Applying Guiding Principles in the Development of Architectures, Acquisition Specifications, and Operating Practices for Affordable and Resilient Satellite Ground Systems

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Project Background and Overview

- **SMC Enterprise Ground Architecture (EGA) Project**
  - *Proposed by SMC/AD and approved by LtGen Pawlikowski (July 2013)*
- **Objective – Develop Ground System Architecture concepts for SMC that are significantly more affordable and resilient**
- **Phase I – The Aerospace Corporation study targeted to provide foundational basis for the project follow-on**
  - *Development of Ground Reference Architectures*
  - *Acquisition strategies and life cycle management processes*
  - *Operational processes*
- **Today's Presentation will:**
  - *Discuss what is different today that drives the opportunity to achieve greater affordability and resilience in Ground Enterprises*
  - *Present Guiding Principles observed from the Phase I study*

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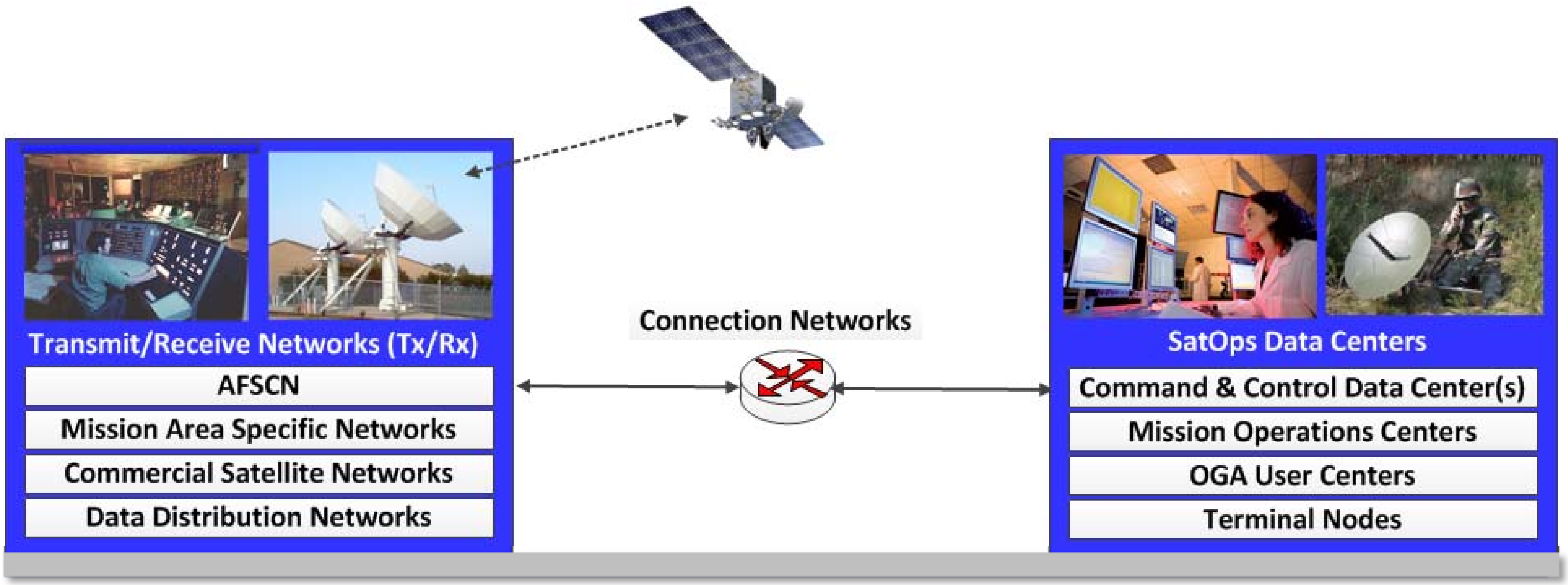
Scope of the SMC Enterprise Ground Architecture Project



Survivable Endurable Ground (SEG) Architecture
Critical Warfighter Support Architecture
Baseline Operating Architecture
Launch Control and Support

