History of Command & Control at KSC

SYSTEM FAILURE

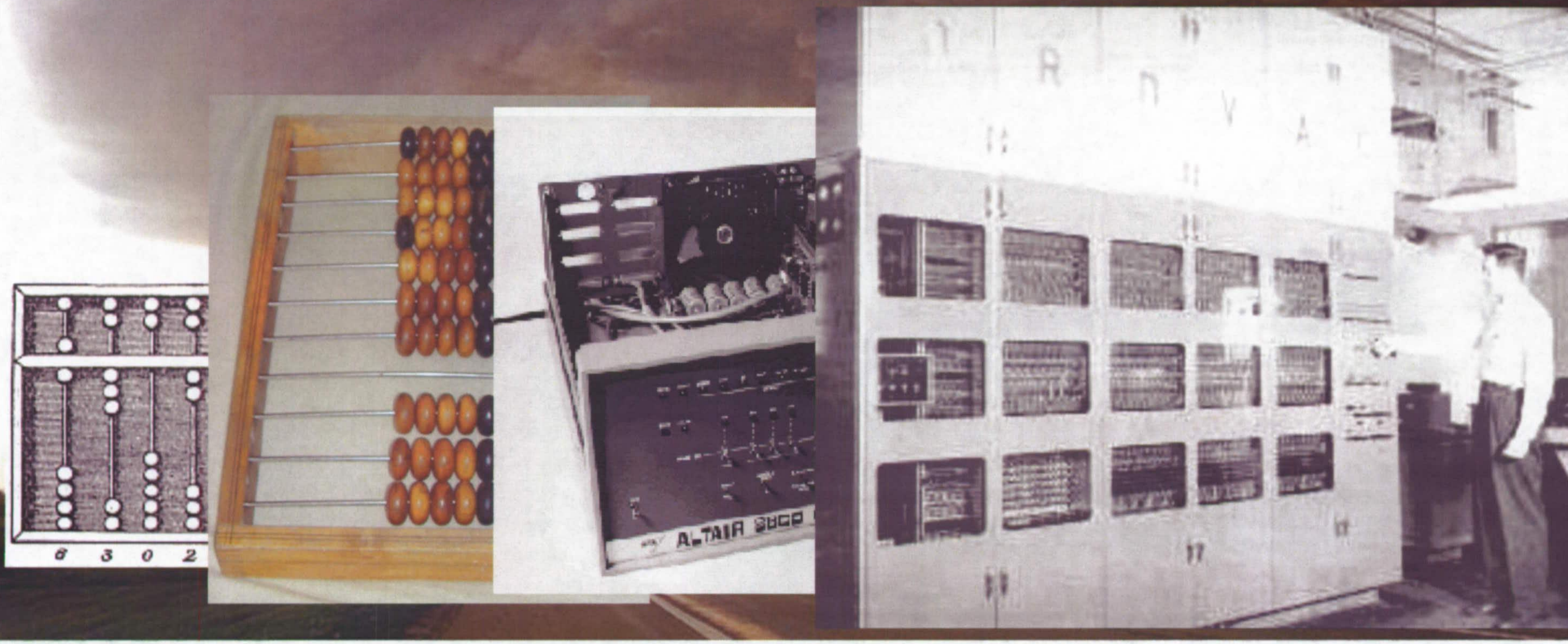
Kennedy Engineering Academy Series

9/27/2007

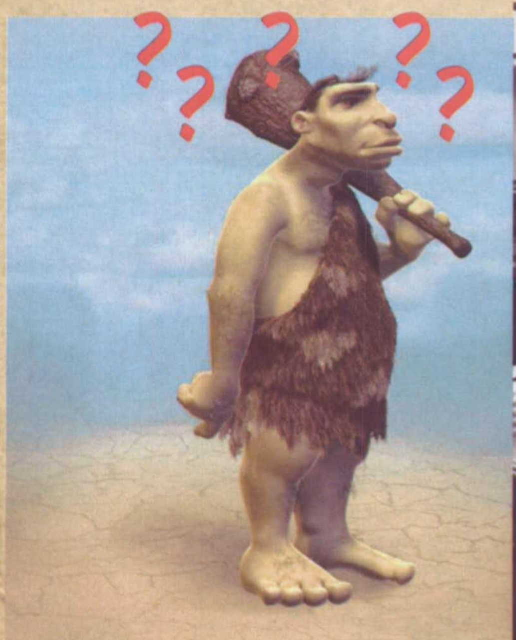
Hidden Agenda

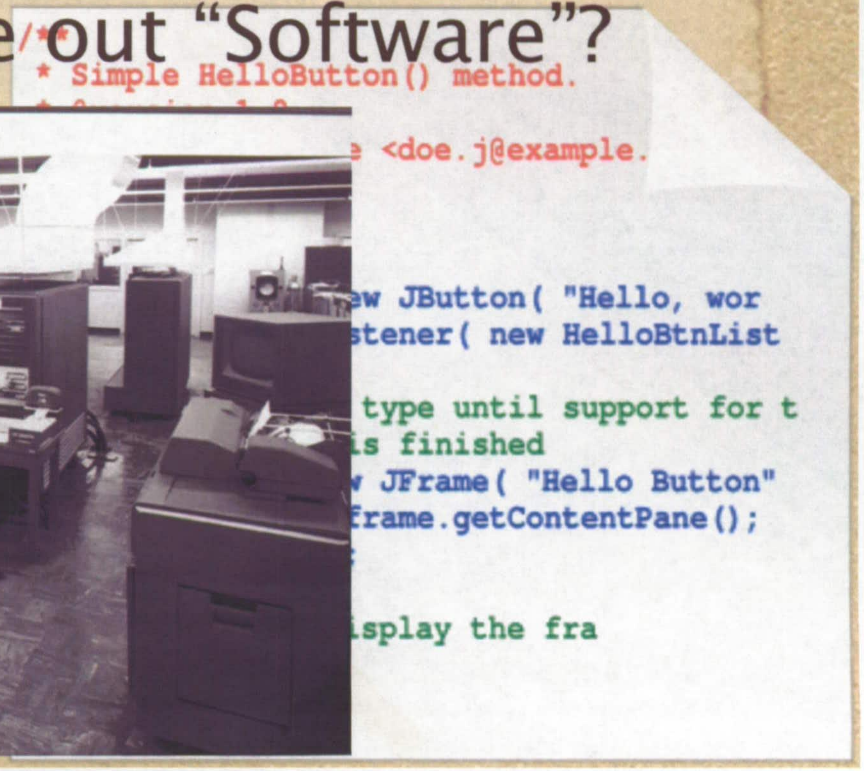
- Intro
- Evolution
- C&C history
- Launch Processing System overview
- Core System Overview
- Checkout & Launch Control System Overview
- Commercial-Off-The-Shelf guidelines
- Panel Discussions

- In the early days of computing, primitive machines were hard to use and had minimal capability

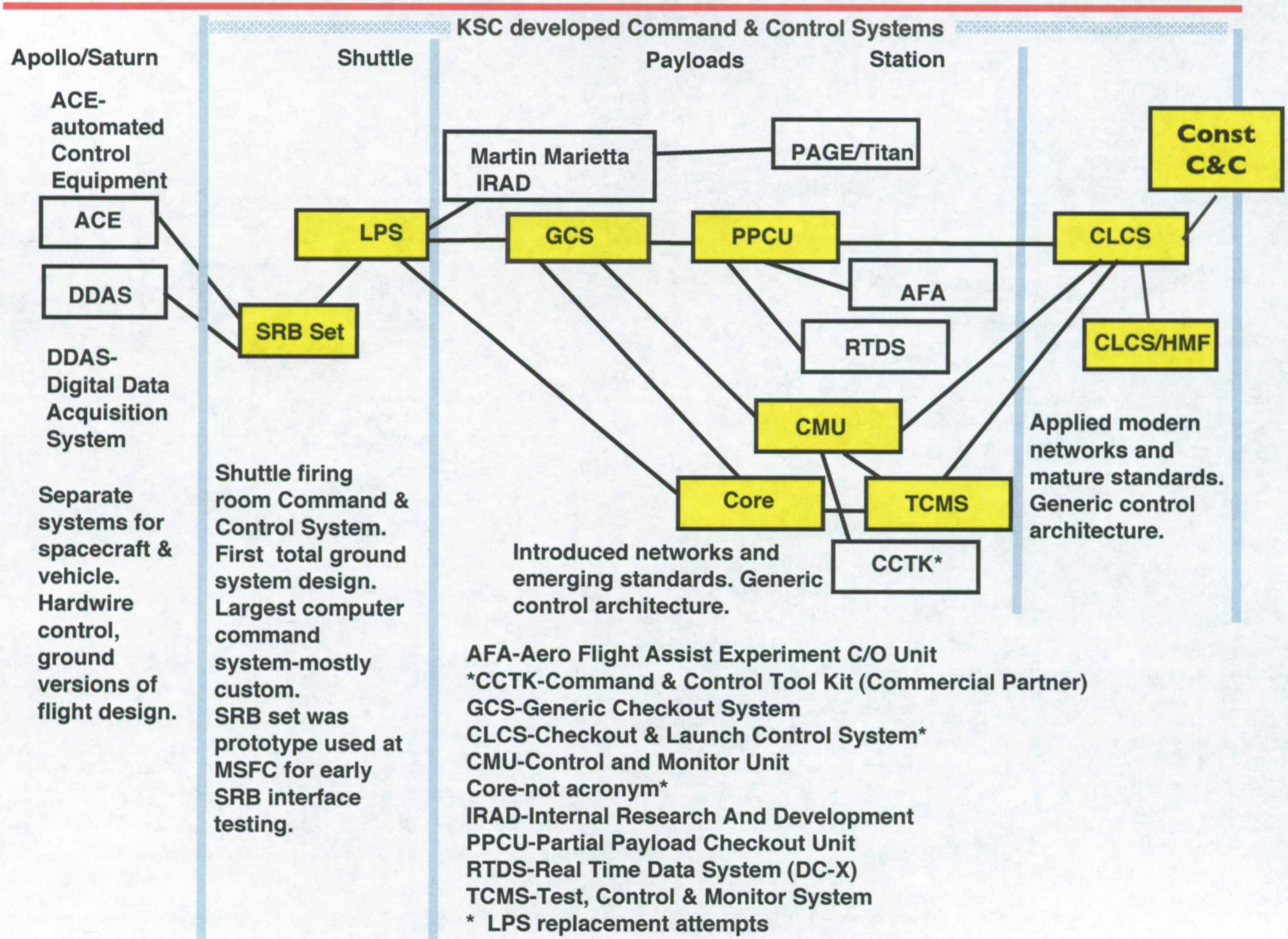


- The usefulness of computers was unclear
- Could anyone figure out “Software”?

