Advanced Modeling, Simulation and Analysis (AMSA) Capability Roadmap Progress Review

Erik Antonsson

Tamas Gombosi

April 5, 2005

Agenda

Advanced Planning & Integration Office

Time	Topic	Speaker
7:30	Continental Breakfast	
8:00	Welcome and Review Process, Panel Chair & NRC Staff	
8:15	NASA Capability Roadmap Activity	Jan Aikins, NASA
8:30	14.0 Advanced Modeling, Simulation, and Analysis Overview	Erik Antonsson, JPL
	-Sub-Team Presentations-	
9:15	14.1 Scientific Modeling and Simulation	Tamas Gombosi, U. Mich
9:45	14.2 Operations Modeling	Ron Fuchs, Boeing
	– Break –	
10:45	14.3 Multi-Spectral Sensing (UV-Gamma)	Mike Lieber, Ball Aerospace
11:15	14.4 System Integration	Walt Brooks, NASA
	– Lunch –	
12:45	14.5 M&S Environments and Infrastructure	Mark Gersh, LMC
1:15	Co-Chair Summary	Tamas Gombosi, U. Mich
	– Break –	
2:15	Open Discussion	NRC Panel

Capability Roadmap Team

Co-Chairs

NASA: Erik Antonsson, JPL
External: Tamas Gombosi, University of Michigan

Team Members

Government

Walt Brooks, NASA
Dave Bader, LLNL
Tsengdar Lee, NASA
Steve Meacham, NSF
Charles Norton, JPL
Carl Peterson, Sandia
Ricky Rood, NASA
Tom Zang, NASA

Industry

Karen Fucik, NGC
Ron Fuchs, Boeing
Mark Gersh, Lockheed-Martin
Mike Lieber, Ball
Irene Qualters, Merck

Academia

Dan Reed U. N. Carolina
John Rundle, UC Davis
Quentin Stout, U. Mich.

Coordinators

Directorate: Harley Thronson, SMD
APIO: Janice Aikins, ARC

Cross-team Coordinators

Systems Engineering CRM: S. Prusha, JPL
Nanotechnology CRM: P. Von Allmen, JPL

What is this all about?

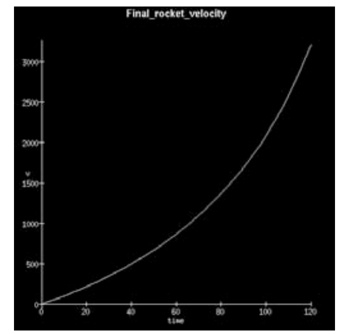
To provide the capability for <u>scientists</u> and <u>engineers</u> and <u>program managers</u> to work together in a virtual environment, using simulation to model the complete system of

phenomenology/ observations/ hardware system/ operations/ data system and analysis

before commitments are made to conduct particular missions or produce physical products

Terminology

What does ‘modeling’ mean ?

Real world behavior	Analytical model of real behavior	Numerical ‘model’ of analytical model	‘Model’ of performance
	$U_f = V_{ex} \ln (M_i / M_f) + U_i$	$U_i = 0$ V_{ex} =4000 Mi = 1000 Δo 1 ΔU_n = VEX*$\Delta M/M_n$ $M_{n+1} = M_n - \Delta M$ 1 END	
	Physicist	*(1) Numerical analyst/* *(2) Project engineer*	*Project manager*

Answer: It depends on your experience/ background

Lesson 1: We must always check our semantics when we talk across disciplines

Capability Description

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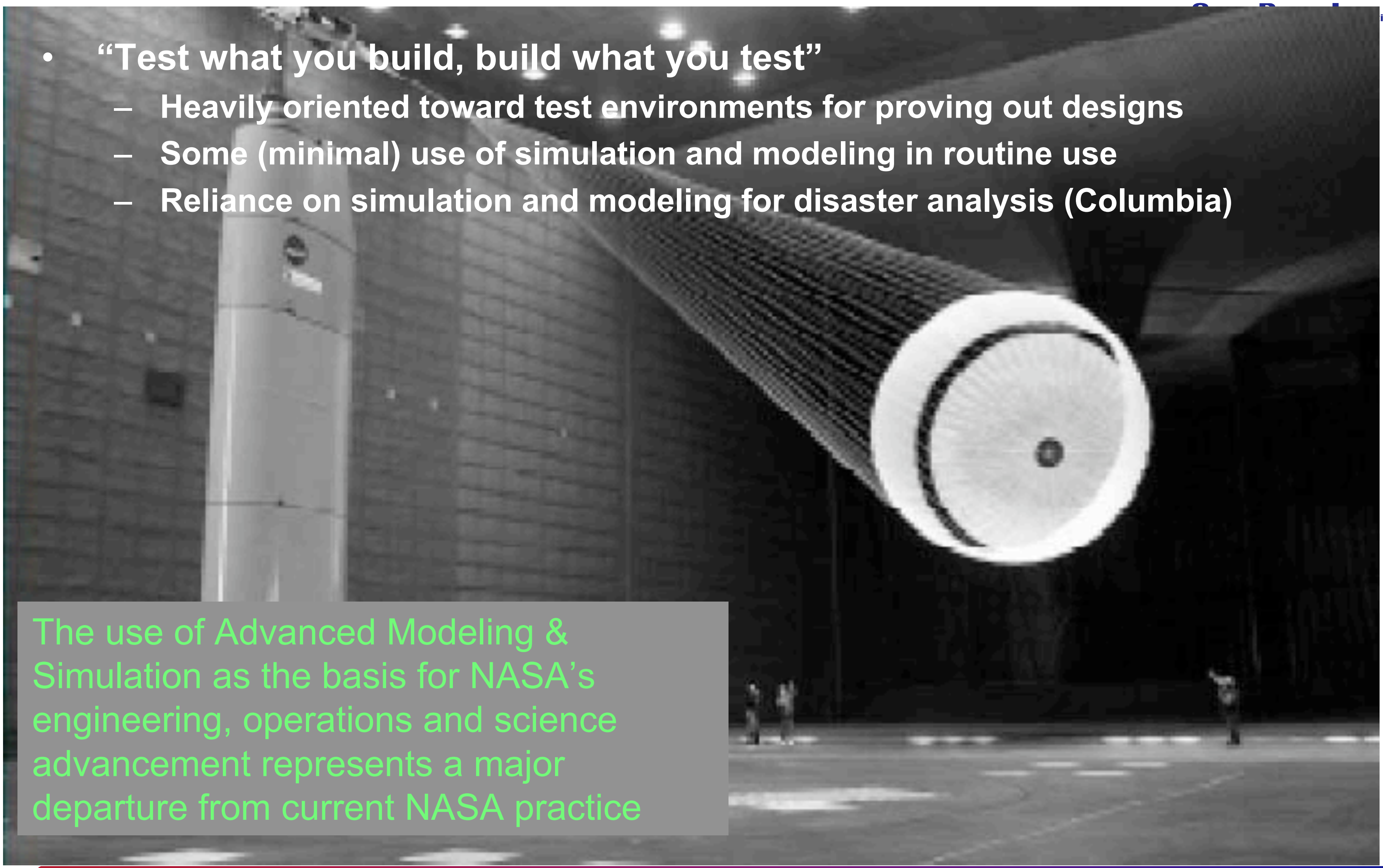
- The AMSA roadmaps include capabilities in Science modeling, Engineering modeling for Mission development, Operations modeling and Science Data analysis.
- Drivers for these roadmaps
  - The Vision for Space Exploration
  - The New Age of Exploration: NASA Strategic Objectives for 2005 and Beyond
  - A Journey to Inspire, Innovate, and Discover: President's Commission Report
  - Design Reference Missions
- These roadmaps present a new future technical paradigm for NASA
  - Invert [experiment primary / analysis and simulation secondary] relationship throughout NASA business
  - Focus on end-to-end systems modeling for increased efficiency
  - Provide viable approach to allow NASA to field aggressive new missions
- Roadmaps build on existing limited demonstration of capabilities
  - SIM use of IMOS
  - Earth Science Modeling Framework
  - Space Weather Modeling Framework

Current NASA Development Approach



- "Test what you build, build what you test"
  - Heavily oriented toward test environments for proving out designs
  - Some (minimal) use of simulation and modeling in routine use
  - Reliance on simulation and modeling for disaster analysis (Columbia)

The use of Advanced Modeling & Simulation as the basis for NASA's engineering, operations and science advancement represents a major departure from current NASA practice

Some Specific Examples

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- Engineering
  - Systems level (multidisciplinary) analysis is performed in early studies (pre-phase A / phase A)
    - Characterized by GSFC-IMDC, JPL-Team X, JPL-Team I
    - Based on table lookup, simple models
    - Point design
    - Exclusive of real technology input
  - Detailed design
    - Integration limited to COTS packages (e.g., TeamCenter)
    - IMOS (Integrated Modeling of Optical Systems) used widely within NASA
    - Virtually no handoff from Preliminary design
    - No link to operations
    - No feedback of engineering data for model validation
- Science
  - Some experimental coupling between Ocean Circulation and Atmospheric modeling
  - Coupling of the Sun, corona, energetic particles, heliosphere, magnetosphere and ionosphere
  - Some experiments with data assimilation in weather modeling

Project Characteristics -- Current Practice --

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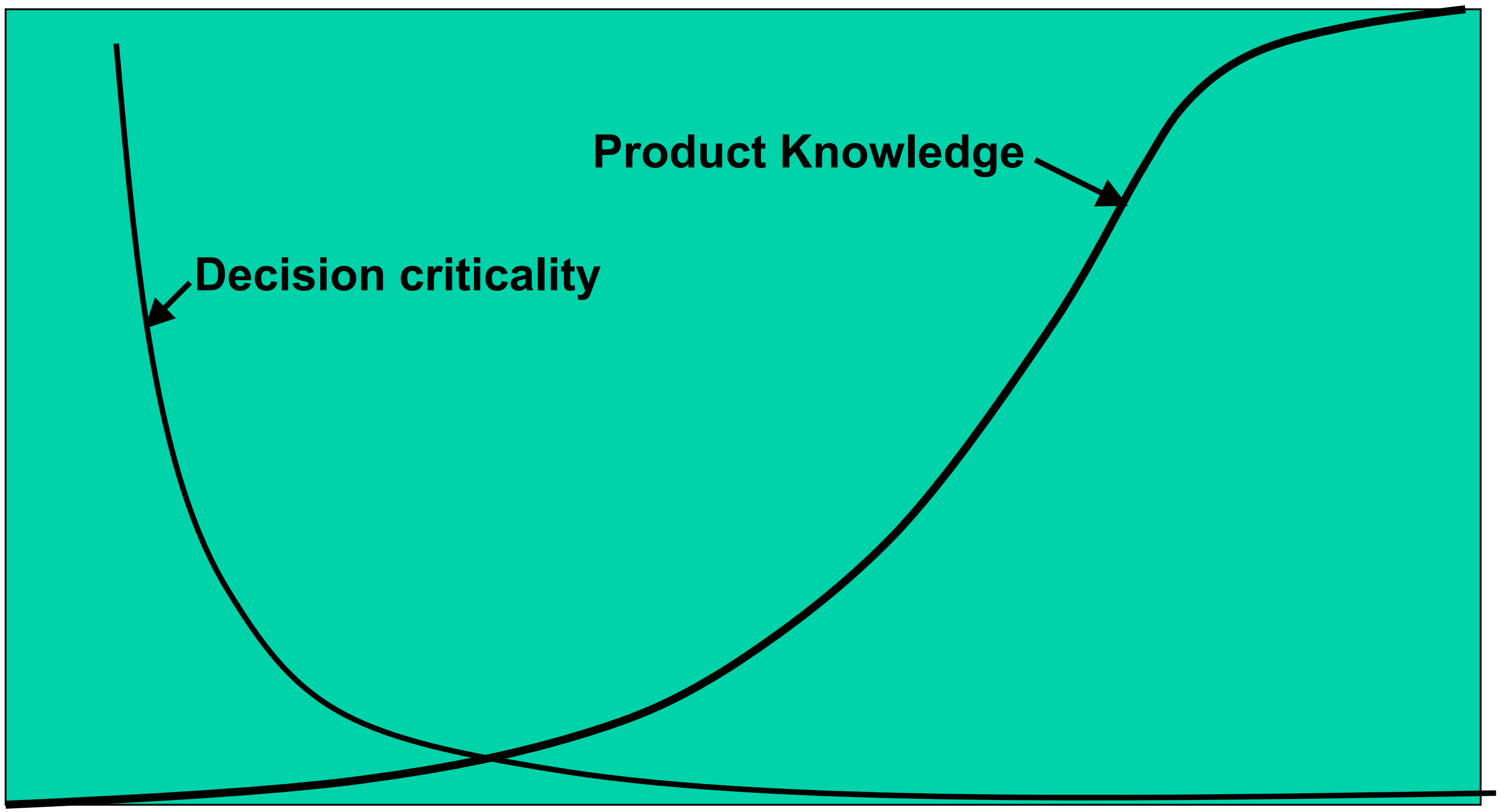

Studies Pre-project Ph A PhB Ph C/D Ph E

So what? What's wrong with this situation?

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- NASA current approach is at the limit of fulfilling system design demands. Evidence:
  - Shuttle failures were not anticipated and were poorly understood until after disasters
  - Missions such as SIM (Space Interferometry Mission)
    - System performance requirements are EXTREME
    - Project has already recognized need for reliance on modeling
- Future missions, even more demanding, require simulation
  - Large apertures that cannot be deployed or tested in 1g
  - Ultra stable platforms requiring precision formation flying that cannot be tested except in space
  - Assessments of instrument performance from highly demanding vantage points (eg, earth from L1, L2) that cannot be tested except in space
  - Complex, inter-dependent systems of systems for missions such as human exploration of Mars

Resolution

- **Expand and complete an AMSA-based systems approach to science & discovery, engineering design, hardware development and mission operations**
  - **Such an approach has already demonstrated in pockets within NASA**
  - **Testing still plays an important role, but the use of Modeling and Simulation creates a *predictive capability* that NASA's test-based approach can never provide**

- **Follow the lead of private aerospace companies and other Federal Agencies in moving to simulation-based systems development**

Project Characteristics
-- Desired Change --

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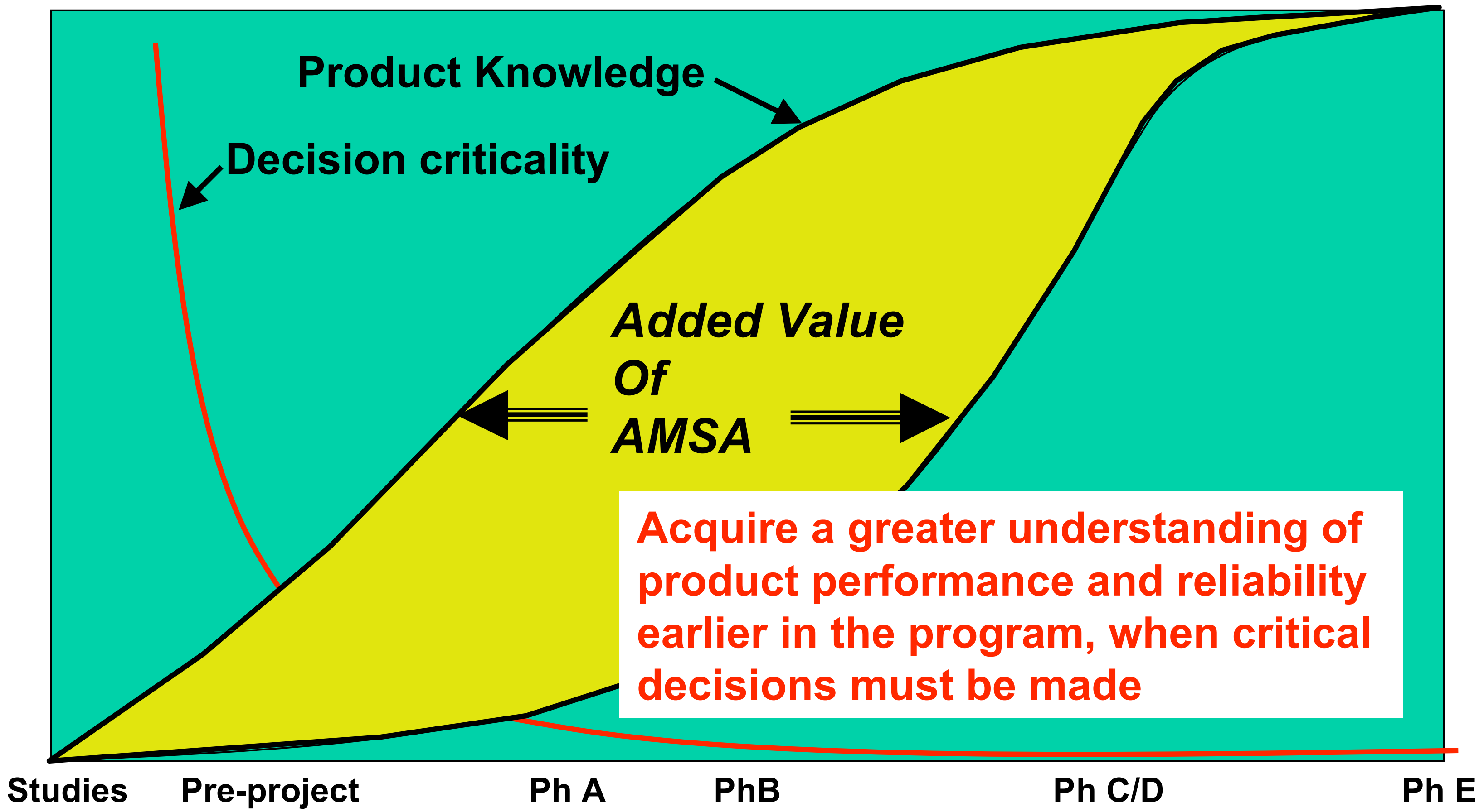
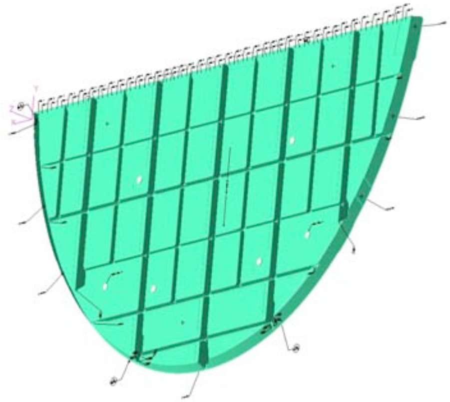
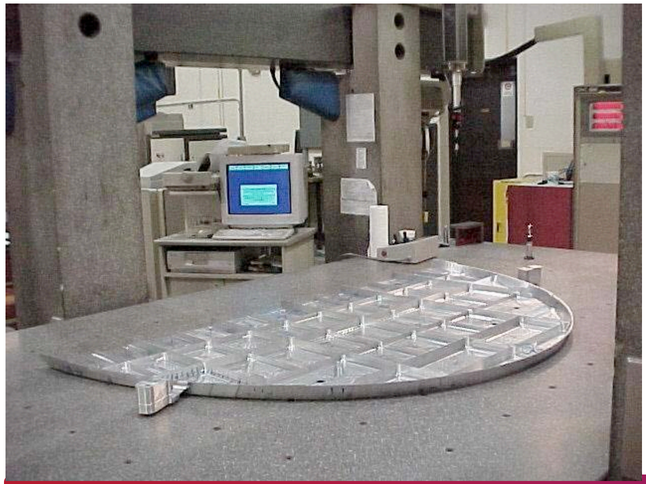


Acquire a greater understanding of product performance and reliability earlier in the program, when critical decisions must be made