Architecture Layers & Services based on Enterprise state

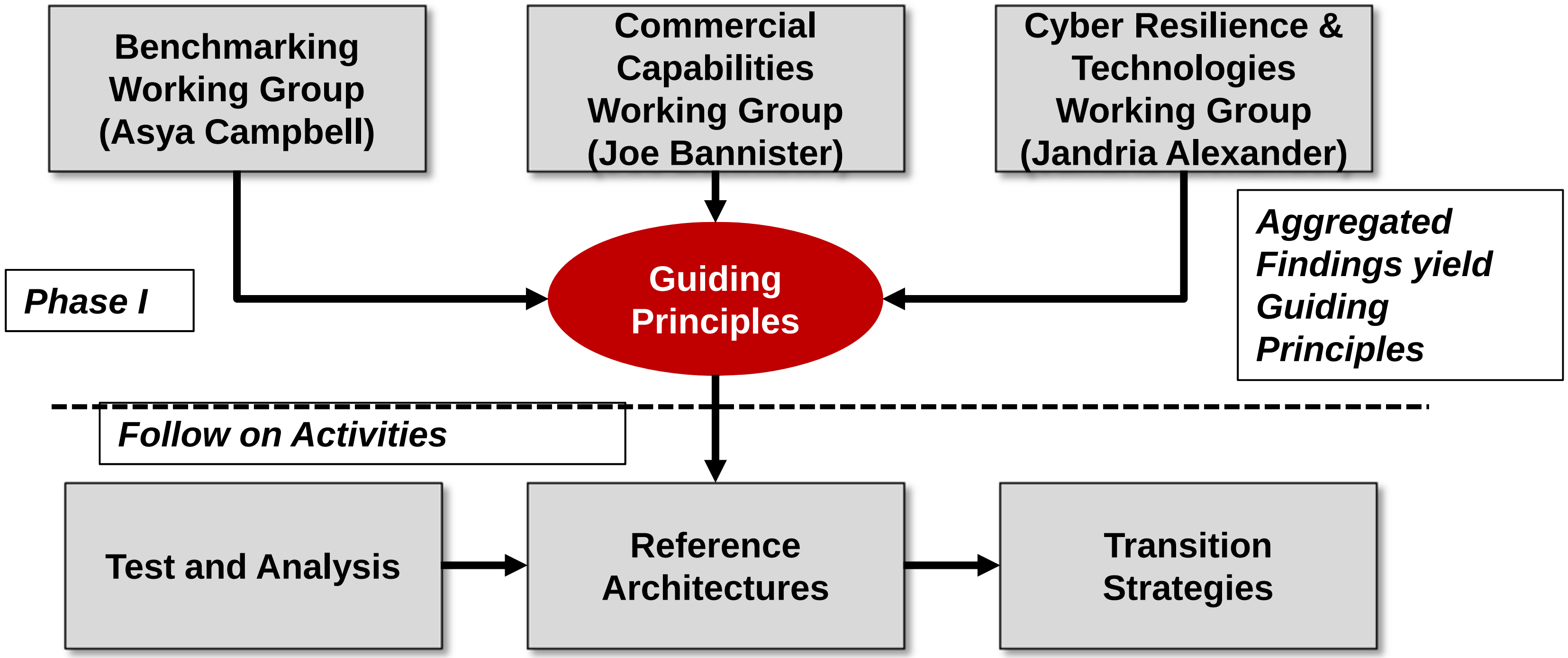
- *Shares common elements as provisioned*

- **Primary focus for The Aerospace Corporation team in Phase I – Ground System Data Centers**
  - ***Major cost drivers are software and people***
- **Other activities underway in Tx/Rx Networks (AFSCN Commercial Provisioning, etc.)**

