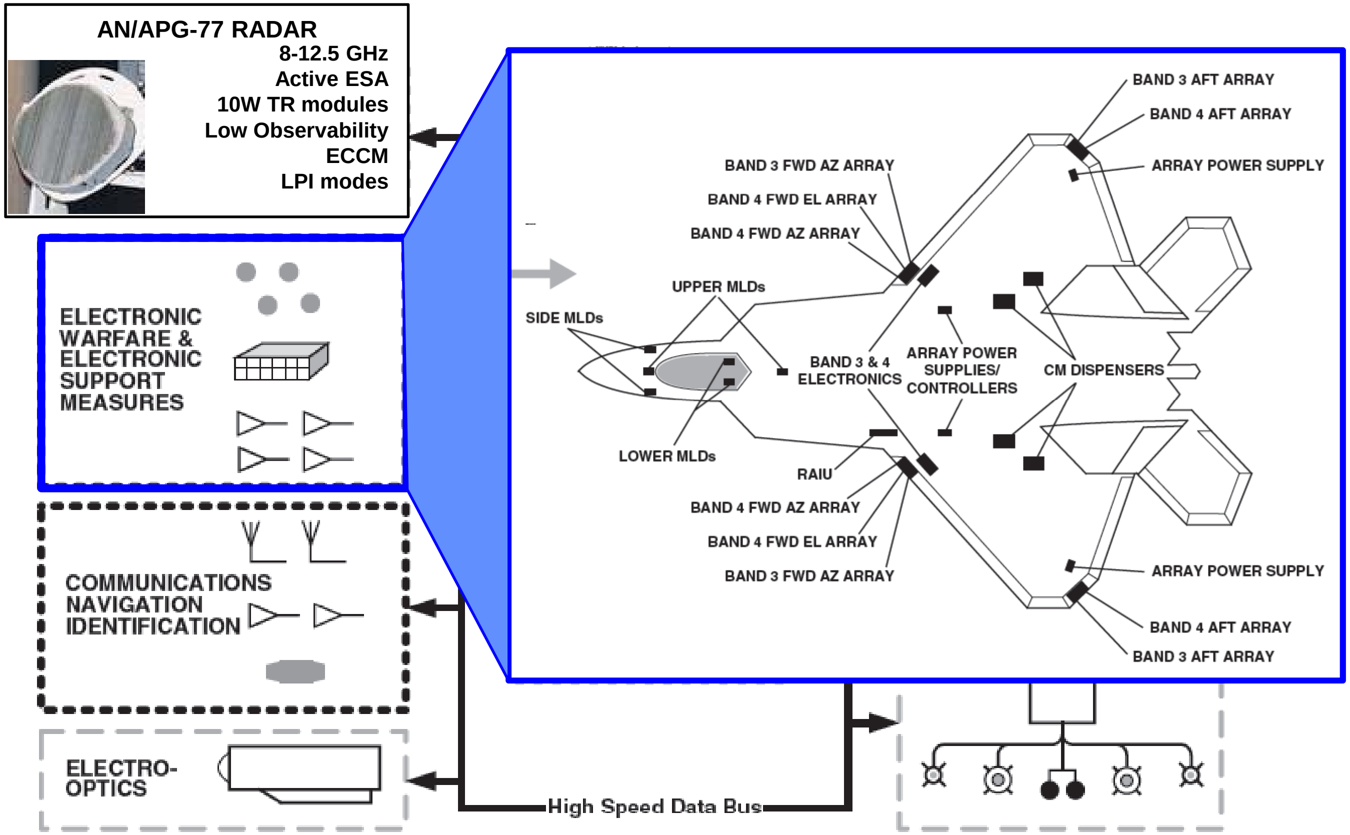

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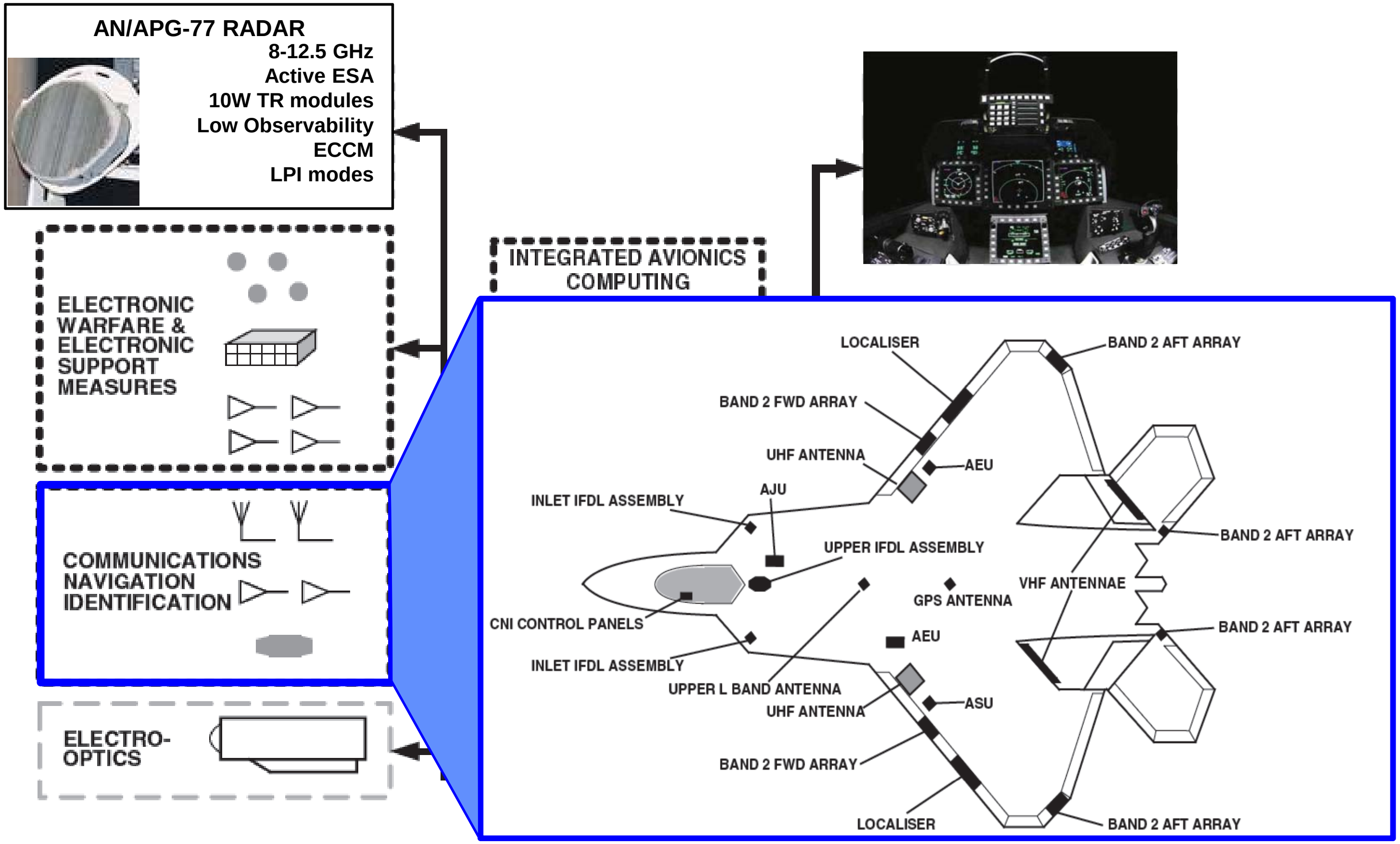

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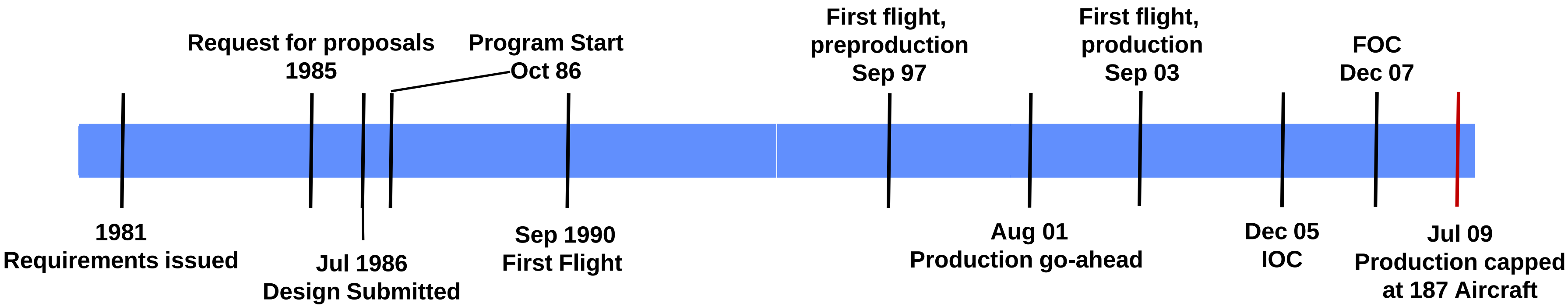
F-22 Acquisition



Sources:
1. Jane's All the World's Aircraft
2. Defense Aerospace.com; Measuring the Real Cost of Modern Fighter Aircraft

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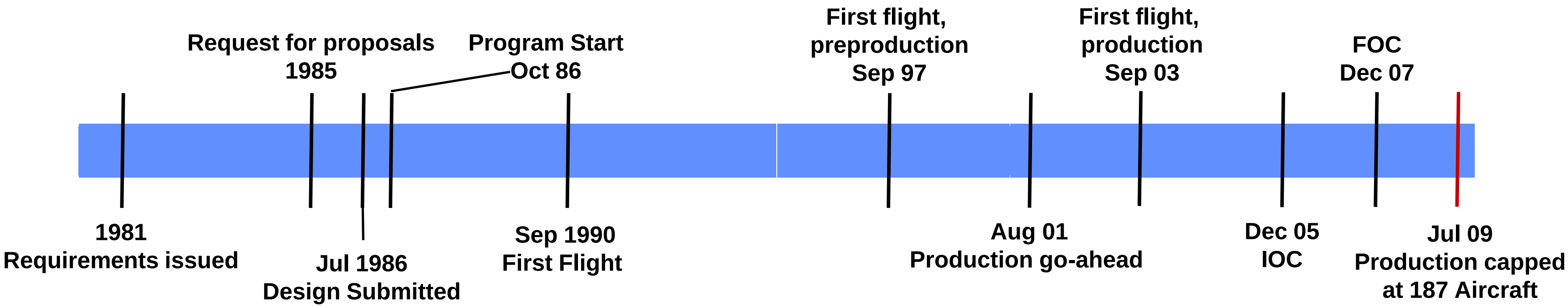

Aircraft	Weight (kg)	Cost ($ million)	Cost per kg ($)
F-15E	20,400	108.2	5,303
caviar			***6,000***
F-18E	13,400	95.3	7,111
JSF	12,000	112.5	9,375
Gripen	5,700	76.07	13,345
Rafale C	9,400	135.8	14,446
Typhoon	9,750	143.8	14,748
gold			***18,700***
F-22	14,400	338.8	23,472

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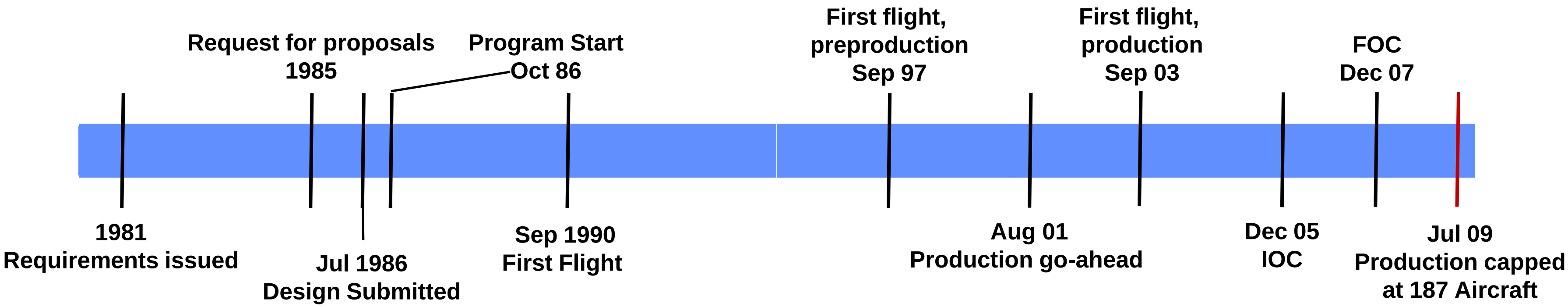

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Cost needs to be balanced with war fighting capability

- **Acquisition, maintenance, and upgrades need to be cost competitive AND timely AND high quality**
- **Open avionics architecture are a fundamental enabler!**