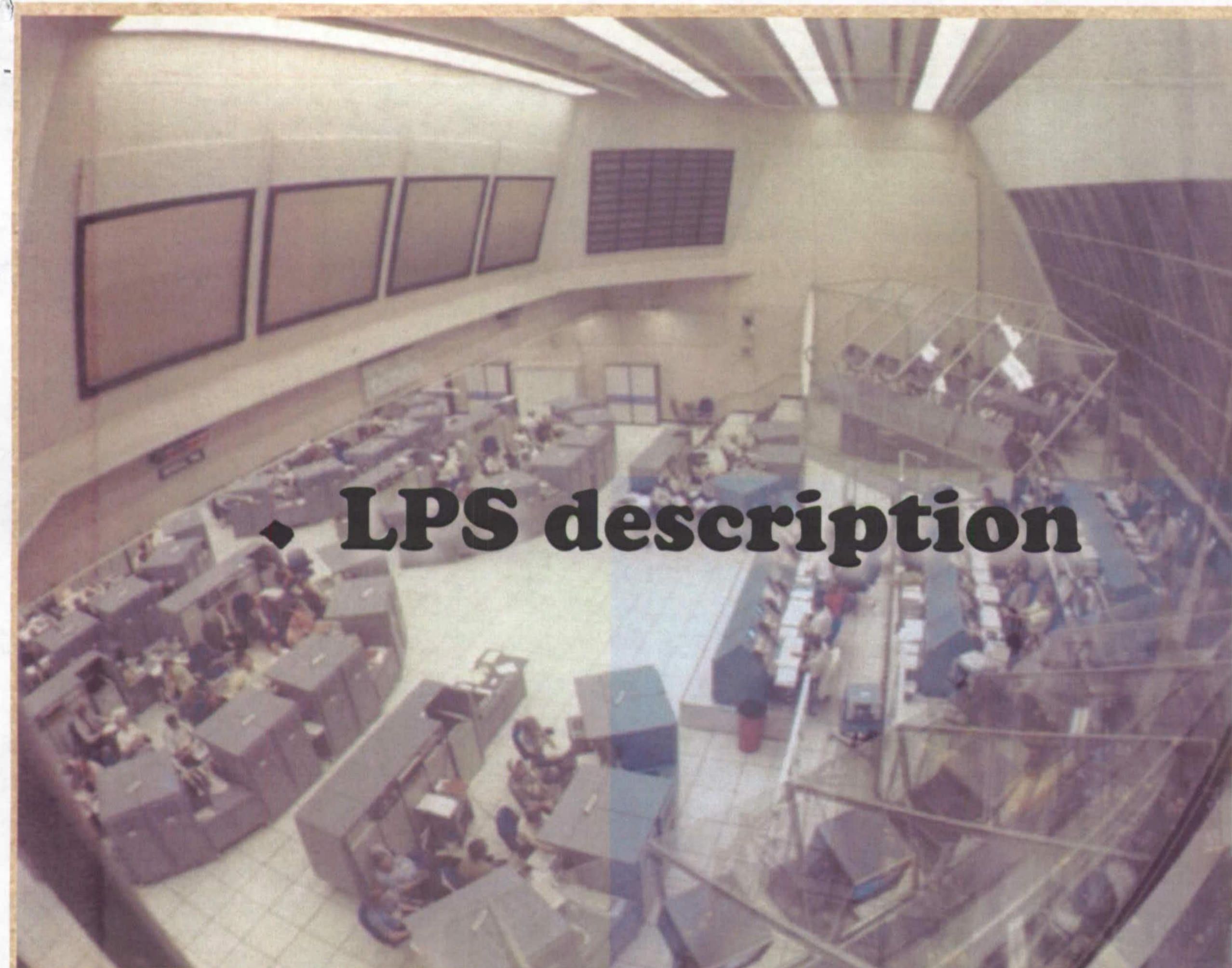


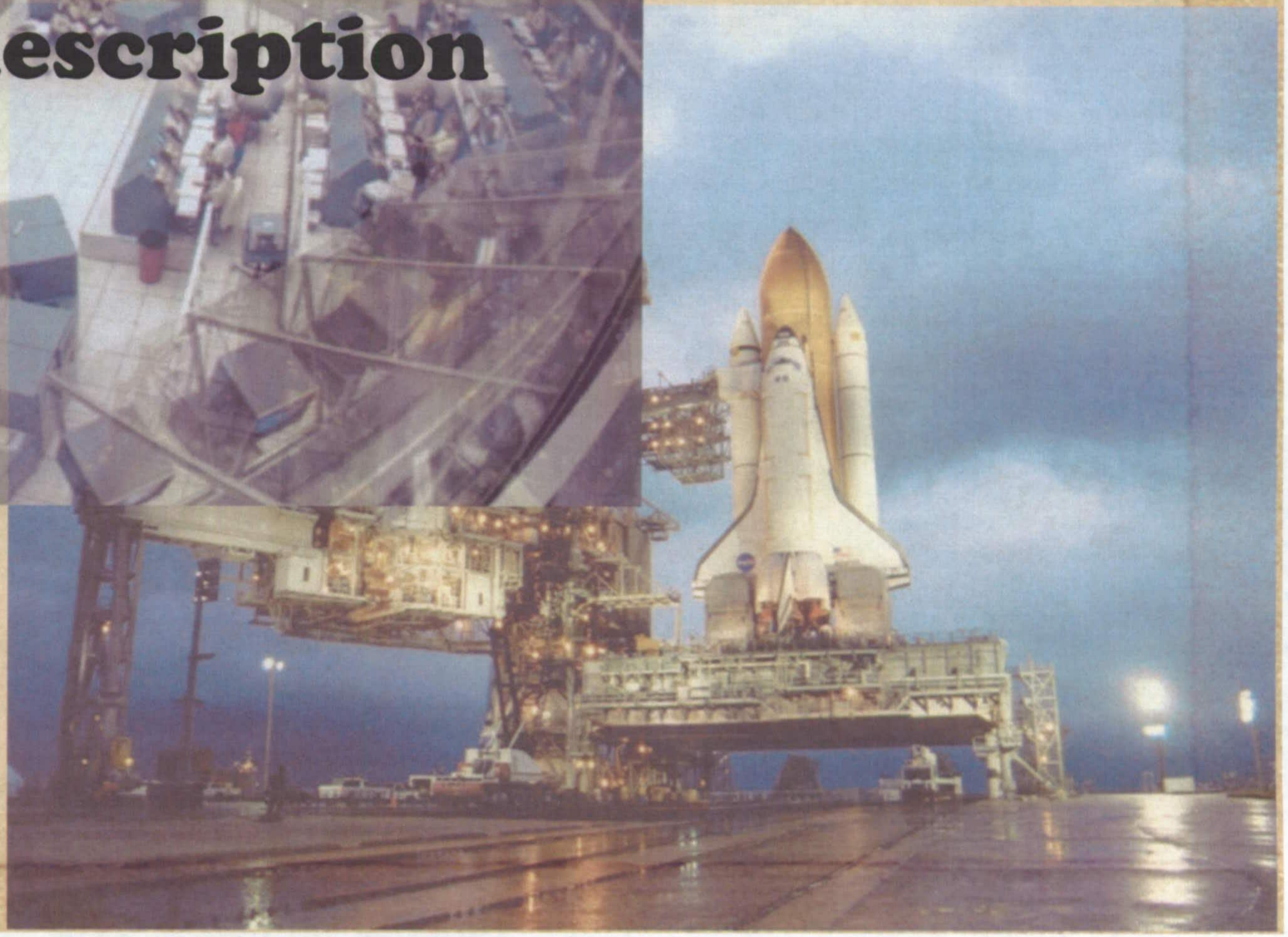


KENNEDY SPACE CENTER CONTROL SYSTEM HERITAGE



- **LPS description**





Core/TCMS Description

Core Overview & Harris Command/Control Systems Approaches

September 26, 2007

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Harris Government Communications Systems
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Core Scope

