National Aeronautics and Space Administration

From ~200 MIAMI participants over 5 years

- Evaluated Lessons Learned
- Performed Gap Analysis

Suggested MBSE Implementation Plan Approaches

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NASA Systems Engineering
MODEL BASED SYSTEMS ENGINEERING

www.nasa.gov

MBSE

Agenda

- MIAMI History and Lessons Learned
- MBSE Strategic Vision Updates
- Suggested Implementation Approach
  - Develop Project MBSE Capabilities
  - Project Deployment
  - Technology and Methodology Evolution
  - Change Process
- Approaches Mapped to MBSE Strategic Vision

NASA MBSE Timeline

Legend
- Loose Partnering
- Tight Partnership
- Mainline Work

Key Activities

- **MBSE Pathfinder** — Strategy and Use Cases Defined
- **NIMA** — 4 Yr Effort, Whitepaper, Benchmarks
- **Request to EDs** — "Volunteers"
- **OCE Cloud** — Enterprise MD Licensing
- **MBSE Pathfinder Kickoff** — 30 Participants, 9 Centers + DoD, 4 Use Cases, Training via GT
- **MBSE Pathfinder Review** — Six Months Later, W/F Adoption, Use Case Value
- **NASA MBSE CoP Start**
- **Pathfinder 2 Kickoff** — 50 Participants, 10 Centers + DoD, 5 Use Cases, Training via GT
- **UMD** — Dsn. Thinking Trng.
- **Pathfinder 2 Midterm Review** — Technical Advisory Board formed
- **Pathfinder 2 Final Review** — ROI 80%, SoS Integration, Discipline Integration
- **APPEL** — training offered
- **MIAMI Kickoff** — 50 Participants, 9 Centers, 11 P/p Applications, CoP Integrated
- **MIAMI Midterm** — Peer Review, Design Thinking
- **Strategy Group** — Kick Off
- **Strategy Delivered** — 20 year vision
- **Engineering Management**
- **Agency Program Management**
- **Imp Plans** — MBSE and MBx
- **MIAMI Knowledge Capture Meeting** — Gaps & Lesson Learned
- **Targeted Deployment** — Testing current resources with ExMC

Can We? → Why? → Infusion → Direction

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2016 | 2017 | 2018 | 2019 | 2020

Partnerships

- NASA Office of the Chief Engineer
- Department of Defense
- Georgia Institute of Technology
- NASA Safety and Mission Assurance
- Japanese Aerospace Exploration Agency
- Academy of Program, Project and Engineering Leadership
- University of Maryland
- NASA OCIO
- NASA Space Technology Missions
- The University of Alabama in Huntsville
- Stevens Institute of Technology
- Boeing
- USMC Strategic Command
- USAF Space & Missile Command
- NIST
- NASA Tournament Lab

Programs and Projects

- Joint Polar Satellite System
- Europa
- NASA Engineering and Safety Center
- Asteroid Retrieval Mission
- SLS
- Commercial Crew Program
- Resource Prospector
- Space Comm and Nav
- X-Ray Imaging and Spectroscopy Mission
- Exploration Medical Capability
- Gateway Lvl1
- Mars Assent Vehicle
- Urban Air Mobility

Chart content is not standalone, complements paper and verbal presentation.

Top Lessons Learned

- Models should have a purpose.
- “Slow and steady wins the race.”
- Bold, committed leadership with authority and resources is needed.
- Modelers and innovators benefit from continual stakeholder engagement and re-engagement.
- New technology aligns with new ways of thinking.

- Amount of resources (time, money, and people) for MBSE innovation and implementation are still difficult to estimate.
- Streamline license access and infrastructure for modeling.
- Training is continually needed.
- Don’t reinvent the wheel. Use and re-use existing modeling infrastructure.
- Configuration Management (CM) and Data Management (DM) are obstacles for using MBSE for a larger or more dispersed group. A model management plan can help.