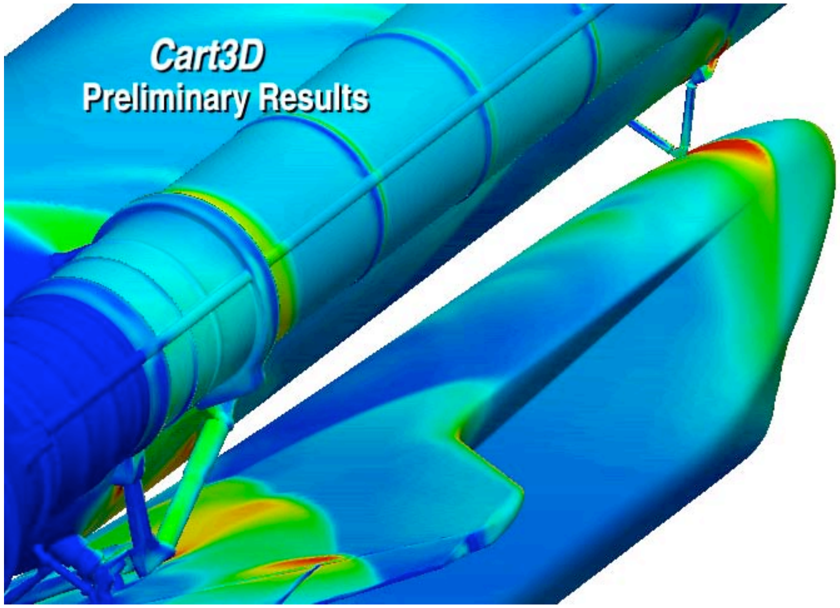
Specific examples

Boeing: Seeing and working with reality before it exists

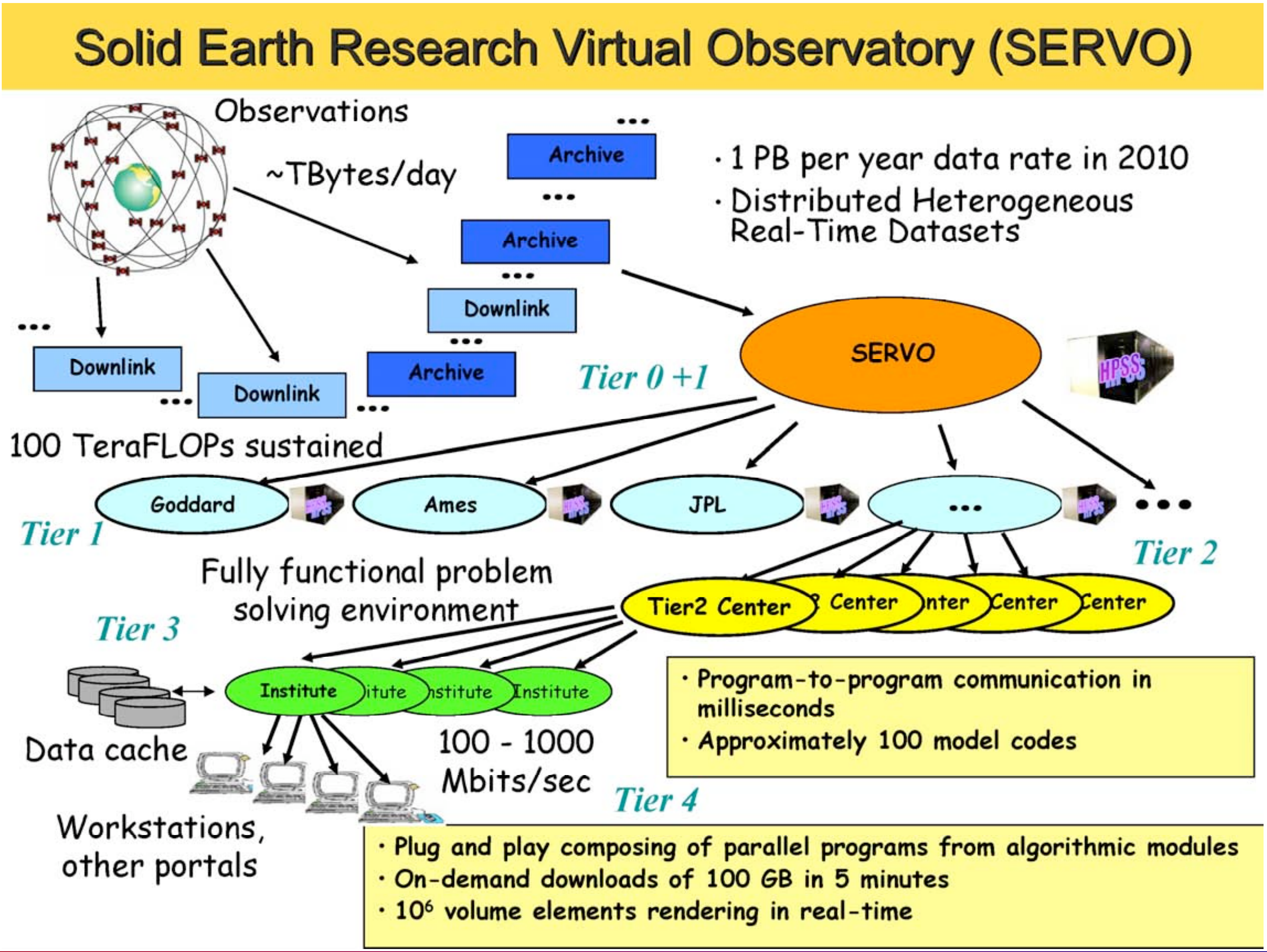




Ames Research Center: Columbia post-disaster analysis



Specific Examples- End-to end integration



Summarizing: Situation Today

Phenomenology modeling

Mission development

Structures

Payload

C&DH

Comm

Power

Etc…

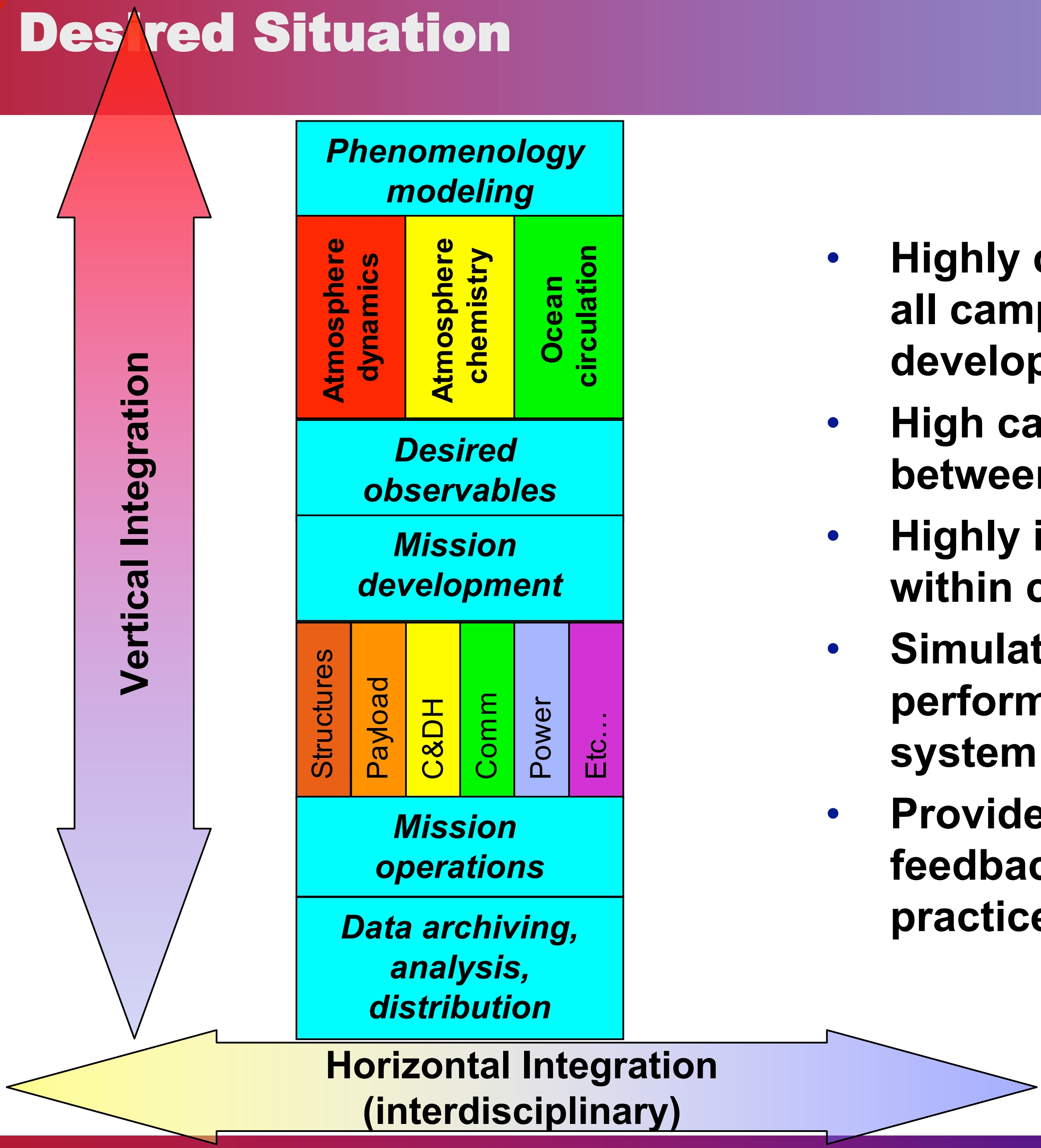
Data archiving, analysis, distribution

Mission operations

Characterized by

- **Camps of system development disconnected**
- **Limited AMSA capability within each camp**
- **Little to no feedback from practice to models for improvement**
- **"Test and hope for the best"**

Desired Situation



- Highly capable models in all camps of systems development
- High capability bridging between camps
- Highly integrated modeling within camps
- Simulate cradle-to-grave performance of entire system
- Provide deliberate feedback from flight practice to improve models

Our history, our future

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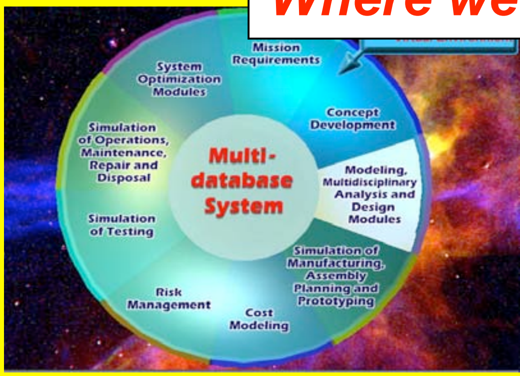
Where we're going



'Phenomenon to Data' system model

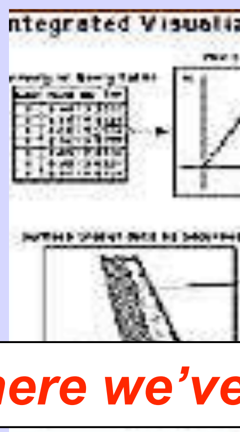
Digital Process

Today

Digital Mockup

Where we've been

Pre-CAD



Pre-CAD

3D-CAD

Summary

It is FAR better to simulate a system and crash it in a virtual environment

Than to

Build a poorly understood system and crash it in the real world

Top Level Assumptions

- Fundamental ASSUMPTION: That commercial progress in High Capability Computing and NASA access to that resource will continue
  - Grid computing will become essential infrastructure
  - Continual exponential increases in computational power (especially via parallelism), communication bandwidth, and storage ca pacity (peta- to yotta- scale data storage)
- Problem complexity will increase and simplification must come from “system of systems” approach (c.f. increased complexity in aircraft industry)
- Delivery dates for AMSA depend on the specific AMSA application. Dates shown correspond to the driving missions launch dates. Actual AMSA need dates are shown in separate table.
- NASA cannot accomplish this program without partnering with other agencies and industry and academia to develop the key components
- Examples and terminology tailored to SMD missions can be applied similarly for exploration and aeronautics.

Capability Breakdown Structure

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14 Advanced Modeling, Simulation and Analysis

Chair: Erik Antonsson, JPL
Co-Chair: Tamas Gombosi, U. Mich.

- **14.1 Scientific Modeling** — Chair: T. Gombosi
  - 14.1.1 Simulate natural and anthropogenic phenomena
  - 14.1.2 Visualize simulation results
  - 14.1.3 Assimilate large data sets
  - 14.1.4 Distribute and mine large data sets
- **14.2 Operations Modeling** — Chair: R. Fuchs
  - 14.2.1 Requirements Development
  - 14.2.2 Mission Rehearsal
  - 14.2.3 Anomaly Resolution
  - 14.2.4 Human-System Interfaces
  - 14.2.5 Training
  - 14.2.6 Subsystem Validation
- **14.3 Engineering Modeling** — Chair: M. Lieber
  - 14.3.1 Large-scale systems modeling
  - 14.3.2 Anomalous behavior Models (ABM)
  - 14.3.3 Virtual test environments (VTS)
  - 14.3.4 Uncertainty models (UM)
  - 14.3.5 Robotics mfg/ Servicing models (RMSM)
  - 14.3.6 Visualization (V)
- **14.4 Integration** — Chair: W. Brooks
  - 14.4.1 V&V "OSSE"
  - 14.4.2 Standards and protocols
  - 14.4.3 Infrastructure Model migration
  - 14.4.4 Archive Data repository
- **14.5 M&S Environments & infrastructure** — Chair: E. Antonsson
  - 14.5.1 Verfication, Validation and Accreditation
  - 14.5.2 Software Engineering environments
  - 14.5.3 Simulation environments
  - 14.5.4 Integration Technology and processes
  - 14.5.5 End-to-end Integration & test

Roadmap Approach

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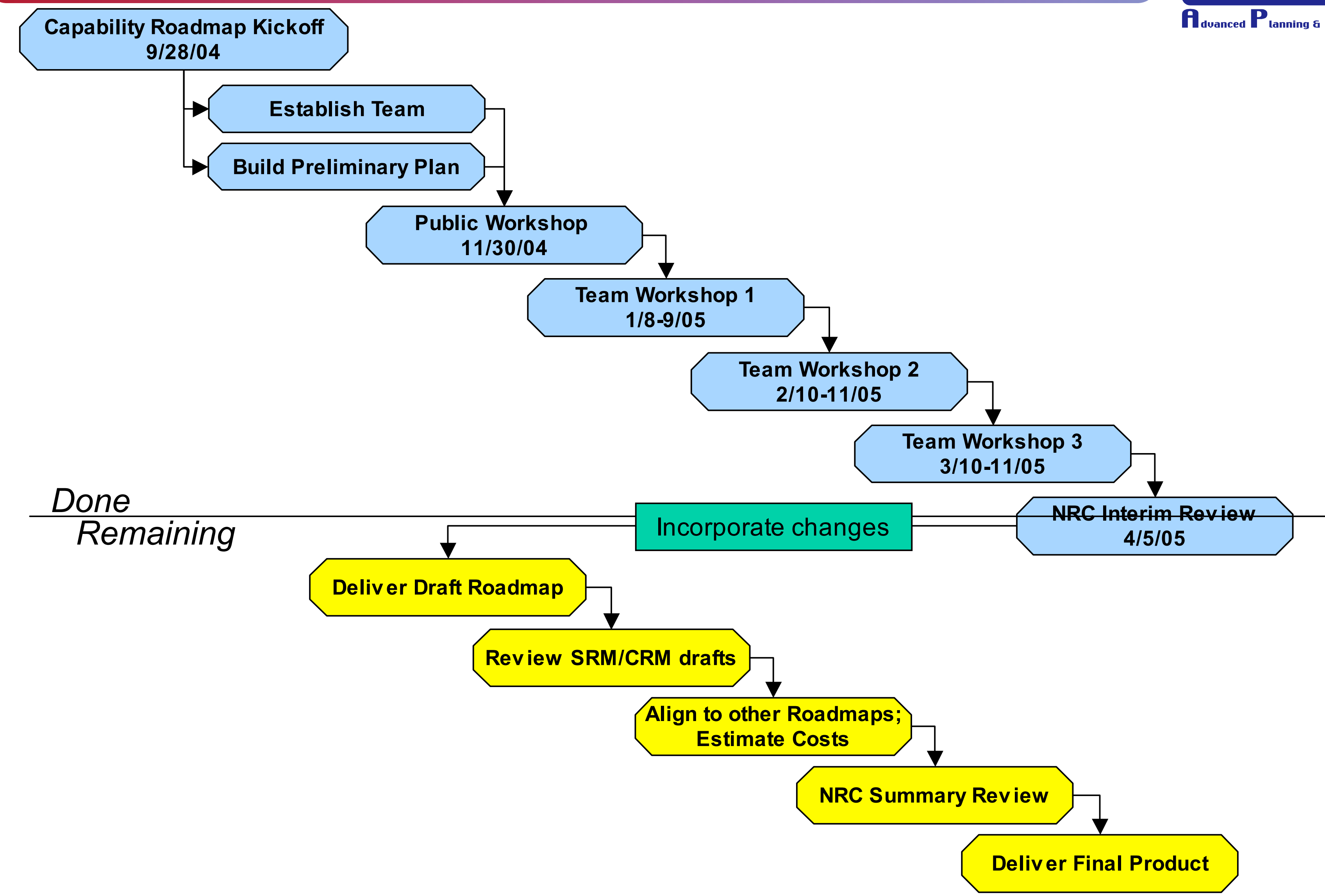
- Advanced Modeling, Simulation and Analysis is a broad and diverse roadmapping topic with significant application challenges.
  - Practiced widely throughout the aerospace, defense, and educational sectors
  - Largely unstructured and uncoordinated, poorly documented, verified and validated
- Public input given high priority
  - 17 Presentations to team leads in Public Workshop; additional 31 white papers submitted but not presented
  - 25 Invited presentations to the full team during workshops.
- Team formation is critical element of roadmapping success
  - Team membership distributed throughout industry, academia, NASA and other government institutions, cross-cuts science, engineering and operations
  - Team-building practiced throughout with weekly telecons and 3 2-day workshops
- Additional reference material accumulated, reviewed analyzed, and archived
  - Design reference missions
  - Related reports sponsored by other agencies
  - Capability needs documents published within NASA
- Final roadmaps developed by sub-teams with membership appropriate to the members' expertise

Roadmap Process Steps



Current State-of-the-Art for Capabilities (1/2)

- Scientific Modeling and Simulation
  - Sophisticated Capabilities
    - Astrophysics
    - Earth Science
    - Space Physics
  - Significant developments in integrating using frameworks
    - Earth Science Modeling Framework
    - Space Weather Modeling Framework
- Operations Modeling and Simulation
  - Work-flow modeling, particularly for ground processing
  - Event tree/sequence generation for mission operations
  - Resource planning/scheduling for communications and other operations assets
  - "Purpose built training simulators"

Current State-of-the-Art for Capabilities (2/2)

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- Engineering Modeling and Simulation
  - Some use of M&S for technology investment decisions
  - Sophisticated disciplinary modeling capability, such as
    - Structures
    - CFD
    - Thermal
  - Limited numerical optimization capabilities
  - Limited multidiscipline integration
    - Preliminary design centers
    - IMOS (Integrated modeling for Optical Systems)
- System Integration
  - Limited integration between observables and science modeling:
    - Observing System Simulation Experiments (OSSE), primarily for weather
    - Solid Earth Research Virtual Observatory
  - No known integration between science, engineering and operations
  - Modeling and Simulation Environments and Infrastructure
  - State-of-capability in high performance computing (Columbia at ARC)
  - Largely COTS-based environments for software and simulation

Traceability Matrix

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- All AMSA capability needs can be traced directly back to the following top-level strategic documentation
  - Design Reference Missions
  - The Vision for Space Exploration
  - A Journey to Inspire, Innovate, and Discover: President's Commission Report
  - The New Age of Exploration: NASA Strategic Objectives for 2005 and Beyond
  - NASA Enterprise Strategies
  - National Research Council Reports

- Traceability Spreadsheets were developed to establish, track, and communicate linkages between design reference missions, science measurement needs, and critical AMSA capabilities.

Traceability Matrix (example)

Area	Mission	launch Date	Mission description	AMSA driver	AMSA impact (at a minimum)
ESS	Solar Orbiter	2014	• ESA Mission • 3-axis stabilized spacecraft will use VGA every third orbit to obtain an increasingly slanting solar orbit at 0.2 AU out of the ecliptic plane to heliographic latitudes of 30-38 degrees • Close approach every 5 months • Perihelion "Hover" period of orbit will allow imaging of solar storm buildup over several days	• Solar Electric Propulsion to be validated on ESA SMART-1 mission in 2003 • High temperature thermal management to accommodate solar intensity 25x than seen at Earth	electric propulsion modeling and thermal modeling
ESS	L-Band MEO InSAR Constellation	2014	Constellation of s//c in MEO to measure land surface topography. Interferometry for vector deformation measurement with global coverage.	Lightweight deployable radar antenna and structure (ex, deployable membrane, L-band, 10m x 40m area) with antenna flatness of lambda/20. Large aperture electronically scanning arrays -low mass (<2-4kg/sq-m structure + aperture + electronics) Pointing knowledge of approx. 0.01deg and control of approx. 0.05deg, free-flying satellite of 3000-15,000km elevation, repeat track to better than 100-200m accuracy.	End-to-end systems modeling; large aperture structure and deployment modeling
ESS	High Resolution CO2	2014	One spacecraft in LEO carrying laser absorption instrument	Autonomous narrowband (~100 kHz) optical heterodyne receiver control, using platform attitude feedback/control. Spacecraft attitude knowledge ~10 micro radians for updating the receiver bandwidth	Attitude control system modeling
ESS	MEO - Global Tropospheric Aerosols	2016	One s/c in MEO, Measure in five spectral bands from 180 GHz to 2.5 THz. Provide global coverage with horizontal resolution of 50 km. Provide vertical resolution of 1-3 km. Provide smart sensor response to atmospheric events.	Cryocooler for ~10 mW heat load at T=4 K, Antenna system for scanning Earth's limb with ~2 km vertical and ~20 km horizontal resolution at 200 GHz, and reflector surface accuracy of ~10 micrometers. 2.0-2.5 THz HEB radiometer with < ~2000 K noise temperature, >2GHz IF bandwidth. Antenna system with ~4x2 m primary reflector, with ~10 micrometer surface accuracy.	End-to-end systems modeling; large aperture structure and deployment modeling; thermal modeling
ESS	Wide Swath LIDAR	2017	One s/c in LEO carrying laser altimeter	Efficient dissipation of multi-kW heat loads on orbit.	thermal modeling
ESS	Quantum Gravity Gradiometer	2018	One s/c in LEO carrying the QGG instrument	Gravitational Reference Sensor with a test mass isolated to less than 1.E-15 m/s**2 rms over 100 seconds and a measurement system for providing a measure of the spacecraft position with respect to the test mass with accuracy of 1 nanometer rms over 100 seconds Micro-Thruster system to adjust the spacecraft position to stay centered on the test mass to within 1 nanometer rms over 100 seconds, with thruster requirement of 2-100 micro-Newton with step size 0.1 micro-Newton and noise less than 0.01 micro-Newton rms over 100 seconds.)	Attitude control system modeling; micro-propulsion modeling

Mission Drivers- examples and complete list

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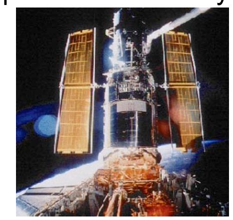
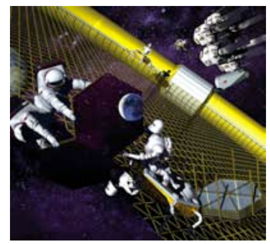
2010 SDO