- Award – 1989
  - Engineer, Design, Develop, Manufacture and Sustain
    - Space Shuttle Launch Processing System checkout system (Checkout, Control and Monitor System – CCMS II)
    - Space Station Freedom checkout system (Test, Control and Monitor System - TCMS)
- Contract Realignment – 1994
  - Eliminated CCMS II
  - Minimized TCMS
- Completed, 1995

Top Level Core Architecture

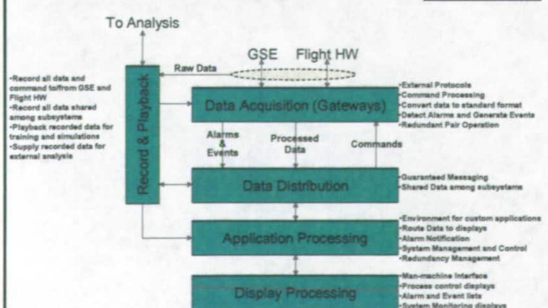
- Develop Core Software
- Develop GOAL Application
- Develop Custom Applications
- Process Shuttle and Payload Data Descriptions
- Build Monitoring and Control Set Loads
- Download software to sets

- Acquire data from GSE, Payload and Vehicle
- Detect and process alarms
- Execution environment for GOAL application and custom applications
- Process monitoring and control displays
- Record all data received from and sent to GSE, Payload and Vehicle
- Playback recorded data

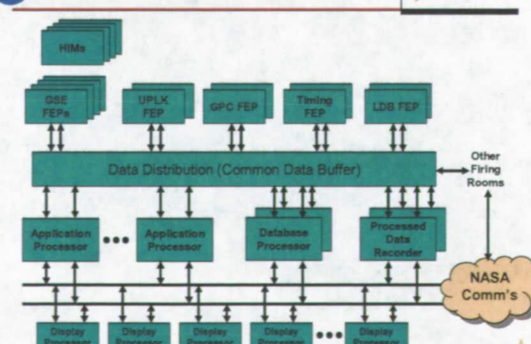
Monitoring and Control Sets

- Kennedy Space Center
  - Firing Rooms 1-4 (FRx)
  - Hypergolic Maintenance Facility (HMF)
  - Hazardous Processing Facility (HPF)
  - Complex Control Set (CCS)
  - Partial Payload Checkout Unit (PPCU)
  - Cargo Integrated Test Equipment (CITE)
  - Space Station Test, Control and Monitor System (TCMS)
- Johnson Space Center
  - Shuttle Avionics Integration Lab (SAIL)

Monitoring and Control Set Configuration



Firing Room Configuration (Core)



Then and Now

Aspect	Then	Now
Redundancy/Failover	Application	COTS (HW/SW)
Design	Object Oriented (emergent)	Service Oriented
Gateways	Custom HW/SW	COTS (PLCs)
Applications	Custom SW	COTS
Data Distribution	Custom (Common Data Buffer)	COTS Networks
Programming Language	Ada	Java/C++

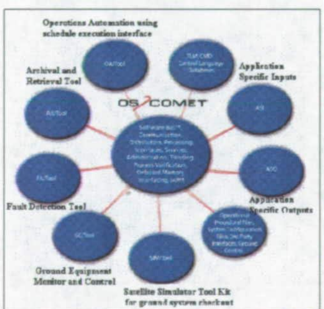
Then- Custom development (HW & SW)
Now- Standards based HW & SW with minimal development

Harris Approaches for Command & Control Systems

OS/COMET

Over 25 years of Guaranteed Mission Assurance for Space Systems TT&C

- COTS product providing Satellite Tracking, Telemetry, and Commanding
- Over 200 active satellites including:
  - GPS
  - Digital Globe
  - DirecTV
  - Iridium
- Some constellations include over 500K telemetry items
- Database-driven system to support any spacecraft, ground system, or mission type
- Extensible by the User: Non-Proprietary Interfaces
- Central Control of Multiple sites
- Reliable and Proven



OS/COMET Lifecycle Reuse

Re-Use of OS/COMET through all phases of the lifecycle minimizes technical risk and nonrecurring cost

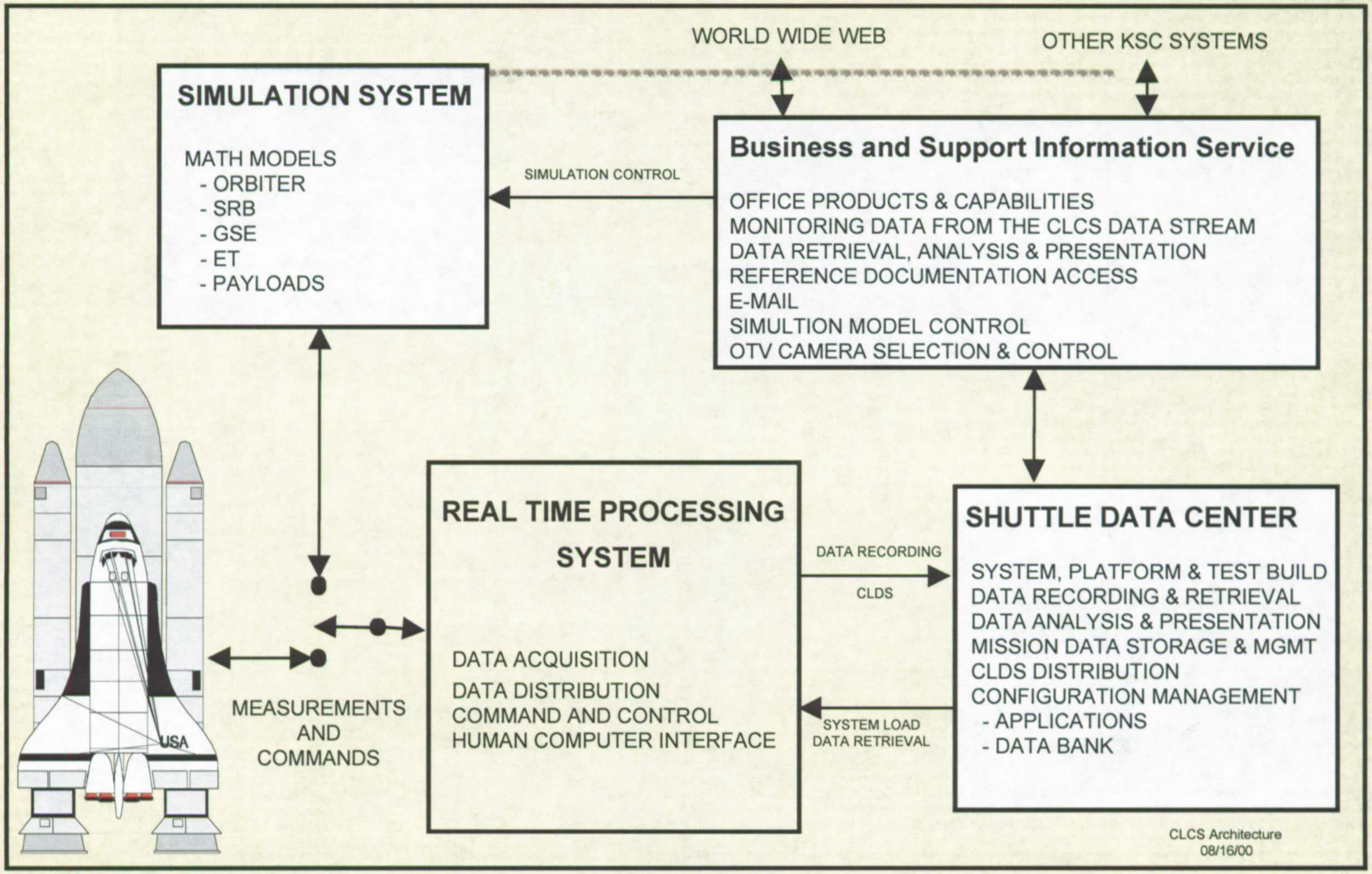
- Databases
- Procedures
- Displays
- Expertise