Suggested Future of MBSE

Strategic Vision

	Work to Date	Near Term	Longer Term	End State
Workforce	- Workforce focused evaluations - Ease of MBSE adoption understood - MBSE CoP(s) established - Lessons learned captured - Partnerships established - Training sources identified - APPEL training established (Basic SE and MBSE) - Basic guidance for getting started and on common problems	- Expand access to skilled modelers - Expand modeling skills - IT Support - Improve speed and quality of SE capability - Improve NASA mission response (do more) - Define implementation leadership authority	- MBSE and SE become "synonymous" - Computer has adopted science of SE - Human is fully focused on art of SE	- Digital Twins - Near instantaneous design cycles - Computer consults human for guidance
Process	- Aligns with NPR7120 & 7123, other NPRs, and NASA endorsed standards - Rigorous technical peer review - Workforce adoption ease validated - Focused MBSE/SE ROI validated - Over a dozen projects supported - External alignment interviews - Standards community participant - Partnerships with DoD, NIST, etc. - Model version control	- Formalize library of existing products to leverage - *Templates for model decomposition* - *Templates for model integration* - Model Management Guidance - *Model Management Handbook* - *MBSE Architecture Framework Handbook* - *Agreement on contract/DRD approach* - *MBE Acquisition Framework Handbook* - Incorporate DE, MA, and/or PM linkages	- Tech baseline is adjusted real-time - M&S reduces complexity overhead - Formulation and implementation bridged - More thorough trade space evaluation - History and M&S validate models and give decisions improved credibility - Validated models become data rich - Concept models become more accurate - Seamless data flow - Standards solidify from best practices	- **Seamless Data Availability** (AI and ML enabled) - SE Integrated with PM (Schedule and Cost) - SE Integrated with Eng. (Digital Twins) - MA easily monitors Eng w/o impacting schedule
Tools	- Enterprise Cloud established - Enterprise Magic Draw with SysML and parametric analysis plug-ins established - Numerous MBSE tools evaluated - Installation FAQ guide - Tool version control	- Expand enterprise cloud to serve larger engineering workforce - *Enterprise Cloud S/W tools expansion* - *Increase Magic Draw, plug-in, and other tool license access* - Incorporate SE data analytics around margins, test data, bounding conditions	- Data availability integration offers major impact - Incorporate richer visualization graphics for internal and stakeholder use - Data is authoritative source of truth - SE tooling becomes highly evolved - Human computer I/F more seamless	- Tools become a transparent agent - Human computer I/F seamless

Agency-wide MBSE Capability

Implement ***Project Adoption today*** while developing ***Enterprise Level Adoption for the future***.

	Project-level (Phase 1)	Enterprise-level (Phase 2)
Workforce	• MBSE-fluent users • Use on multi-center, multi-level, virtual, government and contractor teams • Agency, Center and Mission Directorate MBSE Leadership and CoPs	
Processes	• Project defines the model architecture and model management approach • Agency-wide best practices	• Agency-wide common model architectures and management approaches, based on NASA lines of business • Agency-wide standards
Tools and Infrastructure	• Seamless data approach for systems engineering across the project lifecycle • Seamless data approach for interactions with other disciplines • Host server and software for MBSE collaborative environment • Dedicated IT support personnel • Agency-wide common sets of tools for MBSE and other disciplines	
Strategy and Approach	• Tested and validated for project-level implementation (informs Enterprise)	• Tested and validated for NASA enterprise-level implementation

Change Process: Support the Workforce

- **Help grassroots help themselves**
  - Remove infrastructure, policy, and procedure roadblocks
  - Equal cross-center representation and collaboration is needed to keep MBSE valuable across the agency

- **Build connections** for the workforce
  - Within and across centers
  - Between SEs and MBSE practitioners
  - Between MBSE practitioners
  - Between workforce and management

*When in doubt…, **do what's best for the workforce**.*

Change Process: Small Team of Leaders

- One **senior, visible, respected leader** should
  - Reside within the funding organization
  - Have the **decision-making authority and resources**
- Other leaders can be matrixed; should represent diverse NASA communities

- All leaders need to be **bold and committed** to MBSE implementation
  - Ideally most should dedicate a significant portion of their time (~50%)
  - Positions need to be recognized as serious jobs

- **Today, tomorrow, and future leadership functions** keep the efforts focused on real problems, aligned across timeframes, and connected with real users