Constellation-X

Large-Aperture UV/ Optical Observatory



Space Assembly



Mars manned

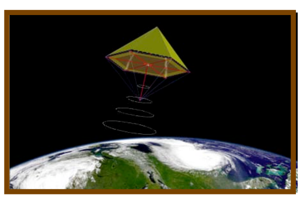
TPF-C

CEV

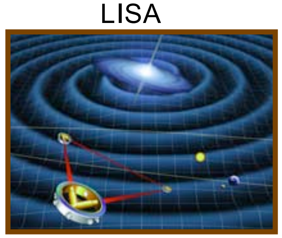
2015 lunar manned

GEO Global Precipitation

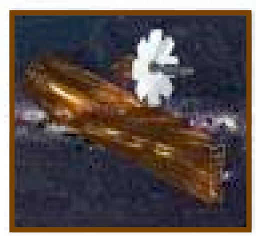
GEO/MEO InSAR



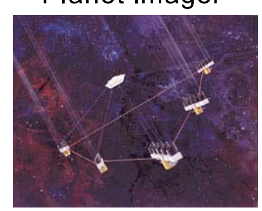
LISA



SAFIR



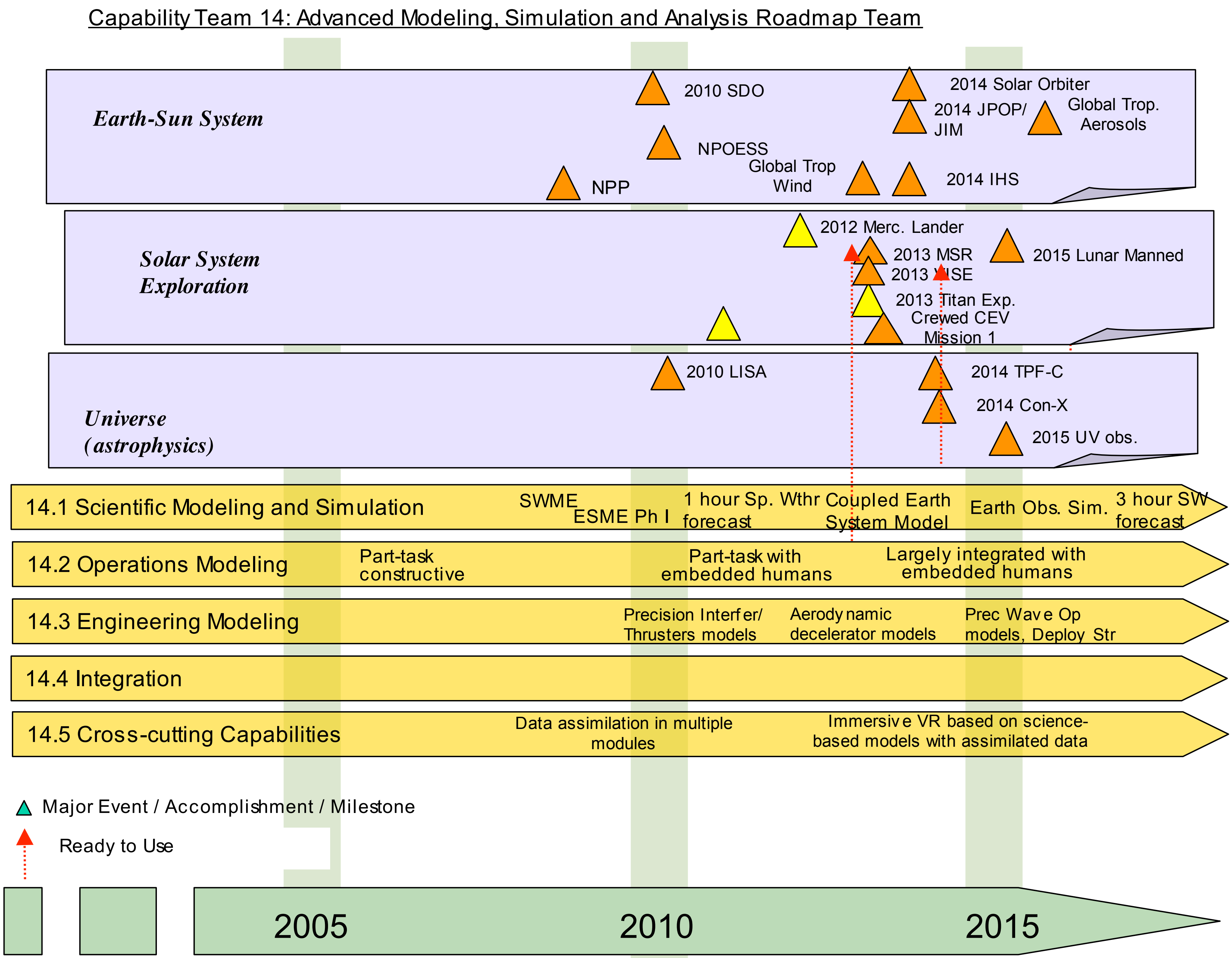
Planet Imager



2010 2020 2030

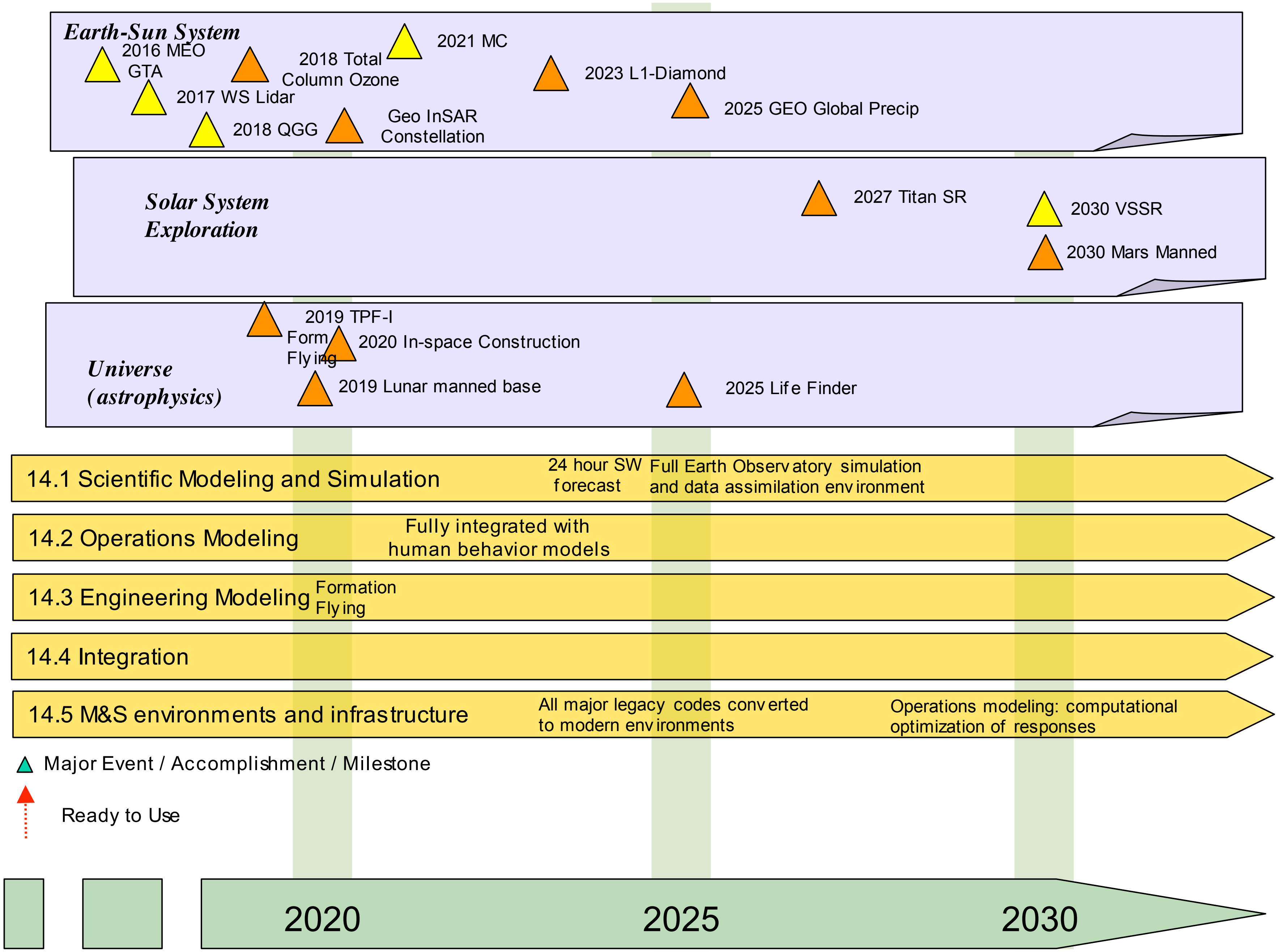
Full AMSA list

Mission	***Year***
NPP	2009
SDO	2010
NPOESS	2010
LISA	2010
Global Trop Wind	2013
MSR	2013
VISE	2013
Crewed CEV Mission 1	2013
Solar Orbiter	2014
JPOP/JIM	2014
IHS	2014
TPF-C	2014
Con-X	2014
Lunar Manned	2015
UV Obs.	2015
Global Trop Aerosols	2016
Total Column Ozone	2018
TPF-I	2019
Lunar manned base	2019
Geo InSAR Constellation	2020
IN-space construction	2020
L1-Diamond	2023
GEO Global Precip	2025
Life finder	2025
Titan SR	2027
Mars Manned	2030



Capability Team 14: Advanced Modeling, Simulation and Analysis Roadmap Team
Earth-Sun System
2010 SDO
2014 Solar Orbiter
2014 JPOP/ JIM
Global Trop. Aerosols
NPOESS
Global Trop Wind
2014 IHS
NPP
Solar System Exploration
2012 Merc. Lander
2013 MSR
2013 VISE
2015 Lunar Manned
2013 Titan Exp.
Crewed CEV Mission 1
Universe (astrophysics)
2010 LISA
2014 TPF-C
2014 Con-X
2015 UV obs.
14.1 Scientific Modeling and Simulation
SWME
ESME Ph I
1 hour Sp. Wthr forecast
Coupled Earth System Model
Earth Obs. Sim.
3 hour SW forecast
14.2 Operations Modeling
Part-task constructive
Part-task with embedded humans
Largely integrated with embedded humans
14.3 Engineering Modeling
Precision Interfer/ Thrusters models
Aerodynamic decelerator models
Prec Wave Op models, Deploy Str
14.4 Integration
14.5 Cross-cutting Capabilities
Data assimilation in multiple modules
Immersive VR based on science-based models with assimilated data
Major Event / Accomplishment / Milestone
Ready to Use
2005
2010
2015

Capability Team 14: Advanced Modeling, Simulation and Analysis Roadmap Team



Capability 14.1:
Scientific Modeling and Simulations

Speaker: Tamas Gombosi, Lead
Tsengdar Lee
John Rundle

Capability 14.1 Description : Science Modeling and Simulation

- The ability to simulate complex natural and anthropogenic phenomena, and to forecast and predict unanticipated outcome
  - M&S is a new instrument of learning and understanding new phenomena
  - Pursue integrated science models (ESMF, SWMF) to integrate science disciplines.
  - Anomaly detection in the environment
- The ability to visualize the results and outcomes of simulations
- The ability to assimilate (ingest) large data sets into simulations, and set the parameters for them
- The ability to mine large data sets for new and unexpected information from space mission data.

Motivation

Exploration and discovery motivates looking in places that are previously unexamined.

Classic tools of exploration are telescopes, which look outwardly into space, and microscopes that look inwardly to finer and finer detail.

Simulations have become an indispensible tool for probing and exploring phenomena that are currently outside of our experience.

Models can be used to explore virtual environments of the moon, Mars and the space environment before we get there.

Capability 14.1: SM&S Benefits

New Vistas in Exploration - will lead to new kinds of science and generate new discoveries.

Measurements will rely on models – to capture, analyze, and characterize features of this environment for interpretation

Models were always part of NASA's culture of exploration

A New Paradigm - Recent major advances in computational capabilities allow numerical simulations to plan, conduct and analyze NASA missions.

Natural Systems are Complex - Simulations of the coupled earth-planetary models and the space environment are essential components of understanding and forecasting

Capability 14.1: Scientific Modeling & Simulation Requirements and Assumptions

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- What missions are driving the requirements?
  - NPP and NPOESS (2008, 2010)
  - InSAR Constellation and Global Precipitation Measurement missions (2014)
  - Solar Dynamics Observatory (2009)
  - Heliospheric Sentinels (2013)
  - Jupiter orbiters and Outer planets/Kuiper belt mission (~2017)
  - NGST (2015)
  - Robotic and human exploration of the Moon(2010-2020)
  - Robotic and human exploration of Mars (2010-2030)
  - Protostellar disks and planet formation mission, Saphir (2020+)
- Additional Assumptions that the team used that drove the need for the capability
  - We are presenting our best estimates for the science drivers, but we have not had a chance to coordinate with the strategic roadmaps yet.
  - VSE is interpreted in a broader sense
  - Grid computing will become essential infrastructure
  - Moore's law continuing and storage capacity will proportionally increase
  - Problem complexity will increase and simplification must come from "system of systems" approach (c.f. increased complexity in aircraft industry)

Capability 14.1: SM&S Current State-of-the-Art

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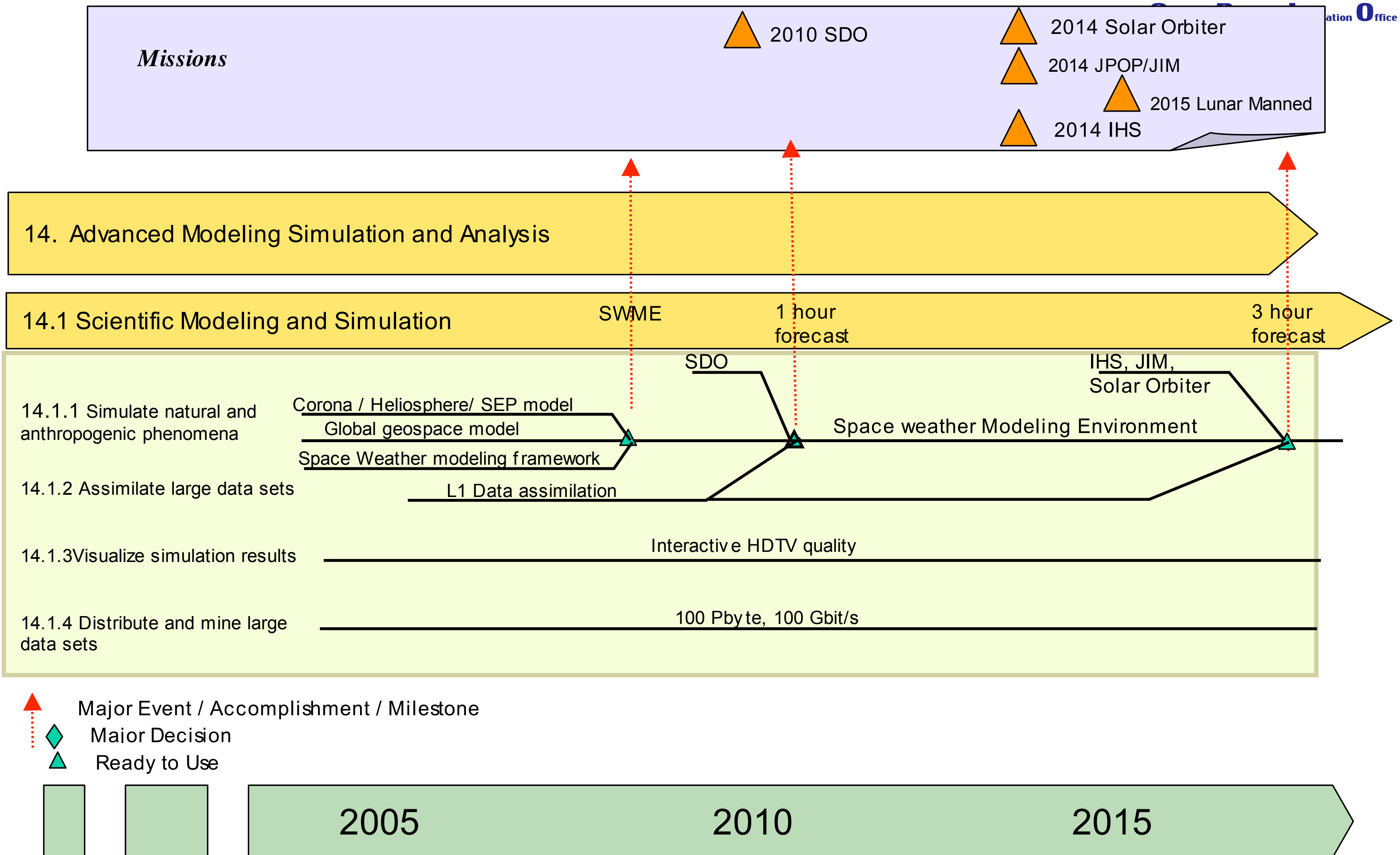
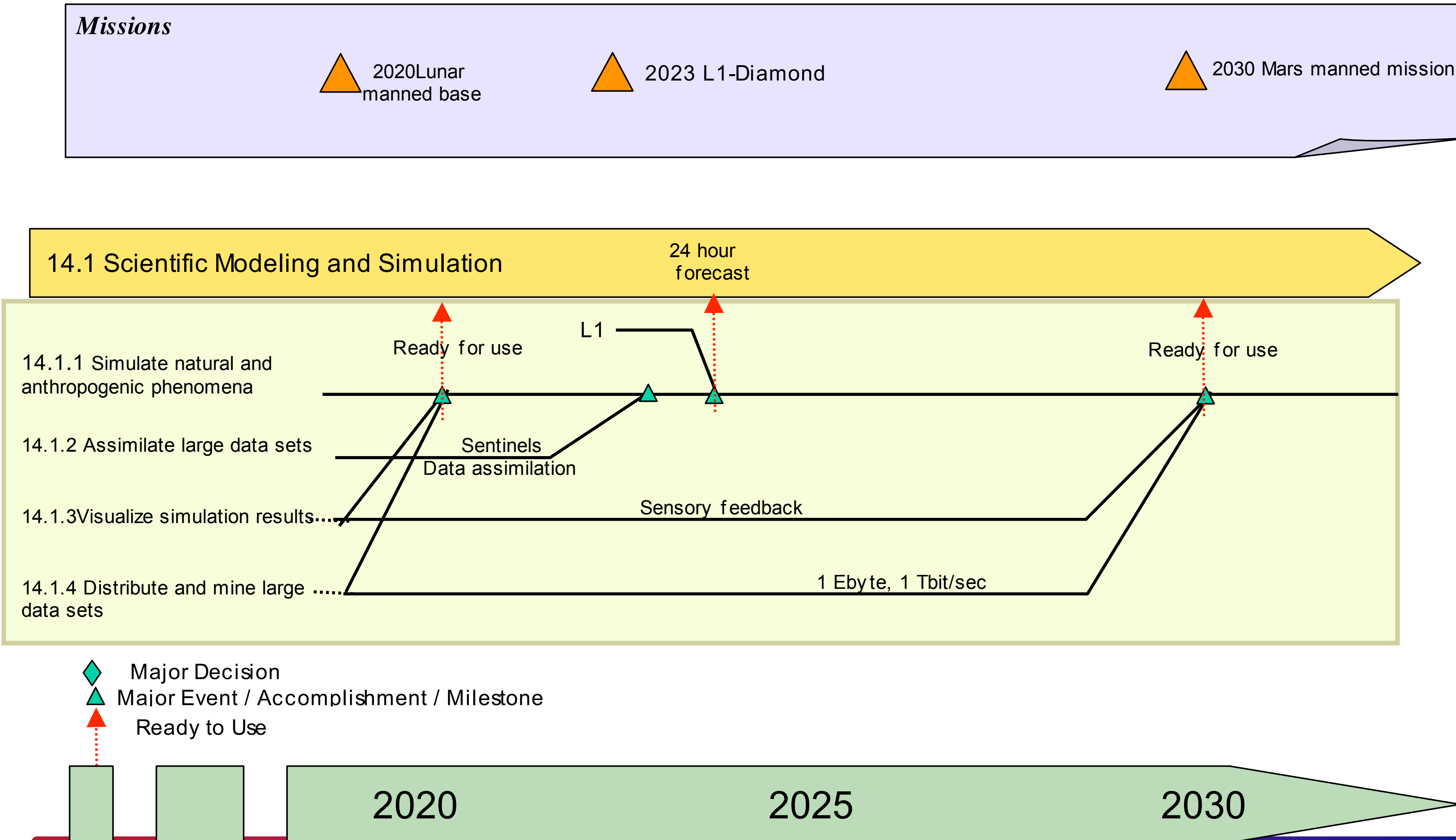
- Simulation technology
  - Simulations: Routine simulations with ~10^6 cells
  - Computing resources: TFlops
  - Visualization: Routine visualization of all simulations and data via post-processing of simulations and data
  - Data volume: Store in federated data bases and distribute 10 Pbyte of data
- Science capabilities
  - Space: 0.25 Re, millions of computational cells; kinetic simulations with 1 billion particles
  - Atmosphere: 1 degree resolution for climate, 0.25 degree for weather simulations
  - Ocean: 0.1 degree resolution (Earth Simulator)
  - Solid earth: millions of interactions (Green's functions), fault length scales of several km
  - Astrophysics: Solve protostellar & planetary disk models with 3D MHD problems with 10 million cells and multiple species