Other Command/Control Systems

Service Oriented Architecture

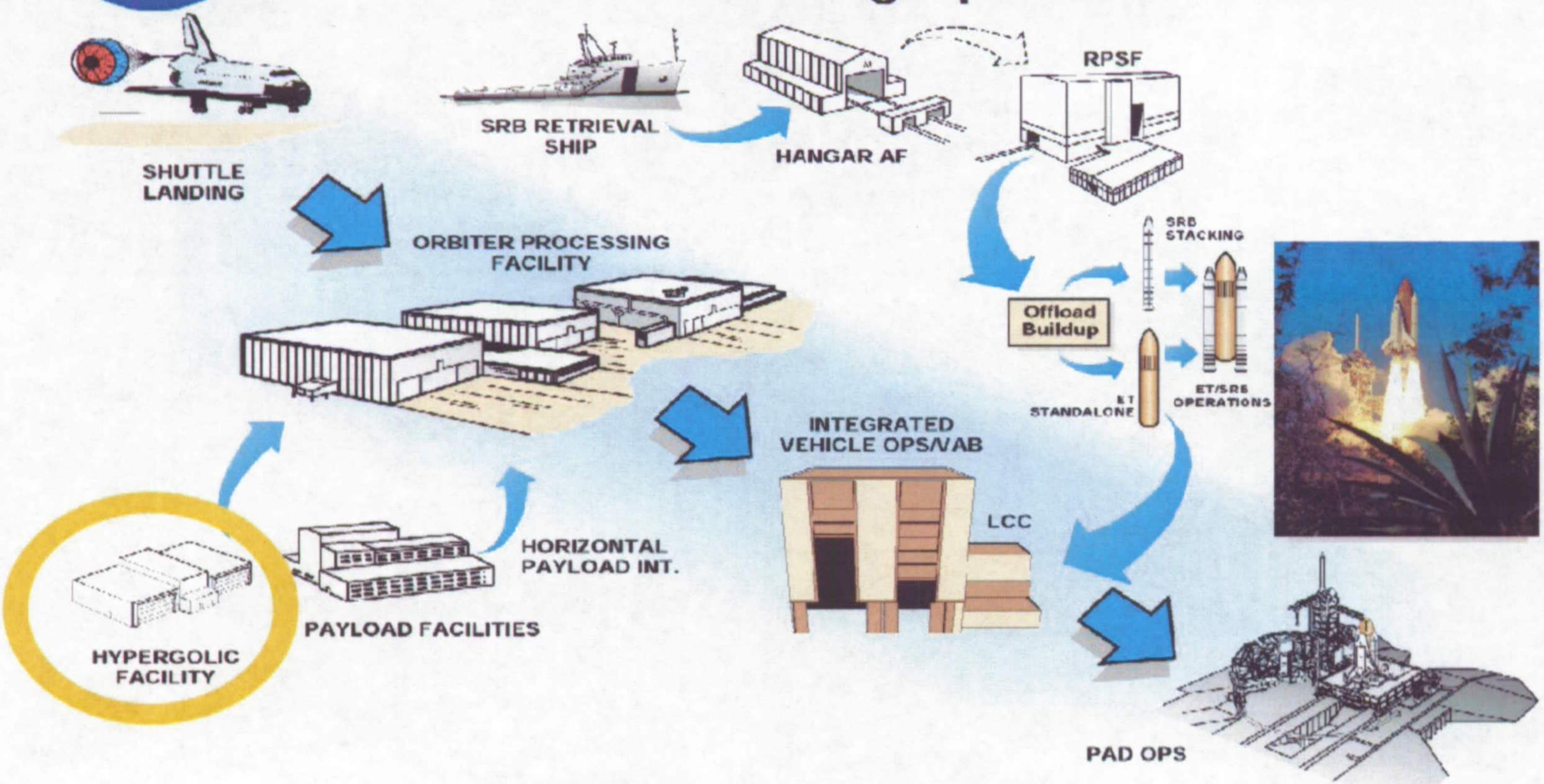
* CLCS Description

CLCS SYSTEM ARCHITECTURE

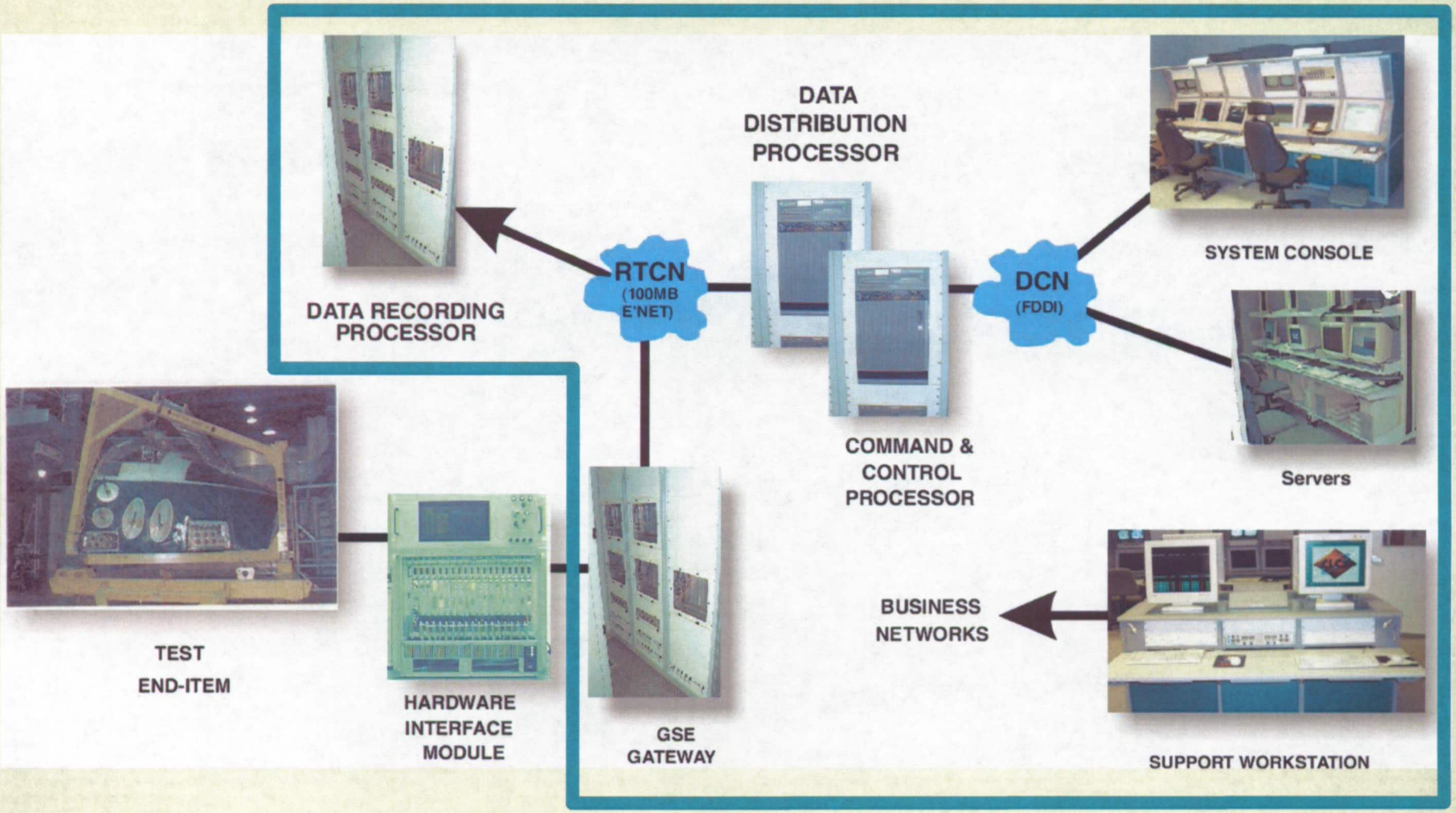


SHUTTLE OPERATIONS OVERVIEW

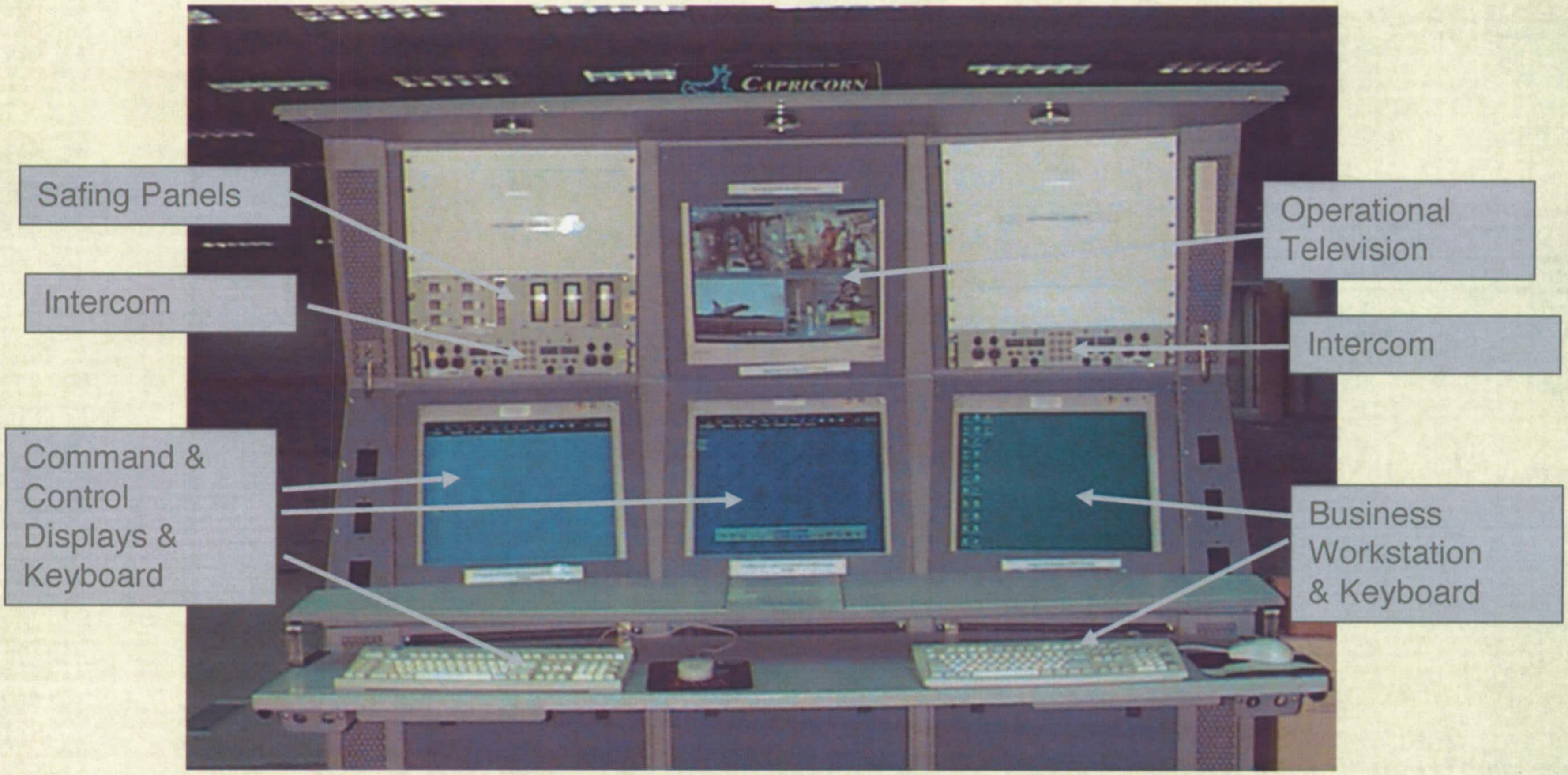
Ground Processing Operations



CLCS Architecture Overview



CLCS Console layout



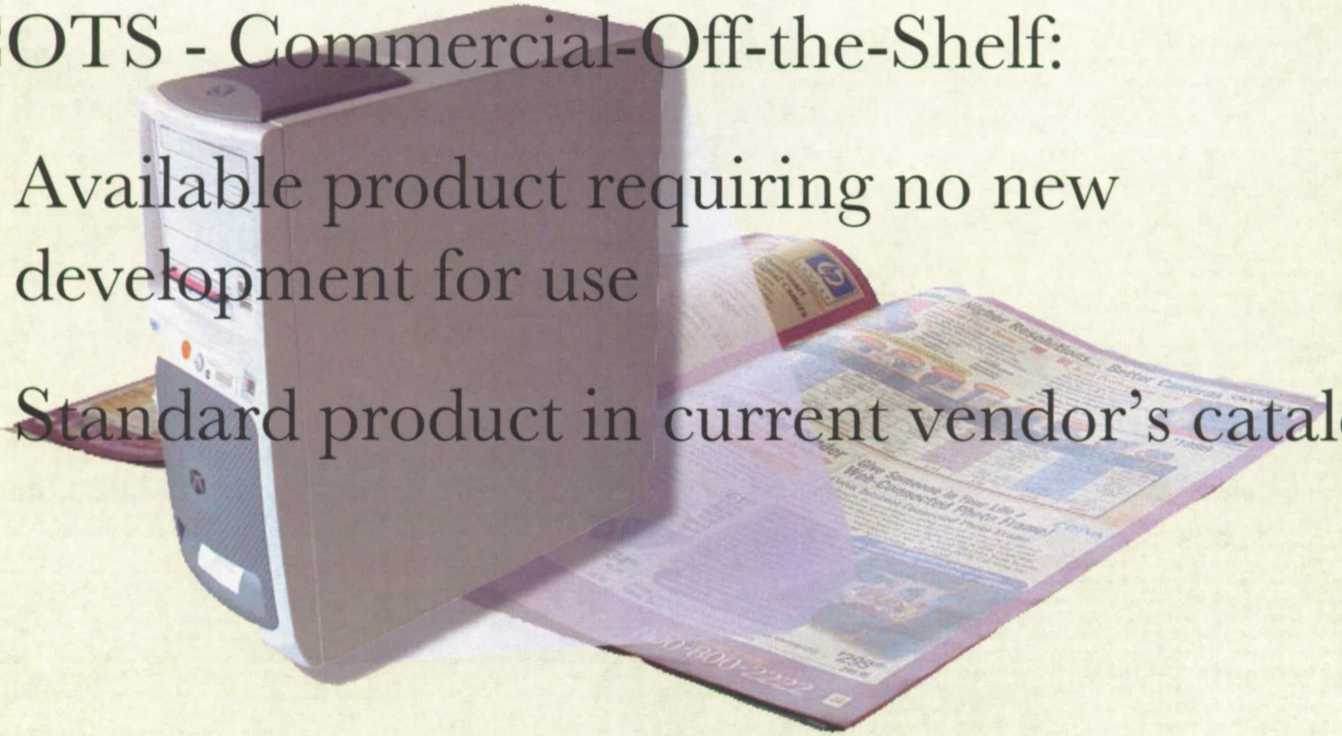
Operations Control Room Console grouping

CLCS Goals

- Deliver safe, reliable, dependable system that meets shuttle checkout needs
- Deliver system which enables increased checkout efficiency
- Deliver system with long useful life
  - Allow upgrades to keep pace with technology
  - Provide expansion room for future needs
- Reduce development & O & M costs
  - *Use COTS where practical*
  - Build on previous designs

