Orbital ATK

THINGWORX AS AN IOT DATA MANAGEMENT MODULE IN A ROCKET MOTOR MONITORING SYSTEM

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AGENDA

- ❑ Company Overview
- ❑ Motivation for Monitoring Rocket Motors
- ❑ Maintenance Approaches
- ❑ Prognostic Health Management
- ❑ Health Management System Development
- ❑ Conclusions

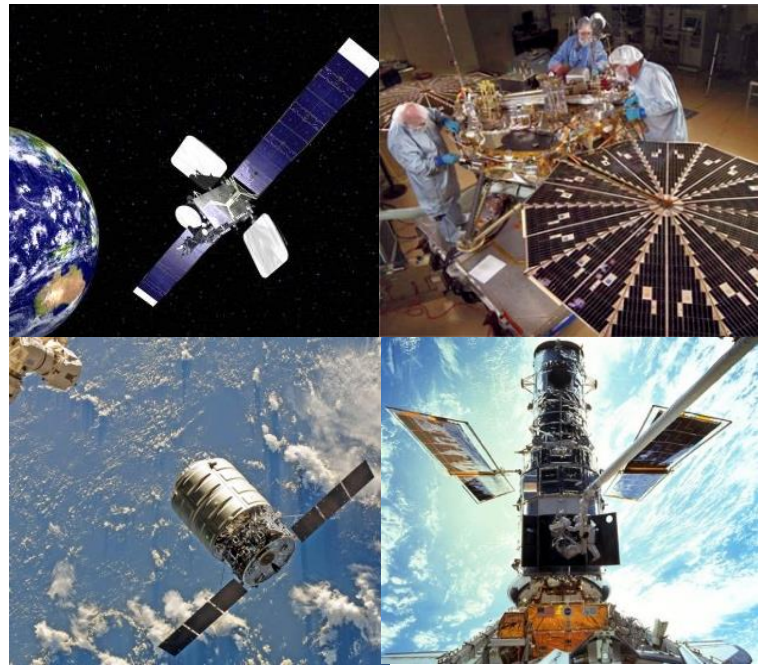
COMPANY OVERVIEW

- $4.5B Global Aerospace and Defense Systems Company
- Innovative, Affordable Products for Government and Commercial Customers
- 12,500 Employees, including 4,300 Engineers and Scientists
- R&D, Production, and Test Facilities in 17 States

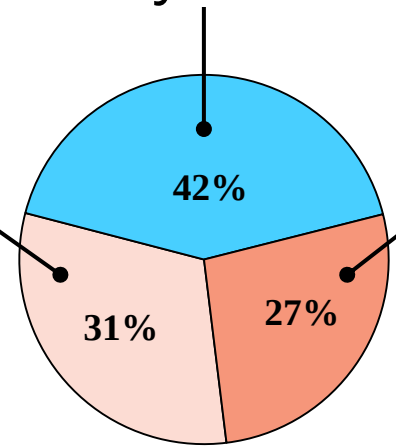
GROUP STRUCTURE

Flight Systems Group

Defense Systems Group



Space Systems Group



FLIGHT SYSTEMS GROUP

Small-Class Launch Vehicles

Medium-Class Launch Vehicles

Large-Class Launch Vehicle Propulsion Systems

Strategic Missile Propulsion Systems

Missile Defense Interceptors

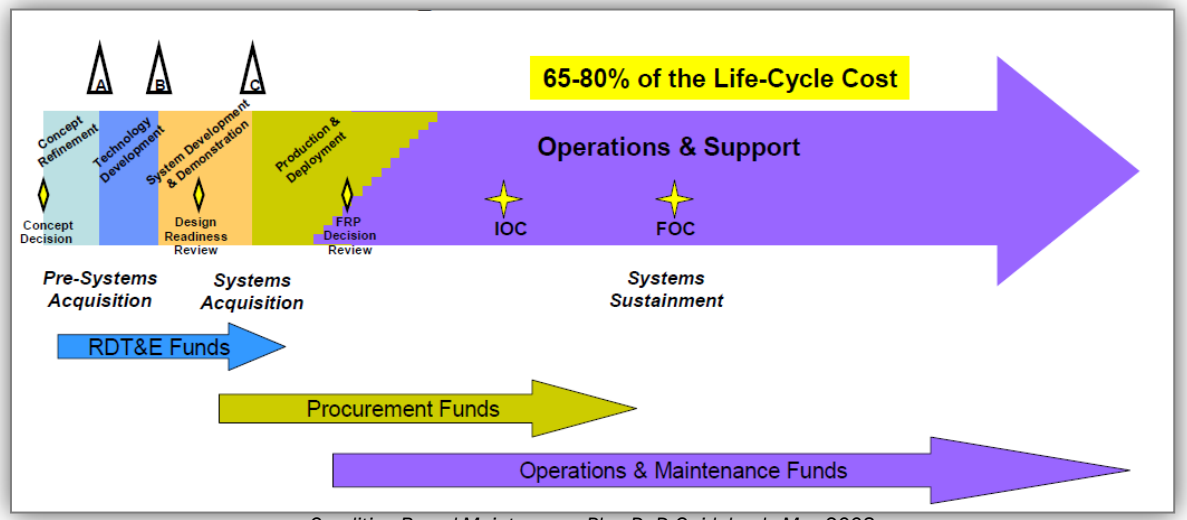
Suborbital Targets

Commercial Aerostructures

Military Aerostructures

THE PROBLEM

- Life-cycle costs dominated by operations and maintenance
- Small number of assets removed from fleet **destructively tested**
- **Empirical data** collected from assets predicts the fleet service life



Condition Based Maintenance Plus DoD Guidebook, May 2008

- **Large variance** in data yields **low confidence** and conservative estimates
- **Entire fleet replaced** when reliability is predicted to be too low
- No way to **identify "bad" assets** and remove from the fleet to increase fleet reliability