Slide 3

DADU2 Dr. Alan D Unell, 12/30/2014

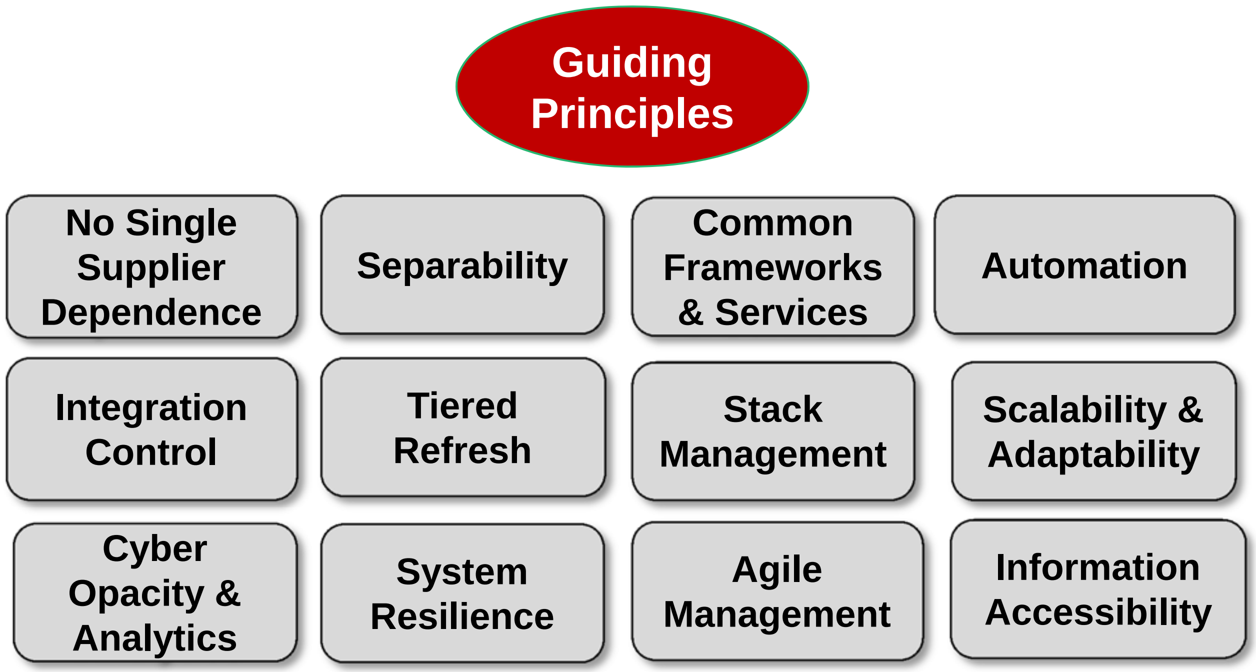
Project Phasing



- **Key findings from each of the working groups will be used to guide the synthesis of Reference Architectures in follow on activities**
  - ***Use of 'Guiding Principles' is similar to the construct of Architecture heuristics****
- **Follow on activities will include supporting test and analysis and transition strategies**

*Heuristics have been described as "Abstractions of Experience" – Maier & Rechtin, **The Art of Systems Architecting**, (2009)

Guiding Principles for Affordable, Resilient Ground Systems



- **These twelve guiding principles have been generated from the findings to date and will be used to support viable EGS architectures and processes***
- **They may not represent a complete set, but they are the most dominant from the findings and reflect both architecture and acquisition guidelines**
- **Use of these Guiding Principles in the Architecting, Acquisition and Life Cycle Management of NSS Ground Enterprises will yield the most cost effective, resilient systems to meet mission requirements**

*Graphic and term taken from TOR-2015-00801. “Framework for an Affordable and Resilient Satellite Ground Enterprise for National Security Space Missions,” The Aerospace Corporation

Benchmarking Project

- **Determine current Architectures and Operational Strategies across the industry**
- **Organizations targeted to Benchmark**
  - ***Government & Commercial Satellite Operations (Study Breadth in Size)***
  - ***Operating and Acquiring Organizations as well as Capability Providers***
- **Met with over 17 commercial and US government organizations and the European Space Agency for site visits and/or Technical Interchange Meetings**
- **Confidentiality through NDAs used where requested**
- **Why Talk to The Aerospace Corporation?**
  - ***Benchmarked organizations want to know the answers to many of the same questions… and where they stand***

Key Commercial Technology Providers

- Survey key commercial technology providers that will impact the architecture and operations in satellite data centers
  - *Direct technical interchange meetings with providers*
- Objective: Identify key technology drivers that can enable cost effective transformation to an Enterprise environment
- Findings included:
  - *Cost impact of system infrastructure – through cloud technologies*
  - *Major shifts in technology providers (market exits and consolidation)*
  - *Emergence of key cyber analytic tools to identify and manage intrusions*

The Process

- **Applied a formal Six Sigma Benchmarking Process***
- **Generated detailed questions for survey and sent to "benchmarking partners"**
  - ***Conducted many site visits coupled with detailed Technical Interchange Meetings***
  - ***Committed to "Reciprocation" – through release of non-proprietary aggregated findings***
- **Inquiry focused on the following areas:**

- **Category I – Business Concerns**
  - ***Business Goals***
  - ***Business Organization***
  - ***Regulatory Compliance***
  - ***Stakeholders***
  - ***Acquisition Strategies***
- **Category II – Information Concerns**
  - ***Data Access***
  - ***Data Organization***
  - ***Data Security***
  - ***Data Storage***

- **Category III -- Applications Issues**
  - ***Alignment***
  - ***Core Applications***
  - ***Deployment Architecture***
  - ***Lifecycle Management***
  - ***Portfolio***
  - ***Security***
- **Category IV – Technology/Infrastructure**
  - ***Network***
  - ***Storage***
  - ***Communications Architecture***