COTS

- COTS - Commercial-Off-the-Shelf:
  - Available product requiring no new development for use
  - Standard product in current vendor's catalog



Options to COTS

- Develop it yourself
  - Incur full development cycle costs
  - Sign up for long term sustaining and maintenance
- Use modified COTS
  - Incur some initial development costs
  - Pay continuing sustaining/maintenance costs

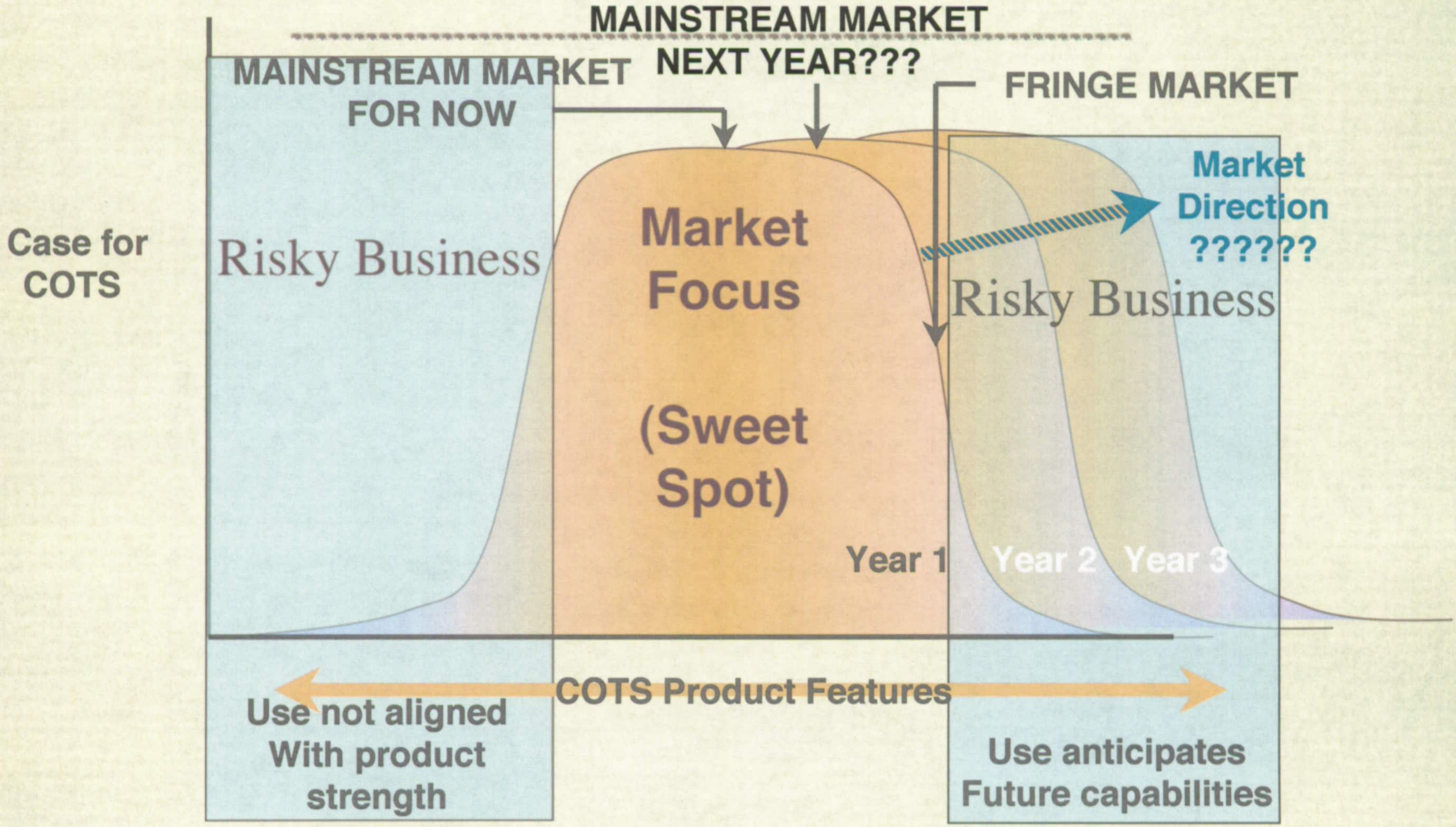
COTS Downside

- Won't match all requirements exactly
- Requires upgrades at vendor's convenience
- Upgrades must be synchronized with other COTS products
- Will require updates to non-COTS products interfacing with COTS
- May drop features in new versions
- Won't be newest ideas
- May not be fastest or biggest
- Little in depth knowledge of inner workings of product