Large cost from possible early system replacement

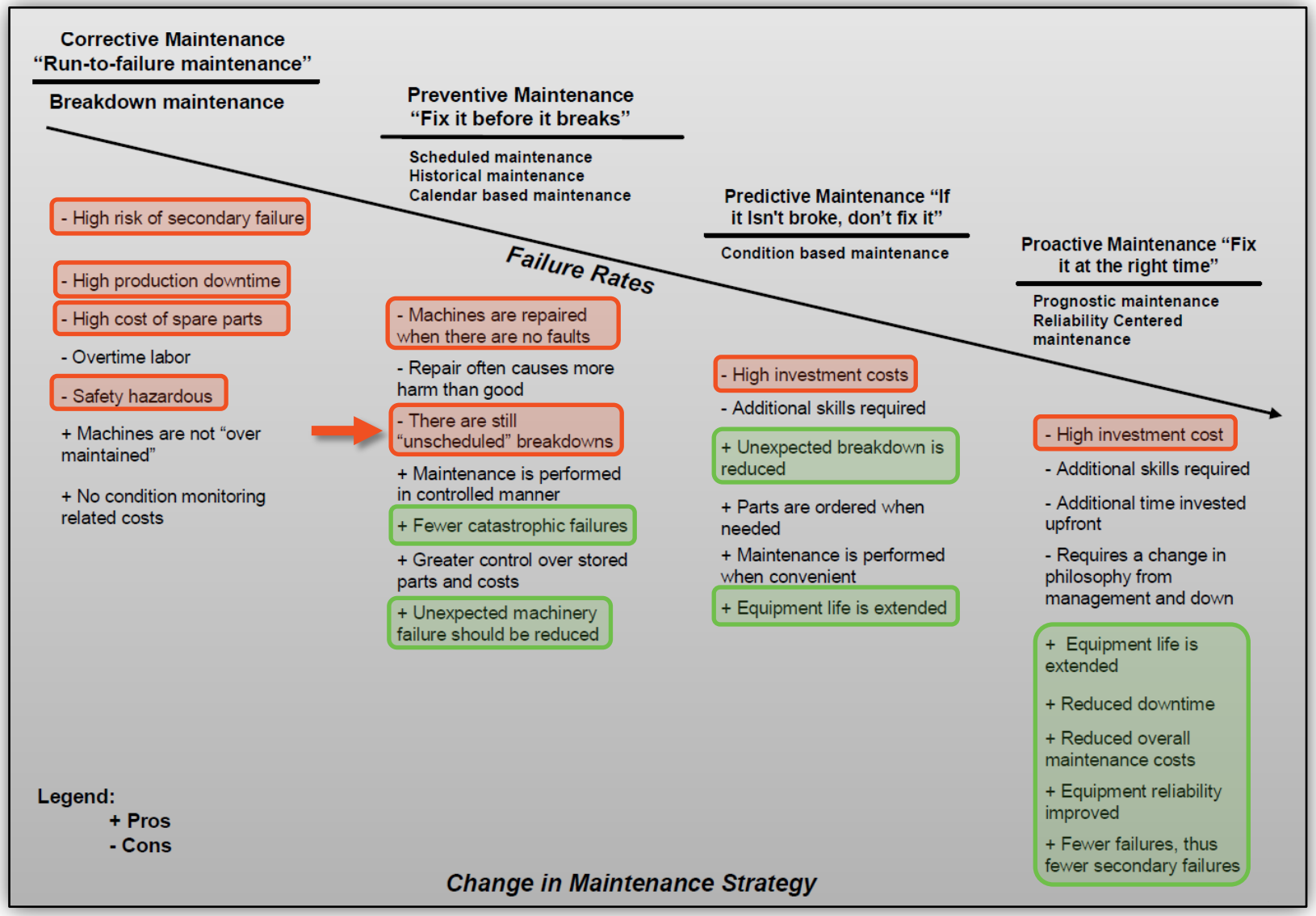
MAINTENANCE APPROACHES

Condition Based Maintenance Plus DoD Guidebook, May 2008

Maintenance Approaches				
Category	Reactive	Proactive		
Sub-Category	Run-to-fail	Preventive	Predictive	
When Scheduled	Fix when it breaks	Scheduled maintenance	Condition-based maint.-diagnostic	Condition-based maint.- prognostic
Why Scheduled	No scheduled maintenance	Maintenance based on a fixed time schedule for inspect, repair and overhaul	Maintenance based on current condition	Maintenance based on forecast of remaining equipment life
	N/A	Intolerable failure effect and it is possible to prevent the failure effect through a scheduled overhaul or replacement	Maintenance scheduled based on evidence of need	Maintenance need is projected as probable within mission time