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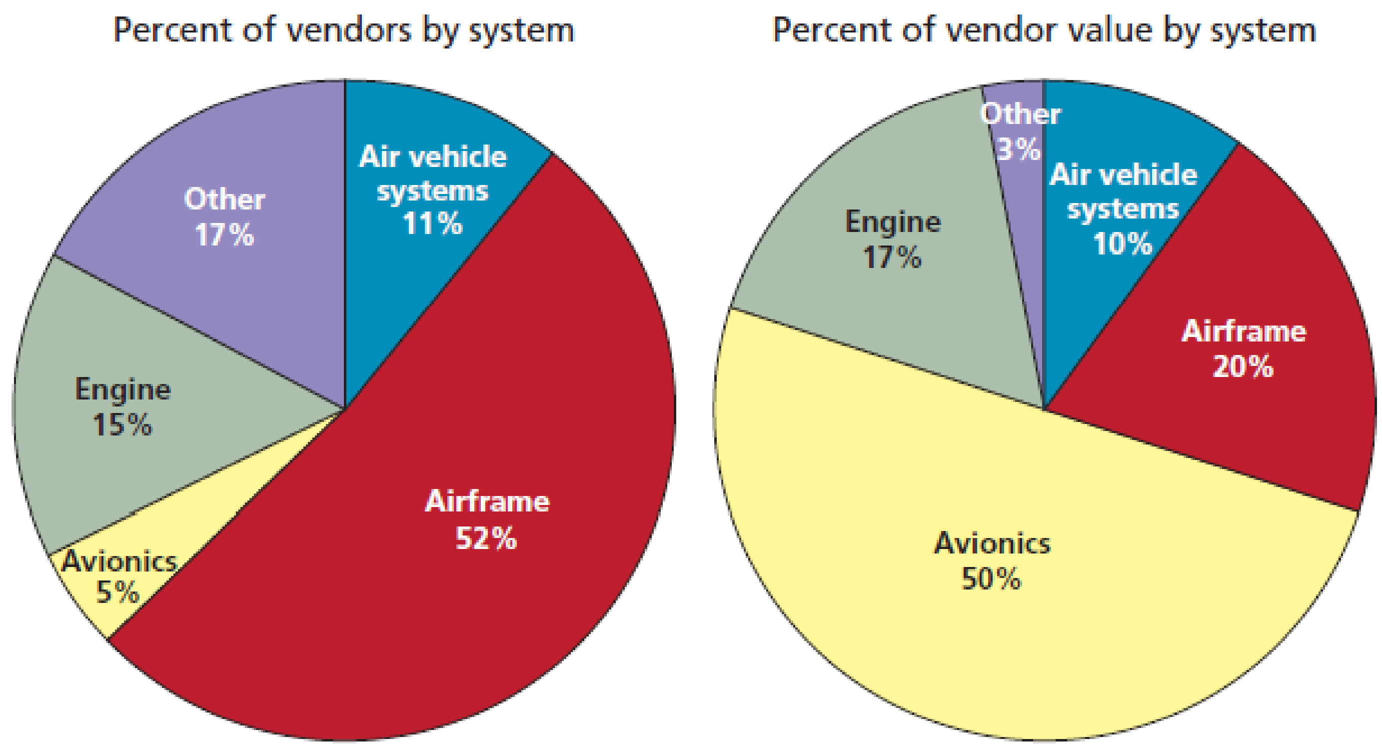
1. Jane's All the World's Aircraft
2. Defense Aerospace.com; Measuring the Real Cost of Modern Fighter Aircraft

F-22 Supply-Chain Vendors

Source: Ending F-22A production: costs and industrial base implications of alternative options / Obaid Younosss … [et al]

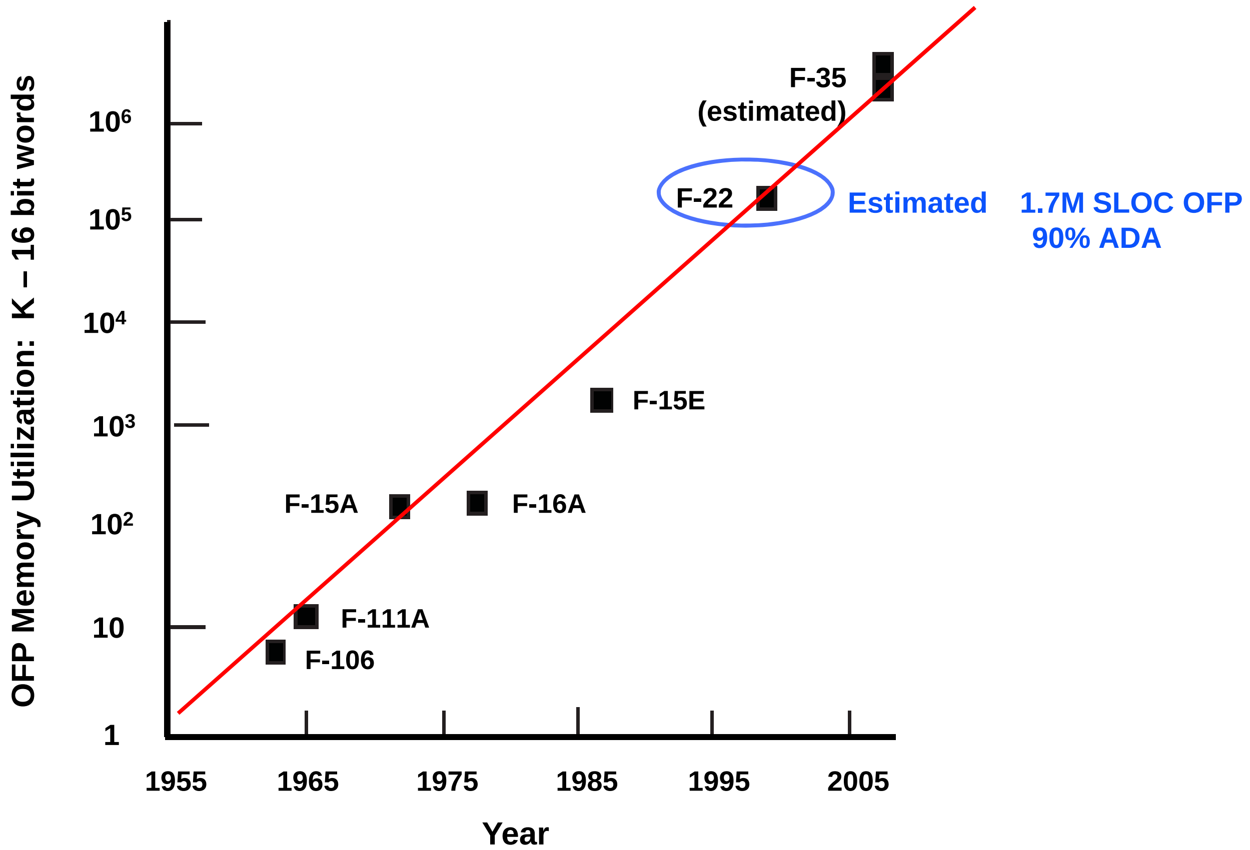


RAND *MG797-5.2*

Avionics supplied by a small set of vendors but are the major cost component in a modern fighter aircraft.

Growth in Operational Flight Program (OFP) Complexity

Aging Avionics in Military Aircraft
http://www.nap.edu/catalog/10108.html



Modern software architectures, technologies, and practices are crucial as the complexity of military aircraft software systems continues to grow exponentially

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  - Layered architecture
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  - Architecture evolution
- Open Avionics and Ground Segments
  - Key open avionics concepts
  - Architectures and testbeds
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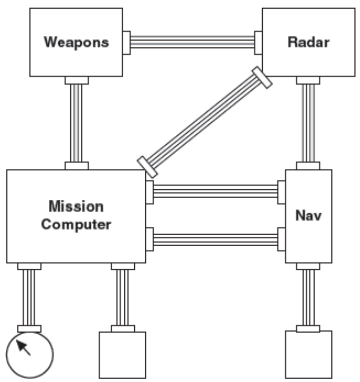
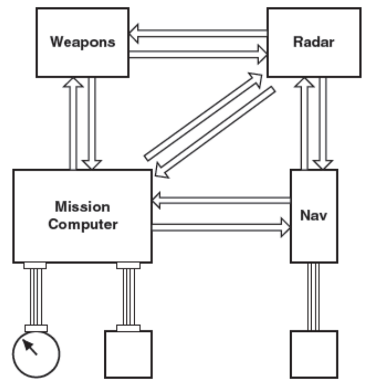
Early Avionics Architectures

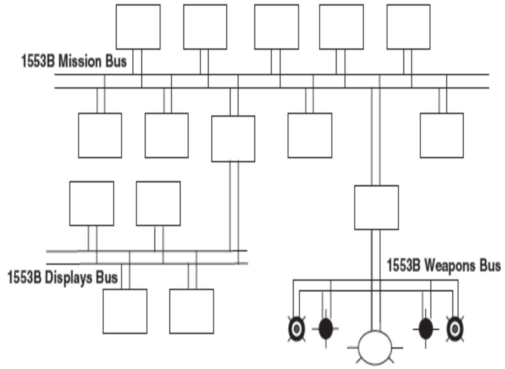
Distributed Analog Architecture
Circa 1960s



Distributed Digital Architecture
Circa 1970s



Federated Digital Architecture
Circa 1980s



F-4 Phantom

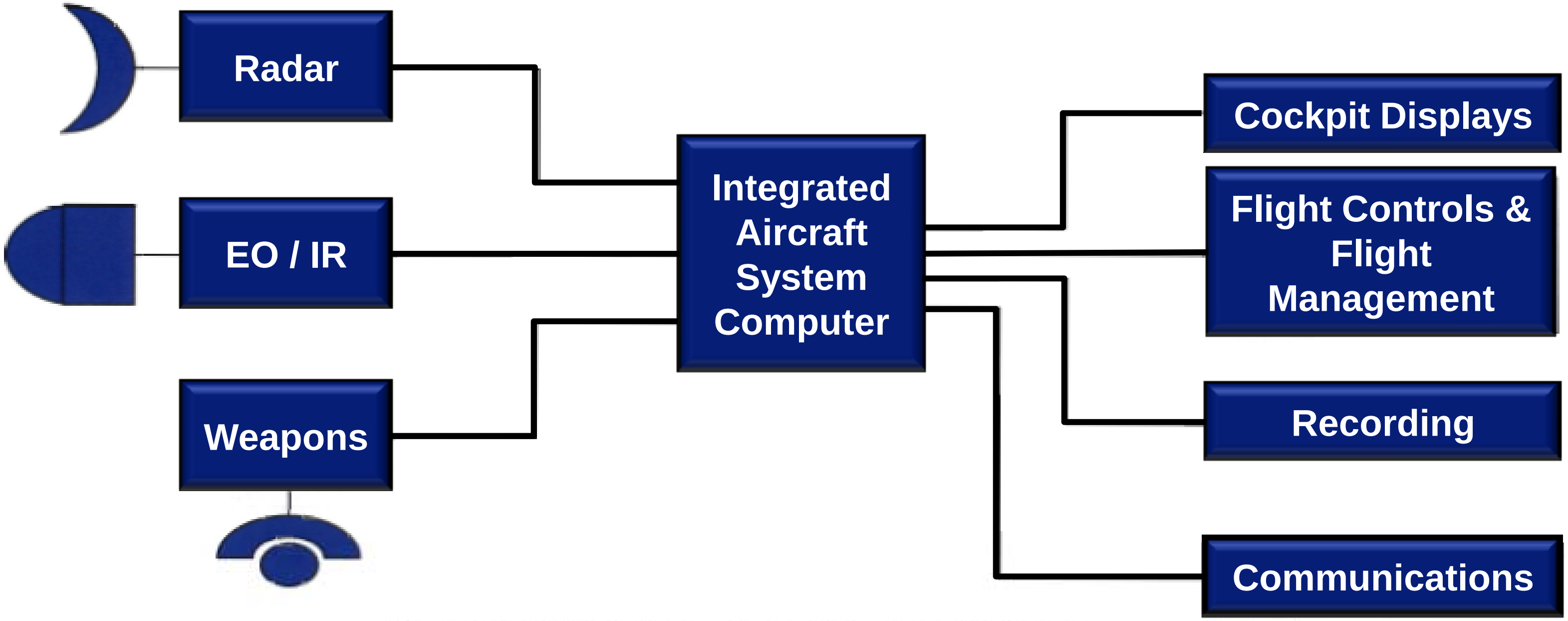
F-14A Tomcat

F/A-18 Hornet

Source: Military Avionics Systems, I. Moir and A. Seabridge
2006 John Wiley & Sons, Ltd