Remove roadblocks for the workforce

Capability: IT Infrastructure

- Converge on **MBSE collaborative environment** and associated server – partner with OCIO
  - Meet users and sponsors needs – Easy access, Data protection, Collaboration with non-NASA partners, Capacity for majority of workforce to use
    - Update to current tools – Including: Teamwork Cloud, Syndeia, OpenMBEE, MapleSoft, Cameo Collaborator, and many others
    - Easy and clear NAMS process – For licenses, project uploads and project access
    - Policies do not yet account for some needs – Most needs are technically possible
  - IT support
    - Readily available to assist projects and users with software implementation
    - Need transition to actual production implementation pilot testing
    - Modelers regularly advise on software and server needs
  - Capture and use lessons from OCE Cloud, XRISM Collaborative Environment, ISS, GRC, and others to fine tune next steps
- **Seamless data flow** – In the near term, continue using and developing scripts and plug-ins to access multiple, independent data centers, … influence grow COTS

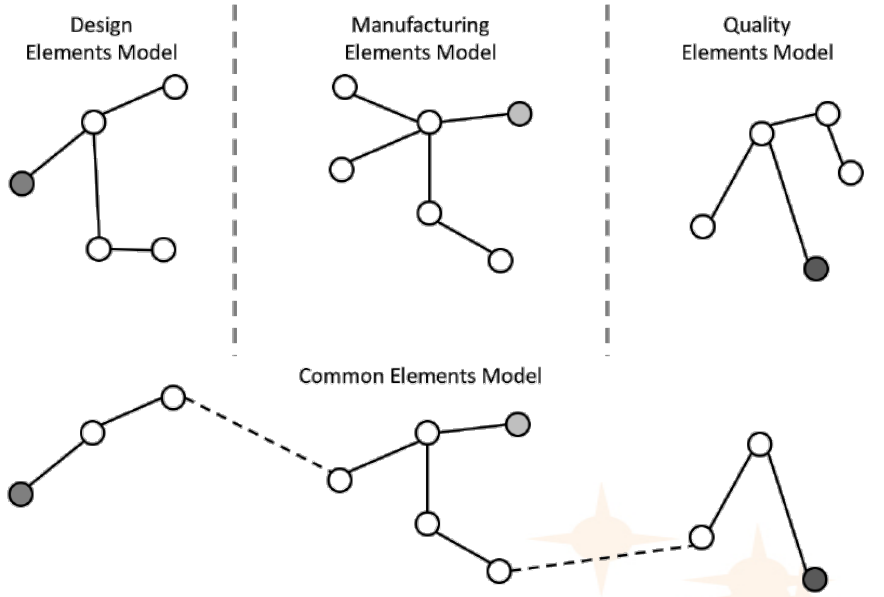
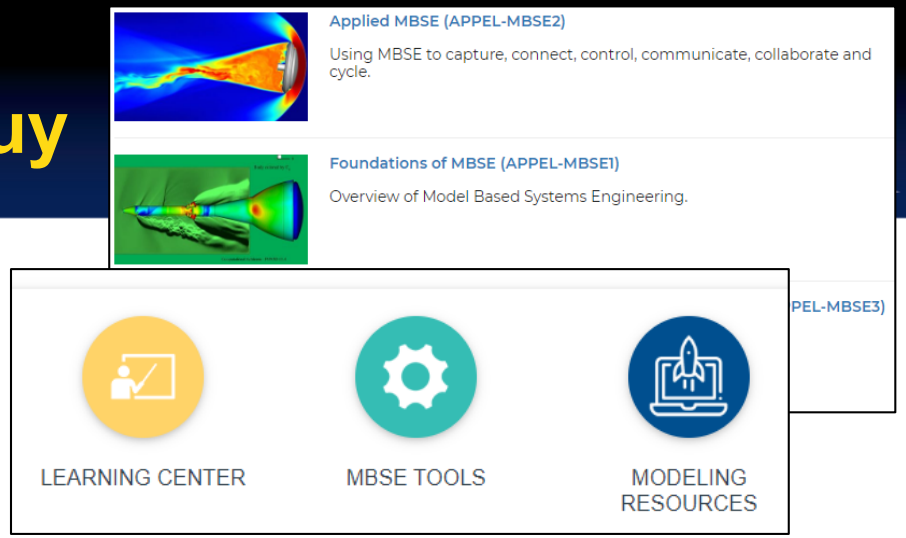