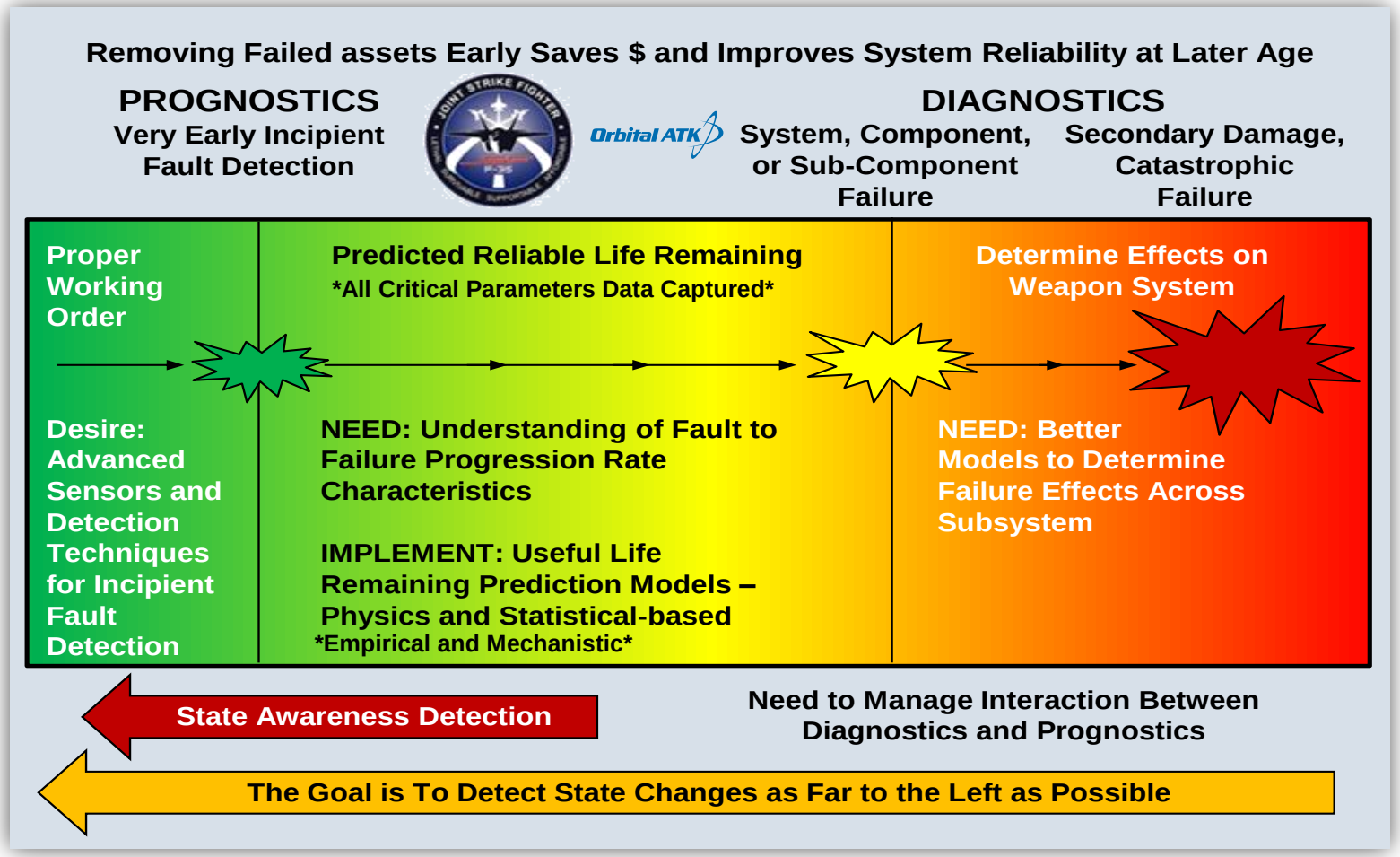
MAINTENANCE APPROACH BENEFITS

Condition Based Maintenance Plus DoD Guidebook, May 2008



PROGNOSTIC HEALTH MANAGEMENT

- PHM is required when:
  - System failure is unacceptable
  - System behavior changes
- System behavior changes driven by:
  - Cumulative physical damage
  - Material changes due to aging
  - Environment state changes
- Systematic Process is used to:
  - Determine required critical performance parameters
  - Capture relevant data to ascertain critical performance
  - Assess Model Viability

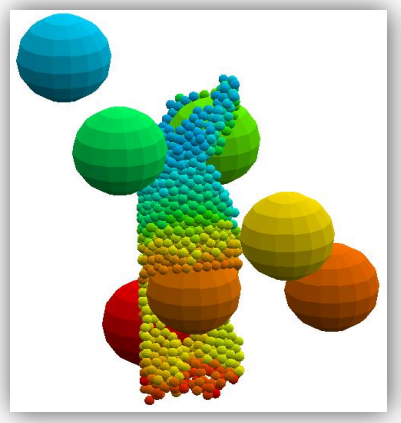


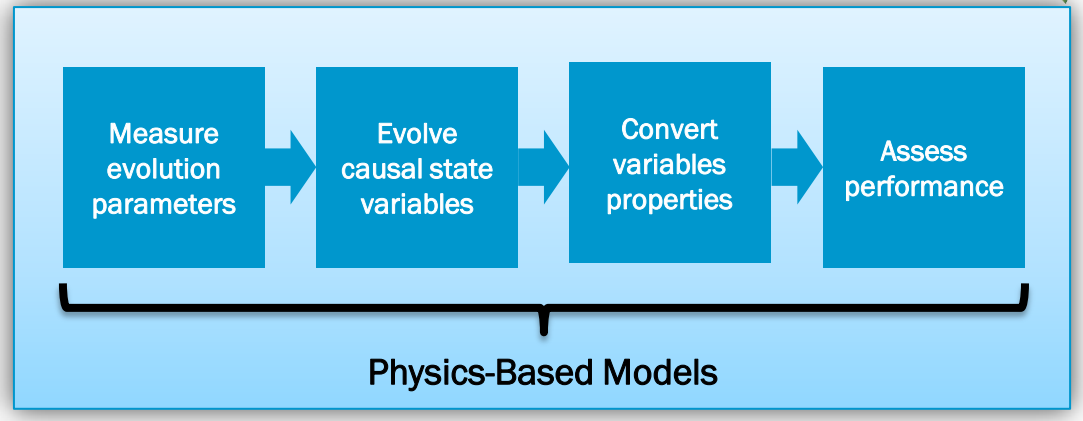
D.R. DeVries, "An Aerospace and Defense Company's PHM System Development Approach," IEEE Aerospace Conference, Big Sky MT, Mar 2016.
A. Hess, T Dabney, "Joint Strike Fighter PHM Vision," IEEE Aerospace Conference, Big Sky MT, Mar 2004.

Degradation is a process that leads to a failure event

PHYSICS-BASED MODELS

- Three groups of mechanistic physics-based models
  - **Evolution** - How do state variables evolve with time?
  - **Conversion** - How are state variables converted to properties?
  - **Performance Assessment** - How will the asset operate with a given set of properties?