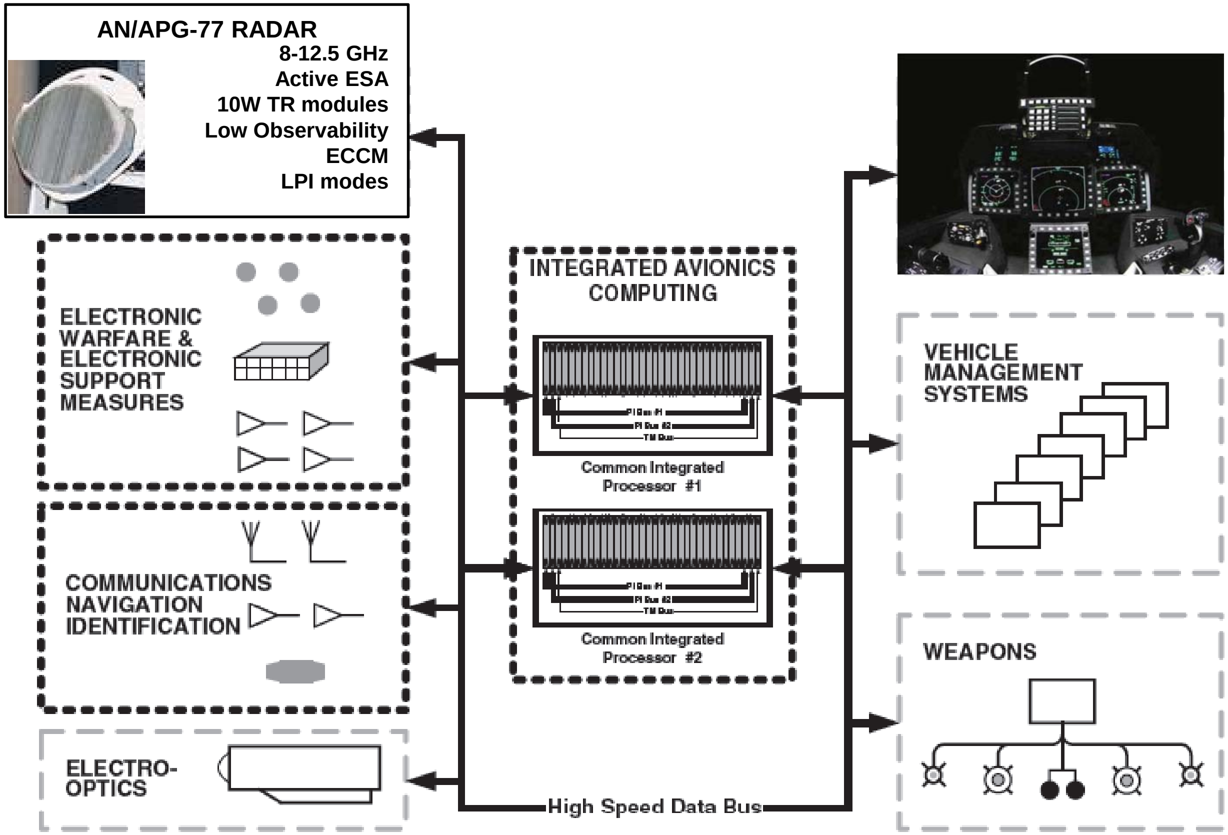
Current Operational Systems

1970s to 1990s



- Integrated systems, proprietary standards
- Cross flow of information between systems
- Computer resources challenged
- Computer use thru single Operational Flight Program (OFP)
- OFP upgrades driven by digital flight control system regression testing
- Avionics capability limited by airframe use of computers
- Airframe prime controls all avionics interfaces

F-22 Avionics Architecture



Highly sophisticated capability based on *integrated avionics system architecture*

Source: Military Avionics Systems, I. Moir and A. Seabridge
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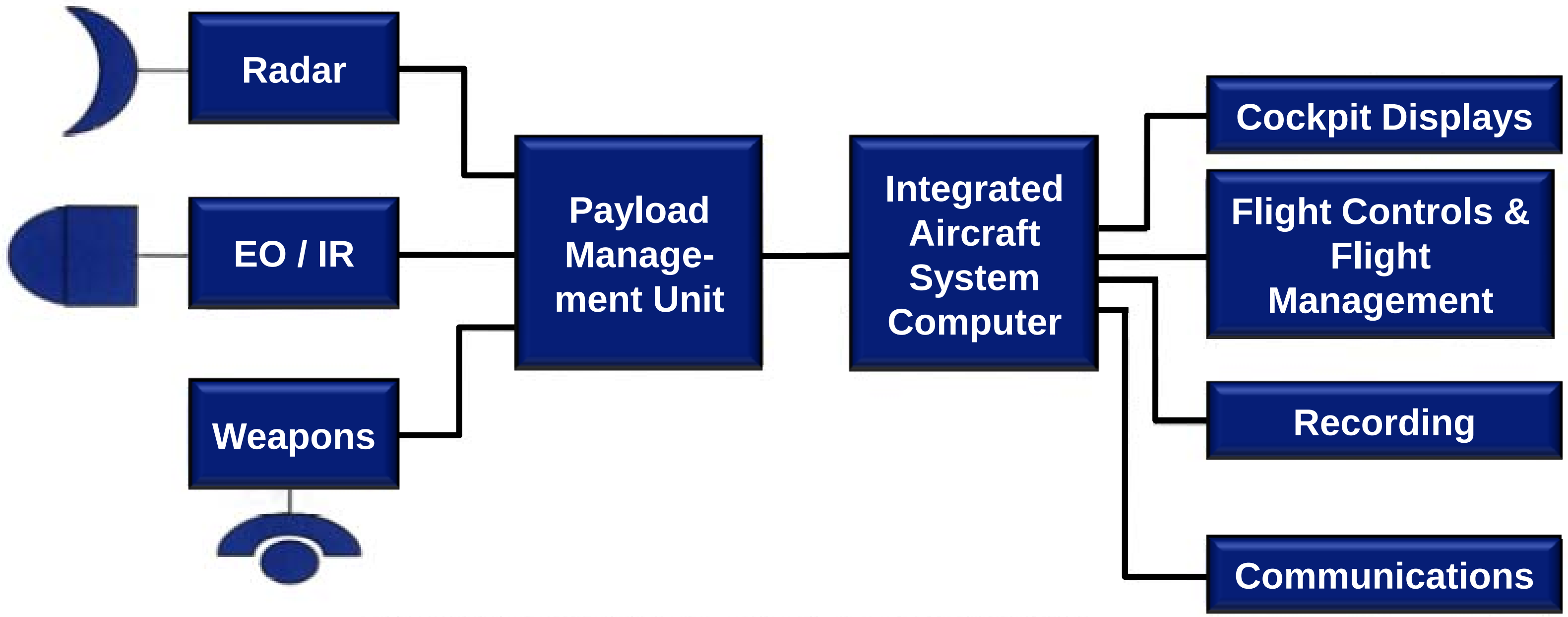
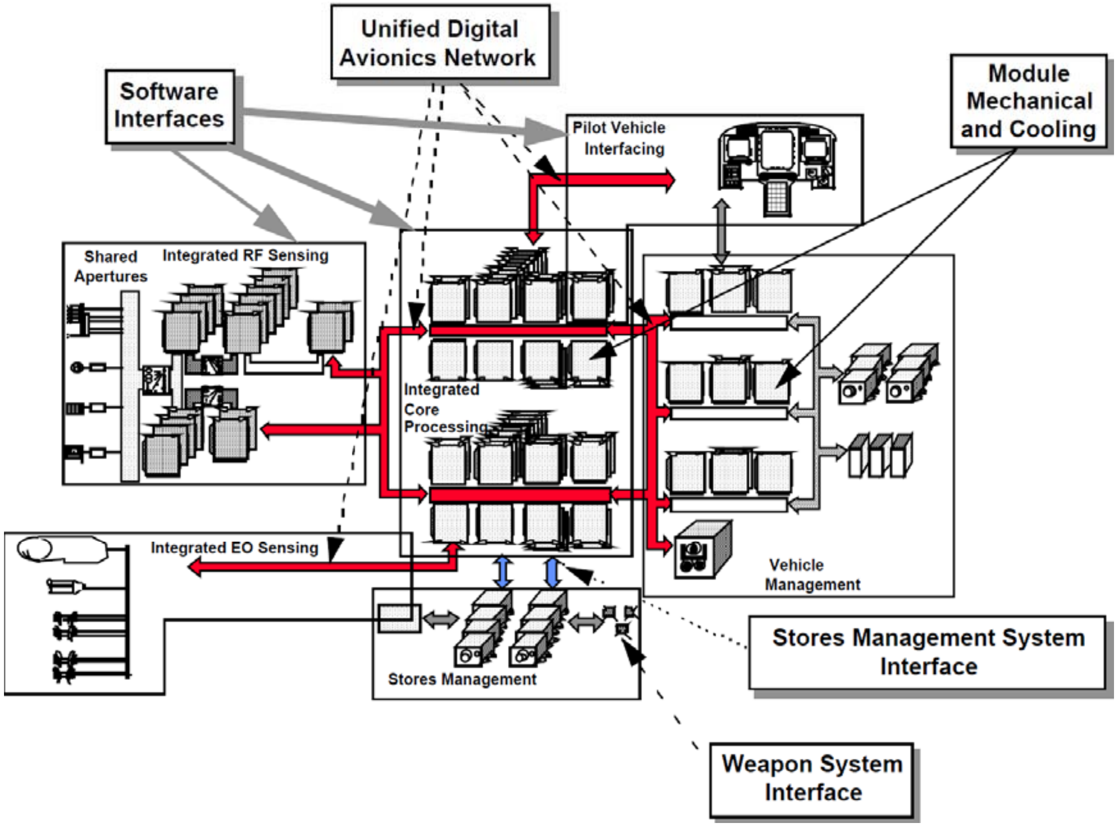
Evolving

1990s to 200X



- Integrated systems, proprietary standards
- Payloads plug and play, defined proprietary interfaces
- Higher speed computers, more memory
- Initial OFP and payload processing separation
- Flight control separate from mission payload functions
- Airframe prime still controls all proprietary avionic interfaces

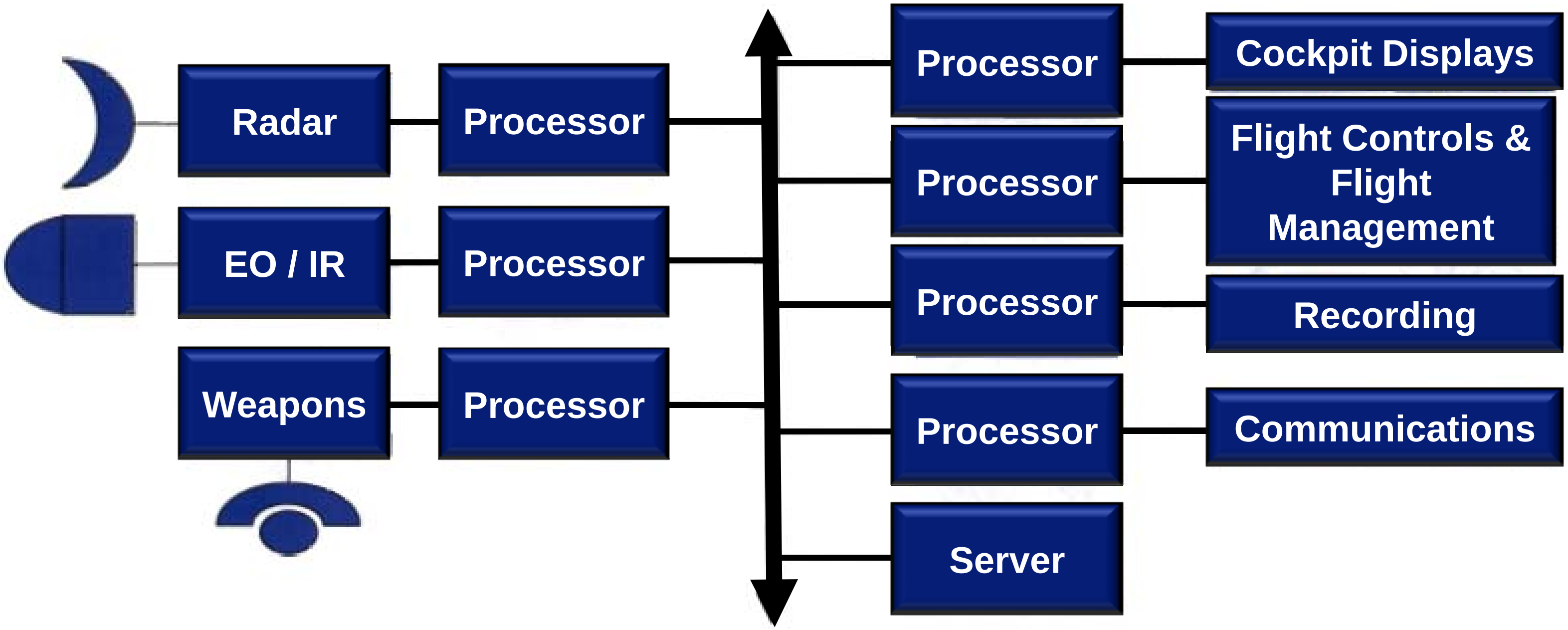
"PAVE PACE" Avionics Architecture



- Extension of F22 *integrated avionics system architecture*
  - Integrates RF sensing / management
  - Unified avionics digital network based on commercial technologies

Open Architecture

201X - future



- Open Systems Architecture, defined, open standards
- Standards are published (non-proprietary) for all to use
- Payloads plug and play, defined open and service oriented interfaces
- Higher speed computers, more memory
- Mission System processing divorced from flight controls/flight safety
- Avionics open interfaces, airframe prime controls physical interfaces
- Avionics upgrades not hostage to airframe prime