Fig. 3. Example Common Elements Model formed by linking domain-specific information models

Hedberg (NIST), et al., "Towards a Lifecycle Information Framework and Technology in Manufacturing," Journal of Computing and Information Science in Engineering, 2016

Capability: Workforce Skills – Make and Buy



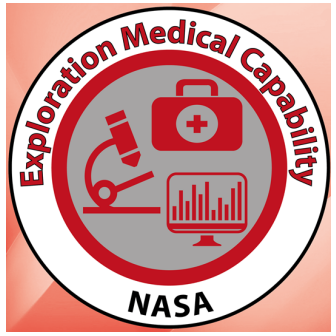
- **Make**
  - Need to make training available to meet workforce and project demand
    - Theory training – like APPEL's current training
    - Practice training – like Georgia Tech's SysML 101/201
  - Communities of Practice (CoPs)
    - Center and Mission Directorate groups should coordinate with and feed into the agency CoP
    - Center and Mission Directorate groups can focus on their specific use cases while the agency CoP looks at common needs
    - Capture and Consolidate best practices (for example: architecture frameworks, configuration and data mgt.)

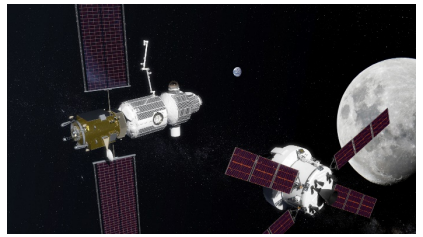
- **Buy** – ***Advice, On the Job Training , and direct modeling support have driven MBSE success***
  - NASA needs more bench depth of people (especially highly skilled ones) to build models
    - Provides surge capability
    - Provides OJT learning opportunities for in-house workforce
  - Desired Attributes
    - Early career and later career members
    - Modeling and scripting skills
  - Challenge is finding an Agency funding source,… money is only available in Projects and Mission Directorates.
    - Programs/projects should fund modelers (could be a common contract or a temporary contract).
    - Agency should decide the level of enterprise integration and sharing across programs/projects and Mission Directorates.

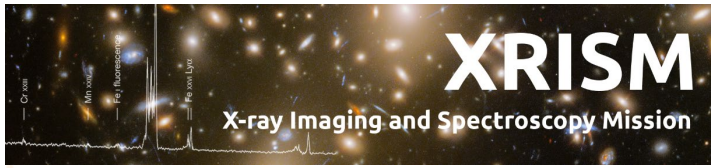
In both cases, work with:
- OCHCO to understand and recruit future staffing.
- OCKO to implement training.

Targeted Projects: Attributes

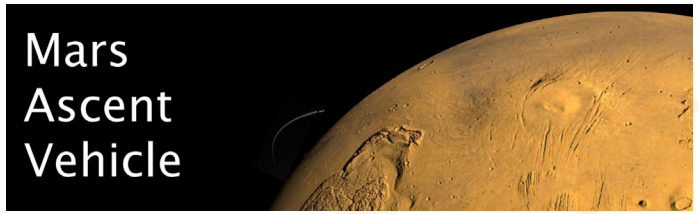
- Potential for **Success with MBSE**
  - ★ Significant, well-scoped problem
  - ★ Ability to meet clear success criteria using NASA MBSE capability
  - ★ Not significantly bought in to another method to solve their problem
    - Relationships with other groups
    - Communicative point(s) of contact
    - Resources to afford the capability







- Willingness to **Communicate Positively**
  - ★ Lead Systems Engineer interested in MBSE
    - Credibility with other engineers
    - Obvious next project