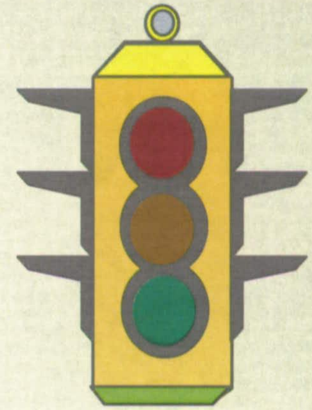
COTS Upside

- Development costs shared across large customer base
- Large market base providing product quality feedback to vendor
- Trained workforce available
- May include features beyond basic requirements
- Compatibility with other COTS products

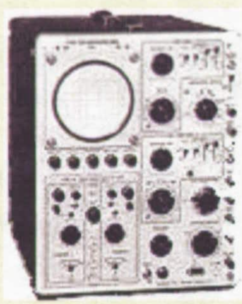
COTS Selection Risk

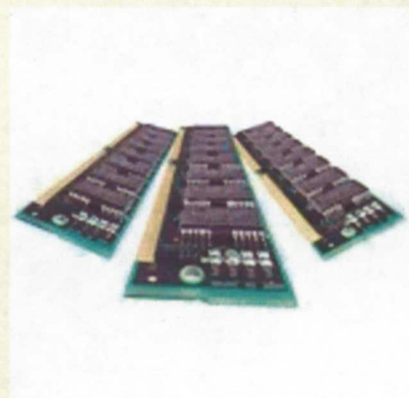


COTS "No-Brainers"

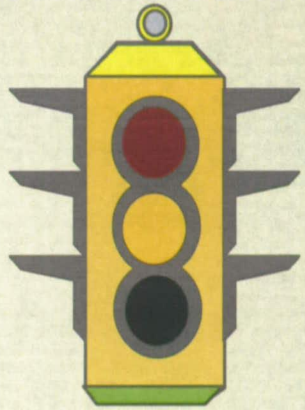


- Standard multi-vendor supplied with large established market:
  - Oscilloscopes, Voltmeters
  - Memory modules, standard interface boards, networks





COTS "Brainers"



- Single vendor supplied products with large established market:
  - Isolated in system with few interfaces
  - Business case driven-savings in development worth risk of replacement
  - Database software, network analyzers

COTS HIGH RISK AREAS

- Single vendor supplied products with no standard interface and small market:
  - Critical to system success
  - No second source conversion available
- Take precautions: Escrow agreements, budget reserve

CLCS EXPERIENCE: NETWORKS

- Asynchronous Transfer Mode network selected due to high capacity and projected commercial support
  - Support did not materialize for real time multicast techniques
  - Switched to high speed ethernet with minimal rework
- Fiber Data Distributed Interface network selected due to wide support and failover techniques
  - Support dropped by vendors
  - Switched to high speed ethernet with minimal rework

CLCS EXPERIENCE: OPERATING SYSTEMS

- Unix selected due to multivendor support and standardization
  - Switched vendor platforms
  - Experienced significant rework even though POSIX standards were mostly followed
    - Threads implementation different
    - Library structure and content different

CLCS EXPERIENCE: DISPLAY BUILDER

- Used for increased productivity in building operator displays
  - Portable across different vendor platforms
  - Remained stable through development life cycle
  - Support has continued to be good

SUMMARY

- Use of COTS can save development time and provide benefits of large use base for testing, user groups and skills availability
- Under the wrong conditions, COTS can cause major down-the-road expense and loss of support

CHOOSE WISELY!

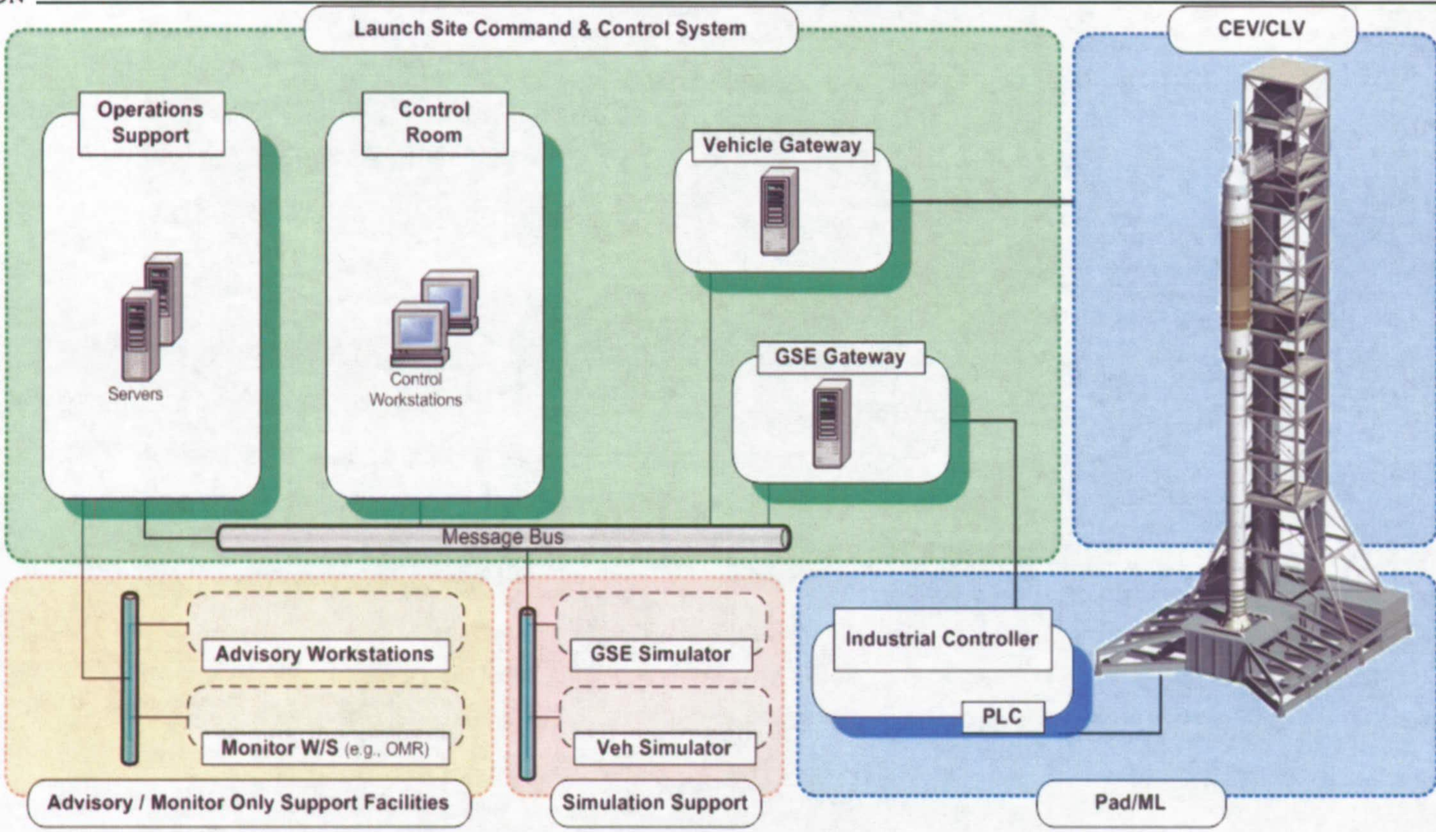
Summary for C&C

- ?

Launch Site Command and Control System (LSCCS) Proof-of-Concept Discussion

July 2007

LSCCS Architecture Overview



- The architecture and design is based upon the use of mature, industry accepted, hardware and software standards and products for command and control applications.
- The architecture and design leverages agency investments in a common approach for information architecture.
- Specialized Software will be developed only when no suitable industry/government product is available

Timeline of events

Date	Event	Outcome
June 2005	Exploration Systems Command and Control Tiger Team Formed	Feasibility study for a Exploration Systems Launch Site Command & Control System
Aug 2005	Senior Review Team Presentation	Recommendation for a Launch Site Command and Control Architectural Trade Study
Oct 2005	KSC Constellation Program office requested trade study to evaluate candidate launch site C&C architectures	Trade Study Team formed to evaluate C&C architectures based on 1) Legacy C&C Systems 2) Commercial C&C Systems 3) Standards Based C&C System
June 2006	Ground Ops Project Control Board Review	PCB accepted recommendation to adopt Standards Based Architecture for Launch Site Command and Control System
Aug 2006	KSC Constellation Program Office requests a Proof-of-Concept study for the Standards Based Architecture	Initial project team formed. Specific goals and objectives for trade study approved, Evaluation H/W and S/W procured.
June 2007	Completion of Proof-of-Concept Activities	Proof-of-Concept findings and recommendations documented. Prototype demonstrations for Launch Site C&C System (through August)
August 2007	Ground System Control Board Authority to Proceed Review	

Proof-of-Concept - Background

- **The main emphasis is to "buy down" risk for GOP associated with the launch site command and control hardware and software development**
- **The Proof-of-Concept centers on the highest risk areas in the architecture**
  - Fault Tolerance
  - Redundancy Management
  - Data Distribution and closed loop performance
  - Telemetry and command processing functionality
  - Scripting language for applications
- **The Proof-of-Concept team consisted of:**
  - NASA Civil Servants from KSC and ARC
  - KSC on-site contractors
  - Support from JPL and industry field engineers
- **Proof-of-Concept was completed in June 2007**
  - An prototype of the critical elements of the LSCCS is an outcome from the Proof-of-Concept
  - Demonstrations of the LSCCS prototype are being provided throughout July and August