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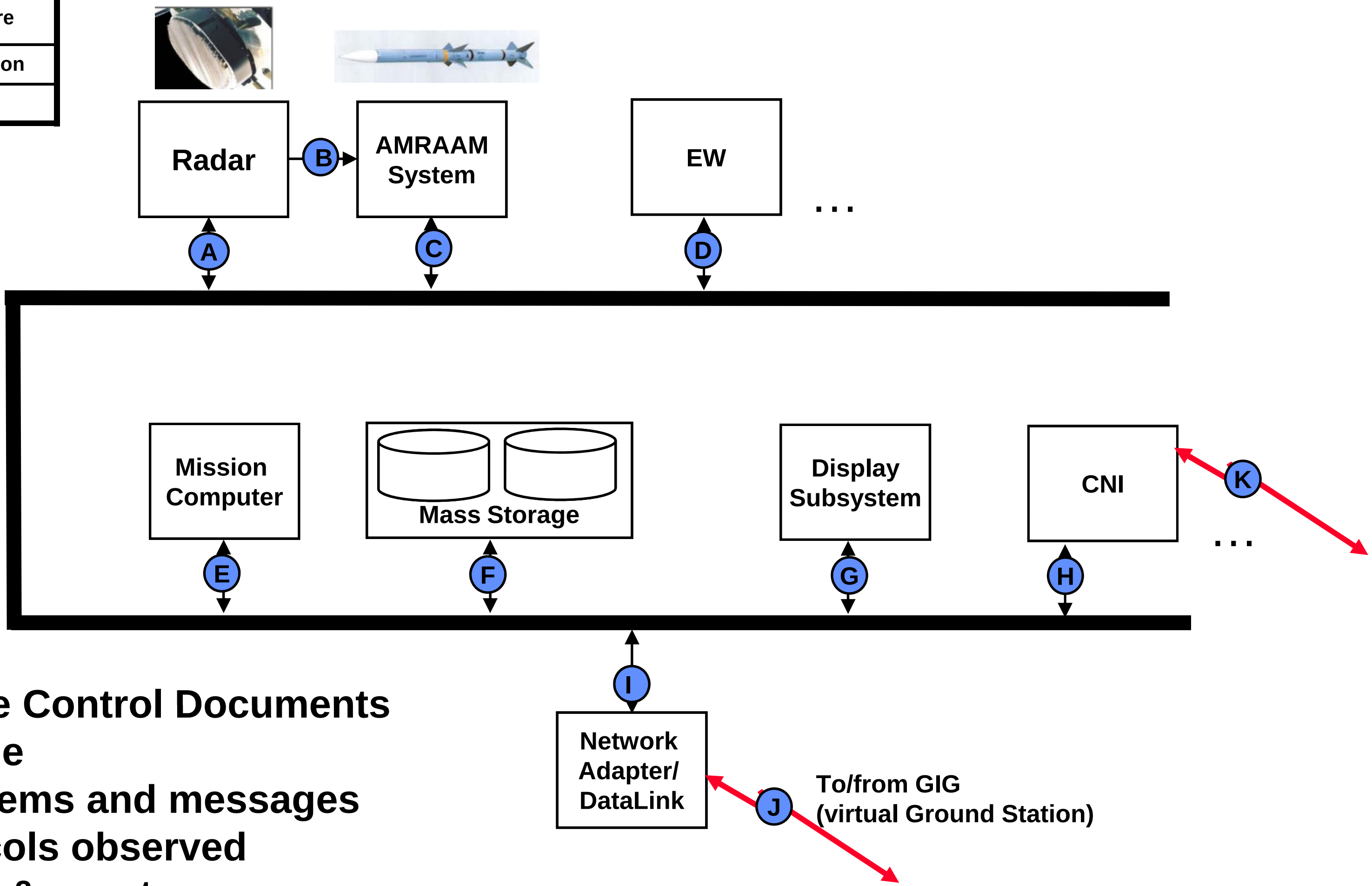
Open Avionics
- Key Technologies -

Concept
Composable Open Reference Architectures
Plug-and-Play Hardware Infrastructure
Service-oriented Subsystems
Service-oriented Middleware
Service and Client Factorization
Avionics Metadata

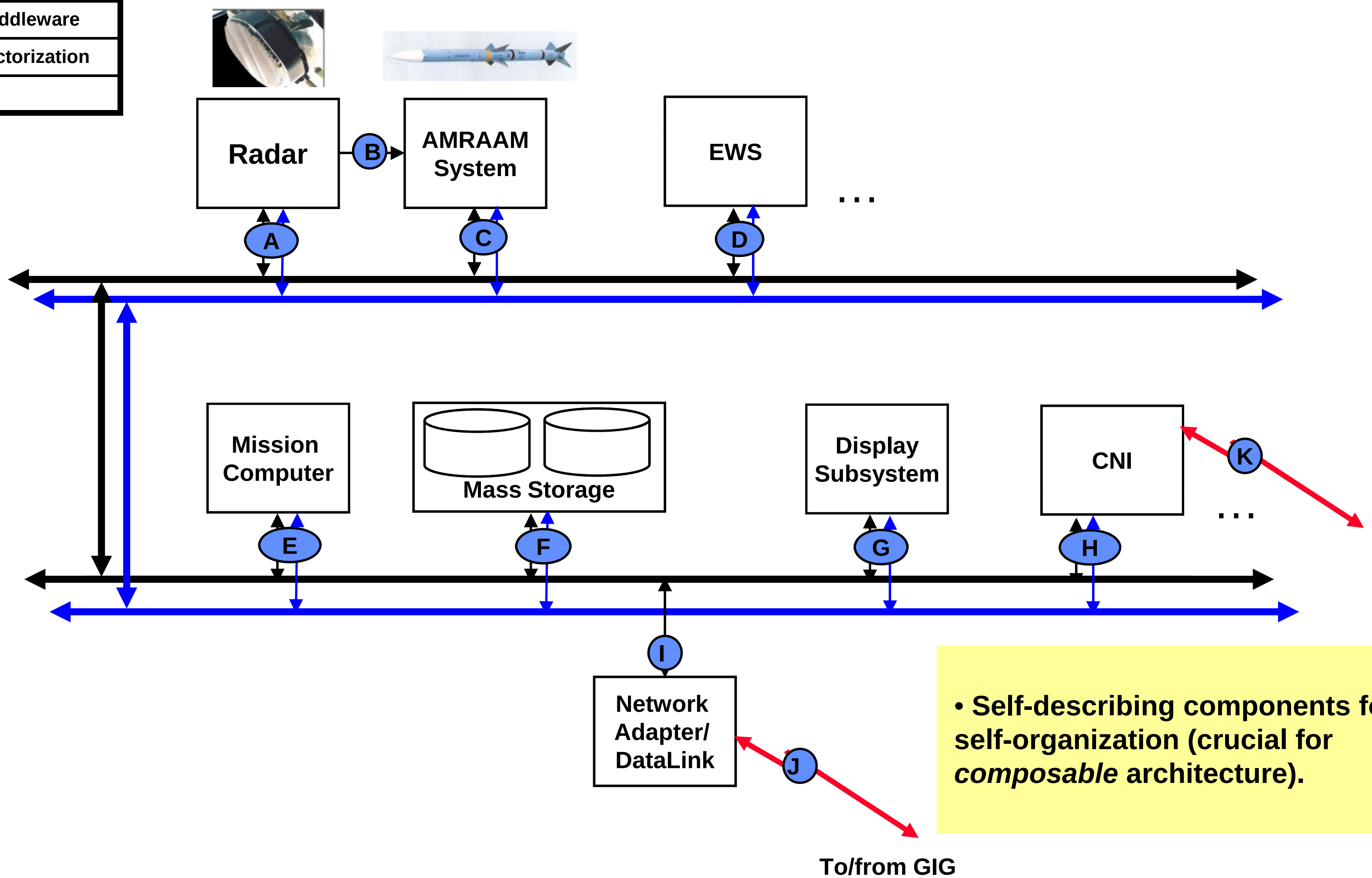
Open Avionics Architecture Elements
- Reference Functional Architecture -



Interface Control Documents (ICD) define

- data items and messages
- protocols observed
- timing & event sequences

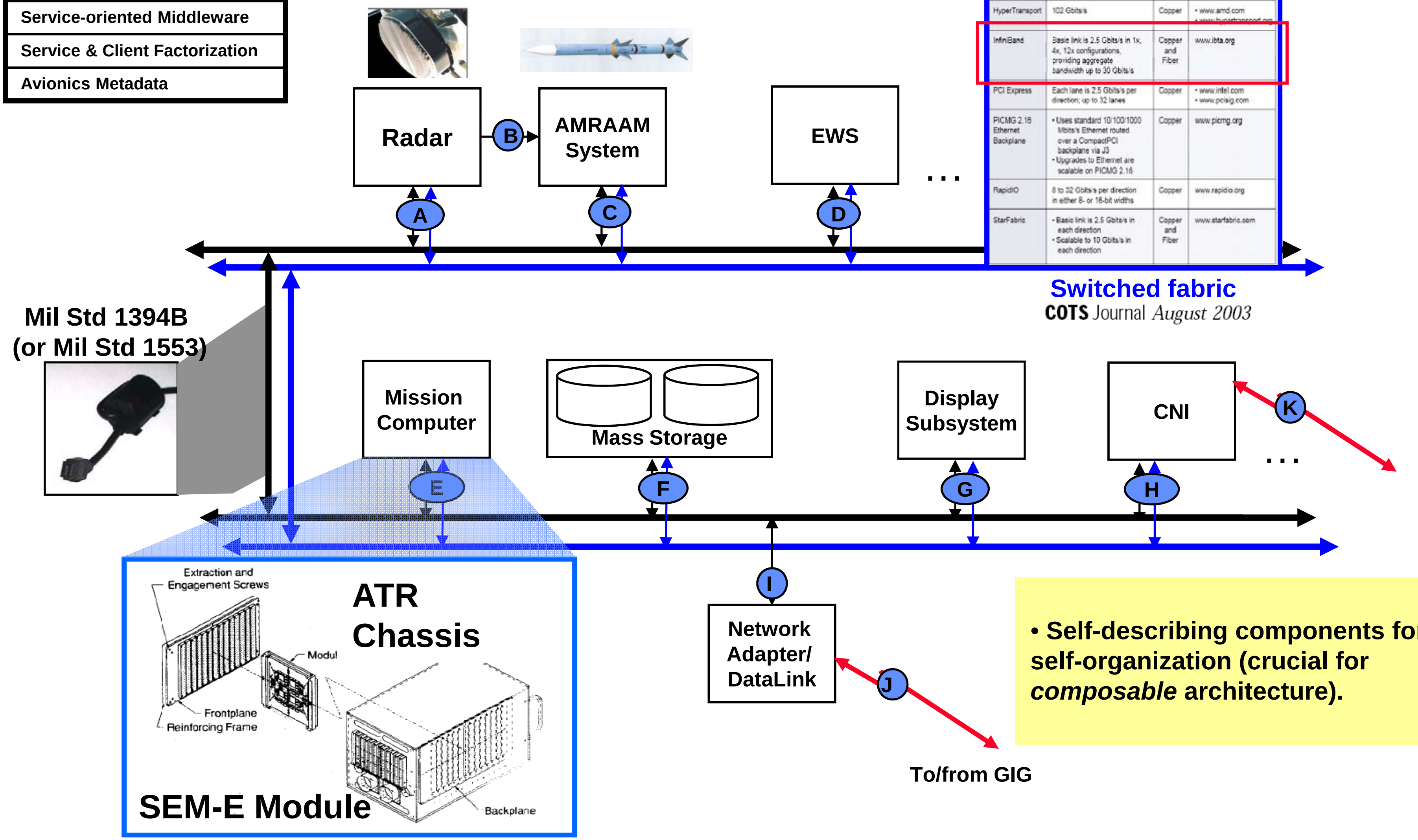
Open Avionics Architecture Elements
- Standard Plug and Play Hardware -



- **Self-describing components for self-organization (crucial for *composable* architecture).**

Open Avionics Architecture Elements
- Standard Plug and Play Hardware -

- Open Reference Architectures
- **Plug-and-Play Hardware**
- Service-oriented Subsystems
- Service-oriented Middleware
- Service & Client Factorization
- Avionics Metadata