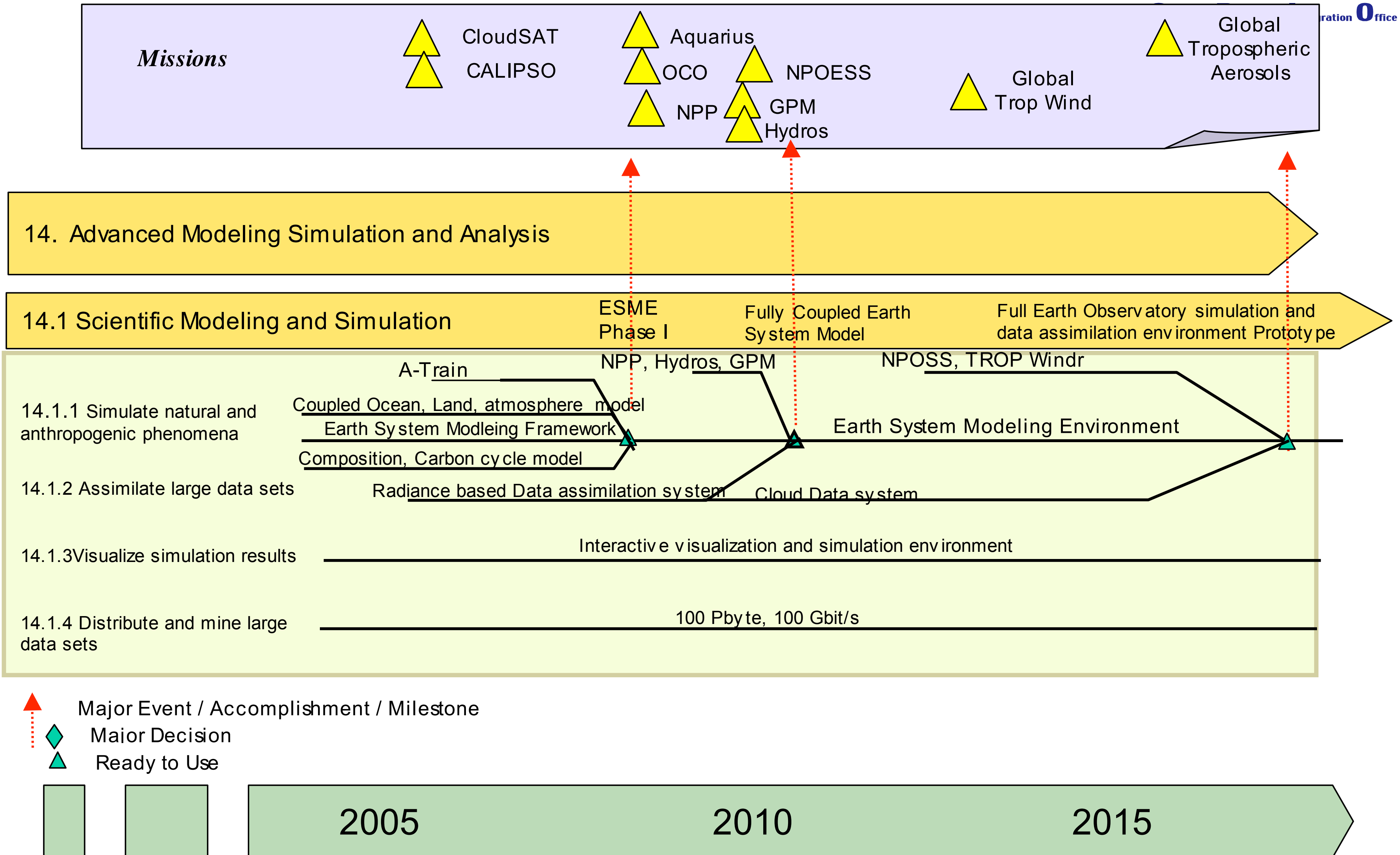
Capability 14.1: SM&S Space weather Roadmap



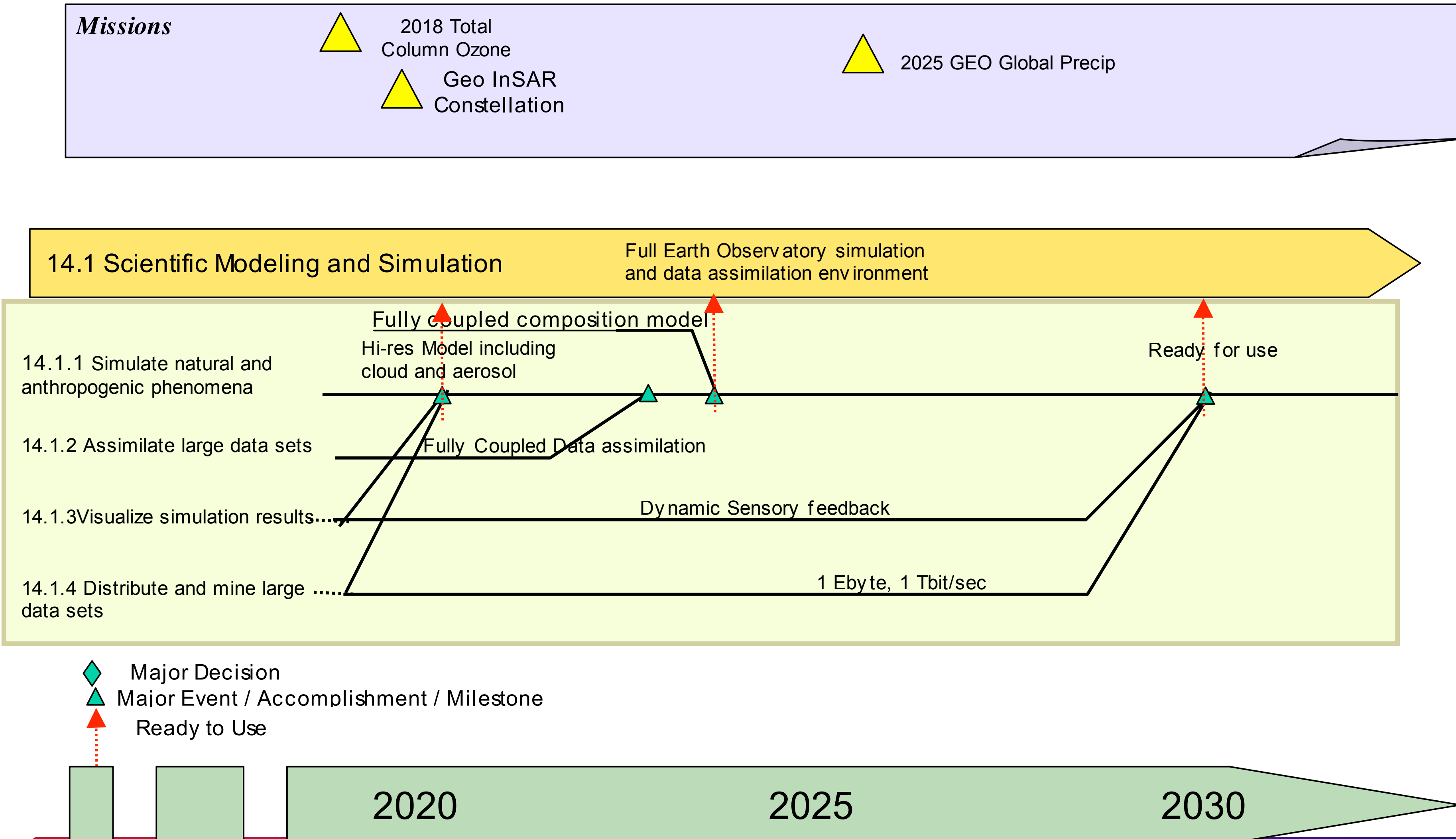
Capability 14.1: SM&S Space Weather Roadmap



Capability 14.1: SM&S Full Earth Observatory



Capability 14.1: SM&S Full Earth Observatory



Capability 14.1: SM&S Goals and Milestones (v1)

Science	Capability	By 2015	By 2020
• Coupled Air-Sea-Land model for weather and climate simulations • Crustal dynamics models for earthquakes and plate motion • Predictive coupled space environment model to simulate space storms and SEP events • Comprehensive planetary hazard models to support human exploration • Cosmological and galactic dynamics models • Disk magentosphere interactions, protostellar disk and planetary formation models	Simulations & Data assimilation	Routine simulations with 1B degrees of freedom	Routine simulations with 1B degrees of freedom
	Visualization	Capability to resolve HDTV quality in a streaming and interactive environment	Capability to resolve HDTV quality in a streaming and interactive environment with full sensory feedback
	Data volume	Capability to store and distribute 100 Pbyte of data from simulations or observations, and to provide streaming data at 100 Gbit/s	Capability to store and distribute 1 Exa-byte of data from simulations or observations, and to provide streaming data at 1 Tbit/s

Capability 14.1: SM&S Goals and Milestones (v2)

2010	2015	2020	2030
Validated, coupled Sun-to-Earth space environment model to simulate space storms and SEP events	Validated, predictive Sun-to-Earth space environment model to provide 3 hours forecast of solar storms and SEP events	Validated, interactive predictive Sun-to-Earth space environment model to provide 24 hours forecast of solar storms and SEP events to support human activities on the Moon	Validated, interactive predictive Sun-heliosphere space environment model to provide 72 hours forecast of solar storms and SEP events to support human exploration of Mars and robotic exploration of the outer planets
Comprehensive planetary hazard models to support human exploration	Validated simulation of Martian atmospheric density, temperature and near surface winds.	Validated simulation of Martian aeolian dust transport and storms. Predictive capability for atmospheric or subsurface transport of biohazards and biogenic materials.	Weather forecasting for atmospheric density, near surface winds, and dust storms. Predictive models for ionizing radiation at the surface.
Crustal dynamics models for earthquakes and plate motion	Validated, predictive simulation of interacting active faults in a region the size of California at a scale of 1 km resolution, to provide 5 years forecast of earthquakes larger than 5.	Validated, predictive simulation of interacting active faults in a region the size of California at a scale of .1 km resolution, to provide 2 years forecast of earthquakes larger than 5, with capability of full data assimilation in real time using interferometric radar data.	Validated, predictive simulation of interacting active faults in a region the size of California at a scale of .01 km resolution, to provide 6 months forecast of earthquakes larger than 4, with capability of full data assimilation in real time, and real time, streaming, immersive visualization of simulation data merged with observed interferometric data.
Coupled Air-Sea-Land model for weather and climate simulations	Validated model of probabilistic predictions of future climates and transitional climate change at several hundred kilometer resolution Full four-dimensional variational data assimilation of aerosol particles, trace gases and satellite properties. Routine , validated predictions of climate anomalies, such as El Nino, 6-12 months in advance.	Integrated earth system model with interactive hydrology, dynamic vegetation and biogeochemistry producing validated results as several hundred kilometer resolution.	Earth system modeling suite , validated through extensive and comprehensive data assimilation systems employing observations from space-based earth monitoring systems. This modeling system will produce probabilistic predictions of regional manifestations of global changes based on scenarios of human activity, including population changes, energy technology strategies and water use.
• Cosmological and galactic dynamics models			

Capability 14.1: SM&S Maturity Levels -- Technology

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- Leading technology candidates
  - Grid computing
  - Leadership class computing system
  - Immersive and interactive visualization
  - Frameworks
  - Federated data bases
  - Web service architectures for distributed/coupled models
- Key gaps between current state-of-the-art and required performance levels
  - Distributed, grid based computing portal that enables to build, run and analyze integrated simulations
  - Collaboratories
  - Model infrastructure tools for high spatial, resolution, and temporal simulations

Capability 14.1: Scientific Modeling&Simulation Related Technologies and Dependencies

Capability 14.1: Priorities

Advanced Planning & Integration Office

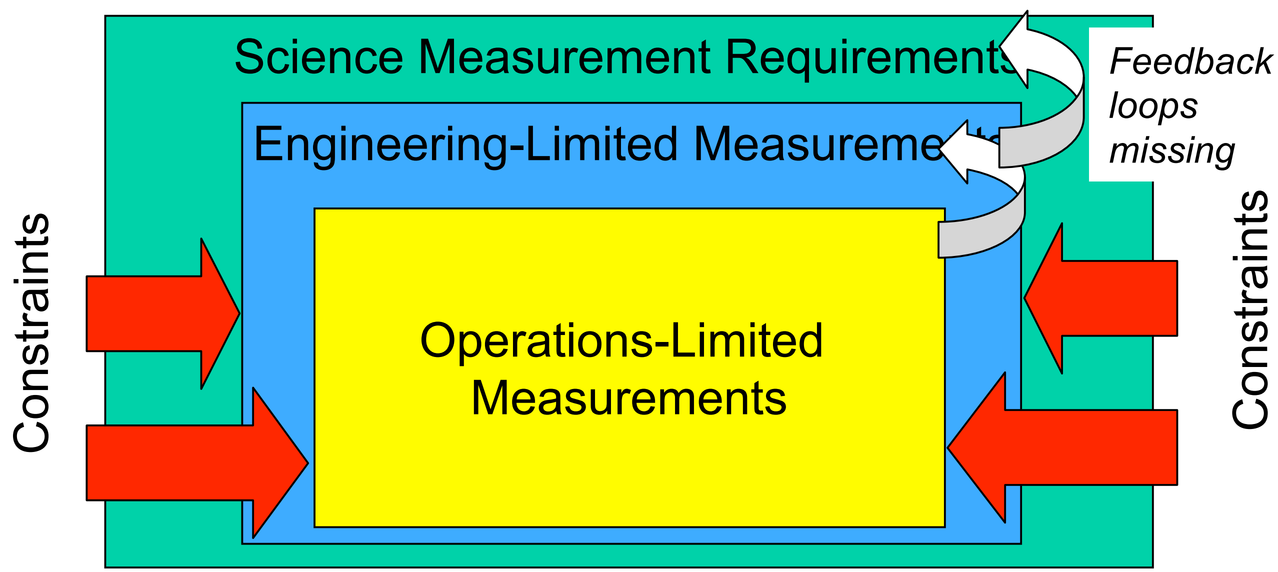
Capability 14.2 M&S for Operations

Speaker: Ron Fuchs, Lead

Erik Antonsson

Capability 14.2 Description: M&S for Operations

- **Simulation of all aspects of missions for the purpose of requirements development, training, mission rehearsal, anomaly resolution, validation of subsystems and systems, or developing human-system interfaces.**
  - **Includes interfaces to scientific and engineering M&S**
  - **Includes Human-in-the-loop simulations**



Capability 14.2 M&S for Operations - Motivation

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- NASA missions are increasing in complexity and inter-dependency
  - Human exploration systems must evolve into tightly integrated partnerships between humans and machines.
  - Increasingly large quantities of data, upon which decisions are based, present needs for models, visualization, situational awareness and decision aids to support human operations in space.
  - Robotic exploration systems require modeling of instrument and spacecraft systems for scheduling, control, mission operations and anomaly resolution.
  - Operations models must be introduced early in the design cycle.
  - Operations modeling depends on the science and engineering models. Development of operations must be done in concert with the development of the science goals and engineering systems.
  - Communications and information management must be included.
  - Models of human biomechanics and human factors must be included.
- Complex missions lead to geometric increase in potential risks
  - Realtime simulations of operations are needed to meet safety targets for human spaceflight.
  - Future missions require training and scenario evaluation for ground controllers and in-space flight operations for both mission execution and anomaly resolution.
- Budget pressures will increasingly stress the ability to meet goals
  - Operations costs have dominated human spaceflight operations.
  - M&S Can reduce these costs by reducing amount of live testing

Benefits of Capability 14.2 M&S for Operations

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***Reduced Risk** – mistakes are made during development and training in the virtual world rather than the real world.*

***Sound system requirements** – essential to the systems engineering process that has been shown to result in better cost effectiveness of programs.*

***Improved Performance** – "Optimal" overall human-machine integration during all phases of a program.*

***Rapid understanding of anomalies** - Simulations are the basis for reconstructing an understanding of systems during anomalous events*

***Preflight understanding of communication limitations** - Impact of communication time-of-flight delays can be evaluated.*

Capability 14.2: Requirements & Assumptions

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- What missions are driving the requirements?
  - All manned missions
    - CEV
    - Human Lunar
    - Human Mars
  - Missions requiring a system of systems approach
    - Lunar Robotic
    - Robotic Mars
    - Air Transportation System
- Additional Assumptions that the team used that drove the need for the capability
  - The increasing challenge of future NASA missions will dictate the need for more integrated system of systems approaches
  - Budget pressures will constrain live testing and experimentation to levels that will significantly increase mission risk without a robust M&S environment
  - Greater international participation will be the norm for ambitious programs, which implies needs ranging from new collaboration techniques to improved export control

Capability 14.2: Current State-of-the-Art

- Requirements Development
  - Simulators at the individual system level
  - Manual interfaces between many system simulated components
- Training
  - Purpose-built single task trainers
  - Limited integrated system training capability
- Mission Rehearsal
  - Good representation of today's relatively simple missions
- Human-System Interfaces
  - Trial and error approach
  - High cost development due to large numbers of labor intensive trials
- Anomaly Resolution
  - Good representation of portions of the systems
- Subsystem Validation
  - Purpose built testing environments that substitute for prohibitively expensive live testing of specific components
- General
  - Lack of integrated simulations makes development and analysis of systems of systems difficult

Capability 14.2: Maturity Level Assessment

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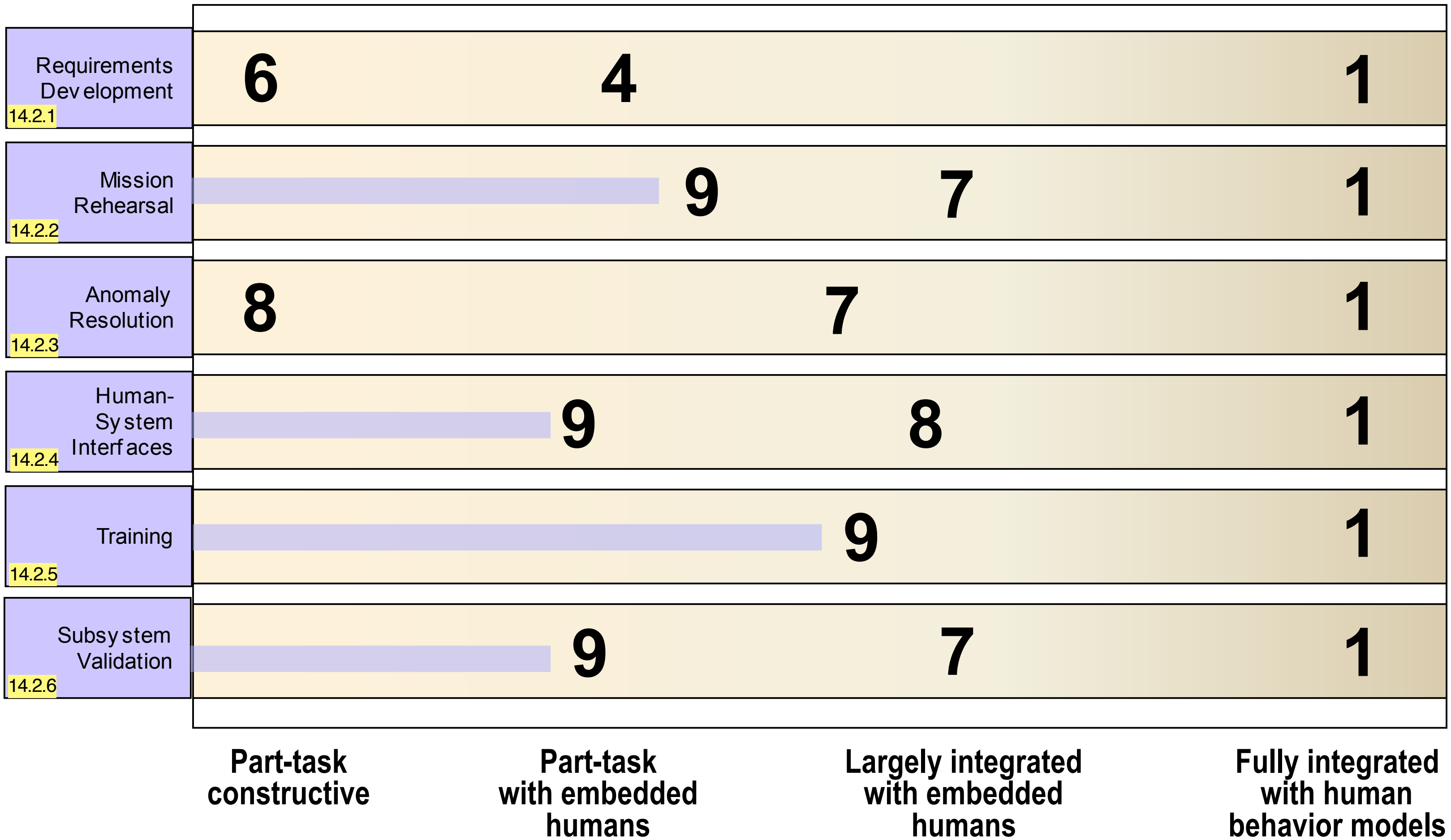
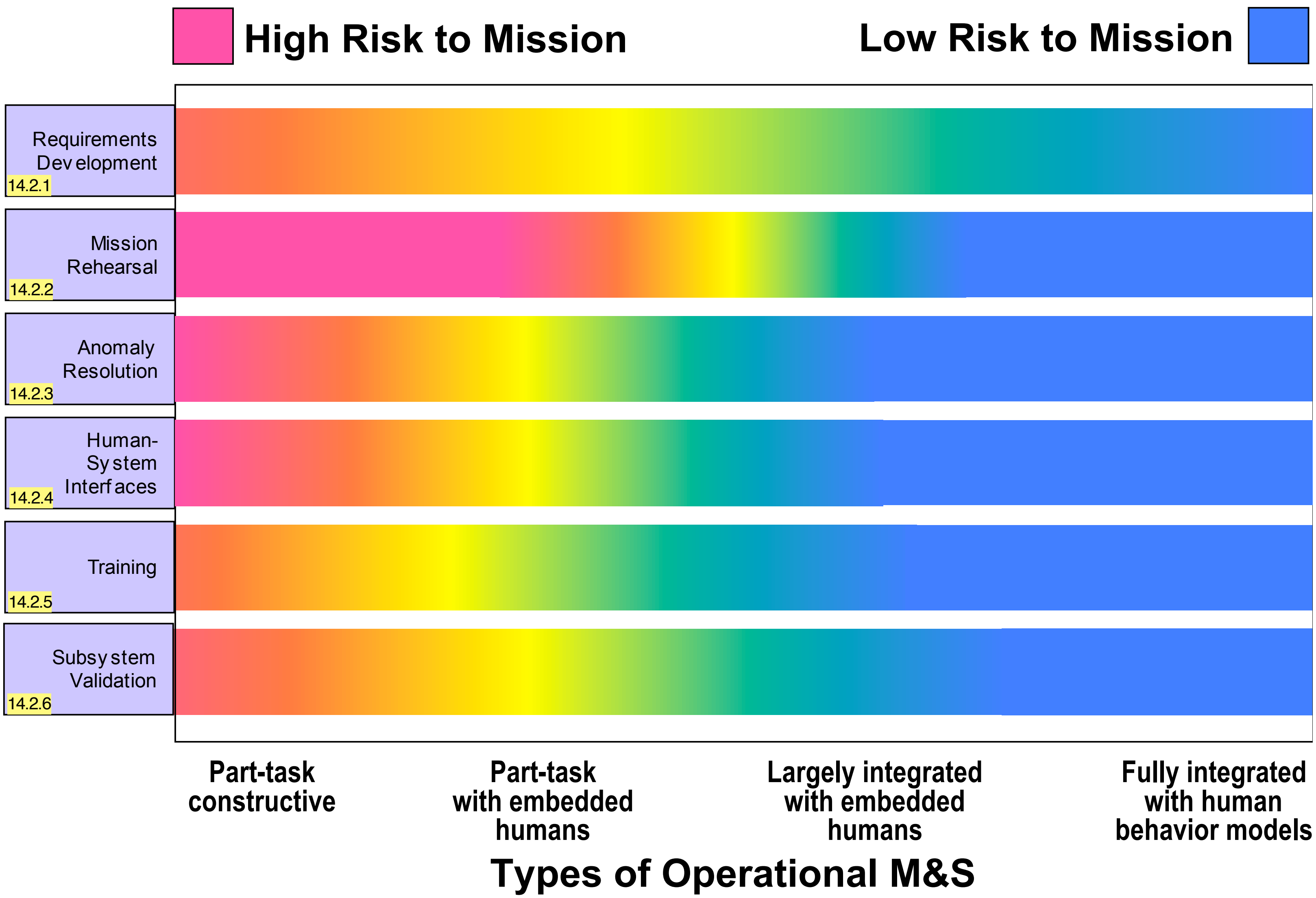
Numbers represent average current TRL for each area