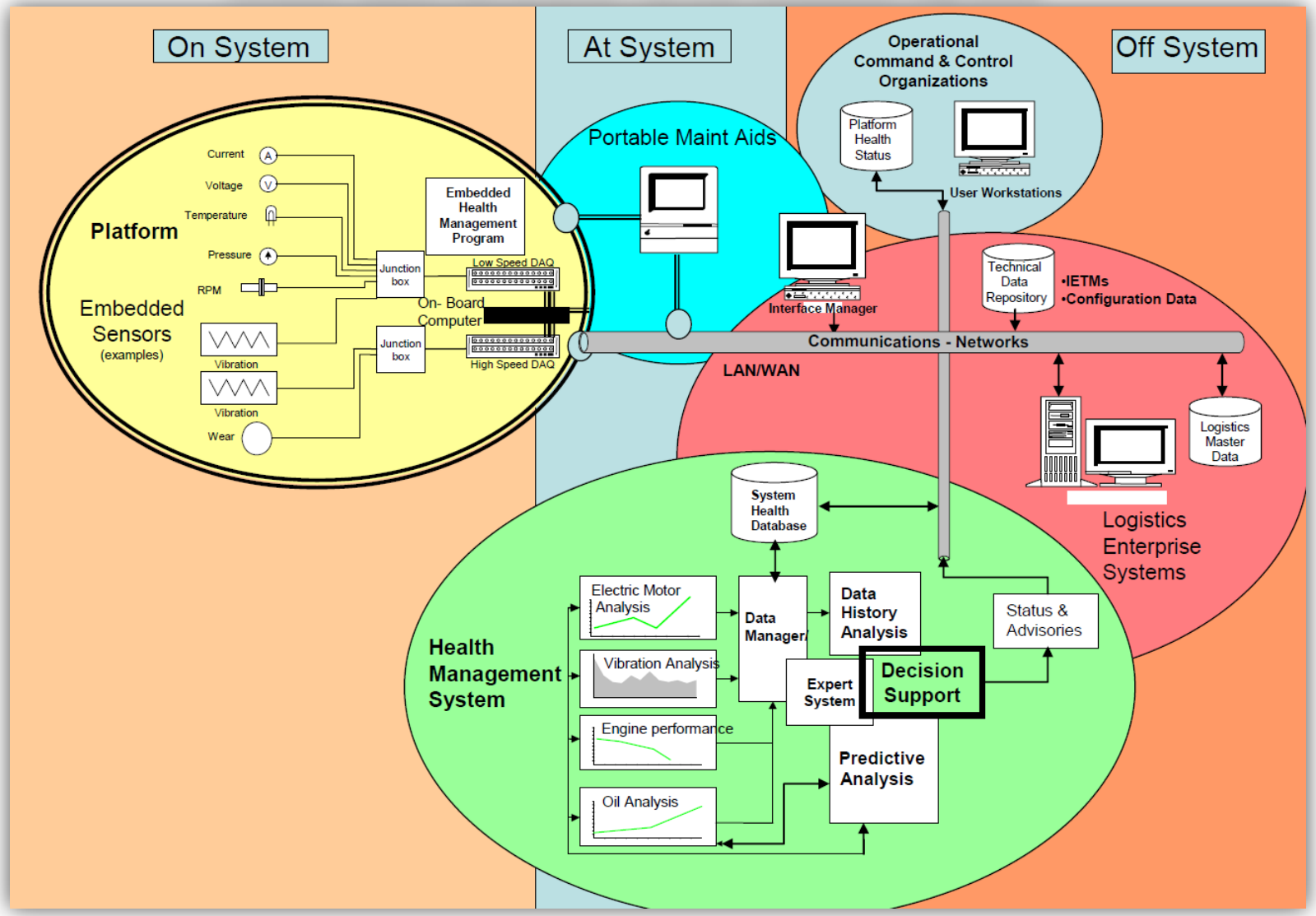




- **Initial Condition**
  - Concrete has varying sizes of particles (sand, gravel, etc.)
- **Evolution**
  - Cement bonding agent ages and degrades chemically and physically with time
- **Conversion**
  - State of particles and bonding agent can be used to calculate strength of the concrete
- **Performance Assessment**
  - Strength of the concrete can be used to predict the performance and/or failure probability of concrete under load