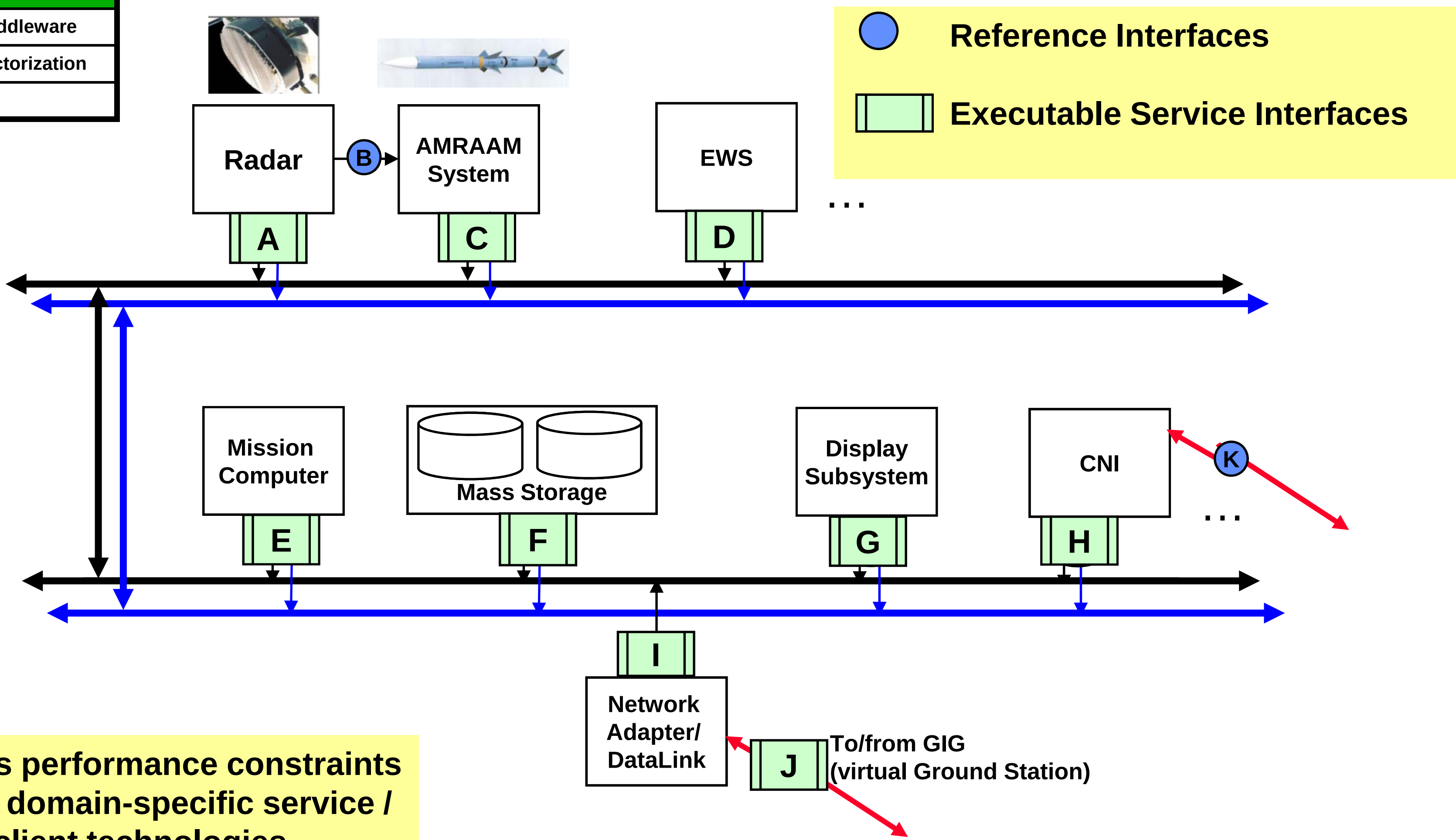


Name	Speed Ranges	Media Types	For Further Information
Fibre Channel	• 266 Mbits/s up to 4.25 Gbits/s • Scalable to 8.5 Gbits/s • Work underway to increase to 10, 40, 160 Gbits/s	Copper and Fiber	• www.fibrechannel.com • www.t11.org
HyperTransport	102 Gbits/s	Copper	• www.amd.com • www.hypertransport.org
InfiniBand	Basic link is 2.5 Gbits/s in 1x, 4x, 12x configurations, providing aggregate bandwidth up to 30 Gbits/s	Copper and Fiber	www.ibta.org
PCI Express	Each lane is 2.5 Gbits/s per direction; up to 32 lanes	Copper	• www.intel.com • www.pcisig.com
PICMG 2.16 Ethernet Backplane	• Uses standard 10/100/1000 Mbits/s Ethernet routed over a CompactPCI backplane via J3 • Upgrades to Ethernet are scalable on PICMG 2.16	Copper	www.picmg.org
RapidIO	8 to 32 Gbits/s per direction in either 8- or 16-bit widths	Copper	www.rapidio.org
StarFabric	• Basic link is 2.5 Gbits/s in each direction • Scalable to 10 Gbits/s in each direction	Copper and Fiber	www.starfabric.com

- **Self-describing components for self-organization (crucial for *composable* architecture).**

Open Avionics Architecture Elements
- Service Oriented Subsystem Interfaces -

- Open Reference Architectures
- Plug-and-Play Hardware
- **Service-oriented Subsystems**
- Service-oriented Middleware
- Service & Client Factorization
- Avionics Metadata



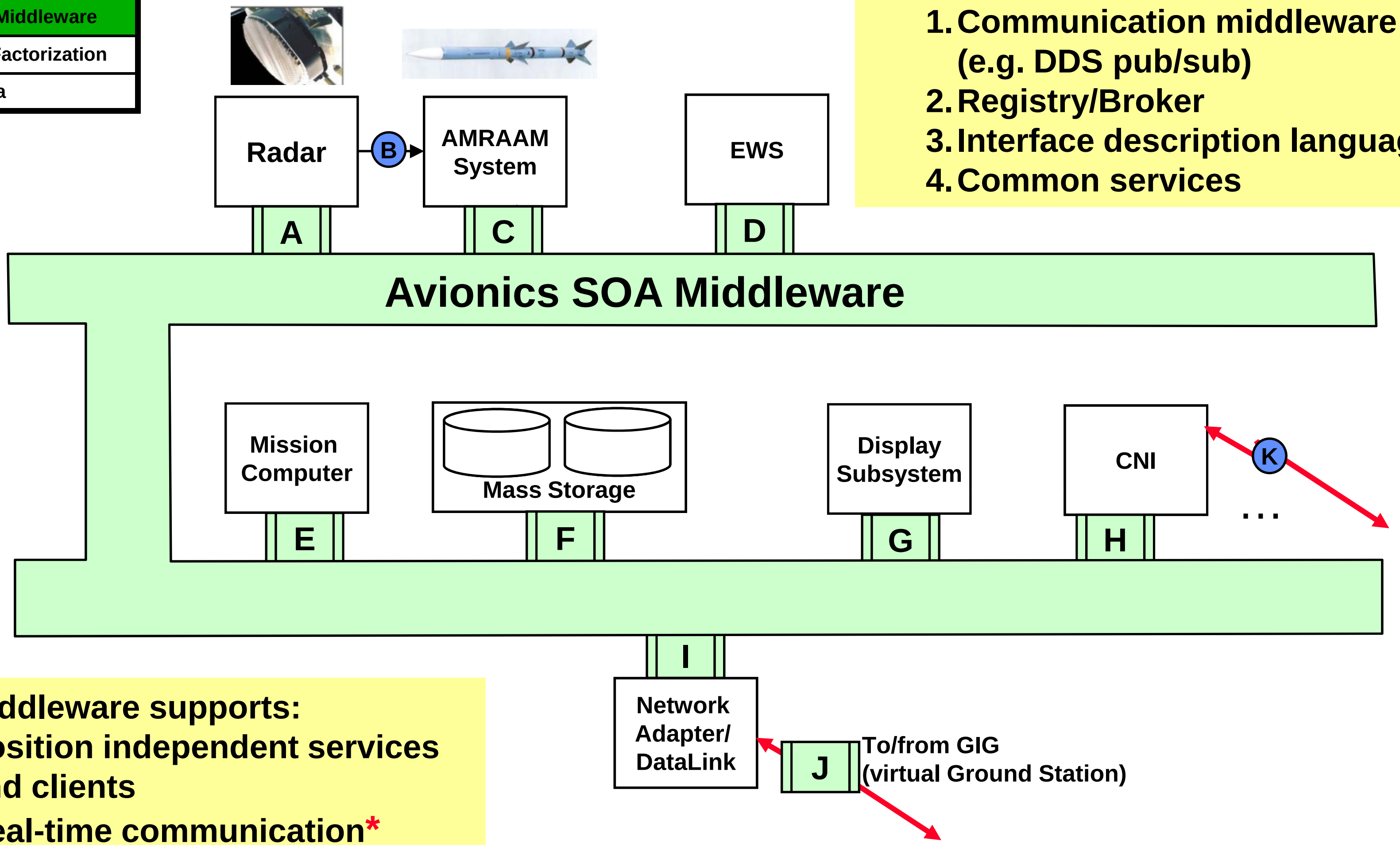
Avionics performance constraints require domain-specific service / client technologies

Open Avionics Architecture Elements
- Middleware -

- Open Reference Architectures
- Plug-and-Play Hardware
- Service-oriented Subsystems
- **Service-oriented Middleware**
- Service & Client Factorization
- Avioincs Metadata

SOA middleware is:

1. Communication middleware (e.g. DDS pub/sub)
2. Registry/Broker
3. Interface description language
4. Common services



SOA middleware supports:

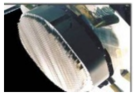
1. Position independent services and clients
2. Real-time communication*

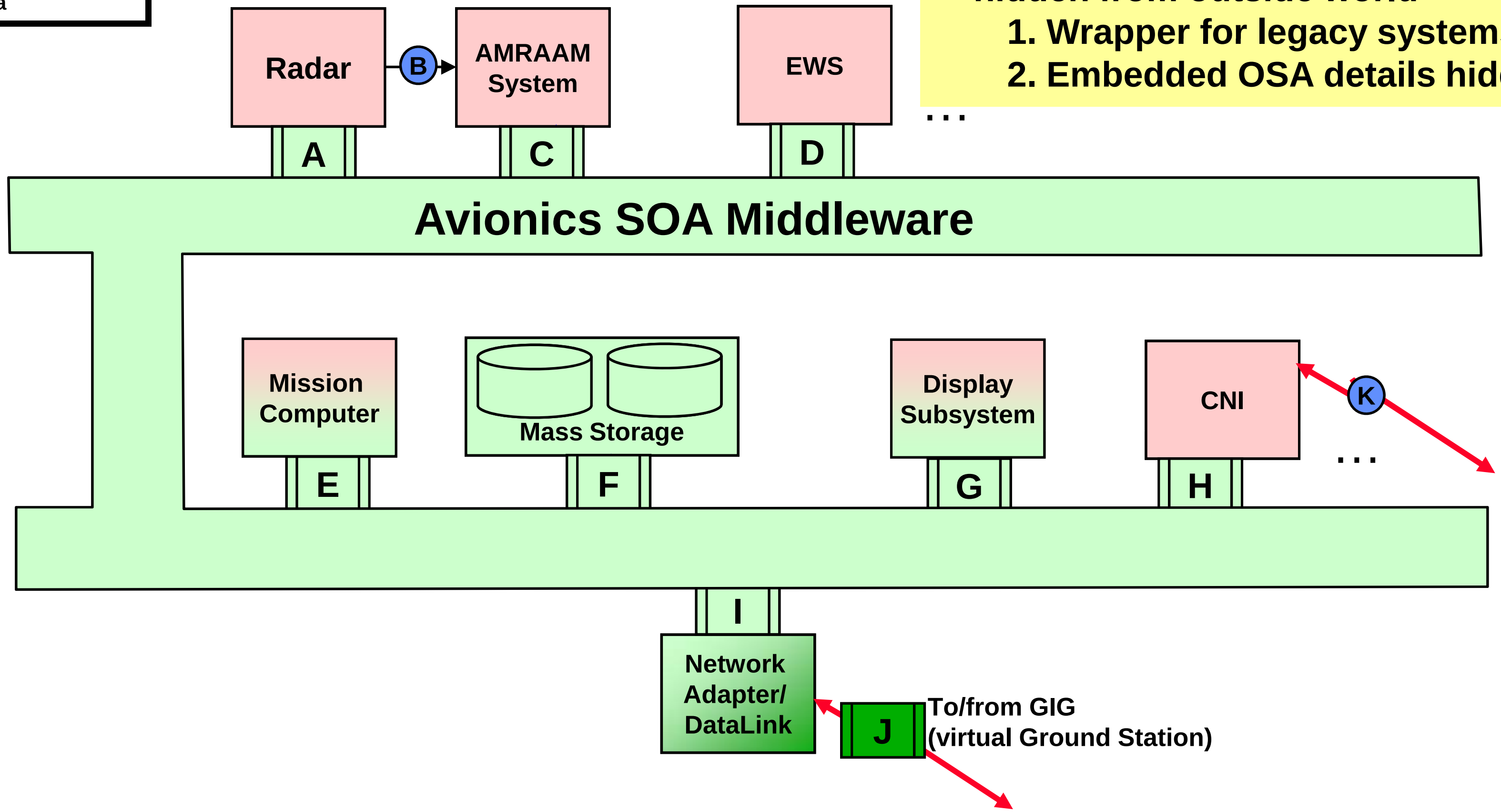
* Domain optimized (not SOAP; maybe DDS)

Open Avionics Architecture Elements
- Service/Client Decomposition -

- Open Reference Architectures
- Plug-and-Play Hardware
- Service-oriented Subsystems
- Service-oriented Middleware
- **Service & Client Factorization**
- Avionics Metadata

1. Define standard behavior of subsystem services
2. Subsystem implementations hidden from outside world
   1. Wrapper for legacy systems
   2. Embedded OSA details hidden