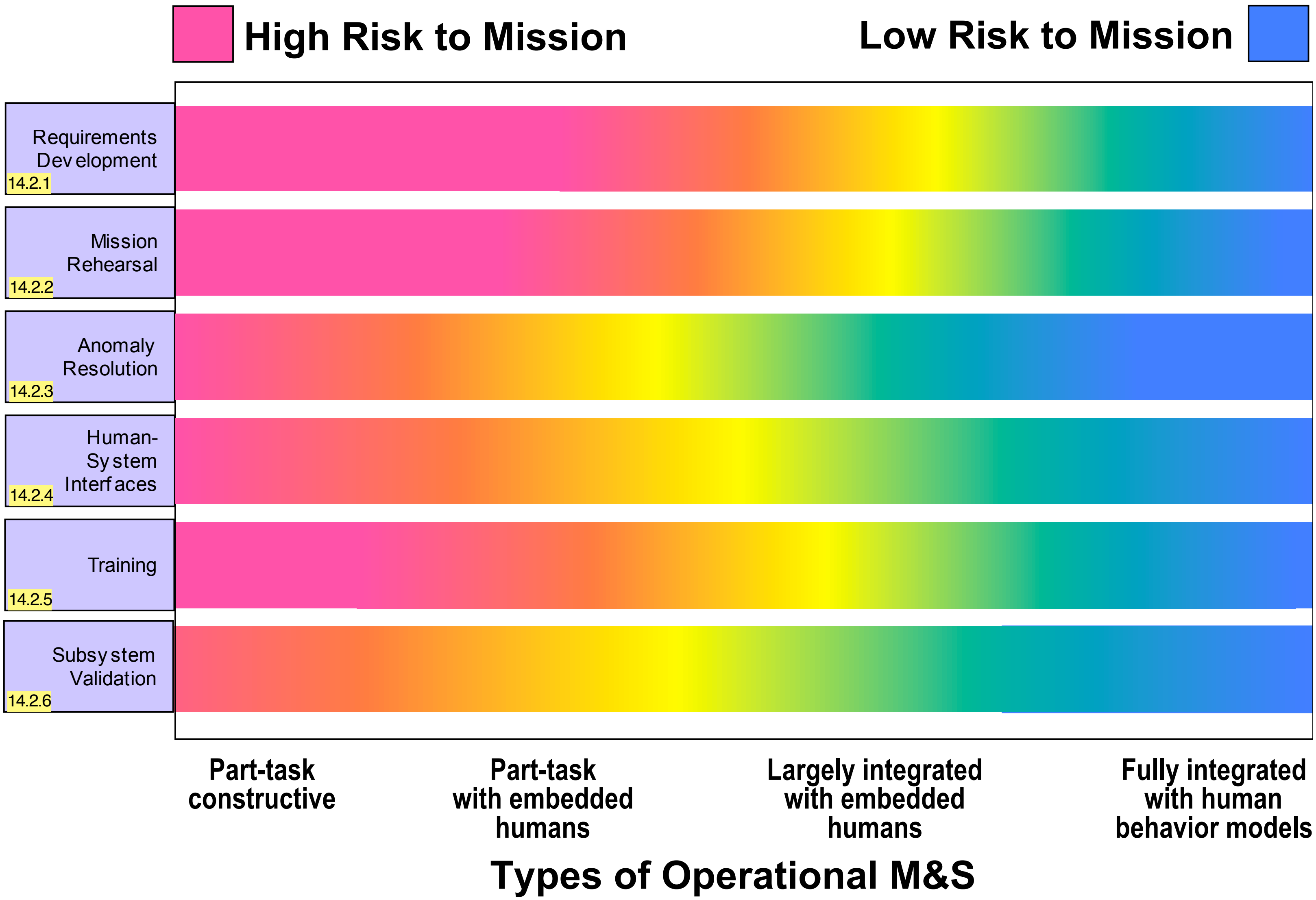


Types of Operational M&S

Capability 14.2: CEV Requirements



Capability 14.2: Mars Human Requirements



Capability 14.2: Capabilities Needed

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- NASA needs an more integrated approach to M&S
  - Distributed simulation capabilities
    - Distributed simulation across long distances (space)
  - Networks tying NASA Centers, international, and industry partners
  - Coupled training simulators
  - Ability to handle data that has many levels of restriction (proprietary, classified, ITAR, …)
- NASA needs a virtual development/production/test/operation environment
  - Virtual system development to expand options and reduce costs
  - Standards for seamless transition of software from virtual to real environments without redevelopment
  - Test programs integrated with modeling and simulation approach
- NASA needs affordable human inclusion in M&S
  - Better simulation of human-machine interface systems
  - Models of human behavior
- NASA needs some new tools
  - System of systems analysis capabilities
  - Communications and information management system models

Capability 14.2: M&S for Operations Roadmap

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Lunar Precursor 1
Mars Precursor 1
Lunar Robotic Mission 1
CEV Acquisition
CEV LV Design Freeze
CEV Ops Design Freeze
Crewed CEV Mission 1
CEV Design Freeze

ESMD

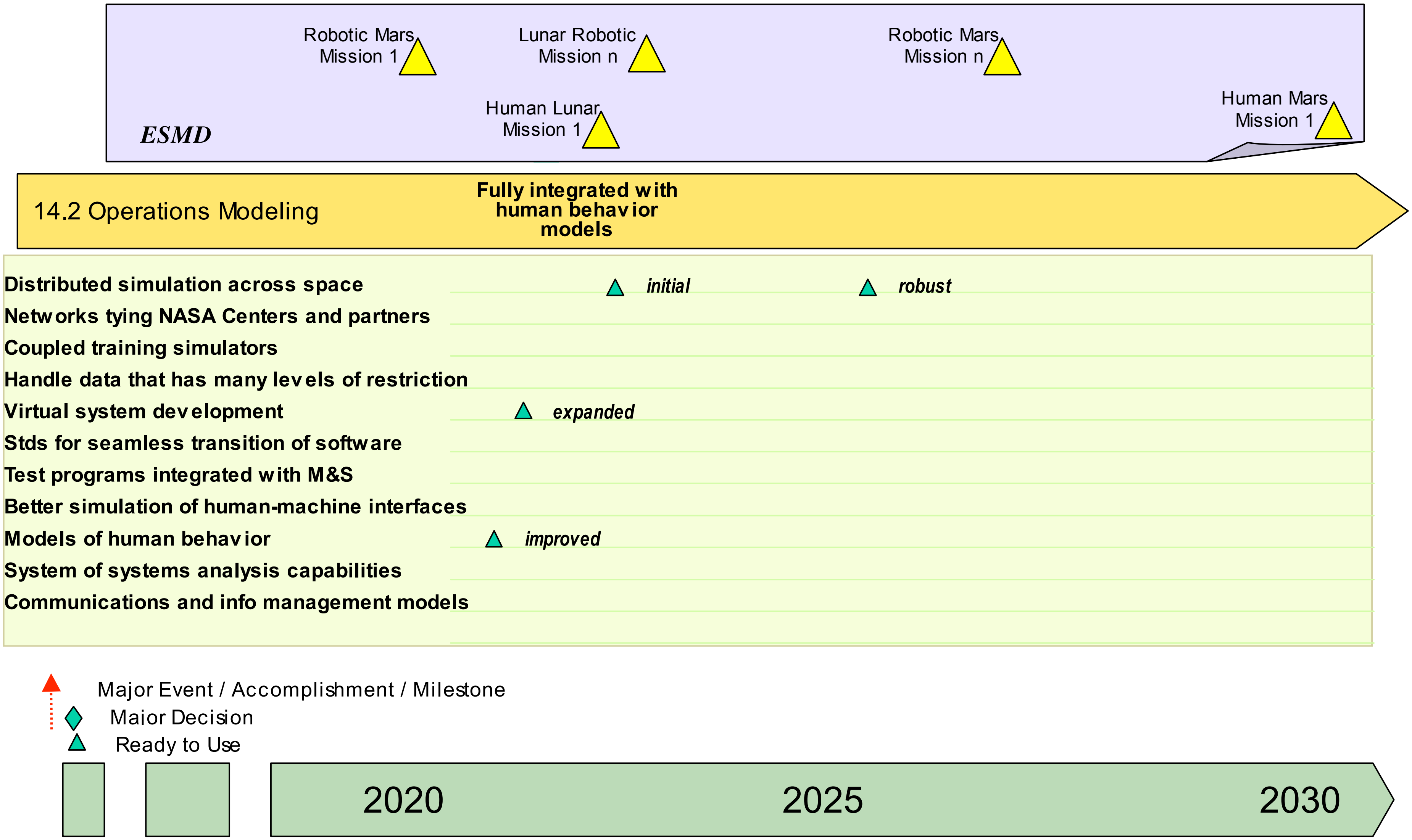
14.2 Operations Modeling	Part-task constructive	Part-task with embedded humans	Largely integrated with embedded humans

Distributed simulation across space	*initial*, *robust*
Networks tying NASA Centers and partners	
Coupled training simulators	
Handle data that has many levels of restriction	
Virtual system development	*initial*, *robust*
Stds for seamless transition of software	
Test programs integrated with M&S	*partial*, *full*
Better simulation of human-machine interfaces	
Models of human behavior	*initial*, *refined*
System of systems analysis capabilities	
Communications and info management models	

Major Event / Accomplishment / Milestone
Major Decision
Ready to Use

2005 2010 2015

Capability 14.2: M&S for Operations Roadmap



Capability 14.2: Metrics

Requirements Development	Time to evaluate a candidate architecture's cost, performance and risk
Mission Rehearsal	Effectiveness in creating a realistic environment as judged by participants
Anomaly Resolution	Time to ascertain root cause Time to develop corrective actions
Human-System Interface	% of time correct decisions are made Consistency of decisions across crew members
Training	Time to train to desired proficiency levels Length of time training effects are retained
Subsystem Validation	% of subsystems that can be fully tested Risk of subsystem failure due to lack of validation

Capability 14.2: OM&S Related Technologies and Dependencies

- Many of the Operations M&S areas overlap with the Systems Engineering needs, particularly in requirements derivation and testing. The technologies developed need to be coordinated across these areas.
- Operations M&S must be integrated with the engineering M&S processes and tools to make relevant trades during the entire system life cycle, but particularly during the design phase.

Capability 14.2: Priorities

1. **NASA needs an more integrated approach to M&S**
   - Distributed simulation capabilities
     - Distributed simulation across long distances (space)
   - Networks tying NASA Centers, international, and industry partners
   - Coupled training simulators
   - Ability to handle data that has many levels of restriction (proprietary, classified, ITAR, …)
2. **NASA needs some new tools**
   - System of systems analysis capabilities
   - Communications and information management system models
3. **NASA needs a virtual development/production/test/operation environment**
   - Virtual system development to expand options and reduce costs
   - Standards for seamless transition of software from virtual to real environments without redevelopment
   - Test programs integrated with modeling and simulation approach
4. **NASA needs affordable human inclusion in M&S**
   - Better simulation of human-machine interface systems
   - Models of human behavior

Capability 14.3 Engineering Modeling

Presenter: Mike Lieber

Thomas Zang

Charles Norton

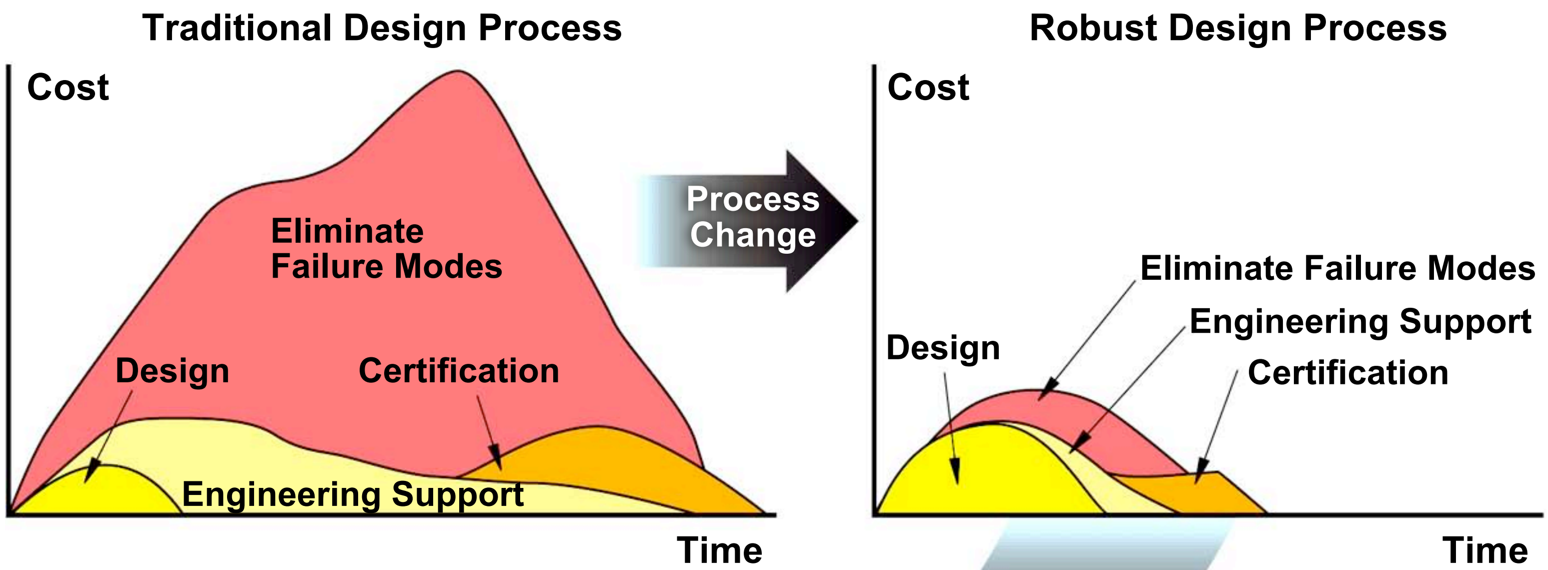
Karen Fucik

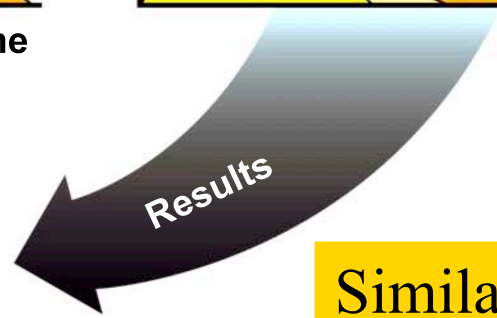
Advances in Engineering Modeling and Simulation Enable Future Missions

Advanced Planning & Integration Office

- **In this section we propose advanced engineering modeling and simulation for adressing the following questions:**
  - **How could NASA reduce overall mission risk, maximize resources, and enhance overall system engineering processes for future missions?**
    - **By evolving current integrated models to a Large-Scale System Modeling architecture and using them early in the design process.**
  - **How do we better address unexpected and sometimes catastrophic events?**
    - **By development of Anomalous Behavior Models with expert system oversite.**
  - **Given the environmental difficulties and cost of system ground testing, how does NASA best insure future mission success?**
    - **By developing and validating Virtual System Test models.**
  - **How does NASA determine the quality and bounds on modeling predictions?**
    - **By developing Uncertainty Models from rigorous mathematics and firm understanding of relationship to performance models.**
  - **How can NASA best utilize robotics in space for assembly and servicing?**
    - **By developing interactive and dynamic machine-machine models to pre-assemble/ service in a virtual environment.**

The Challenge to Reduce Development Cost - Industry Experience





Test-Fail-Fix Cycle
Representing 73% of Cost

REDUCE BY FACTOR OF 4

Similar experiences in auto and jet Engine industries

* Borrowed from Rocketdyne/ Boeing presentation

Description of Capability 14.3 Engineering Modeling(1/2)

- **14.3.1 Large-scale system modeling**
  - Rapid integrated model deployment, cradle-to-grave, evolutionary, hierarchical structure, discrete event, hybrid system modeling, advanced data structures.
  - Imbedded data management, design space exploration/ multiple optimization engines.
  - Distributed grid computing, distributed collaboration.
- **14.3.2 Anomalous Behavior Models**
  - Failure modes and effects, mitigation, real-time anomaly resolution, sabotage evaluation.
  - AI driven “agents of doom” for scenario generation.
  - High-fidelity predictions of performance under damaged/ abnormal conditions.

Description of Capability 14.3 Engineering Modeling(2/2)

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- **<u>14.3.3 Virtual System Testing</u>**
  - **Modeling the untestable, updates flight large-scale model, test definition (reverses paradigm)**
  - **Selective replacement testing with modeling, HIL emulation.**
  - **Robotic exploration and virtual world interactions.**
- **<u>14.3.4 Uncertainty Modeling</u>**
  - **Supports V&V with advanced modeling techniques for characterizing and propagating system uncertainty.**
  - **Characterizes modeling error bounds.**
- **<u>14.3.5 Robotics manufacturing and servicing</u>**
  - **Dynamically replicated virtual environment for assembly, servicing and repair in space.**
- **<u>14.3.6 Visualization</u>**
  - **Converting data into knowledge. Dynamic, multidimensional.**

Benefits of Capability 14.3 - Engineering Modeling (1/2)

- <u>14.3.1 Large-scale system modeling</u>
  - Rapid integrated model deployment, design tracebility throughout life cycle.
  - Increased design knowledge leads to better system decisions (enables system trades with respect to performance, risk, and costs).
  - Increased multidiscilinarian communication.
  - Decreased number of "test-fail-fix" cycles.
- <u>14.3.2 Anomalous behavior models</u>
  - Minimize failure modes and consequences in the design phase.
  - Anticipate and avert incipient failure during operations.
  - Real-time Identification of alternative failure recovery paths.

Benefits of Capability 14.3 - Engineering Modeling (2/2)

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- **14.3.3 Virtual System Testing**
  - Modeling the untestable, the unobservables, enhanced visualization.
  - Cost/schedule benefit.
  - Robotic path planning in remote environments optimizes resource.
- **14.3.4Uncertainty Modeling**
  - Supports V&V, confidence builder for decision maker, design robustness, reflects true environments.
- **14.3.5 Robotics manufacturing and servicing models**
  - End-to-end evaluation of machine-machine dynamics for design feedback and system engineering optimization and failure predictions.
- **14.3.6 Visualization**
  - Enhanced communication tools.
  - Facilitates understanding of model and results.