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Summary of POC Activities

Product Group / Component	Demonstration	Prototype	Analysis / Market Survey	RFI
System Software				
Record and Retrieve			X	X
System Monitoring and Control	X	X	X	X
Command & Telemetry Svcs	X	X	X	
Data Distribution Svcs	X	X	X	
Common Services	X	X		
Application Framework / Software	X	X	X	
Display Framework	X	X	X	
Application Framework	X	X		
Application Software	X	X		
Displays	X	X	X	
Information Architecture	X	X	X	
Industrial Controllers				
Hardware	X	X	X	
Servers - Gateways, Apps	X	X	X	
Networks		X	X	

LSCCS Proof of Concept
Software Trades & Studies

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- **System Monitor and Control**
  - RFI released to SEWP vendors
  - IBM & HP submitted responses and provided onsite demonstration of their tool capabilities
  - HP Openview selected for use in Prototype
- **Command and Telemetry Services**
  - Performed a Market Survey of 3 commercial toolkits/systems
  - Harris OS/Comet selected for use in the prototype
    - Derived from Naval labs common test environment
    - Has many existing aerospace deployments including Iridium Satellite Control
    - Suitable for C3I architecture and interface requirements compliance
- **Data Distribution Service**
  - Performed a Market Survey of 2 middleware standards supporting publish/subscribe
  - Prismtech Opensplice selected for use in the prototype
    - Has many existing aerospace and DOD deployments

LSCCS Proof of Concept
Software Trades & Studies

- **Domain Specific Languages (DSL)**
  - Performed Market Survey and engineering assessment of 22 COTS/GOTS languages
  - Down selected to and completed detailed assessment of 6 languages
  - Python selected for use in the prototype
- **Information Architecture**
  - Working closely with the Level 2 representatives
  - Developed initial prototype concept ontologies using the ARC selected IA tool set
  - Providing feedback/modifications to Constellation Foundation Ontology based on experience gained populating the ontology with legacy shuttle data
- **Recording and Retrieval**
  - Considers shared, centralized data recording, retrieval, and archiving for all types of Constellation vehicle processing data.
  - RFI has been released to industry, and have received 42 responses
  - Evaluated all RFIs, developing requirements for RFP

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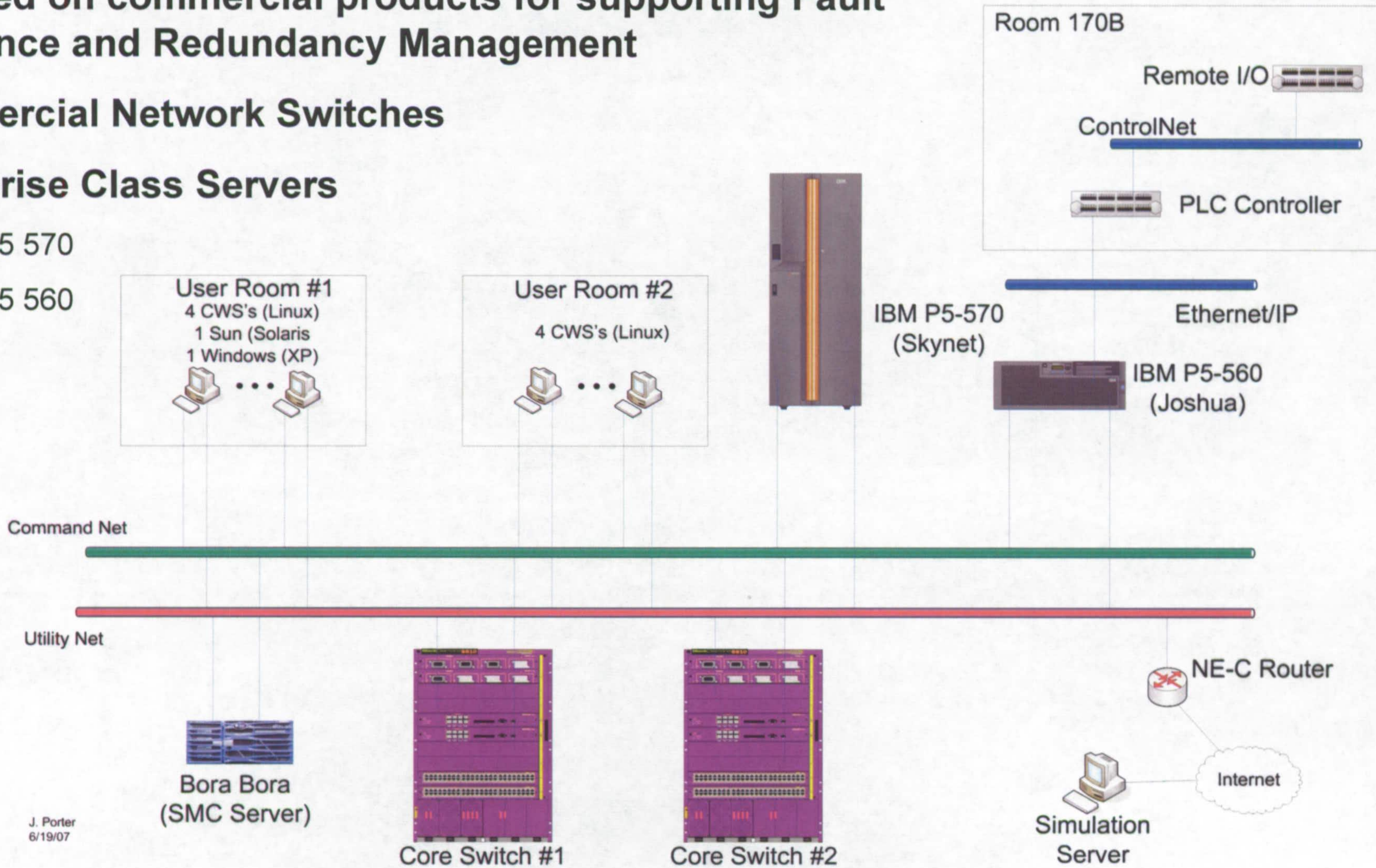
LSCCS Proof of Concept
Hardware Trades & Studies

- **High Reliability Availability and Serviceability Technology**
  - Networks Capability Testing
    - Testing focused on the applicability of 'best-of-breed' network technologies and ability to meet the performance, fault tolerance, and redundancy management requirements of the LSCSS networks
    - No significant surprises were encountered
  - Server Capability Studies
    - Empirical analysis using procured Enterprise class servers provided promising results for meeting the reliability, availability, and serviceability (RAS) requirements.
    - Visit to the IBM facility in Austin TX has facilitate in-depth analysis
    - Planned trip to the Sun Microsystems in Sunnyvale later this summer
- **Allocation of Control**
  - Determination of criteria and design guidelines for allocation of command and closed loop control requirements for the GSE has been completed
    - Engineering study has documented approach for balancing the control and monitor functions across the control room and the PLC sub-systems with respect to performance, safety, and situational awareness
    - Engineering data has been modeled and control scenarios investigated using test software

- **Focused on commercial products for supporting Fault Tolerance and Redundancy Management**
- **Commercial Network Switches**
- **Enterprise Class Servers**
  - IBM P5 570
  - IBM P5 560



POC Hardware Architecture

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LCS Software Architecture
Overview