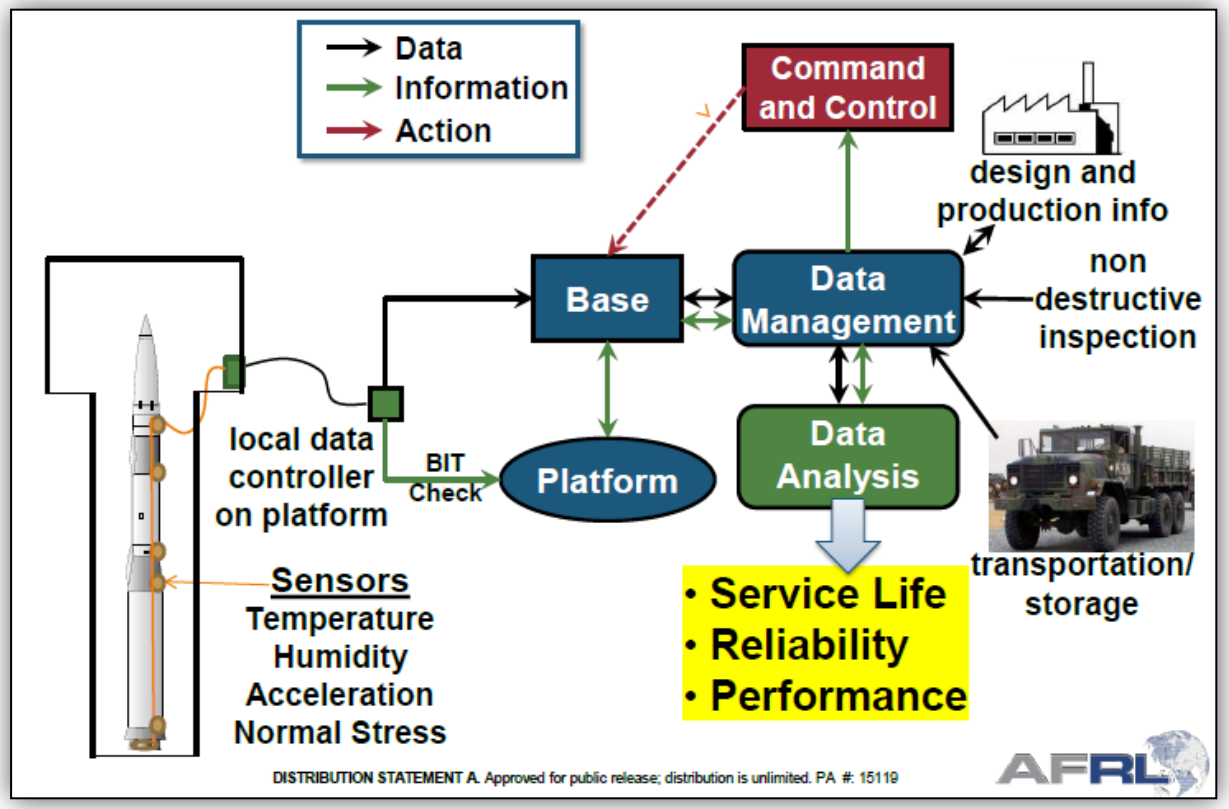
CBM ARCHITECTURE

Condition Based Maintenance Plus DoD Guidebook, May 2008



DEVELOPED MOTOR MONITORING SYSTEM

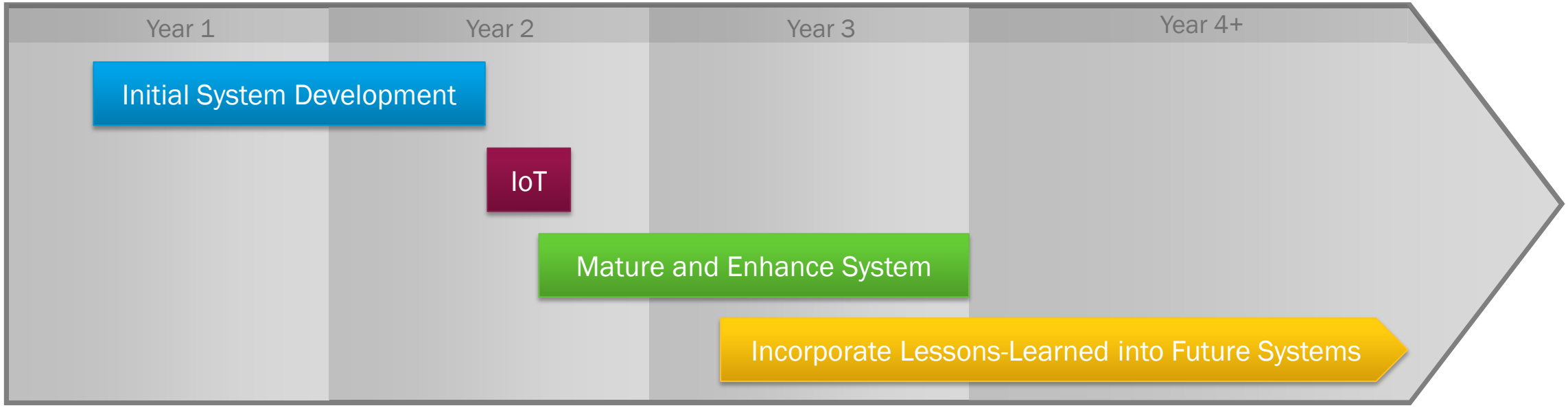
- Integrated Motor Life Management, Data Acquisition, and Analysis System (IMLM DAAS)
- Air Force Research Laboratory Program
- Develop a system to predict ability of a specific motor to perform its mission



E. Weber, Air Force Research Laboratory, Motor Aging and Surveillance Technology (MAST) Call 2 Industry Day, Mar 2015.

MATURING DEVELOPED SYSTEMS

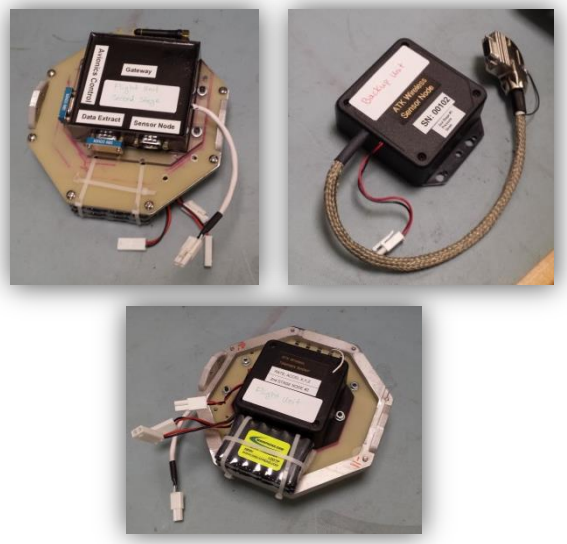