***** *Strategic Benchmarking Reloaded with Six Sigma*, G.H. Watson (2007)*

Guiding Principle

No Single Supplier Dependence

- **The Principle of having <u>No Single Supplier</u> enables the creation of supply chain options and architecture independence as a standard practice**
  - ***Includes***
    - **Hardware, software, supporting tools/OS/algorithms**
- **Potential Benefits:**
  - ***Separation of ground and satellite procurements***
  - ***Acquire by family of services and or architectural layers***
  - ***Avoid vendor lock-in***
- **Supporting Findings:**
  - ***Commercial Companies build constellations with multiple bus suppliers – not locked in to a single satellite type or single software vendor***
  - ***Frameworks allow best solution “app” to be put in service***
- **Counter Examples:**
  - ***Some SMC programs have encountered difficulty transitioning complex legacy code/algorithms and have remained with the current vendor as a result***

Guiding Principle

Separability

- **<u>Separability</u> is the Principle of decomposition of system functions into separable layers with <u>interchangeable</u> options**
  - ***Includes***
    - **Decoupling acquisition of the satellite bus from the C2 control system**
    - **Decoupling of Application Layers from Infrastructure Layers in the "Stack"**
- **Potential Benefits:**
  - ***Separability between component layers in the space system provides more opportunity for competition, innovation and cost management – Similar to modularity***
  - ***Separability supports better cyber protection***
    - **Enables ongoing monitoring and patching**
  - ***Separability is essential to many of the other Guiding Principles***
- **Supporting Findings:**
  - ***Commercial Companies have separated major ground functions such as teleport, ground operations, and payload processing***

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Guiding Principle

Common Frameworks & Services

- **The principle of <u>Common</u> Frameworks & Services is to have a structured set of software components, services, and standards, and possibly hardware, upon which to build <u>mission specific</u> functional ground systems**
  - ***Also encompasses control of interfaces, and data rights (where applicable).***
  - ***Generally requires non-proprietary interface standards***
- **Potential Benefits:**
  - ***Standardization of interfaces enables competition and innovation***
  - ***Full data rights, including redistribution***
- **Supporting Findings:**
  - ***Some companies maintain a suite of common applications for missions to tailor for their use. A common change board maintains the baselines.***
  - ***ESA has a standardized ground Mission Control Systems and vehicle suite that they fully own. Mission specifics account for 10% of the system. New ground Mission Control Systems only modify their specific 10% thus keeping costs low. They maintain full control of the hardware and software and APIs.***

Guiding Principles

Automation

- **The Principle of <u>Automation</u> is the translation of manual processes into machine/software defined execution of sequences. This includes satellite command and control operations, mission operations, control of ground assets, and IT functions.**
  - ***Achieved through scripting of system sequences***
- **Potential Benefits:**
  - ***Increased accuracy (less opportunity for operator error)***
  - ***Reduced staffing – One commercial satellite operator controls 75+ satellites with 5 operators/shift***
  - ***Enables remote operations***
  - ***Widely used by commercial satellite operators to reduce errors and provide traceability in command execution of satellite operations***
- **Supporting Findings:**
  - ***Commercial Companies, NASA Landsat, and MDA, all have significantly automated operations to reduce errors***
    - **Also cross train operators**
    - **They often script manual processes to ensure repeatability**

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Guiding Principle

Integration Control

- **A core Principle for Affordable and Resilient Ground Systems is Integration Control, where the integration control organization owns the architecture**
  - ***Integration Control refers to the responsibility for planning, evaluating, assembling, and testing the components of a Ground System***
  - ***Integration Control also encompasses control of interfaces, use of standards, and data rights (where applicable)***
  - ***The Integration Control organization is responsible for approving and releasing the "Stack" as required on a periodic basis***
  - ***The Integration Control organization should be independent from the supply chain and component providers***

- **Integration control includes responsibility for configuration management of hardware and software**

- **Integration control merges the infrastructure and applications components to ensure the delivery of mission capability**

Guiding Principle

Tiered Refresh

- The Principle of Tiered Refresh is the life cycle programmed replacement and upgrade of Ground System hardware and software based on utility and currency, not when the asset is no longer functioning as required. Refresh when you should… not when you have to.