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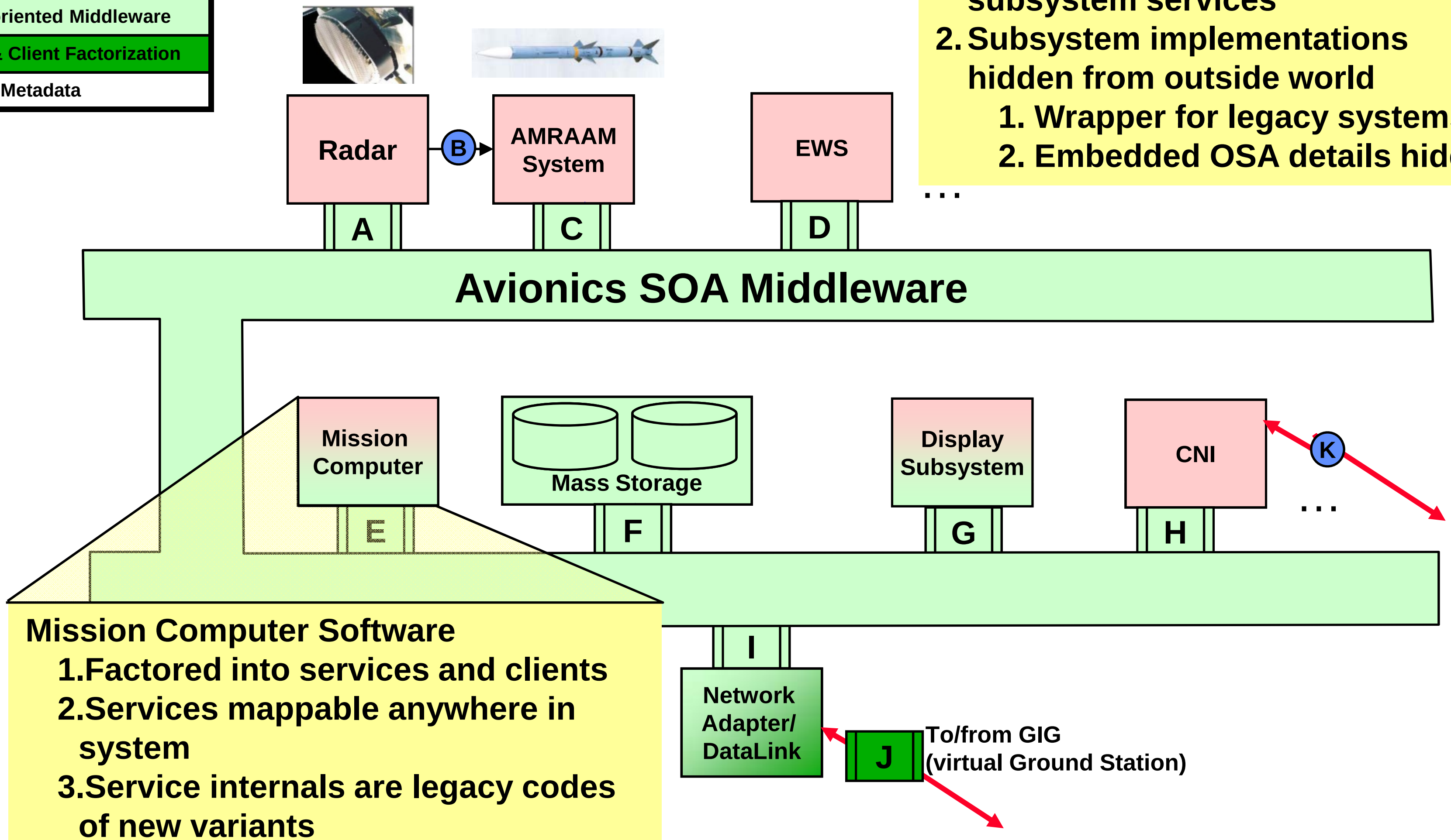
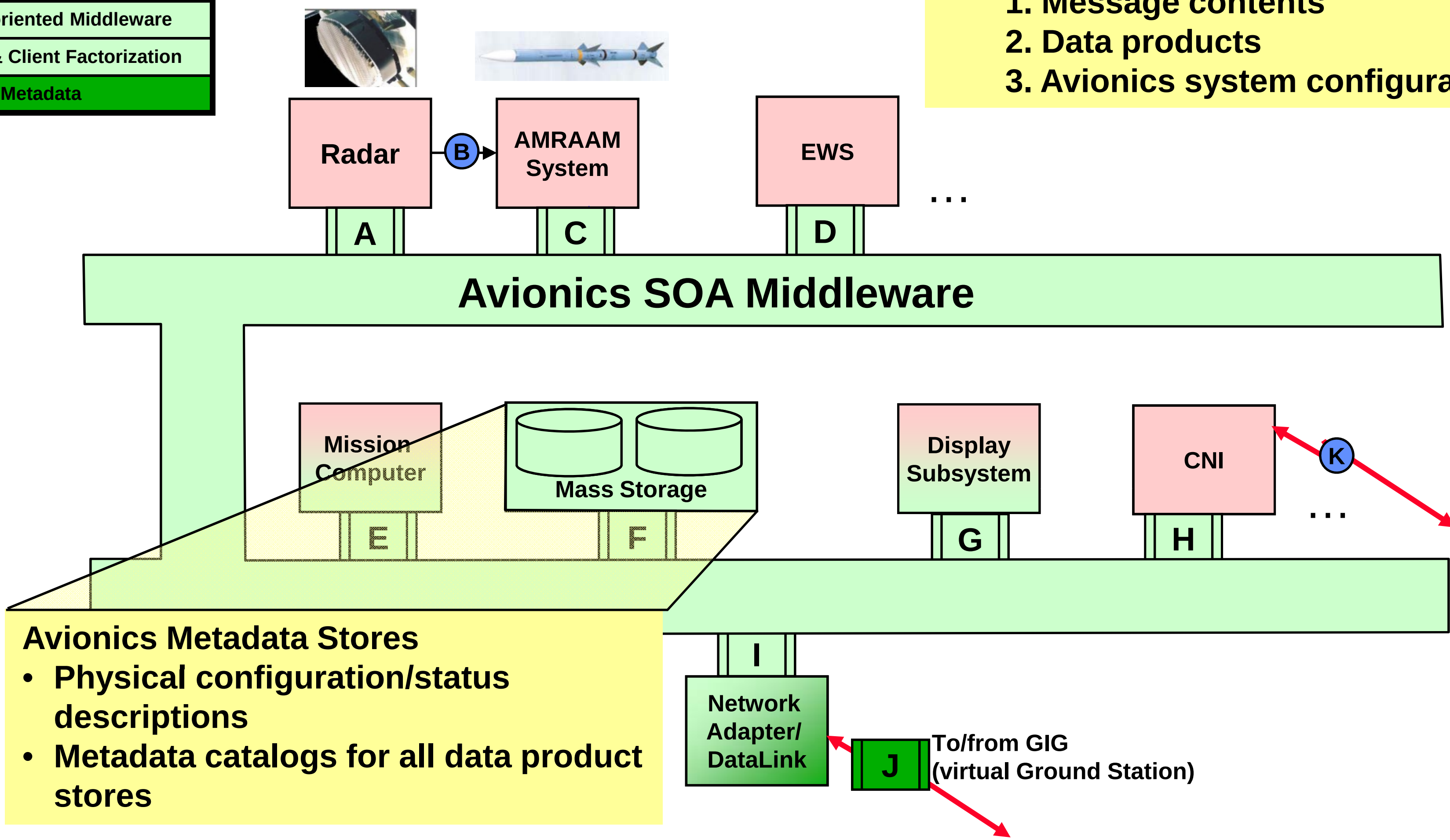


Mission Computer Software
1. Factored into services and clients
2. Services mappable anywhere in system
3. Service internals are legacy codes of new variants

Open Avionics Architecture Elements
- Metadata Definition -

- Open Reference Architectures
- Plug-and-Play Hardware
- Service-oriented Subsystems
- Service-oriented Middleware
- Service & Client Factorization
- **Avionics Metadata**

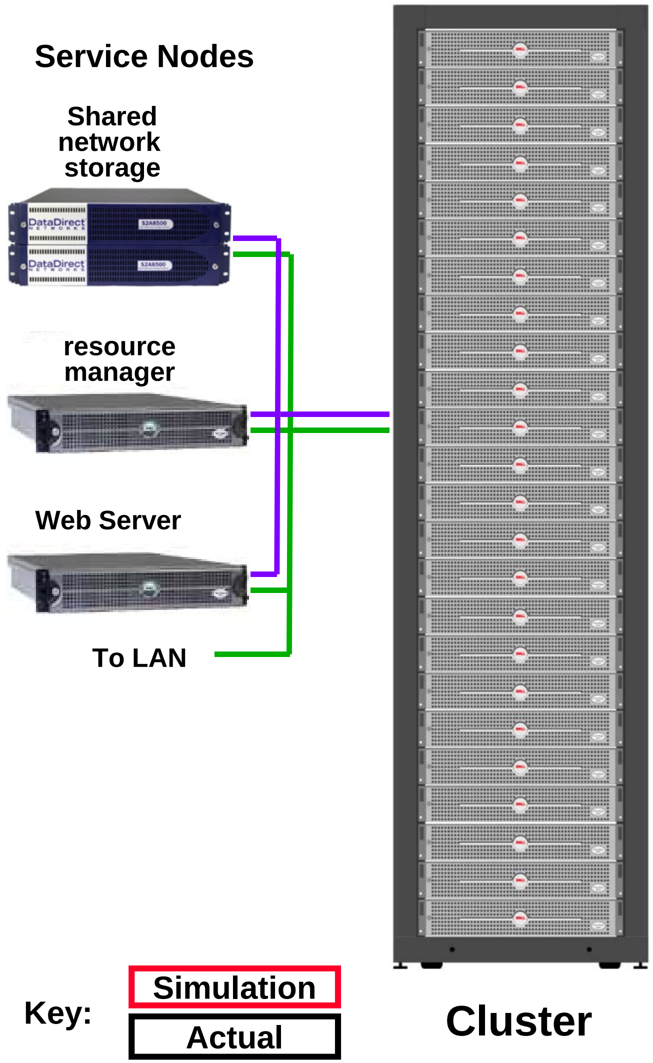
1. Metadata specifications describe
   1. Message contents
   2. Data products
   3. Avionics system configuration

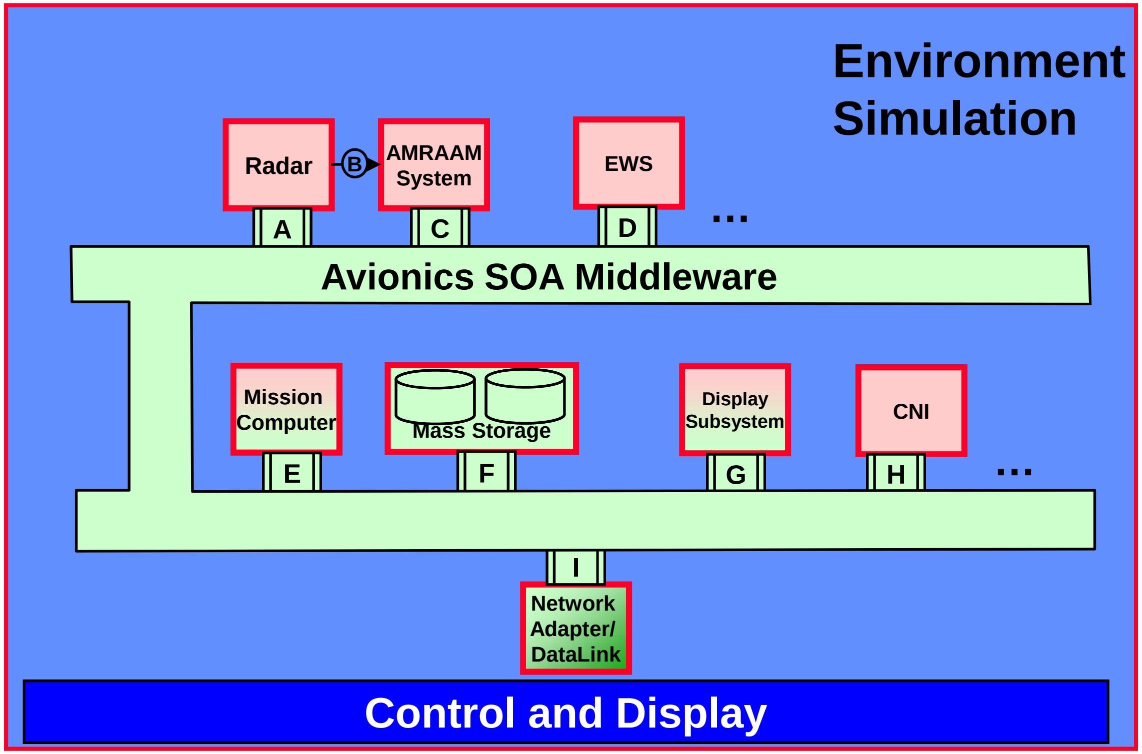


Avionics Metadata Stores
- Physical configuration/status descriptions
- Metadata catalogs for all data product stores