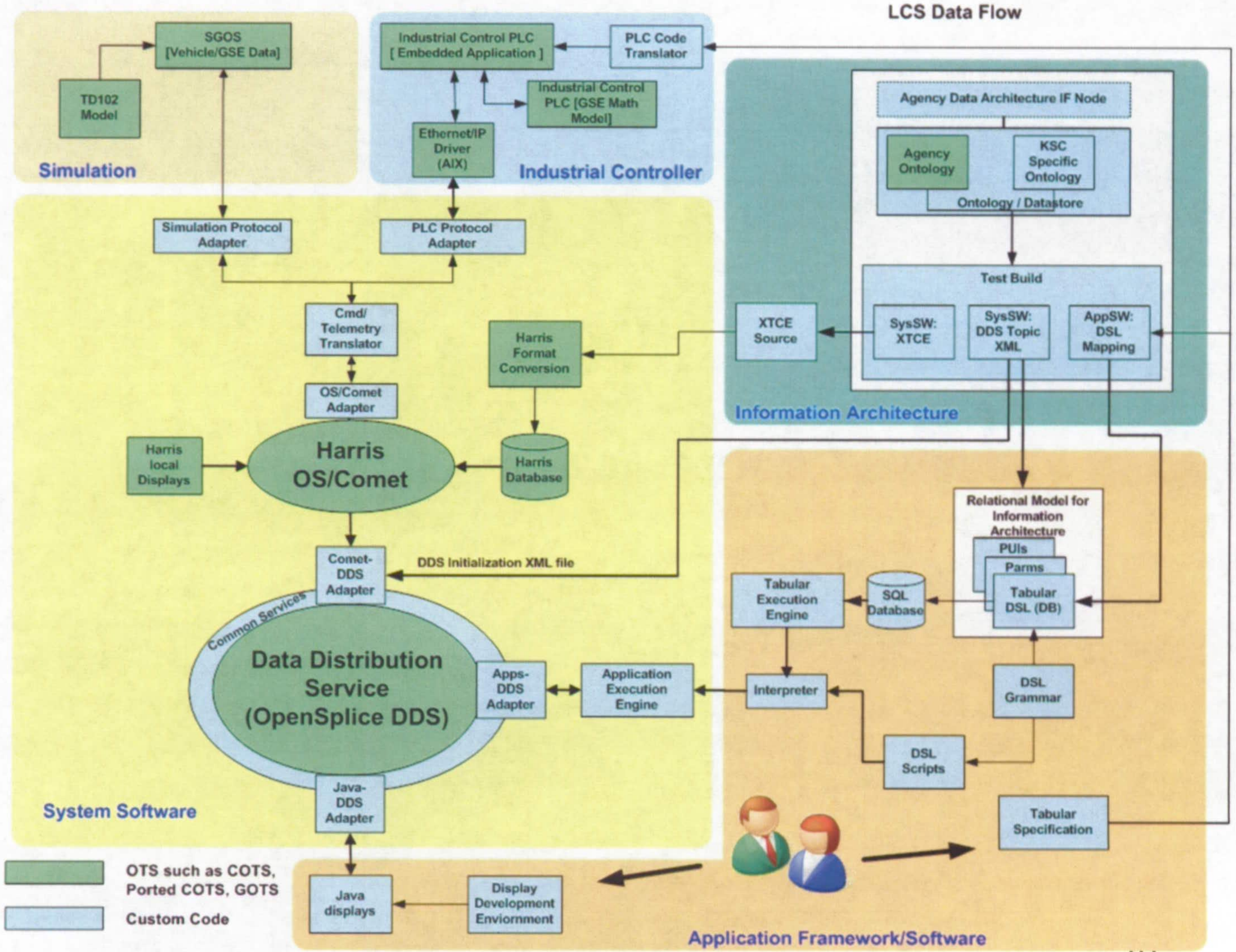
Simulation
- GSE/Veh Shuttle Simulation

Industrial Controllers
- PLC application
- GSE math model

Information Architecture
- Data Ontology
- Build Products

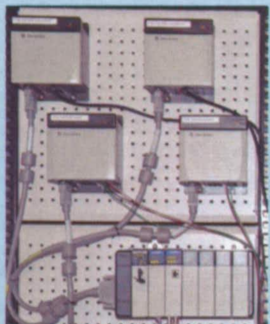
System Software
- Data Distribution
- Isolation layers
- Telemetry processing

Application Framework/Software
- User displays
- Application specification



LSCCS Proof-of-Concept
Selected Prototype Architecture

Industrial Controllers



- Redundant Power
- Redundant Controllers
- Switchover transparent to software

Gateway Interface Server

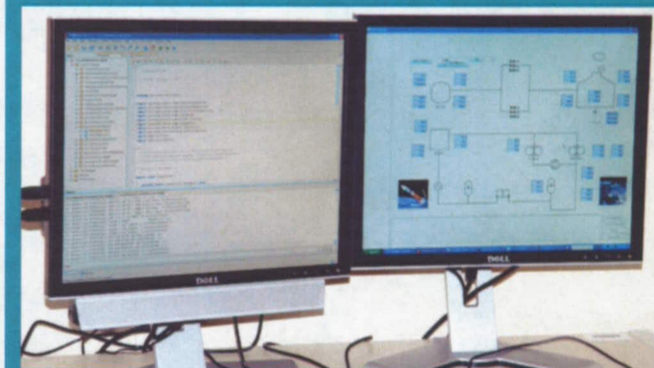
- PLC/GSE Data Processing – Harris OS Comet
- Telemetry and Command Processing – Harris OS Comet
- Data Distribution – OpenSplice DDS
- Health & Status Monitor – HP Openview

Application Server

IBM P-570 Enterprise Class Server

- Data Distribution – OpenSplice DDS
- Application Scripting Engine – Python
- Prototype Application – LH2 (Script and Tabular based)
- System Monitor and Control – IBM/Tivoli and HP Openview
- High Reliability Availability and Serviceability Technology – IBM Hypervisor and Robust N/W Switches

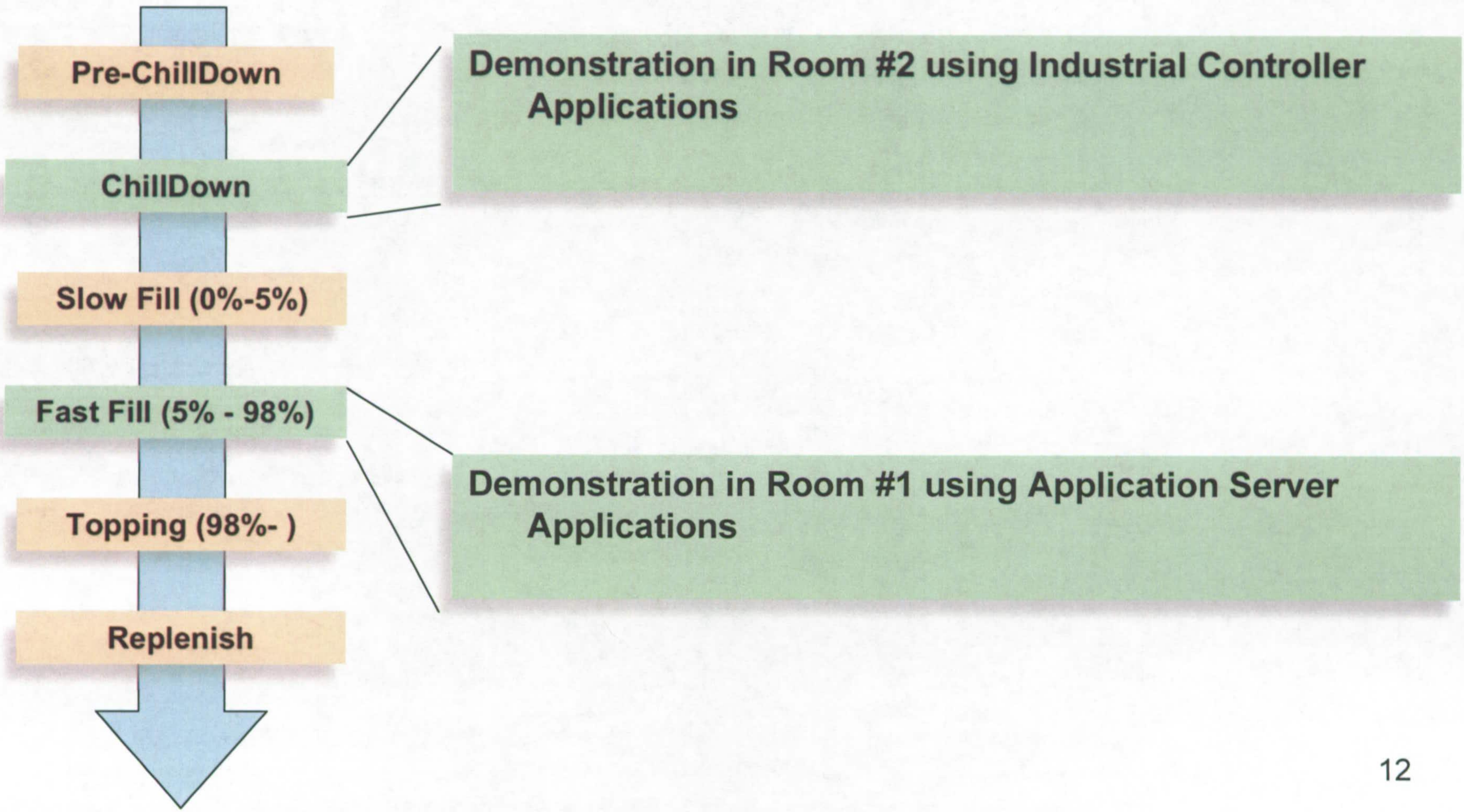
User Workstation



Windows Based Dell Desktop

- Data Distribution – OpenSplice DDS
- Display Engine – Java
- Prototype Dispalys – LH2 and PLC
- Health & Status Monitor – Tivoli and HP Openview

- **Demonstrated scenarios will be based upon Shuttle LH2 launch support operations**



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LSCCS Proof-of-Concept Observations and Findings

- **Validation of Architectural Approach for LSCCS**
  - ☑ The proposed architecture for the LSCCS supports Constellation Program operational concepts and element processing requirements.
  - ☑ The proposed LSCCS architecture enables an optimized life cycle cost for control system development and sustaining engineering.
  - ☑ The proposed LSCCS architecture is robust and flexible to accommodate forthcoming and refined CxP operational support requirements.
  - ☑ Commercially available, high availability, high reliability hardware and software are mature technologies and can provide a base for the LSCCS architecture.

- **Validation of Development Approach for LSCCS**
  - ☑ Development of launch site command and control check-out system using commercially available products is achievable within the baseline schedules.
  - ☑ Development team approach using NASA Civil Servants, supporting contractors, and acquired products is a viable approach for the delivery of the LSCCS to support Constellation operational requirements.

LSCCS Proof-of-Concept
Early Observations and Findings

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♦ Challenges- Documented Risks

- Compliance with agency level software development documents remains a challenge
  - Expectations of NPR 7150.2 and available evidence of compliance from industry not always directly compatible
  - Capability Maturity Model Integration (CMMI) compliance requirements not consistently viewed across Level II and Level III
- Assuming a great deal of automation on board for CEV check-out and launch operations
  - Less lines of code needed for ground to flight applications
  - Minimizes tolerances for closed loop control between vehicle and ground
- Although it significantly reduces the development time, integration of COTS hardware and software has been more challenging than expected in some areas,