History of Command & Control at KSC

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

Apollo/Saturn
- ACE-automated Control Equipment
- DDAS
  - Digital Data Acquisition System

Separate systems for spacecraft & vehicle. Hardwire control, ground versions of flight design.

Shuttle
- Shuttle firing room Command & Control System.
  - First total ground system design.
  - Largest computer command system-mostly custom.
  - SRB set was prototype used at MSFC for early SRB interface testing.

KSC developed Command & Control Systems
- Martin Marietta IRAD
- PAGE/Titan

Payloads
- CLCS
  - CLCS/HMF

Station
- Core
  - TCMS
  - CCTK*

Introduced networks and emerging standards. Generic control architecture.

AFA-Aero Flight Assist Experiment C/O Unit
*CCTK-Command & Control Tool Kit (Commercial Partner)
GCS-Generic Checkout System
CLCS-Checkout & Launch Control System*
CMU-Control and Monitor Unit
Core-not acronym*
IRAD-Internal Research And Development
PPCU-Partial Payload Checkout Unit
RTDS-Real Time Data System (DC-X)
TCMS-Test, Control & Monitor System
* LPS replacement attempts
LPS description
Core/TCMS Description
Core Overview & Harris Command/Control Systems Approaches

September 26, 2007

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

Software Production Facility
- 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

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

To Analysis

Data Acquisition Gateways
- Alarm Outputs
- Processed Data
- Commands

Data Distribution

Application Processing

Display Processing

Firing Room Configuration (Core)

DATA DISTRIBUTION

SPLX

Firing Room

LGS TFP

Other

Nasa

Comm's
### Then and Now

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Then</th>
<th>Now</th>
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<tbody>
<tr>
<td>Redundancy/Availability</td>
<td>Application</td>
<td>COTS (HW/SW)</td>
</tr>
<tr>
<td>Design</td>
<td>Object Oriented (emerged)</td>
<td>Service Oriented</td>
</tr>
<tr>
<td>Gateways</td>
<td>Custom HW/SW</td>
<td>COTS (PLCs)</td>
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<tr>
<td>Applications</td>
<td>Custom SW</td>
<td>COTS</td>
</tr>
<tr>
<td>Data Distribution</td>
<td>Custom (Common Data Buffer)</td>
<td>COTS Networks</td>
</tr>
<tr>
<td>Programming Language</td>
<td>Ada</td>
<td>Java/C++</td>
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Then - Custom development (HW & SW)  
Now - Standards based HW & SW with minimal development

### Harris Approaches for Command & Control Systems

### OSICOMET

- Over 25 years of Guaranteed Mission Assurance for Space Systems TT&C
- COTS product providing Satellite Tracking, Telelemetry, and Commanding
- Over 200 active satellites including:
  - GPS
  - Digital Globe
  - Direct TV
  - Indium
- 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

### OSICOMET Lifecycle Reuse

- Re-Use of OSICOMET 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

SIMULATION SYSTEM
- Math Models
  - Orbiter
  - SRB
  - GSE
  - ET
  - Payloads

REAL TIME PROCESSING SYSTEM
- Data Acquisition
- Data Distribution
- Command and Control
- Human Computer Interface

Business and Support Information Service
- Office Products & Capabilities
- Monitoring Data from the CLCS Data Stream
- Data Retrieval, Analysis & Presentation
- Reference Documentation Access
- E-mail
- Simulation Model Control
- OTV Camera Selection & Control

SHUTTLE DATA CENTER
- System, Platform & Test Build
- Data Recording & Retrieval
- Data Analysis & Presentation
- Mission Data Storage & Mgmt
- CLDS Distribution
- Configuration Management
  - Applications
  - Data Bank

CLCS Architecture
09/16/00
SHUTTLE OPERATIONS OVERVIEW

Ground Processing Operations

- SHUTTLE LANDING
- SRB RETRIEVAL SHIP
- HANGAR AF
- INTEGRATED VEHICLE OPS/VAB
- LCC
- PAD OPS
- ORBITER PROCESSING FACILITY
- HYPERGOLIC FACILITY
- PAYLOAD FACILITIES
- HORIZONTAL PAYLOAD INT.
CLCS Architecture Overview
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

Case for COTS

Mainstream Market

Mainstream Market

For Now

Market Focus

(Sweet Spot)

Risky Business

Risky Business

Year 1

Year 2

Year 3

Mainstream Market

Next Year???

Fringe Market

Market Direction

??????

Use not aligned
With product strength

COTS Product Features

Use anticipates Future capabilities
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
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

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

<table>
<thead>
<tr>
<th>Product Group / Component</th>
<th>Demonstration</th>
<th>Prototype</th>
<th>Analysis / Market Survey</th>
<th>RFI</th>
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<tr>
<td>System Software</td>
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<td>Record and Retrieve</td>
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<td>Command &amp; Telemetry Svcs</td>
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<td>Data Distribution Svcs</td>
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<td>Common Services</td>
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<td>Application Framework / Software</td>
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<td>Display Framework</td>
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<td>Application Software</td>
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<td>Displays</td>
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<td>Information Architecture</td>
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<td>Hardware</td>
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<td>Servers - Gateways, Apps</td>
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<tr>
<td>Networks</td>
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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
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
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
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
- 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 Displays - LH2 and PLC
- Health & Status Monitor - Tivoli and HP Openview

NASA Constellation
Demonstrated scenarios will be based upon Shuttle LH2 launch support operations.

- Pre-ChillDown
- ChillDown
- Slow Fill (0%-5%)
- Fast Fill (5% - 98%)
- Topping (98%- )
- Replenish

Demonstration in Room #2 using Industrial Controller Applications

Demonstration in Room #1 using Application Server Applications
LSCCS Proof-of-Concept Observations and Findings

♦ Validation of Architectural Approach for LS CC S

☑ The proposed architecture for the LS CC S supports Constellation Program operational concepts and element processing requirements.

☑ The proposed LS CC S architecture enables an optimized life cycle cost for control system development and sustaining engineering.

☑ The proposed LS CC S 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 LS CC S architecture.

♦ Validation of Development Approach for LS CC S

☑ 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 LS CC S to support Constellation operational requirements.
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,