Open Architecture Testbed

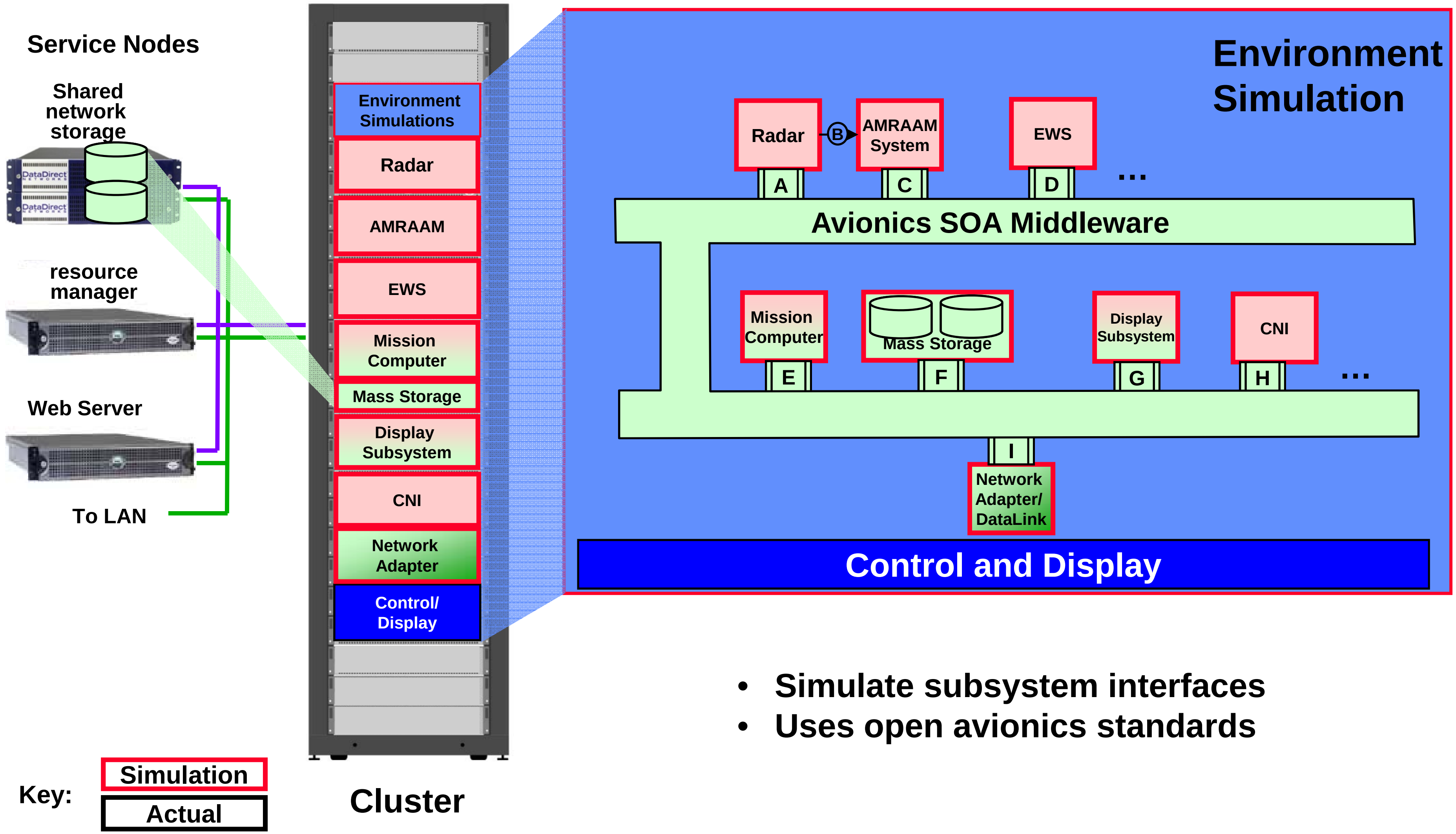
- OA Testing -





- Simulate subsystem interfaces
- Uses open avionics standards

Open Architecture Testbed
- OA Testing -



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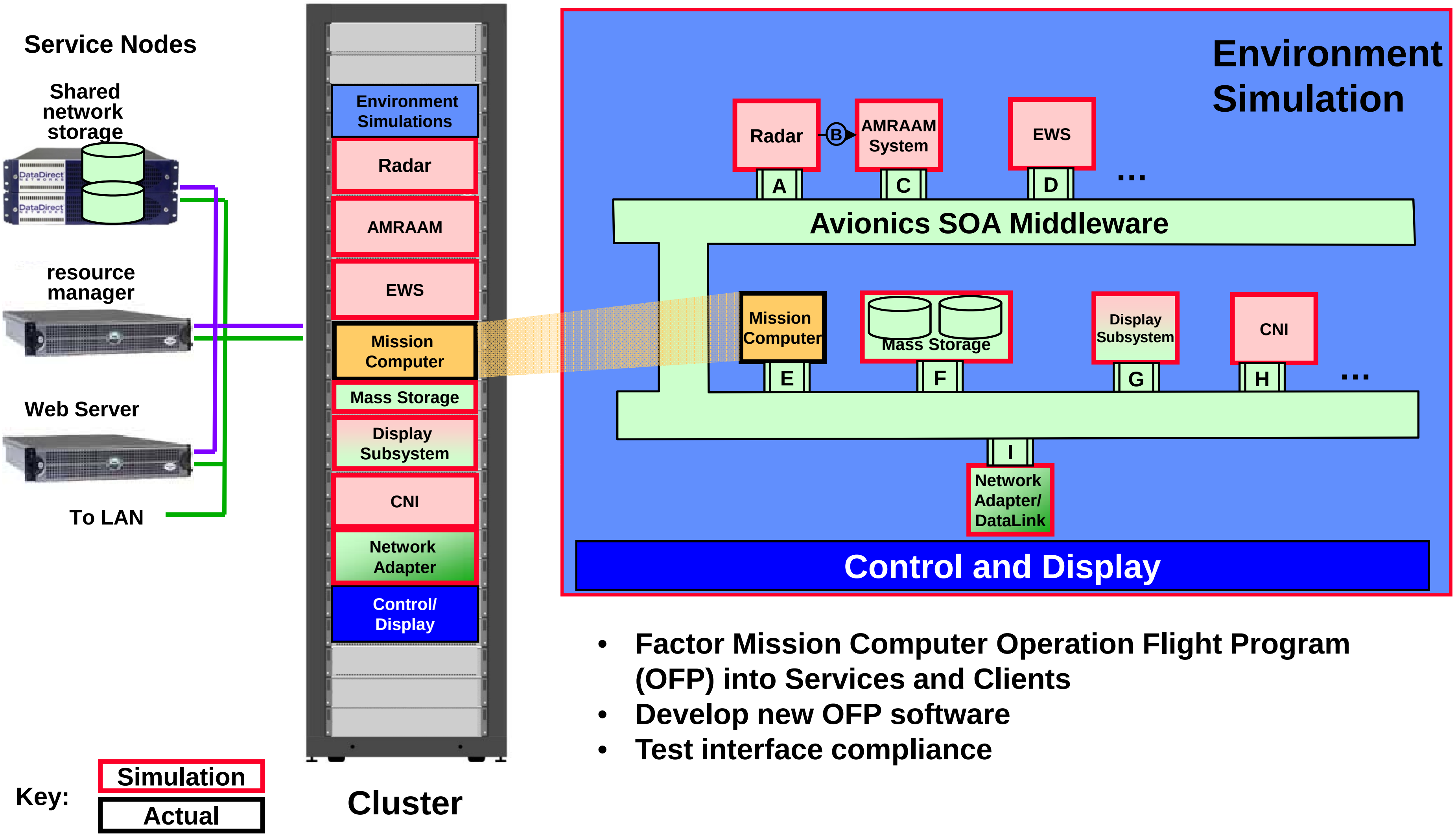
Open Architecture Testbed

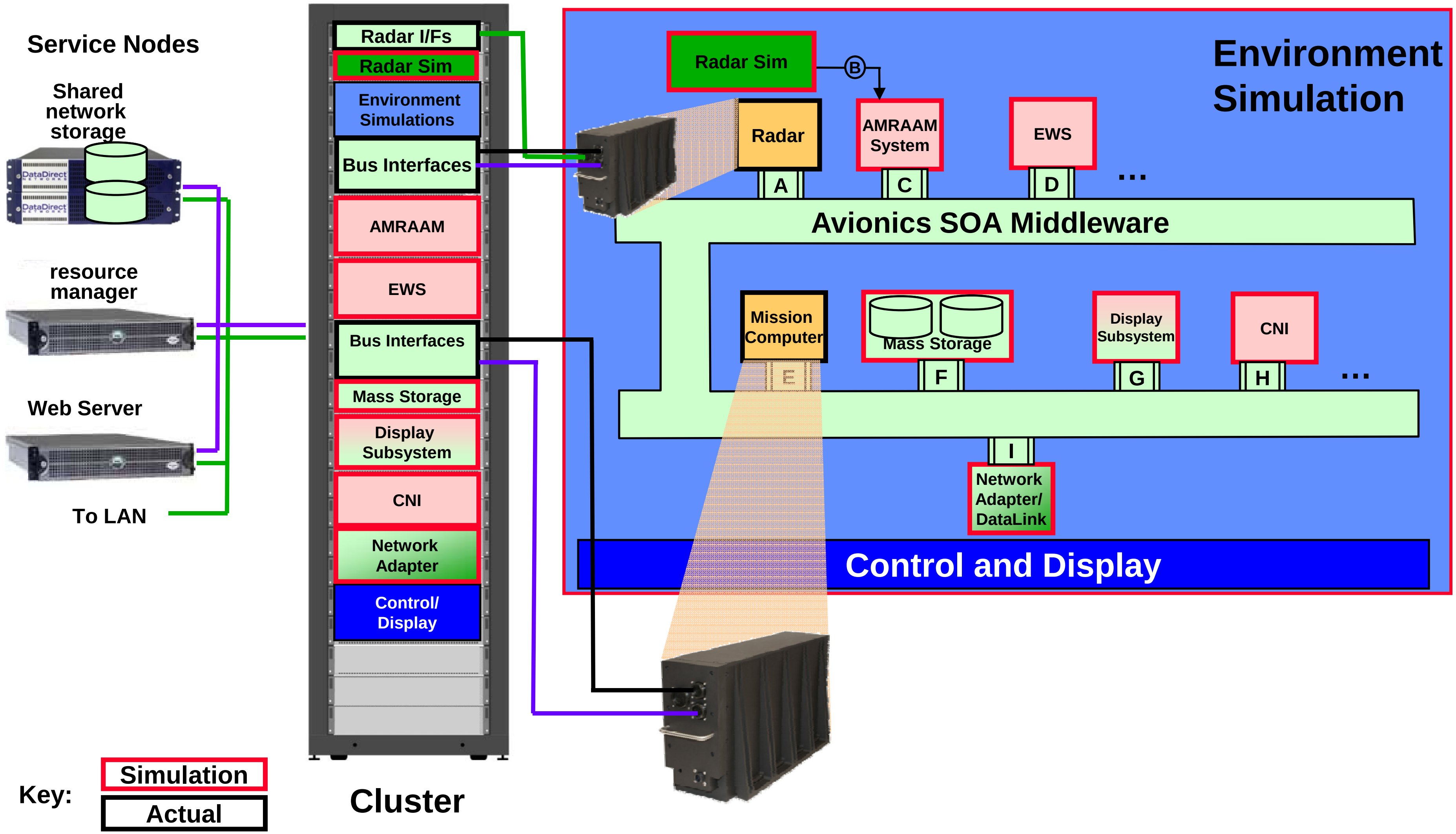
- Operational Code Development -



- Factor Mission Computer Operation Flight Program (OFP) into Services and Clients
- Develop new OFP software
- Test interface compliance

Open Architecture Testbed

- Selective Build Out -



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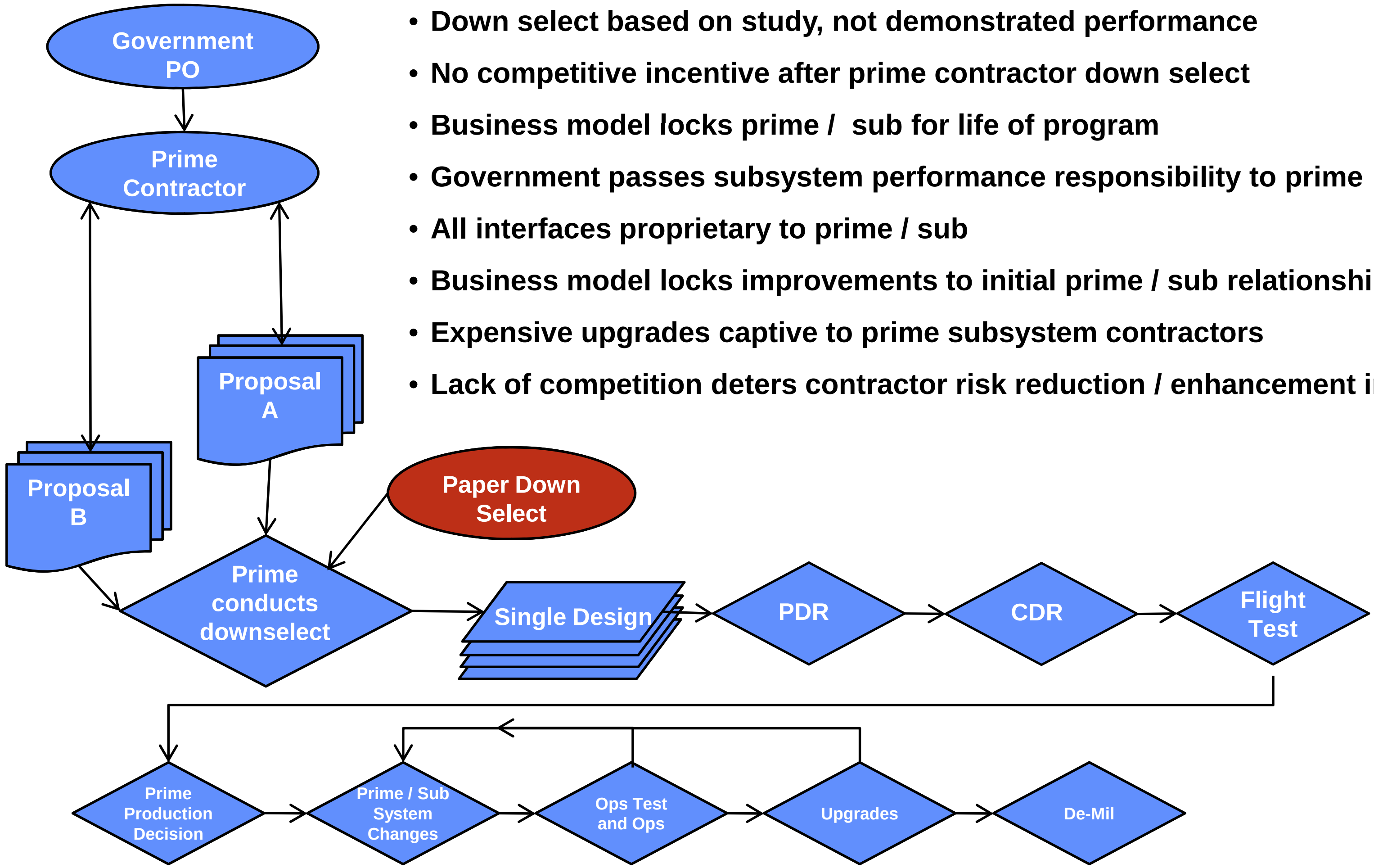
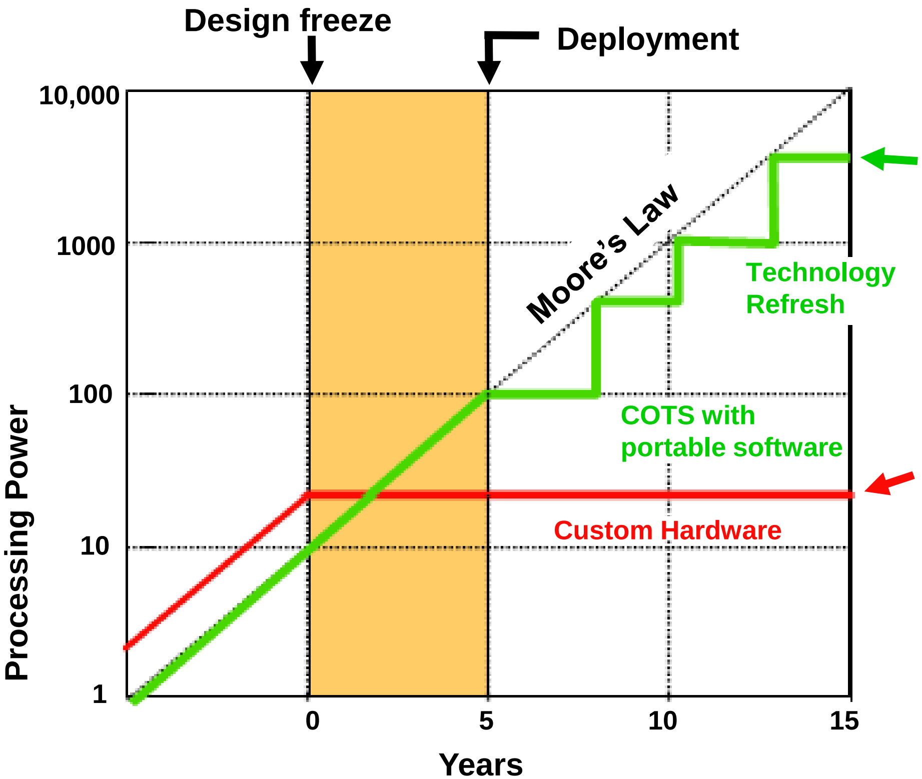
  - Architectures and testbeds
- Acquisition in an Open Architecture Context
  - Leverage and adapt
  - “Open” acquisition
- Conclusion