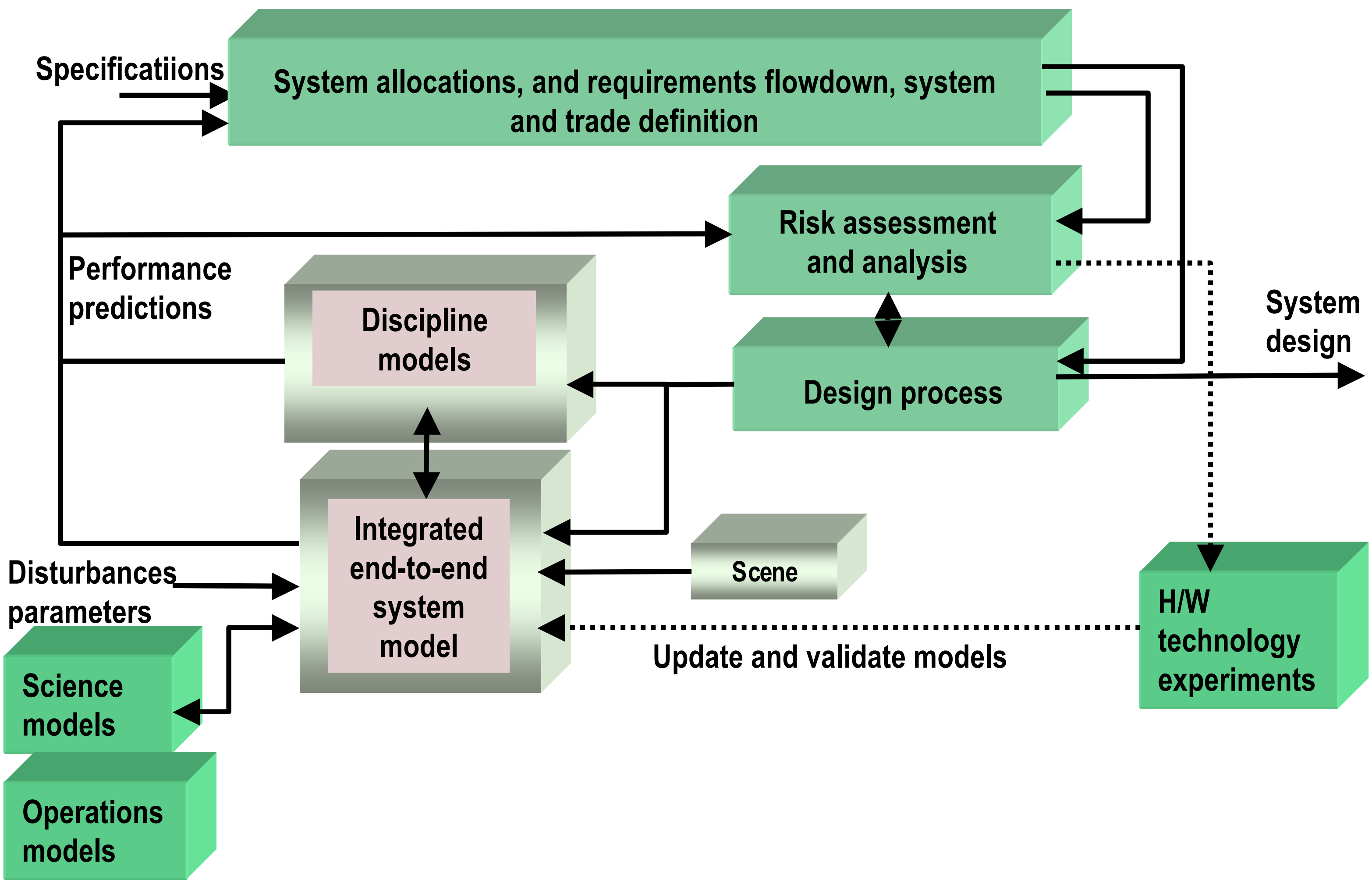
Current State-of-the-Art for Capability 14.3 Engineering Modeling(1/2)

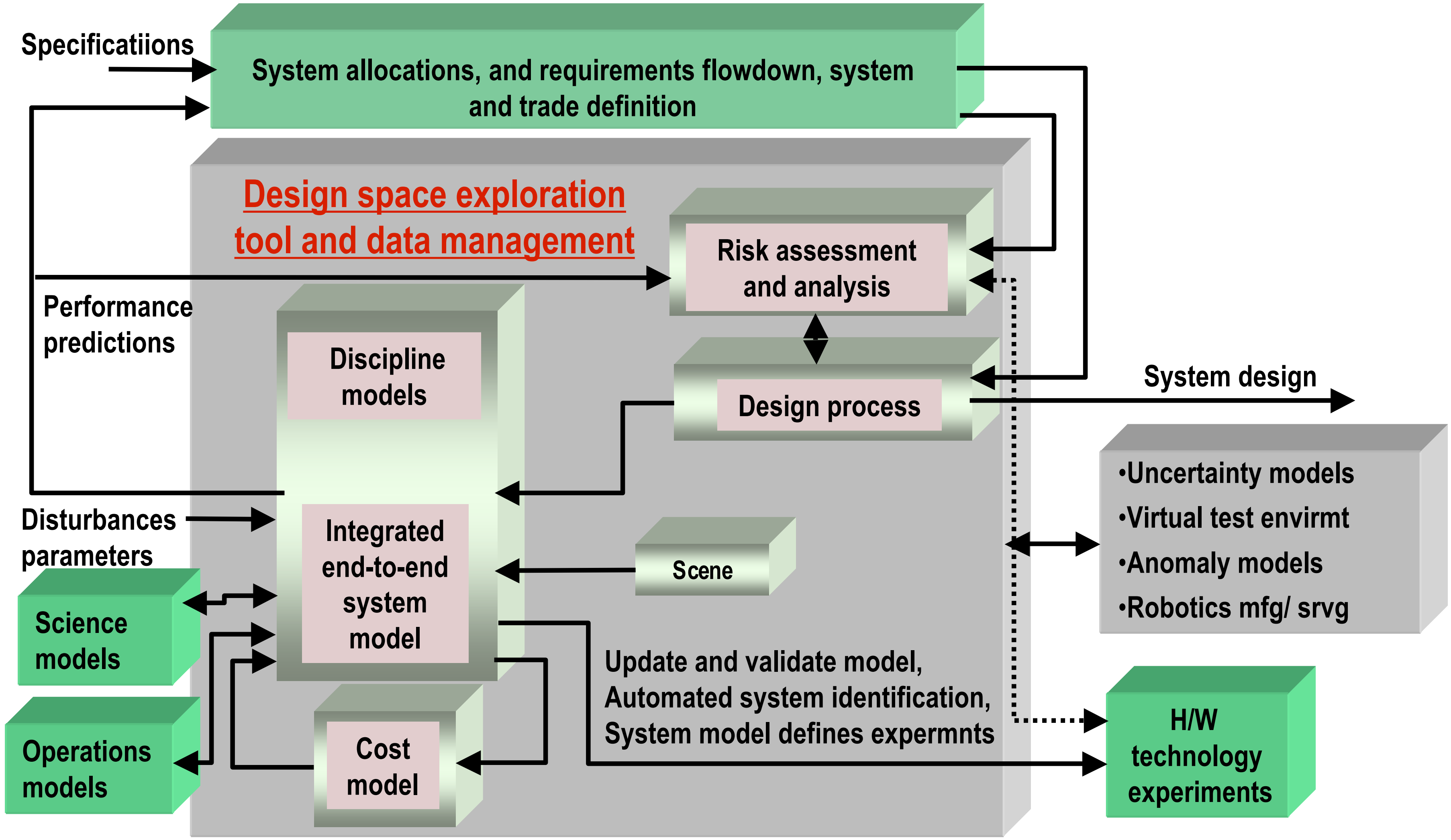
- 14.3.1 Large-scale system modeling
  - Remaining heritage to bucket brigade approach and "test-fail-fix" approaches.
  - Integrated modeling, like JPL IMOS, picemeal developed in parallel with program resulting in many architectural gaps.
  - Tie in weak or missing to optimization engines, comprehensive data management, cost and risk linkage, rapid deployment, science and operations.
  - Cradle-to-grave system capability not part of mission cycle.
- 14.3.2 Anomalous behavior models
  - Not typically part of engineering cycle except as part of parameter variability studies.
  - Modified versions of models for post-mortem or emergency response.
- 14.3.3 Virtual System Testing
  - Capability very scale dependent.
  - Complete end-to-end virtual system not in place.

Current State-of-the-Art for Capability 14.3 Engineering Modeling(2/2)

- <u>14.3.4 Uncertainty Modeling</u>
  - Many COTS tools for propagation of probabilistic uncertainties.
  - Underlying parametric uncertainties poorly characterized.
  - Modeling of non-probabilistic uncertainties, e.g., model fidelity uncertainty, is very primitive and often mathematically unsound.
- <u>14.3.5 Robotics manufacturing and servicing models</u>
  - Complete dynamics models exists for robotics systems but incomplete characterization for prediction of machine-machine processes.
  - Architecture advancements required for complete assembly/ servicing scenario.
- <u>14.3.6 Visualization</u>
  - Embedded into commercial design modeling tools, exists as
    - separate packages and tool libraries,
    - high-end/experimental systems appropriate for large data sets on parallel computers for time-dependent 3D modeling.
  - Design space exploration visualization just starting to emerge.

14.3.1 Current Engineering – Discipline and Integrated System Modeling




Specificatiions
System allocations, and requirements flowdown, system and trade definition
Design space exploration tool and data management
Risk assessment and analysis
Performance predictions
Discipline models
Design process
System design
•Uncertainty models
•Virtual test envirmt
•Anomaly models
•Robotics mfg/ srvg
Disturbances parameters
Integrated end-to-end system model
Scene
Science models
Operations models
Cost model
Update and validate model, Automated system identification, System model defines expermnts
H/W technology experiments

14.3.1 Large-Scale System Modeling (LSSM) Environments Enables Future Missions

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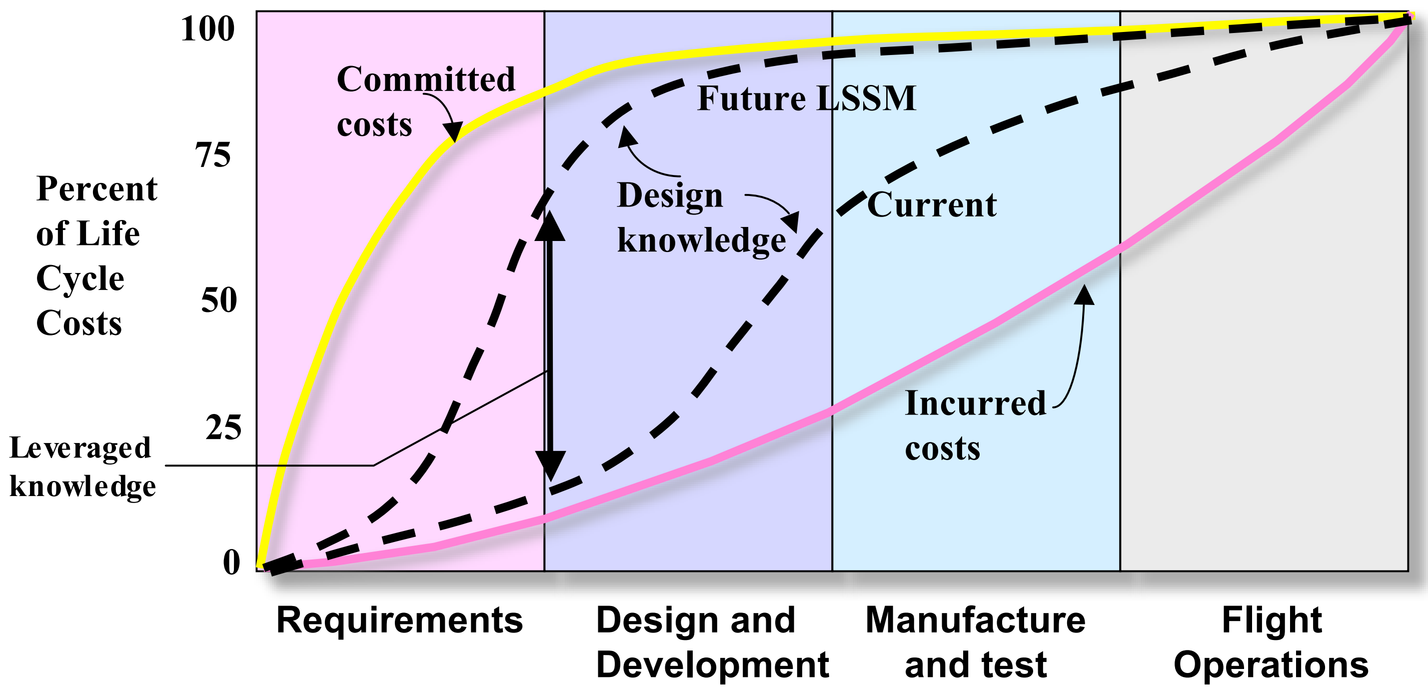
- Much of mission costs are committed within the first part of the development cycle.
- LSSM environments proposed for the future provide early in-the-process knowledge for reducing mission cost and risk.
  - Much of current modeling resources not used efficiently.

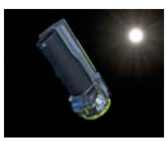


14.3.1 Current Modeling Support Over Mission Cycle

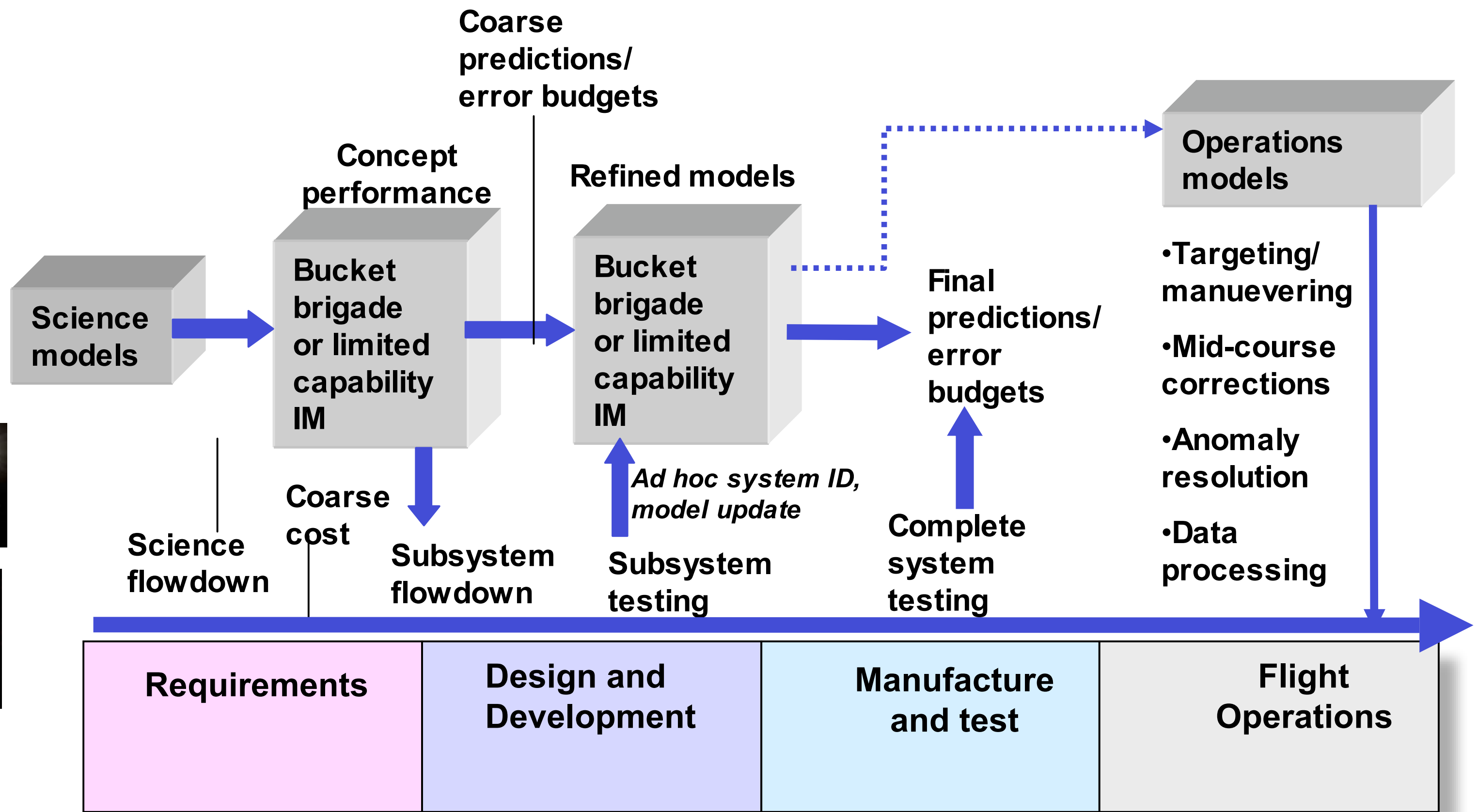
Current missions - Just-in-time modeling, serial modeling support

- Discipline/ developmental integrated models, Monte Carlo methods
- Local computing

Spitzer



Chandra



14.3.1 Future of Modeling - Cradle-to-Grave System Engineering Support

Current missions

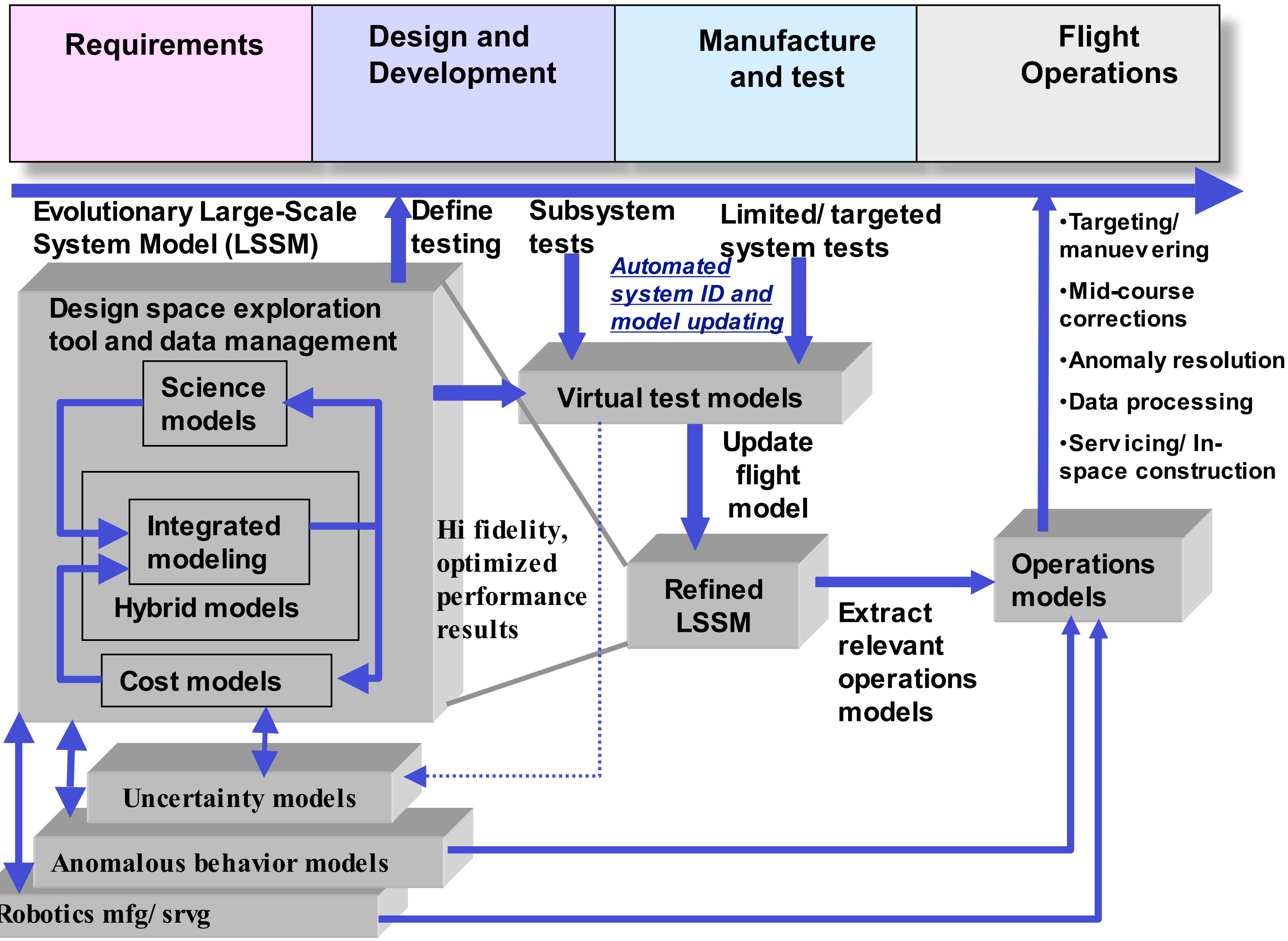
Complexity increasing, subsystem coupling, ground testing constraints (environmental, programatics)

Future missions -

Large-scale integration, cradle-to-grave, rapid prototyping, multple models, expert systems, uncertainty bounds, distributed computing, anomalous behavior models, model-driven testing.