- "Tiered" recognizes that not all assets should be refreshed on the same cycle.
  - *Software refresh cycles are different than hardware or antennas*
- Keeping outdated assets functioning generally costs more than the replacement costs
  - *Example: Keeping outdated IT equipment running generally is a significant cost for IT the staff*
  - *Data center hardware will increase performance 4X every three years (10X every 5 years)*
    - Increased performance = reduced footprint and reduced power
- The "stack" represents integrated capability coming from multiple software and platform assets – compatibility synchronization becomes significant when the version gap between components becomes significant

Guiding Principle

Stack Management

- **The Principle of <u>Stack Management</u> is the practice of managing ground functional capability through the stack of software and hardware infrastructure, operating systems, tools, applications, standards and documentation, as an integrated set, separable in concept, but tested and deployed as an integrated unit. The "Stack," like its component pieces, has its own life cycle, as a tested and operational capability.**

- **The "Stack" embodies not only its respective components, but standards, defined interfaces, and test procedures**
- **The "Stack" is a continuously evolving configuration of software and hardware**
  - ***Hence "Stack Management" is coincident with ongoing test and evaluation, even after periodic release***
  - ***"Stack Management" includes awareness and impact assessment of the continuous change environment from its respective components***
    - **i.e., virtualization "hypervisor" patching for security**

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Guiding Principle

Cyber Opacity & Analytics

- **<u>Cyber Opacity</u> is the Principle of allowing only limited and controlled access to the data denter system and associated networks**
  - ***The satellite data center should be "opaque" to the outside world***
    - ***Decoupling contractors***
    - ***Decoupling data users***
  - ***A major issue today is direct network access to data centers by cleared defense contractors –should be avoided in future ground systems***
  - ***Need to safely connect from Satellite Operations Centers (SOCs) to Enclaves, Enclaves to Joint Information Environment (JIE)/Users***
- **<u>Cyber Analytics</u> is the Principle of applying tools to monitor overall system behavior to detect intrusion, unauthorized monitoring, and potential attack**
  - ***Means to delivering Cyber Situational Awareness (SA)***
  - ***Perceived to be essential in protecting against the Unknown Threat or Advanced Persistent Threat (APT)***

- **These two principles together (Cyber Opacity & Cyber Analytics) support Anti-Access Area-Denial (A2AD) extended to the Cyber Domain**
  - ***Deny adversary visibility and access to the domain (networks and data)***
  - ***Situational Awareness of adversary in the domain (Cyber SA)***

Guiding Principle

System Resilience

- System Resilience is the ability of the overall system to be resilient to adverse events, whether cyber related or other threat events
  - *Ground System Architectures must support overall System Resilience*
- Cyber Systems will be essential to the monitoring, reconstitution and recovery of Ground Systems
  - *Consequently, the cyber protection systems and the system architecture must facilitate support of rapid system reconstitution*
- Ability to rapidly reconstitute, either through redundancy or recovery must ensure reconstitution to last known good state
  - *Ground system software and security tools must be essential parts of the reconstitution architecture*
  - *Manual reconstitution is likely not an option – since it will be unacceptably slow during a period of conflict*
- Resiliency also requires ability to continue operations, even in a degraded state, through adverse events

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Guiding Principle

Scalability & Adaptability

- **Ability to easily incorporate new requirements, missions or functions and to grow the system to accommodate additional components , e.g. similar satellites, teleports or ground stations**
  - ***<u>Scalability</u> is the rapid and cost effective growth in asset control capability***
    - **Especially important in cost effective transition from prototypes to full scaled operations**
    - **Includes flexibility in adding additional satellites, and adding ground assets**
  - ***<u>Adaptability</u> is the ability for an Architecture to adapt new missions and requirements***
  - ***Both enable commercial operators to grow business without major infrastructure redesign***
- **Supporting Findings:**
  - ***Commercial Operators' software architectures allow for rapid addition of new satellites, rapid incorporation of new teleports, and ground stations***
  - ***ESA encapsulates core software so that mission specific software resides in 10% of the Mission Control System***
    - **Allows them to adapt by changing only 10% of software for added missions**