Historical Approach



- **Down select based on study, not demonstrated performance**
- **No competitive incentive after prime contractor down select**
- **Business model locks prime / sub for life of program**
- **Government passes subsystem performance responsibility to prime**
- **All interfaces proprietary to prime / sub**
- **Business model locks improvements to initial prime / sub relationship**
- **Expensive upgrades captive to prime subsystem contractors**
- **Lack of competition deters contractor risk reduction / enhancement investment**

Open Systems Support "Leverage Adapt" Strategy



"Leverage & adapt"

- Good for rapidly changing technology
- Good for rapidly changing requirements
- Built-in refresh and improvements
- More difficult to manage

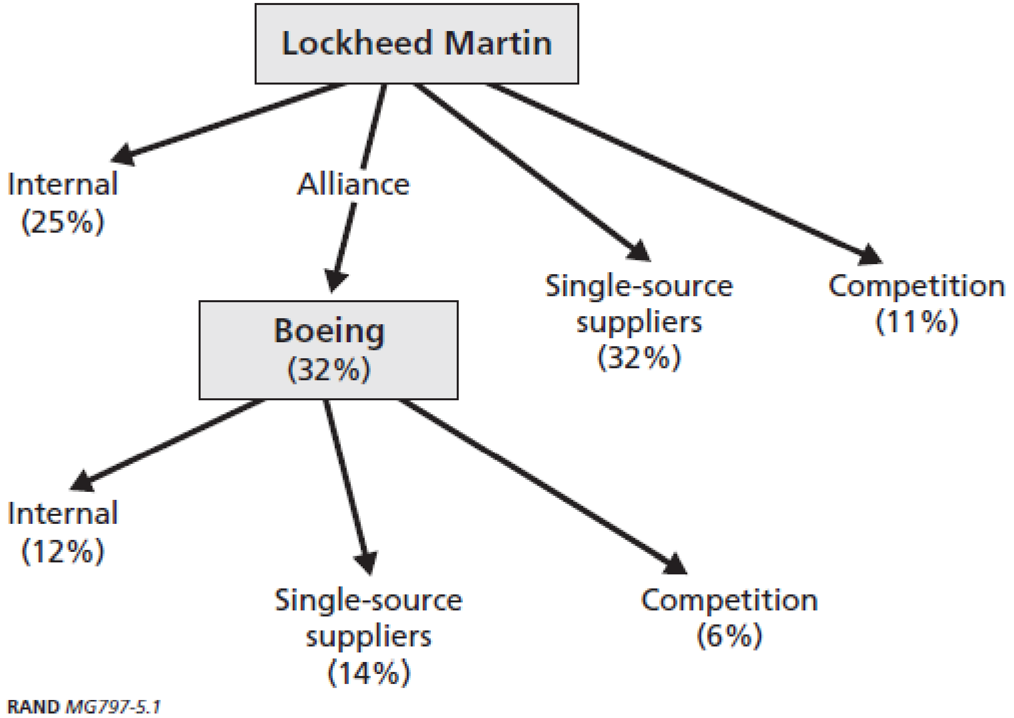
"Freeze & build"

- Freezes technology and builds to fixed design
- Acceptable for slow moving technologies
- Requires stable requirements throughout lifecycle
- Easier to manage with current acquisition strategy

- **Open Systems support "leverage and adapt" strategy; allows DoD to leverage commercial industry's investment**
- **Continuous upgrade/refresh possible to meet evolving threats and obsolescence**

Need for Competitive Procurement
- E.G. F-22 Industrial Base -

Source: Ending F-22A production: costs and industrial base implications of alternative options / Obaid Younosss … [et al]



- **Need to change competitive posture of military aircraft industrial base:**
  → Competitive procurement and upgrade of components with high "Intellectual Property" content.

Need for Competitive Procurement
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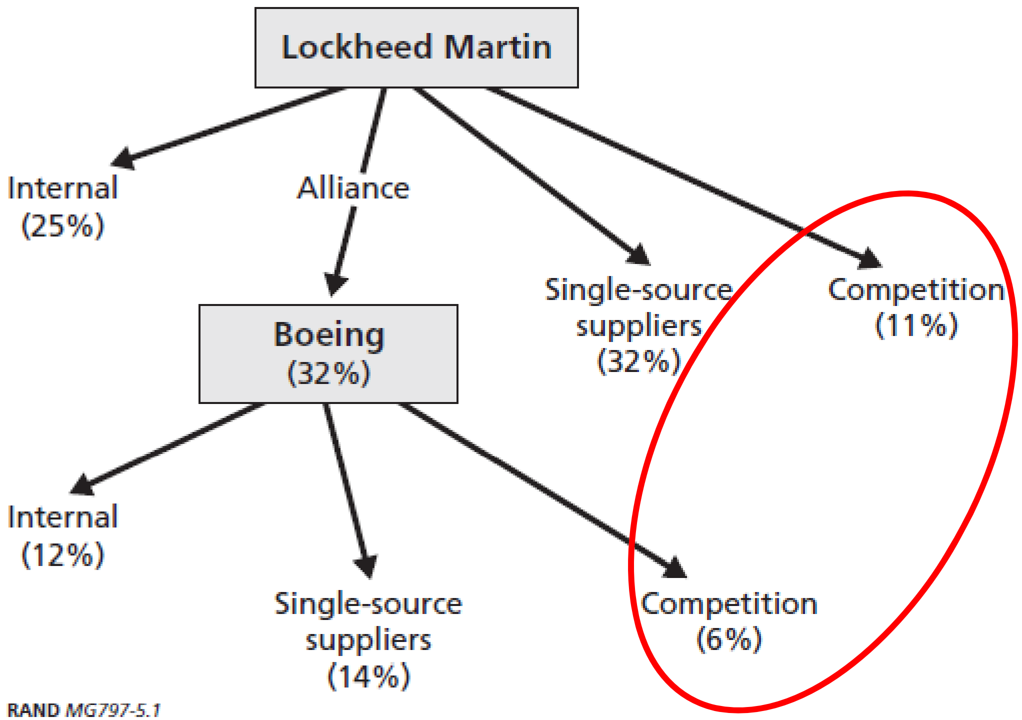
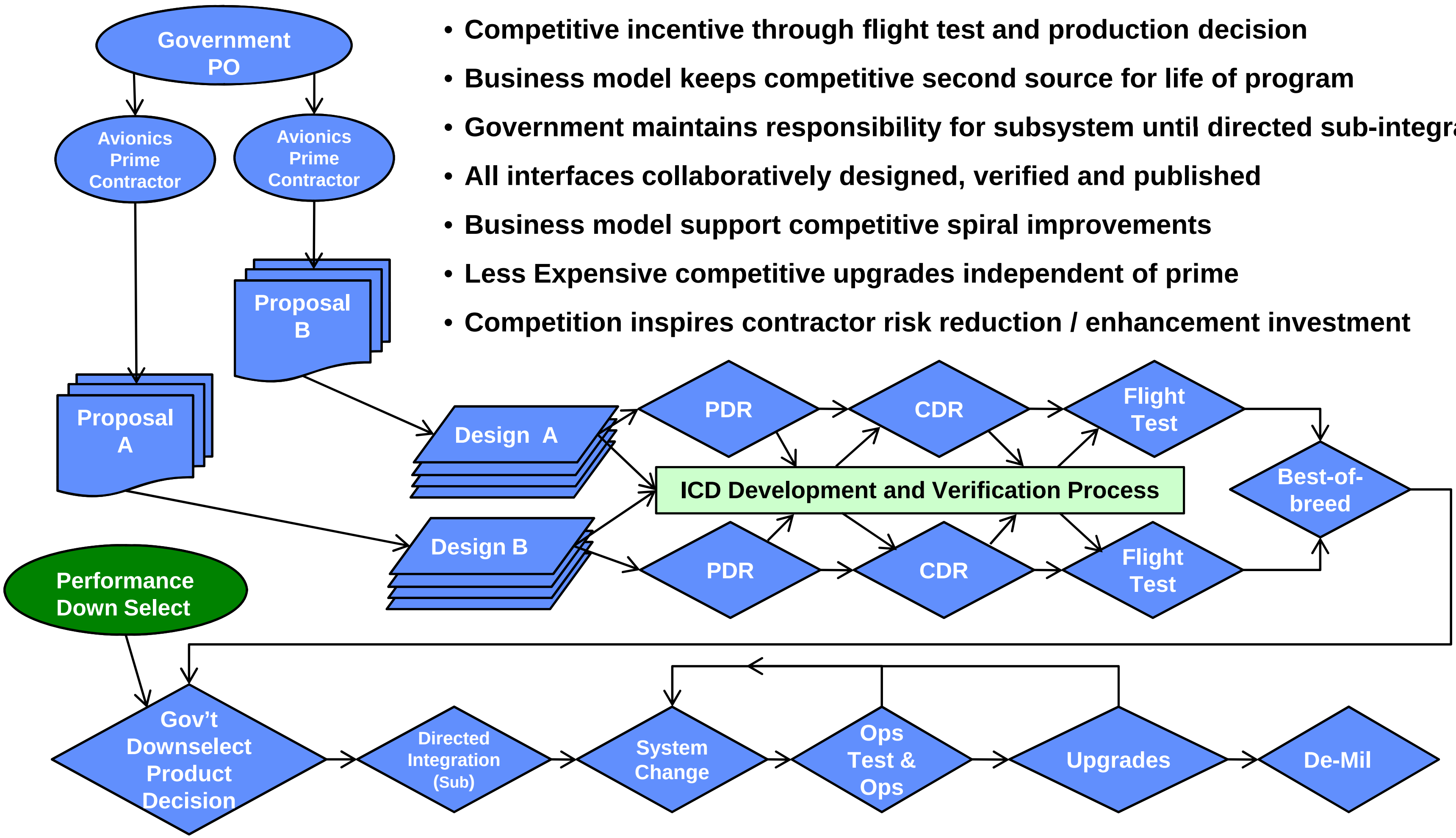


1. **Competition restricted to less complex items**
2. **Little "IP" competition**

- **Need to change competitive posture of military aircraft industrial base:**
  → Competitive procurement and upgrade of components with high "Intellectual Property" content.

Open Architecture Approach

- Down select based on demonstrated performance (fly before buy)
- Competitive incentive through flight test and production decision
- Business model keeps competitive second source for life of program
- Government maintains responsibility for subsystem until directed sub-integration
- All interfaces collaboratively designed, verified and published
- Business model support competitive spiral improvements
- Less Expensive competitive upgrades independent of prime
- Competition inspires contractor risk reduction / enhancement investment



Outline

- **Open Architecture Vision for the Air Force**
  - **Layered architecture**
  - **Technologies**
- **Air Force Avionics Architectures**
  - **F22 Raptor case study**
  - **Architecture evolution**
- **Open Avionics**
  - **Key open avionics concepts**
  - **Architectures and testbeds**
- **Acquisition in an Open Architecture Context**
  - **Leverage and adapt**
  - **“Open” acquisition**
- **Conclusion**

Conclusion

- The Air Force is pursuing a layered open-architecture vision to improve system (of systems) capabilities in a cost effective and rapid manner.
- Open avionics are crucial to enabling the competitive, cost effective, and timely introduction of new war-fighting capabilities in platforms that will persist for decades.
- Service oriented concepts judiciously combined with embedded open system techniques will deliver the next generation of open avionics technologies and architectures.
- Open architecture test beds based on executable specifications will accelerate avioincs integration and provide the mechanism to compete new avionics technologies.