LISA

TPF-I



Assumptions
for Capability 14.3 - Engineering Modeling

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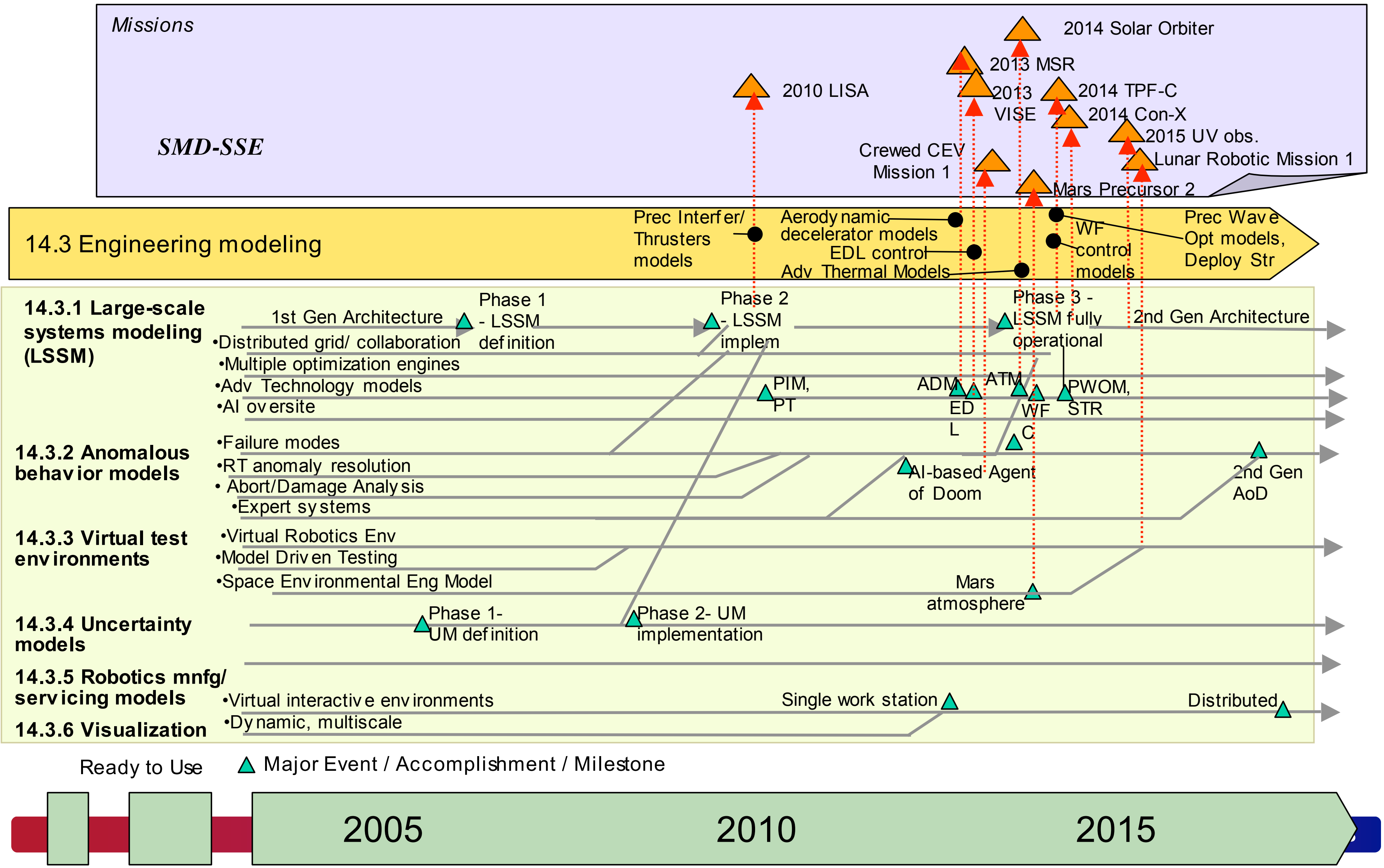
- Modeling is part of all programs at many levels and scales.
  - "State-of-the-art" is actually state-of-the-practice, ie, exceptions can be found.
- Detailed engineering technology/discipline models are discussed in other roadmaps. Detailed modeling needs align with technology needs.
- System engineering roadmap will cover cost and risk modeling whereas AMSA includes integrating these into large scale modeling architecture.
- Current COTS discipline tools will evolve to support general engineering analysis tools with a broad market, but not a NASA-driven market.
- Historical trends will continue in terms of engineering system and technology complexity increasing.
- Engineering CBS includes design-driven Operations models that are critical to engineering process, such as Anomalous Behavior and Robotics Assembly/ Servicing.
- Modeling of human-machine interaction is covered under other Operations CBS.
- Examples and terminology tailored to SMD missions, with an instrument focus, but have clear anologies for exploration and aeronautics.
- Technology identified on capability timeline charts is developed several years prior to program infusion.

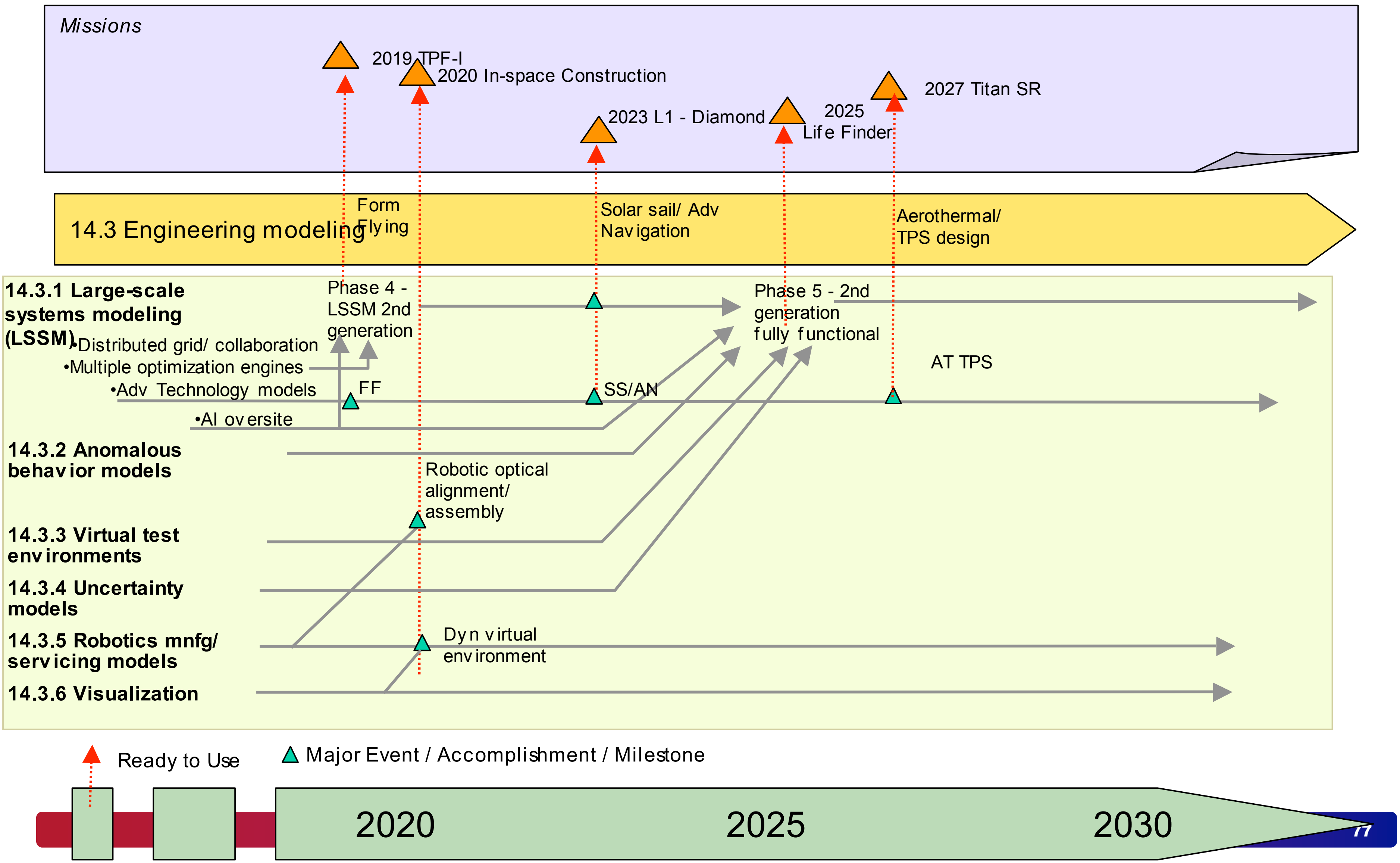
Drivers for Capability 14.3 - Engineering Modeling

- ***Large scale system modeling*** **driven by large, technically complex programs but useful to all missions:**
  - **LISA, TPF, Black Hole Imager, SAFIR, Planet Imager, Life Finder, Explorer Vision**
- ***Virtual test environment*** **drivers same as above with planetary exploration missions especially critical drivers.**

Capability 14.3: Engineering Modeling



Capability 14.3: Engineering Modeling



Capability 14.3 Engineering Modeling- Goals and Milestones

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Engineering	Today's Capability	2010-2015	2016-2020	2021-2035
Large-scale system modeling	Bucket-brigade Developing integrated system modeling, significant discipline modeling & optimization, approximate models	Cradle-to-grave models, rapid model deployment, imbedded data management, integrated cost models, selected advanced discipline models, MDO	Seamless model evolution through design phases, integrated risk models, design traceability, additional advanced discipline models, agent-based.	Distributed, MDO, environment for optimization, advanced data management, cost/ risk integrated, science and operations, cradle-to-grave models, rapid prototyping.
Virtual test environment	Widely varies, not baseline approach. Fit tool for manufacturing	Human exploration hazard models	Robotic assembly testing	Expansive HWIL, max modeling/ min testing, auto sys ID/ model update, order of magnitude reduction I&T.
Uncertainty models	Pprobabilistic uncertainty propagation tools. Some uncertainty characterization.	Non-probabilistic uncertainty tools. Expanded uncertainty characterization.	Tools for rigorous uncertainty bounds in the validation domain.	Tools for rigorous uncertainty bounds in the predictive domain. Input uncertainties fully characterized.
Anomalous behavior models	Typical using current models with some add-ons as mishap investigation.	Subsystem AI agent of doom. High-fidelity abort & damage analysis..	Full system AI agent of doom.	Explore full failure/ anomaly mode space during design. AI agent of doom. Real-time isolation and resolution.
Robotics mfg/ servicing (MS) models	Commercial mainly, minimal space-based modeling (servicing), Mars exploration.			Virtual toolset enabling dynamic assessment of designs for space/ planetary based MS.
Visualization technology	3D, small-scale dynamic visualization, single discipline analysis.	Multidiscipline analysis, design space exploration	Interactive design steering, design space exploration agents	Hologram, instant visualization of dynamic events at multiple scales.

Capability 14.3: Related technologies / dependencies

Capability 14.3: Priorities

Capability 14.4 Integration

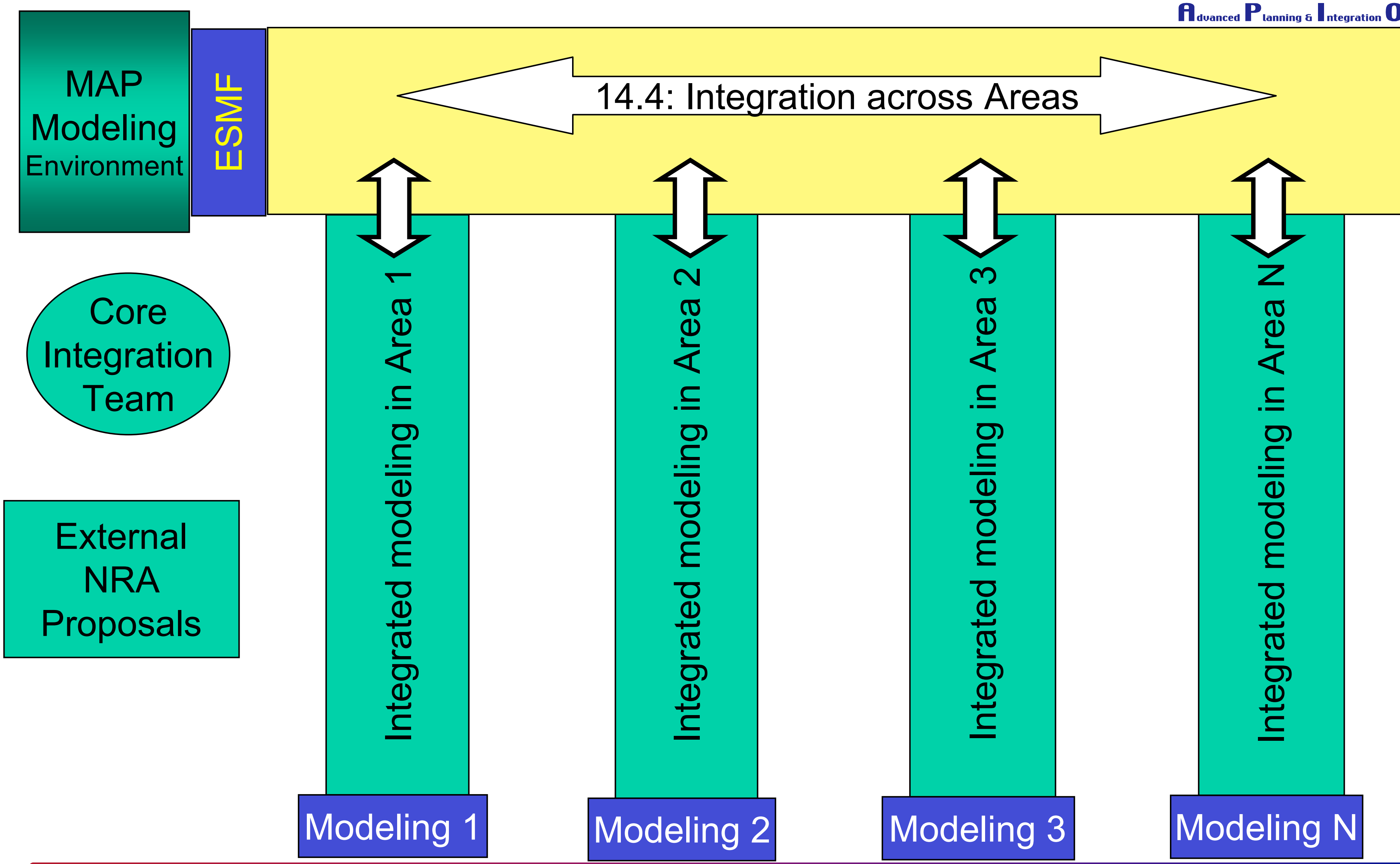
Speaker: Walt Brooks, Lead
Ron Fuchs
Mark Gersh
Loren Lemmerman

Capability 14.4 Description : Integration

Integration occurs recursively at all levels

- Definition: In this section we treat a level of integration of ops, eng and sci. that enables a full system simulation enabling mission optimization in engineering, ops and science
  - Assumes that progress is being made at the science, engineering and operations level, each of which has their own internal integration challenges
  - Customer: A primary customer of this is Systems engineering
  - uses this capability in a "mixed" initiative mode to stimulate engineering design trades
- Motivation: Goals of defining and supporting a focus on integration
  - -product/capability that will not emerge through normal science or engineering processes
  - decisions support in full system simulation
- Essential Eventual ability to assess risk and cost across the entire mission
- State of the art now is mixed mode
  - Deep analysis with heuristics simple models not yet characterized the holes in this process - have not characterized where we have sufficient fidelity
  - Huge high fidelity codes are "manually" integrated using Viper
  - Trusted legacy codes - keeping them vital moving to new platforms- V&V

Capability 14.4 Description : Integration



Capability 14.4: Benefits

- Mission design phase you gain more complete insight into feasibility creating better costs estimates and risk assessments
  - Model inputs that didn't exist before so that all major technical issues and subsystems are handled analytically and interact dynamically as opposed to using approximations and manual integration
  - Allows you to explore design optimization earlier, more realistically and to explore a larger design space
- During anamoly resolution allows rapid response with self consistent underlying assumptions
  - Integration insures rapid response and eliminates the labor intensive and sometimes insurmountable issues associated with linking complex models that have been developed in the absence of a framework
- Directly validated a fully integrated system
  - Individual validation of models ignores the linear and non linear interactions of the subsystems and systems of systems

Capability 14.4: Requirements /Assumptions

- Missions driving the requirements
  - Engineering
    - CEV
  - Complex operations
    - Moon Mars spirals -
  - Reference Science list
    - - "whole" earth Model
    - Large aperture telescopes-TPF,...

- Additional Assumptions that the team used that drove the need for the capability
  - Discipline model development wil continues and that integration at the component level
  - NASA cannot do this on its own we will partner with other agencies and industry and academia to develop the key components
    - There are some areas in which NASA is the world leader and these models must continue to be developed
  - Somebody has to be responsible
  - You don't integrate in the absence of a problem/reqts
  - Infrastructure will exist and be supported within the agency to facilitate the process of developing this

Capability 14.4: Current State-of-the-Art

- Integration is occurring within science and engineering sub discipline disciplines-
  - a few selected examples of focused science and engineering integration
  - Specific Examples
    - IMOS
    - ESMF
    - SWMF
    - Mars EDL
- The Infrastructure tools required for science and engineering teams in compute, viz and networks are just adequate to handle this first tier of integration - full system integration will require several orders of magnitude increase in these capabilities
  - Computing -TFLOPS
  - Networks-Gbps
  - Viz-Tbyte data sets
- Archives, collaboration and integration tools are marginally integrated
- Standards and protocols are emerging within communities there is no focus on bringing these together at a system level

Capability 14.4: Need Statement / Gap analysis

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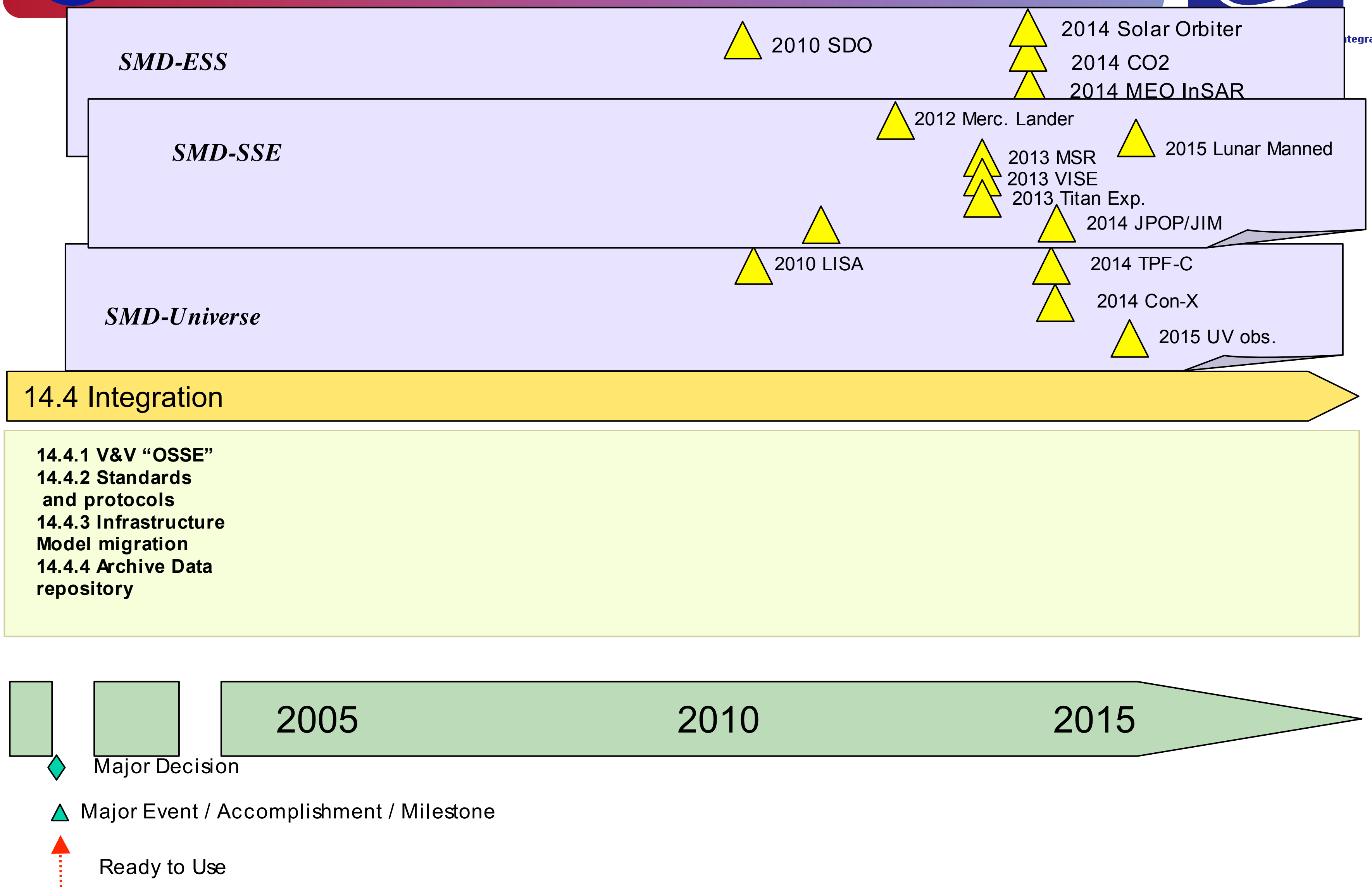
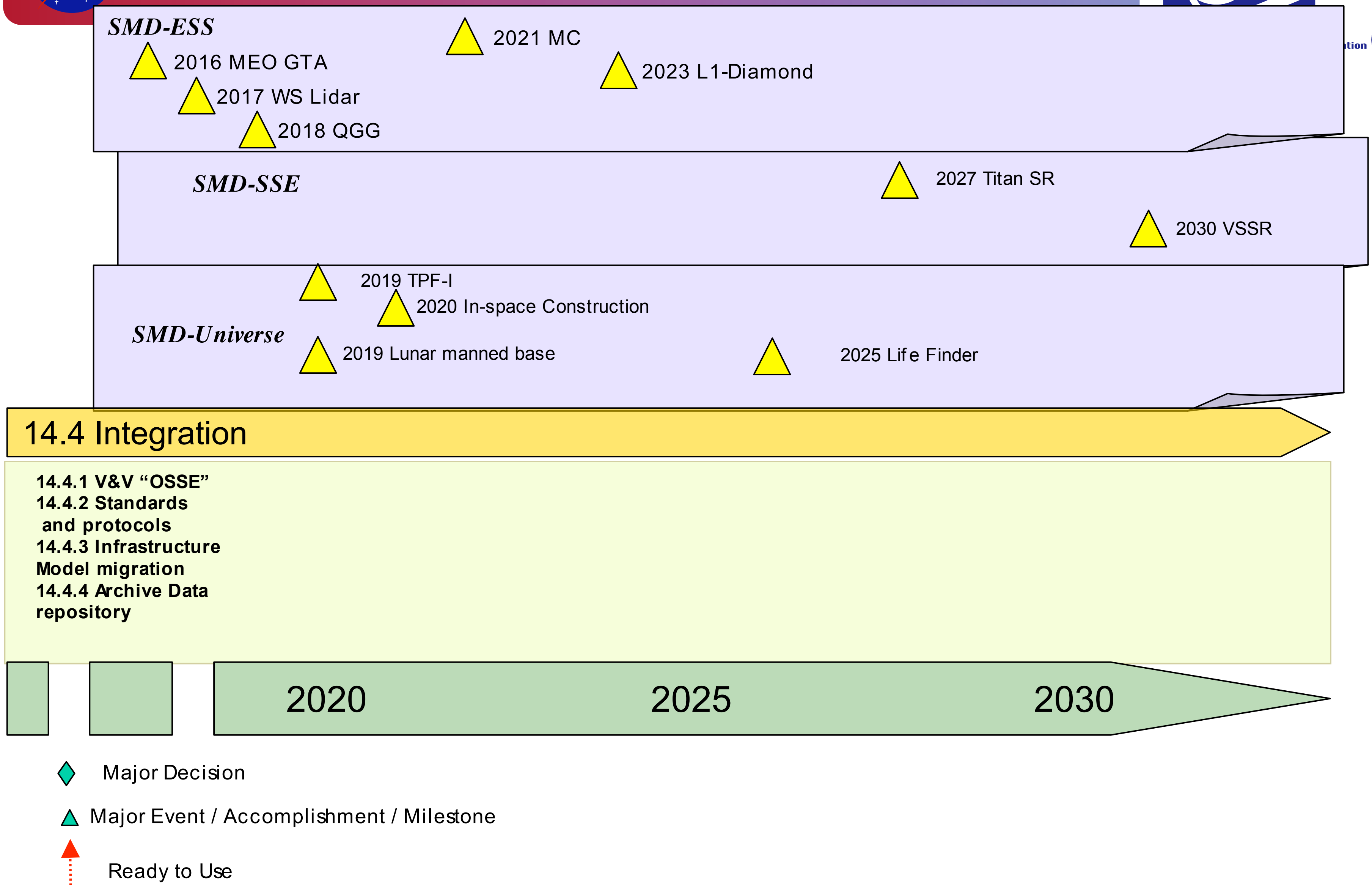
Capability 14.4: Integration Roadmap