- Series of internal development and demonstration programs
- Evaluate new technologies
- Augment the IMLM DAAS system
- Enable system use on future programs



TECHNOLOGY DEMONSTRATION SYSTEM

Build → Install → Launch → Learn

System Hardware



Rocket Payload

NASA MSFC
Nano Launch Rocket

L. Watson-Morgan, "Nano Launch 1200: MSFC's Role and Vision for Small Launch Vehicles". 16th Annual Space & Missile Defense Symposium, Aug 2013.

Nano Launch Flight Test

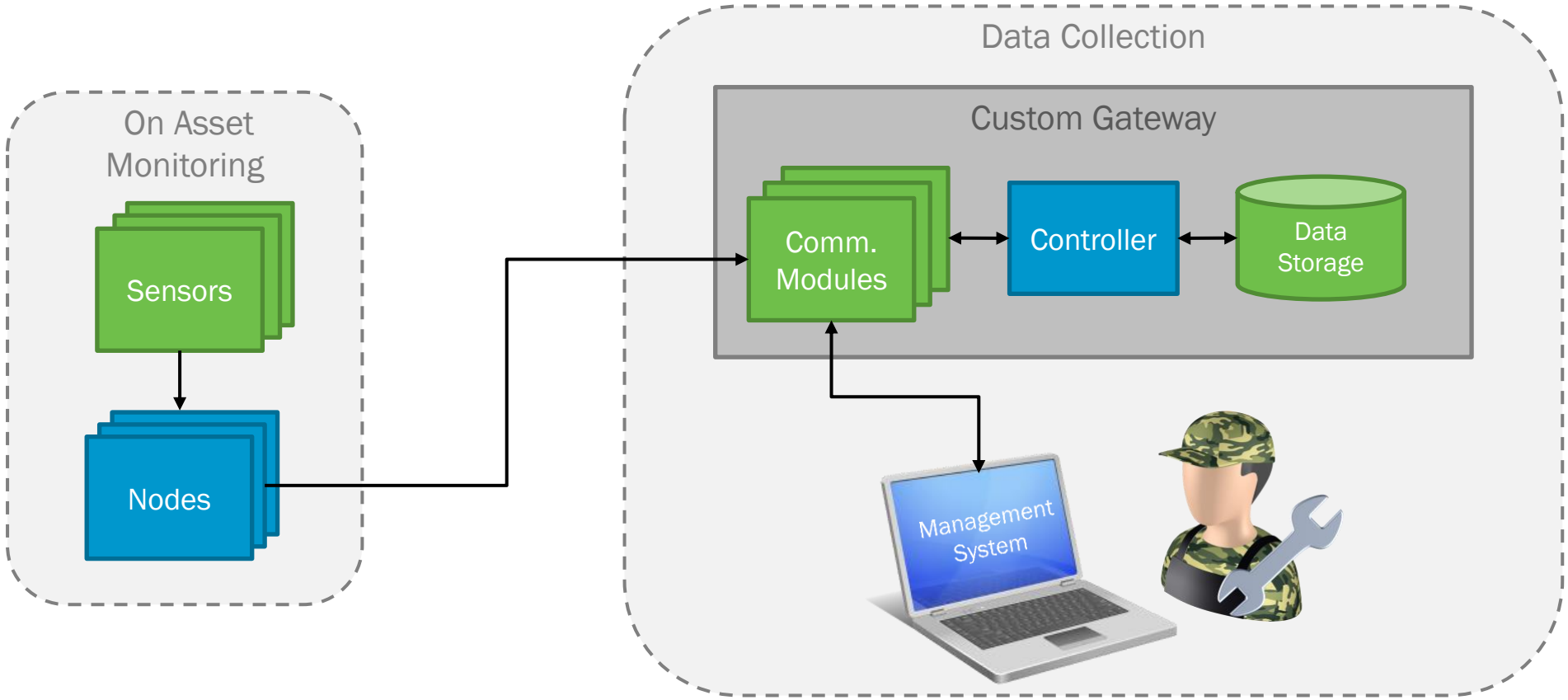
L. Harris, "NanoLaunch Project". 17th Annual Space and Missile Defense Symposium, Aug 2014.