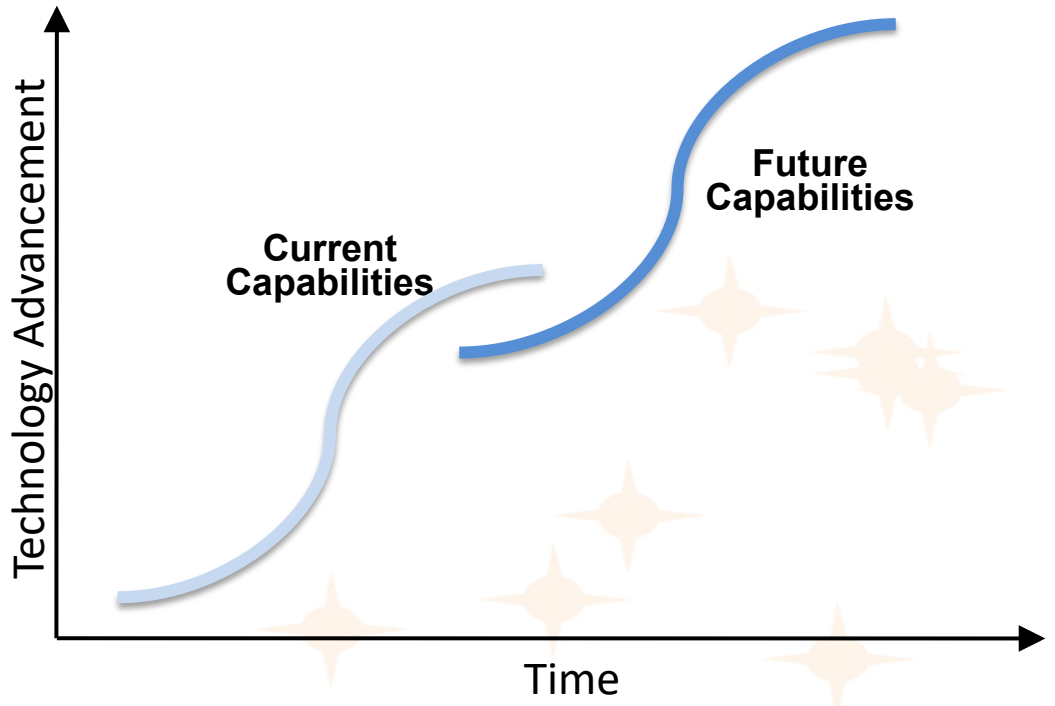
Technology and Methodology Evolution

- **Project Minimum Need** – pursue immediately
  - Seamless data flow – what is it and where is it needed… (PM, MA, Eng…?) for the longer-term investigate options with OCIO for enterprise level seamless data flow (inter-model and inter-IT).

- **Enterprise level** – implement in 3 to 5 years
  - Enterprise solution – What is the enterprise? What are the options?
  - Integration between SysML tools and between organizations
  - Integration with other disciplines – SMA, cost, other engineering disciplines, acquisition, etc.
  - Best practices evolve into standards?
- **Beyond SysML** – for both current implementation and future
  - SysML 2.0
  - Data centrism – right now we are model centric
  - Other tools – SysML based or not
  - Visualization
  - Enhanced systems analysis capabilities

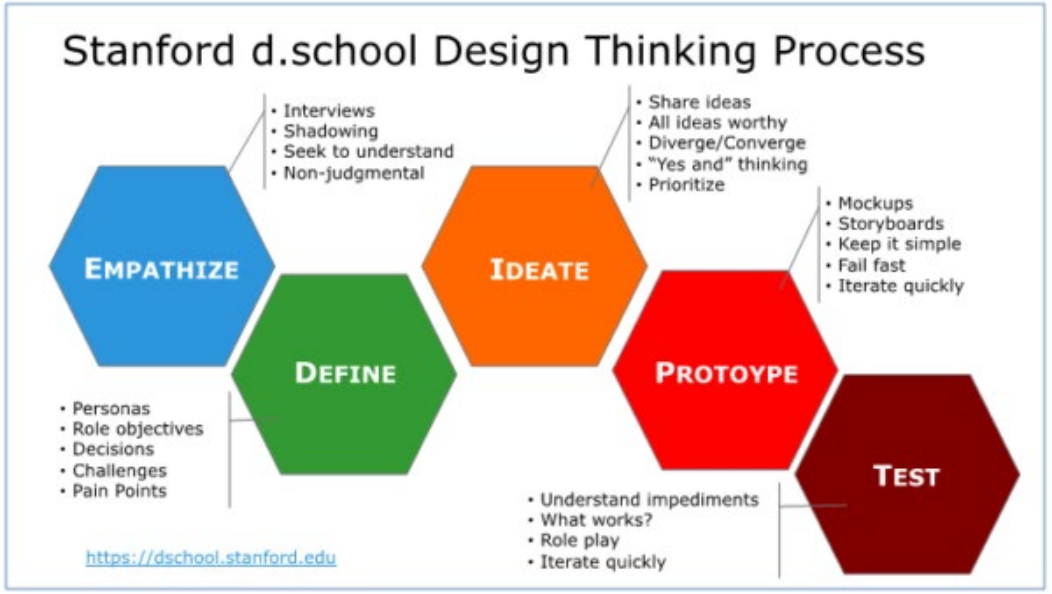
WYFIWYG!