Guiding Principle

Agile Management

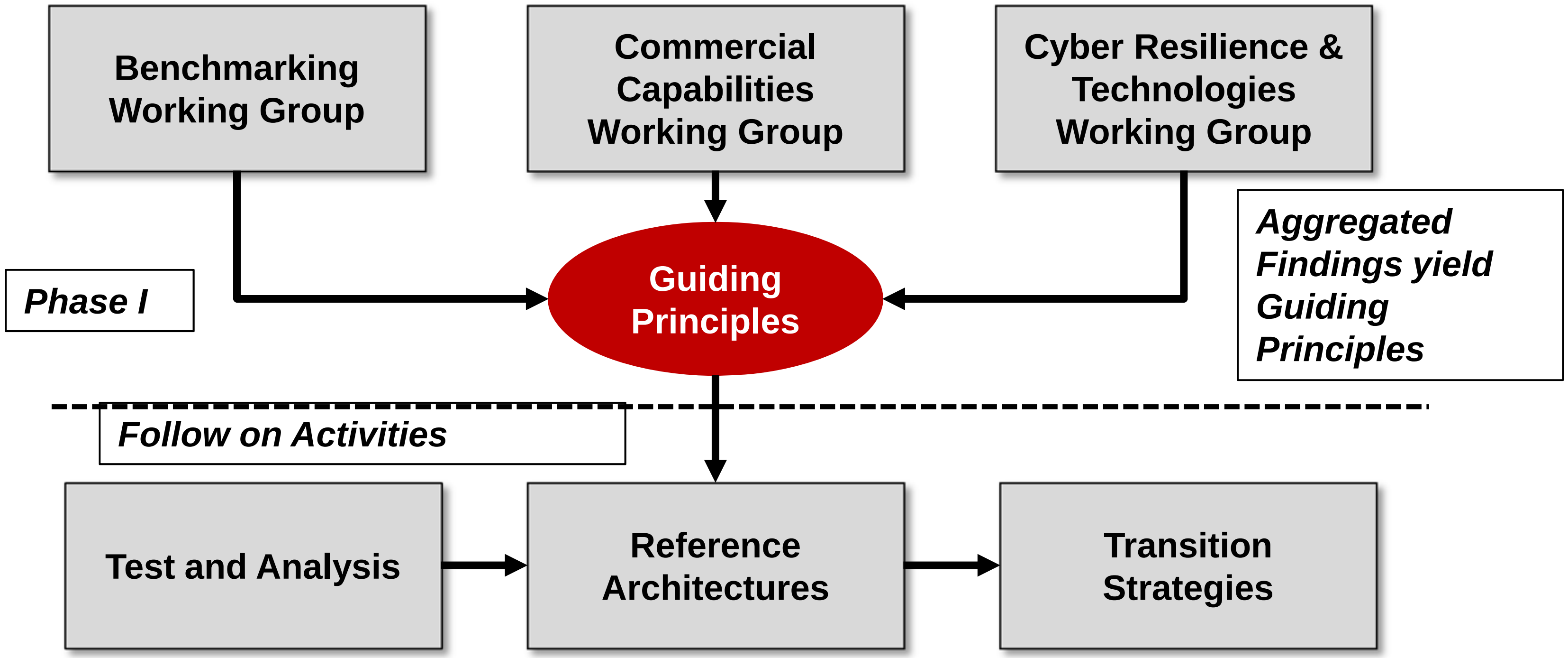
- <u>Agile Management</u> refers to the ability to adapt to a changing world, and a movement away from the decades it takes to field a system. This implies a less deterministic end state or a continuous state of transition. It acknowledges that the end state of development is not completely known at the beginning of acquisition.
  - *Short time to market/rapid repair*
  - *Assumes requirements creep: system is designed for change*
  - *Allows for more cost effective change control management*
- Supporting Findings:
  - *Agile Management is the dominant strategy in software development firms*
  - *All commercial vendors and satellite operators demonstrated lean management, short decision making chain, direct customer contact that enables them to adapt rapidly. Commercial teams have thin management hierarchy allowing quick direction of development and maintenance teams*
  - *Commercial software providers as subs are allowed direct customer contact to fix problems*
  - *All commercial vendors and satellite operators were mission focused rather than "process focused." They make money when they fly and transmit data.*

Guiding Principle

Information Accessibility

- Information Accessibility as a Guiding Principle is recognition that stakeholders, specifically warfighters, will seek near real time data on a broader scale
  - *Relevant data must be available to those who have appropriate privileges and credentials without direct network access to Satellite Data Centers*
  - *Future Ground Architectures must include capability to rapidly push data to secure enclaves*
  - *Information likely to be used in manner not originally conceived*
- Supporting Findings:
  - *Major push within DoD and the IC to harvest information from fusion of system data*

Summary



- **Key observations and findings came from investigations of the three working groups**
- **They have been coalesced into prescriptive guidelines to be used in**
  - ***Development of reference architecture(s)***
  - ***Development of acquisition and life cycle management strategies***
  - ***Guidance in technical and acquisition specifications***
  - ***Development of operations processes***