Space Launch System

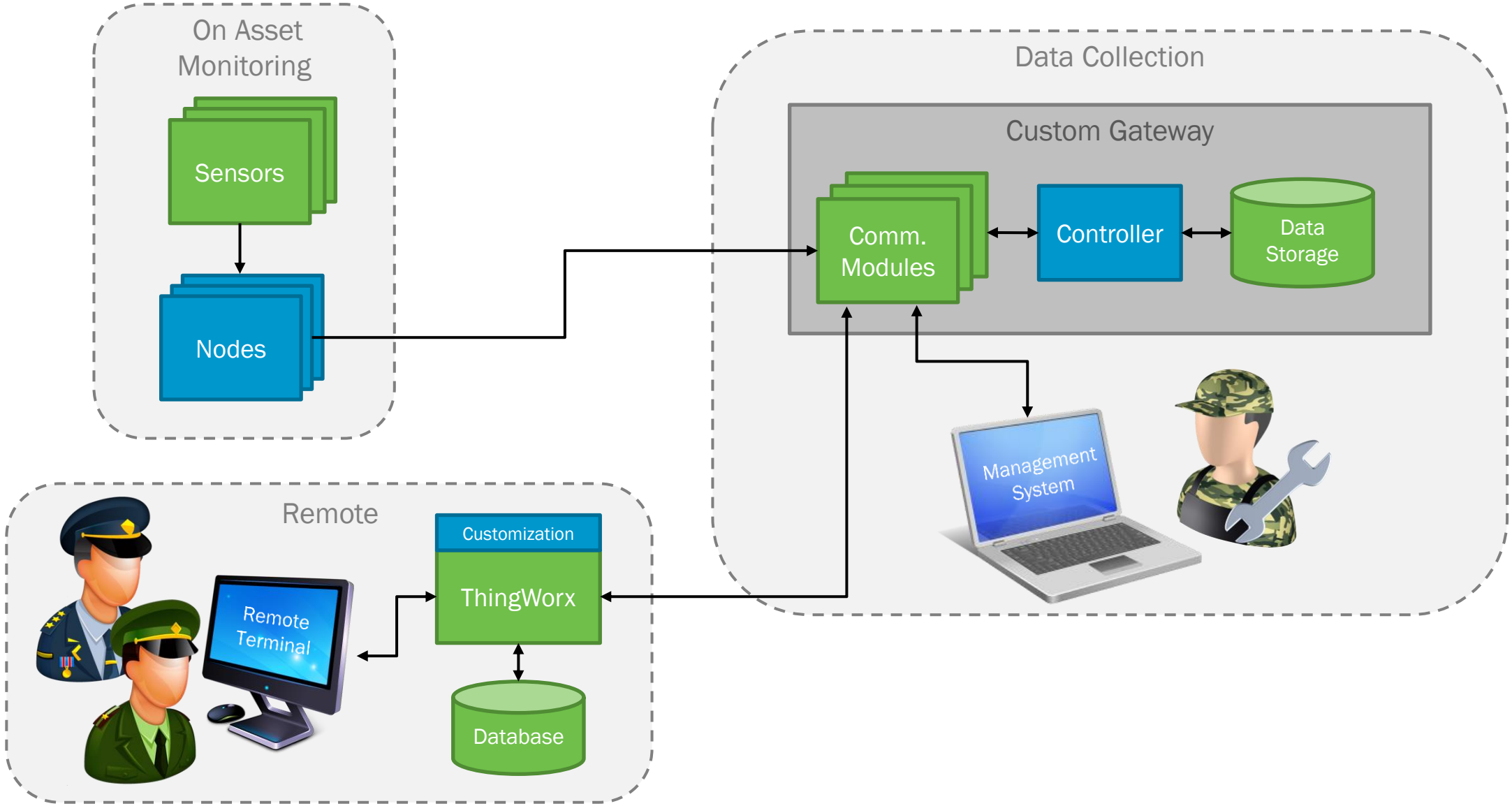
Minute Man

Trident

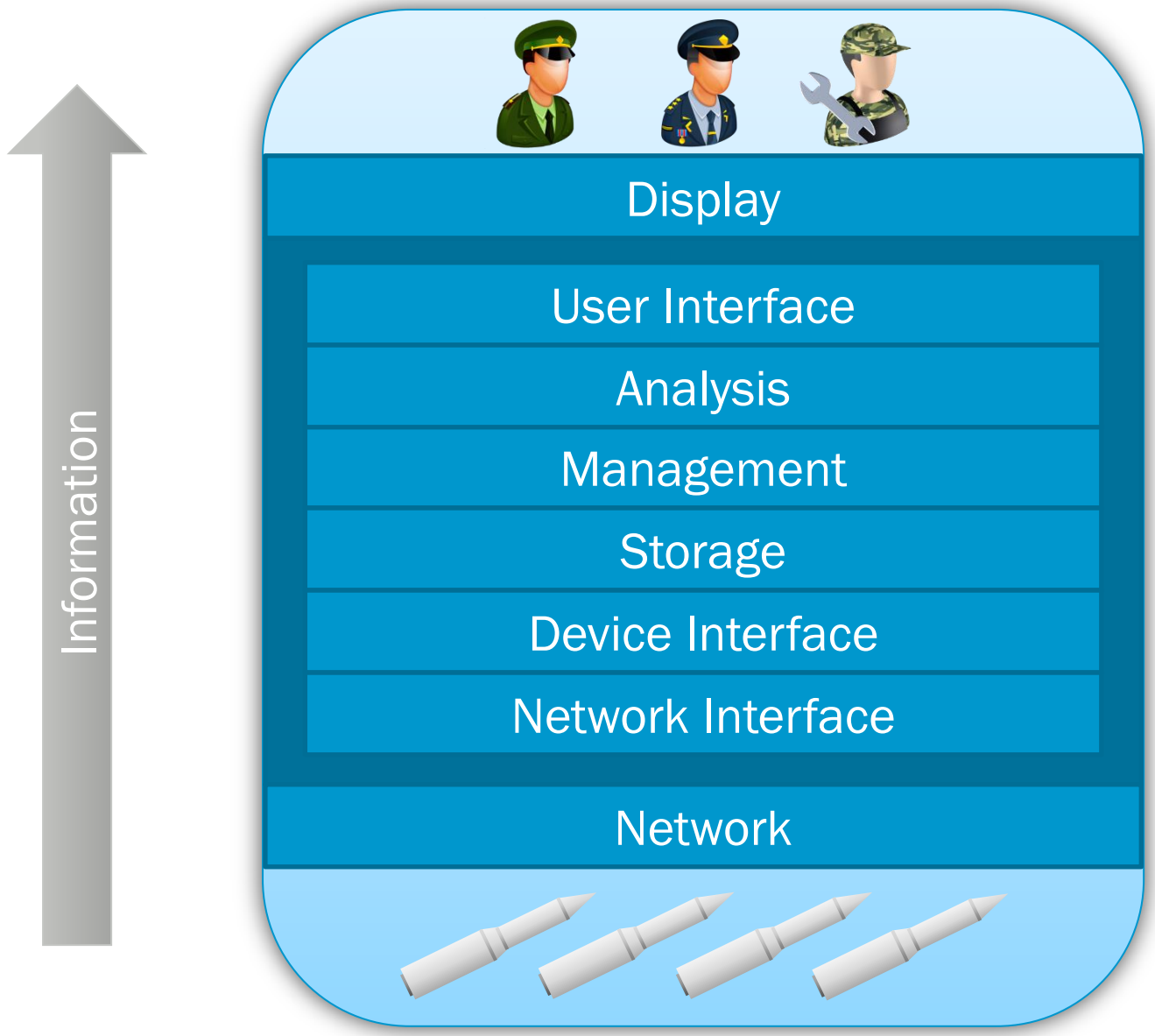
TECHNOLOGY DEMONSTRATION SYSTEM



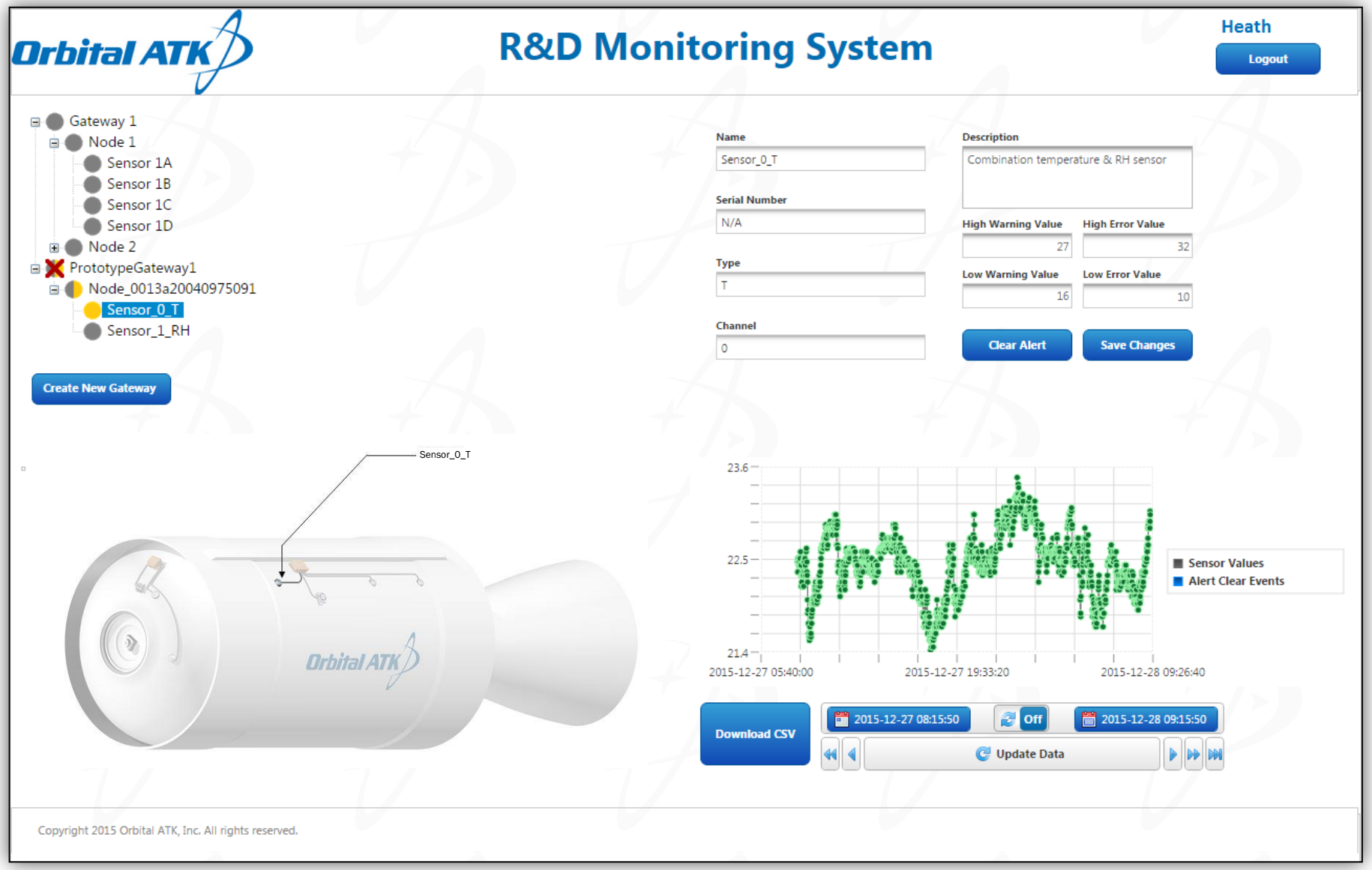
TECHNOLOGY DEMONSTRATION SYSTEM WITH THINGWORX



IOT TECHNOLOGY STACK



USER INTERFACE



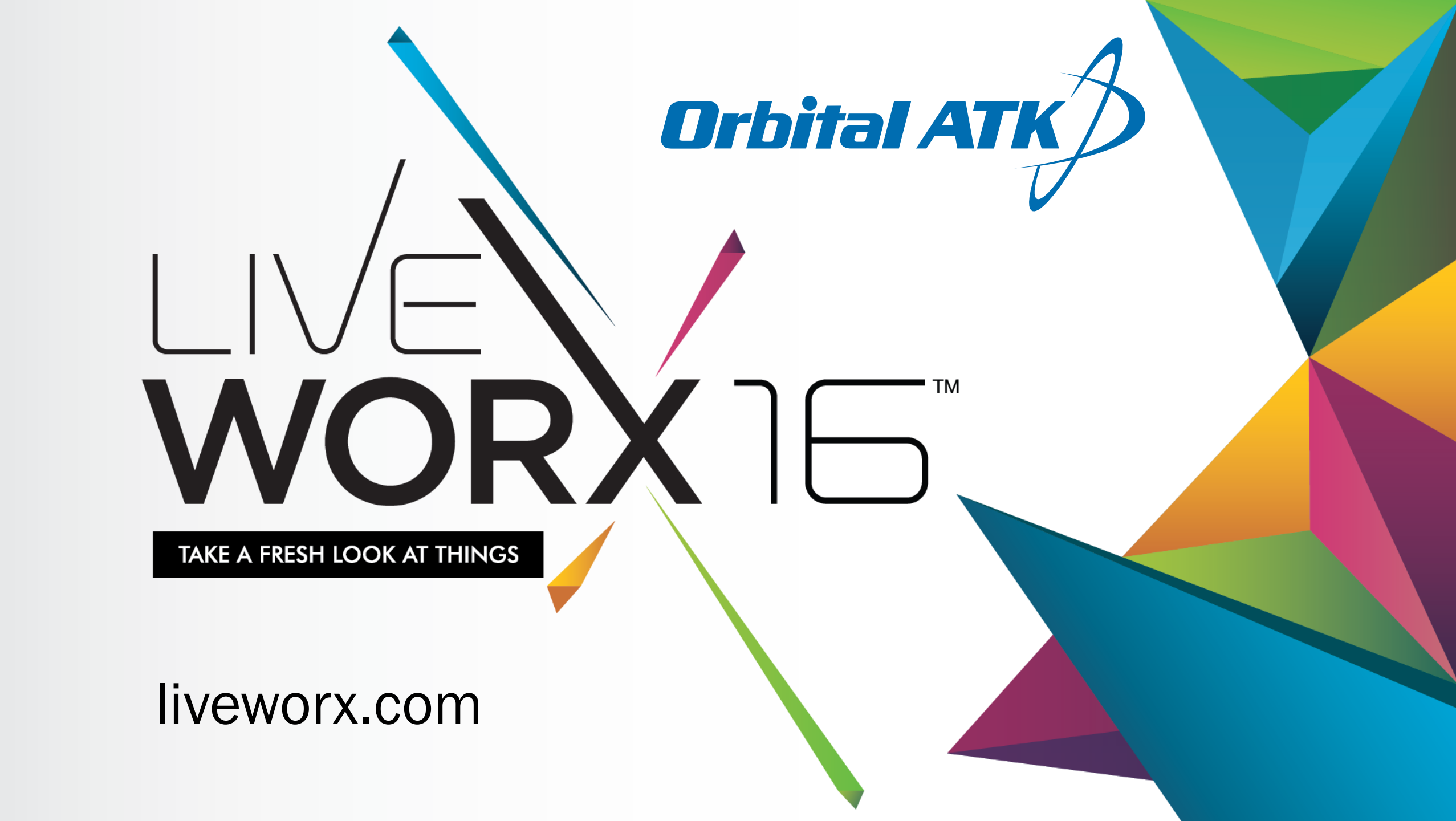
WHY USE COTS TOOLS?

- Development time of connectivity and interface
  - IMLM DAAS took > 1 year
  - Technology demonstration system took < 1 month
- Maturity
  - Products are well vetted by users
  - SIL test may be more focused to application
- Maintenance
  - Good support system for development and initial fielding cycle
- Security
  - Experience base to leverage during development
- Predictable life-cycle costs
  - Licensing costs are relatively constant
  - Required staffing levels are relatively constant

- Additional Costs
  - Licensing costs can be significant over the lifetime of a fleet of assets
  - Version certification and control costs
- Sustainability Risks
  - Significant risk if licensing lapses during life-cycle
  - Maintenance and sustainability limited to commercial product viability
- Security
  - Introduction of new vulnerabilities

CONCLUSIONS

- **Use prognostic health management where appropriate**
  - Maximize reliability, minimize operation and maintenance costs
  - Requires significant up-front investment in constructing the models
  - Required when failure is not an option
- **Design open architecture and modular systems**
  - Upgradable throughout lifecycle
  - Define a process for control and assessment before implementation
    - Rollout with complete confidence vs. rollout to find issues
- **Stay abreast of new technologies**
  - The IoT industry is changing rapidly
  - Reevaluate both new and legacy systems with the latest technologies
- **Utilize COTS solutions where appropriate**
  - Perform cost and risk trade studies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