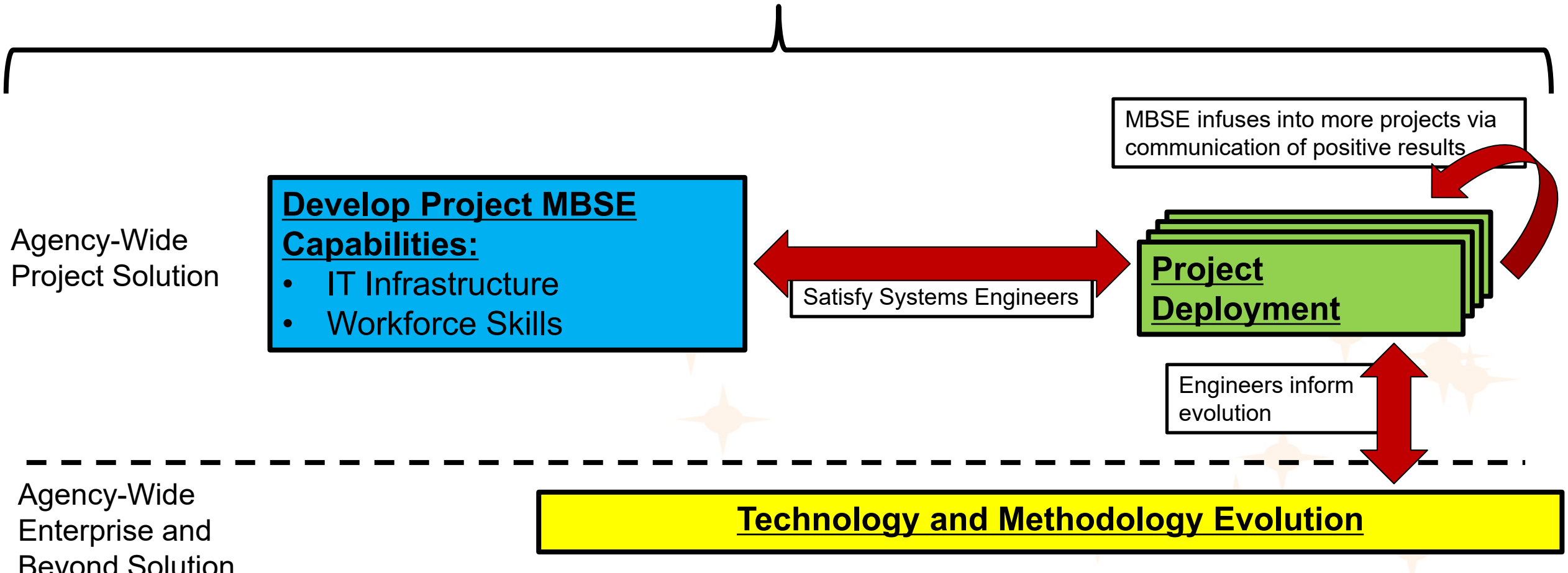
(What You Foresee Is What You Get!)



Change Process: Small Steps

- Acknowledge that we don't know enough to move ahead confidently
- Use **iterative small step** principles
  - Talk to current users to understand the why's and how's of what they're using – both inside and outside of NASA
  - Get a little bit and try it out
  - Assess and iterate or pivot
- **We are not alone** – Leverage and collaborate with interested partners like OCE, OSMA, OCIO, JAXA, ESA, DoD, NIST, and potentially others like Boeing, Ball Aerospace, and Blue Origin



Suggested Implementation Approach

Change Process: Dedicated Institutional Leadership Oversees Iterative, Incremental Growth