Capability 14.4: Integration Roadmap



Capability 14.4: Metrics

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- Identify metrics (specify for technology or sub-capability)
  - Number of models integrated
  - Acceptance and use by broad system engineering community
  - Success in using initial integration to contribute to near term missions
  - Migration of the tools to next generation missions and spirals
  - Acceptance and eventual "commercialization"
  - Reduction in the number and disparity of models
    - -evolution of standard models that are V&V
- Figures of merit for the technology
  - Radical reduction in the cost of mission development and time to "market"/solution
  - Ability to have a complete view of the system and it's sensitivities and interactions
  - Ability to query and to make broad system trades while maintaining the relevant "physics"

Capability 14.4: Maturity Level Assessment

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- Assessment of current state-of-the-art of capability
  - Description of how key component technologies or sub-capabilities are integrated to provide the capability
  - Current Capability Readiness Level (CRL) (Note: In limited cases where CRLs do not apply, other appropriate methodologies may be used to assess capability readiness)
  - Capability development needed to achieve CRL required by a mission; level of performance and expected deliverables
  - Need date
  - (THIS CAN BE A TABLE)

Needed

Capability 14.4: Related technologies/ dependencies

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- Assessment of current state-of-the-art of key component technologies
  - Leading technology candidates
  - Current technology readiness levels (TRLs)
    - Define TRL for specific capabilities (Note: In limited cases where TRLs do not apply, other appropriate methodologies may be used to assess capability readiness)
    - What current/planned capabilities is this being applied to?
  - Key gaps between current state-of-the-art and required performance levels
  - Need date to reach required TRL f[illegible] (or text description of readiness level)

Needed

Capability 14.4: Priorities

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Capability 14.5: M&S environments and infrastructure

Speaker: Mark Gersh, Lead

Dave Bader	Irene Qualters
Mark Gersh	Dan Reed
Tsengdar Lee	Ricky Rood
Steve Meacham	Quentin Stout
Charles Norton	Thomas Zang

Capability 14.5 Description: M&S environments and infrastructure

- Specifies processes, specialized infrastructure, and technology required to enable successful development and implementation of modeling and simulation constructs
  - Product model libraries and data repositories
    - Hierarchies of model components with static and dynamic behavior attributes
    - Geographically distributed but logically coherent
  - Verification, Validation & Accreditation new capabilities
    - Processes using modeling & simulation to test
    - Testing and calibrating models & simulations
  - Simulation tools and environments
    - Visualization tools
    - Data assimilation techniques
  - Modeling application tools, methods and environments
    - Modeling frameworks
    - Software engineering
    - Parallelization of codes
    - Legacy code integration
  - Model-based contracting
    - Going beyond digital text to facilitate procurement transactions between customer and supplier

Capability 14.5: Benefits

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- Captures capabilities and technologies that “crosscut” and span the science, engineering, operations, and integration elements
  - Capabilities and technologies extend commercially available abilities
  - Raises visibility, focuses attention and insight
- Identifies issues that transcend individual elements
  - Every mission affected by each crosscutting theme
  - Cost- and time-to-solution considerations dictate that activities identified as cross-cutting be approached in a consistent manner
- Recommends resolution approaches that benefit the broad constituency
  - Provides vehicle for sustainable leverage from cross agency and industry collaborations

Capability 14.5: Underlying Assumptions

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- **Recognize computational community and technology will continue to march forward and NASA cannot dictate pace**
- **Standards & Protocols:** will continue to evolve driven by standards bodies, professional societies, government intervention, and marketplace dynamics
- **Information Security and Access:** systematic vigilance, commercial and federal standards and best practices followed
- **Availability of infrastructure capabilities assumes progressive technology trends**
  - **Computing trends:** massively parallel systems, hybrid computing architectures
  - **Communication trends:** exponential growth in traffic, universal high bandwidth
  - **Data storage and management:** peta- to yotta- scale data storage, development of scalable management tools and methodology
  - **Integration technology and capability:** tools continually expand their range of applicability and scale

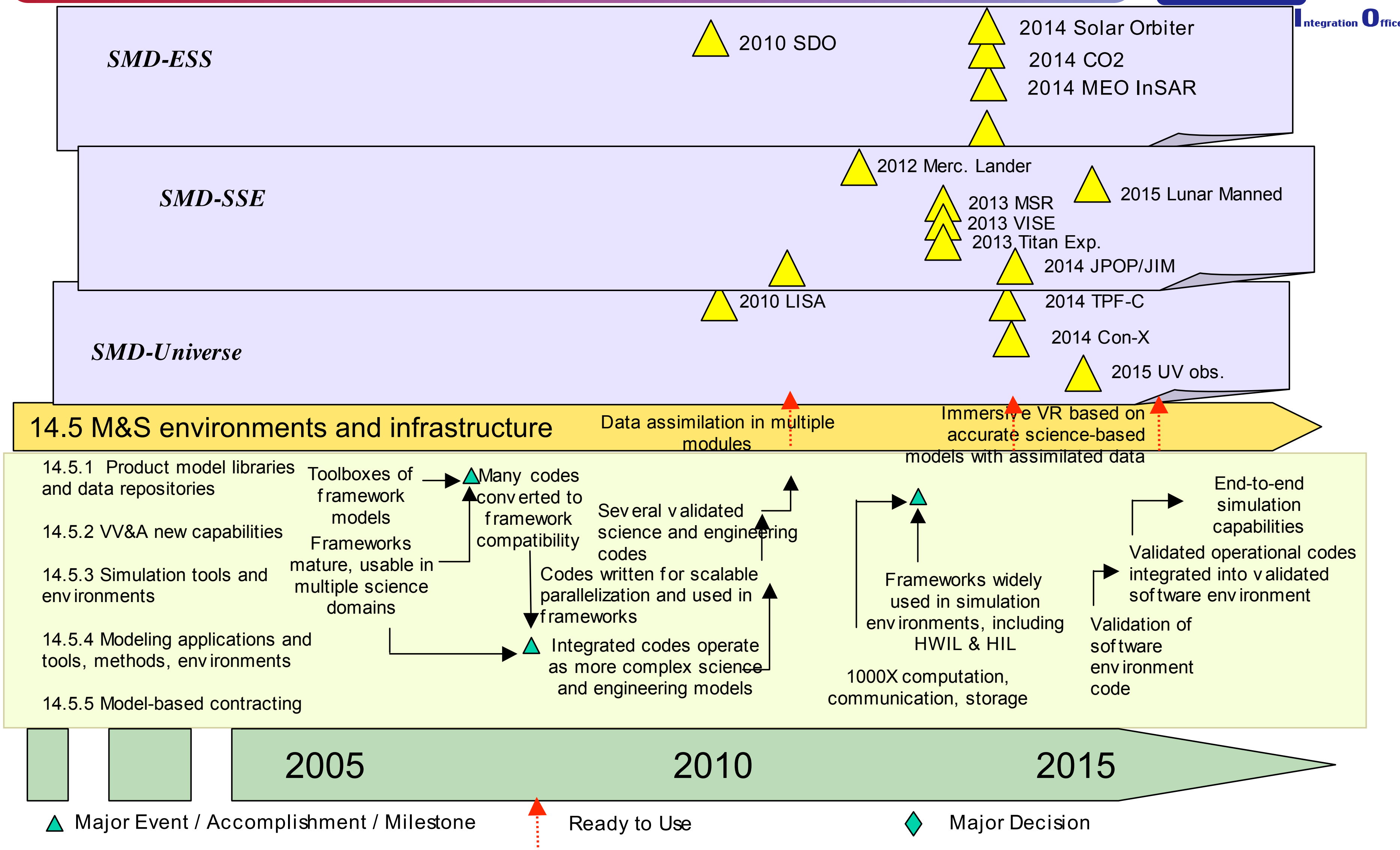
Capability 14.5: Current State-of-the-Art

- **Product model libraries and data repositories**
  - Rudimentary, discipline-explicit libraries with little cross domain integration
  - Creation of some generic, tailor-able components
- **Verification, Validation & Accreditation**
  - Little methodology and directives for using M&S within VV&A processes
  - Limited use of M&S techniques in VV&A
- **Simulation tools and environments**
  - DoD High Level Architecture Run Time Environment supports military operational war fighting simulations
  - Highly limited to domain specific implementations
- **Modeling applications and tools, methods, environments**
  - Fragmented; difficult to integrate multidisciplinary models
  - Very few models are implemented in scalable parallel codes
  - Data management is more document driven than granulized to the object level
- **Model-based contracting**
  - Mostly research constructs and prototype demonstrations
  - No defined legal or organizational policies and procedures in place

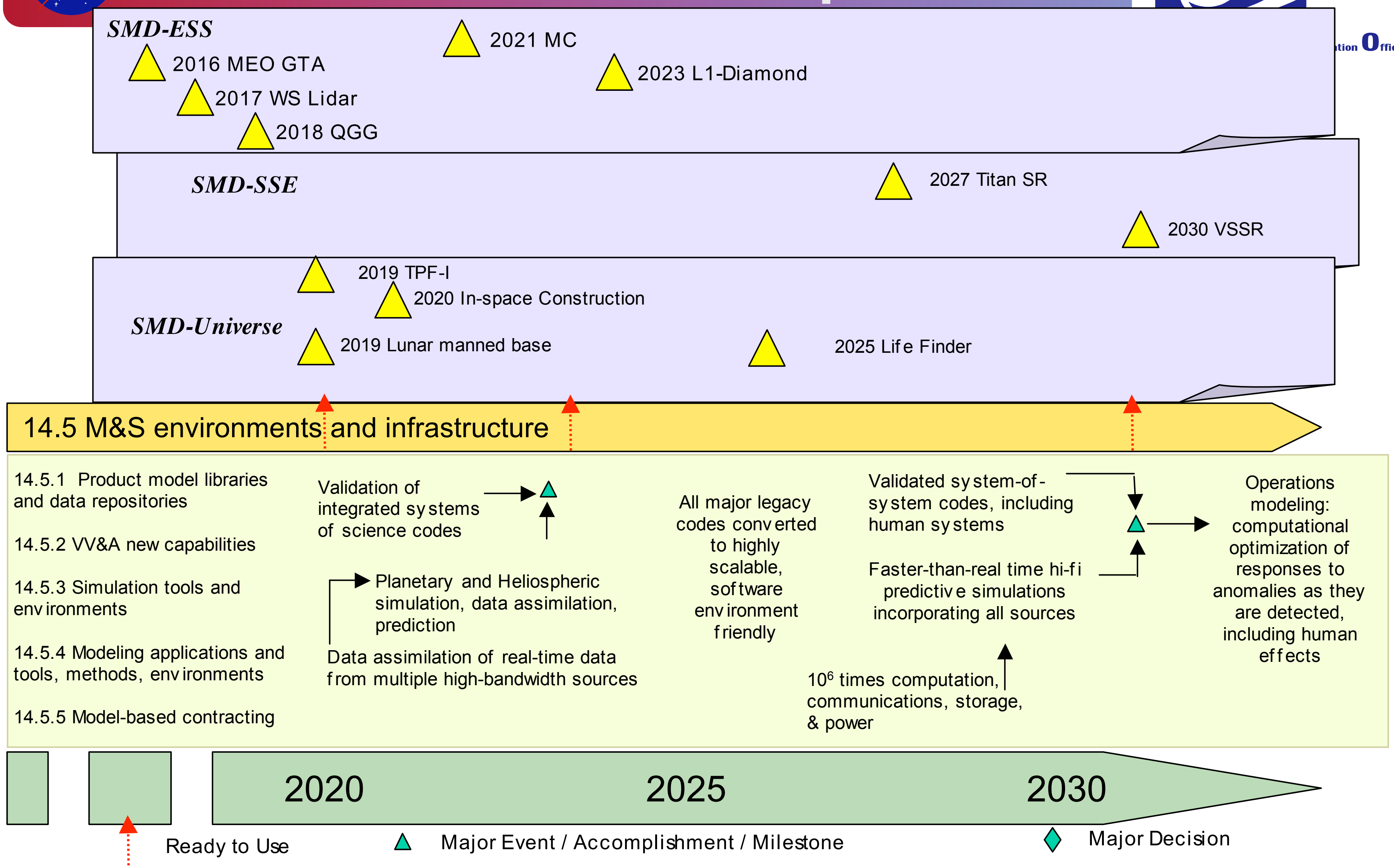
Capability 14.5: Need statement / Gap Analysis

Advanced Planning & Integration Office

Capability 14.5: M&S environments and infrastructure Roadmap



Capability 14.5: M&S environments and infrastructure Roadmap



Capability 14.5: Maturity Level

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Capability Element	2005	2010	2015	2020	2030
Product model libraries and data repositories	Individualized meta data models and model libraries Data repositories logically and physically distributed	Meta data Standards Model interfaces Logical Data Architecture	Full data life cycle	Full system life cycle implemented for selected model communities	Full system life cycle for all mission critical modeling communities
Verification, Validation & Accreditation new capabilities	No process No use of automation Ad hoc unit-level complexity	Uniform systematic Unit-level complexity	Uniform systematic Subsystem-level complexity	Uniform systematic System-level complexity	Uniform systematic Systems-of-systems-level of complexity
Simulation tools and environments	Virtual reality demo projects Data assimilation typically ad hoc manner.	VR quite common Data assimilation techniques expanded	High fidelity VR Mature science-based unit data assimilation for single data modes Simulations run in software frameworks	Use of hifi VR with systems-level data assimilation incorporating restricted data modes	Systematic use of hifi VR using system of system models with science-based assimilated multimodal real-time data
Modeling applications and tools, methods, environments	Demo frameworks, Parallel codes available for some components, most based on legacy codes.	Frameworks used by selected communities. Parallelization tools expand their range of usefulness.	All new codes are written for software environment with parallelization.	Major legacy codes replaced by scalable parallel ones which run in software environment.	Systematic use by all M&S developers for full lifecycle of NASA missions. Complete complex models run efficiently on highly parallel systems.
Model-based contracting					

Capability 14.5 Critical Supporting Considerations

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- Intellectual Property/ITAR and Data Rights
  - Envision a marketplace of models interfacing within a bazaar of simulations
  - Sharing and integrating best of breed will rule the day
- Enabling Partnerships
  - NASA must leverage extensive DOD and DOE experience and efforts in "high-end" M&S policies, procedures, and infrastructure
  - NASA must exploit COTS software when available and fund needed functionality as an extension to commercial capability
  - NASA, along with other Agencies, must support university and industrial research to help achieve capabilities
- Human Resources Development
  - Success requires cultural change in Agency attitudes and available abilities catalyzed by focused training and education of civil servants and contractors
- Sustained software infrastructure maintenance
  - Incorporate funding mechanism to support full system life cycle including maintenance and evolution of M&S tools used throughout Agency
  - Create suitable career paths for people designing and maintaining software infrastructure

Capability 14.5: Priorities

AMSA Summary

Tamas Gombosi

Capability 14: AMSA Summary

- AMSA is about fundamentally changing the way NASA does technical business
  - To lower risk of future demanding missions
  - To enable classes of missions not doable with today's modeling technology
  - To improve decision-making throughout NASA by enabling end-to-end system simulations.
- Key capabilities are
  - Scientific modeling simulation
  - Operations modeling
  - Engineering modeling and simulation
  - Integration
  - M&S environments and infrastructure

Capability 14: Driving Missions

Full AMSA list		Driver for				
Mission	***Year***	***Science***	***Operations***	***Engineering***	***Integration***	***M&S Env.& infra.***
		√				
NPP	2009	√				
SDO	2010	√				
NPOESS	2010			√		
LISA	2010	√				
Global Trop Wind	2013			√		
MSR	2013			√		
VISE	2013			√		
Crewed CEV Mission 1	2013	√		√		
Solar Orbiter	2014	√				
JPOP/JIM	2014	√				
IHS	2014			√		
TPF-C	2014			√		
Con-X	2014	√		√		
Lunar Manned	2015			√		
UV Obs.	2015	√				
Global Trop Aerosols	2016	√				
Total Column Ozone	2018			√		
TPF-I	2019	√				
Lunar manned base	2019	√				
Geo InSAR Constellation	2020			√		
IN-space construction	2020	√				
L1-Diamond	2023	√				
GEO Global Precip	2025			√		
Life finder	2025			√		
Titan SR	2027	√				

Capability 14: Capability Technical Challenges for AMSA

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Key technical challenges:

- Major challenges in meeting required technologies/capabilities

- Alternatives or offramps

AMSA relationship to other CRMs-Overview

	High Energy Power & Propulsion	In-space Transportation	Advanced telescopes & observatories	High-capacity telecom /information transfer	Robotic access to planetary surfaces	Human planetary landing systems	Human Health and support systems	Human exploration systems and mobility	Autonomous systems and robotics	Transformational Spaceport and Range	Scientific instruments/ sensors	Insitu resource utilization	Advanced modeling and simulation	Systems engineering cost/ risk analysis	Nanotechnology/ advanced concepts
High Energy Power & Propulsion															
In-space Transportation													???		
Advanced telescopes & observatories															
High-capacity telecom /information transfer															
Robotic access to planetary surfaces															
Human planetary landing systems													???		
Human Health and support systems															
Human exploration systems and mobility													???		
Autonomous systems and robotics															
Transformational Spaceport and Range															
Scientific instruments/ sensors															
Insitu resource utilization													???		
Advanced modeling and simulation															
Systems engineering cost/ risk analysis															
Nanotechnology/ advanced concepts															

Moderate Relationship

No Relationship

Critical Relationship

Relationship to other CRMs-Detail

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Advanced Modeling, Simulation, Analysis capability	**Capability Flow and Criticaltiy**	**Related Roadmap**	**Nature of Relationship**
Scientific modeling and simulation engineering modeling and simulation All instrument/sensor types	→	**Scientific Instruments & Sensors**	*Enables Systems architecture studies *Provides applications for science discovery and analysis *Enables instrument design tradespaces *Allows end-to-end instrument design and performance assessment
Engineering modeling and simulation	→	**Systems engineering and cost/risk analysis**	*Provides advanced modeling techniques for all aspects of project *Provides frameworks for tying multiple models together
Operations modeling and simulation	→		Requirements determination, and expansion of the trade space
Engineering modeling and simulation	→	**Advanced telescopes and observatories**	Provides understanding of system trades and risks across implementation approach Enables system level assessment of size and stability (mechanical & thermal) properties from both passive and active approaches
Engineering modeling and simulation	→		Provides advanced mission system and subsystem level modeling, simulation and analysis tools to analyze and do design trades on future telescope and observatory architectures and systems.
Engineering modeling and simulation Operations modeling and simulation System Integration	↔		Provides advanced modeling, simulation and analysis software and hardware tools for highly integrated end to end modeling (structural, thermal, optical, control, …)
M&S Environments and Infrastructure	→		Provides infrastructure tools that enable efficiently managed data for future advanced telescopes and observatories
Engineering modeling and simulation	→	**Nanotechnology and advanced concepts**	Provides multi-scale modeling for materials, devices and systems
Engineering modeling and simulation	→	**Robotic access to planetary surfaces**	Provides EDL modeling (CFD) for entry systems
Engineering modeling and simulation	→		Prov ides EDL Control sys modeling for entry systems
Scientific Modeling and Simulation	→		Prov ides planetary atmospheres modeling for designing entry controls systems
Engineering modeling and simulation	→		Provides TPS modeling for TPS design

Relationship to other CRMs-Detail

Advanced Modeling, Simulation, Analysis capability	Capability Flow and Criticaltiy	Related Roadmap	Nature of Relationship
Engineering modeling and simulation		**Space Communications**	Improved modeling and manufacturing process increases power efficiency for RF communications
Engineering modeling and simulation		**Autonomous Systems, Robotics, and Computing Systems**	High fidelity terrain modeling and analysis; Model-based detection for ISHM; Logistics: Modeling of failure mechanisms; ISHM: V&V methods for models;
M&S Environments and Infrastructure			Collaborative information analysis and sharing
Operations			Activity plan development and analysis; Autonomous Science Analysis, Predictive Modeling, and Optimization
Engineering modeling and simulation		**High Energy Power and Propulsion**	Autonomous Control (Nuc Power) Design/Model; Heat Rejection System design analysis and trades; Shield design analysis and trades.
Engineering modeling and simulation		**Human Health & Support Systems**	Space Human Factors Models & simulations; Design tools & requirements; Maintain, improve risk assessment models/ Analyze proposed mission architectures; Risk analysis model for med events; Med simulation model (testbed); Biomedical models of human systems

AMSA Relationship to SRMs

Advanced Planning & Integration Office

AMSA Identified Need ○
SRM Identified Need ●

Broad Topics Captured / SRM Teams	Lunar: Human & Robotic	Mars: Human & Robotic	Solar System Exploration	Search for Earth-Like Planets	Exploration Transport System	International Space Station	Space Shuttle	Universe Exploration	Earth Science & Apps. From Space	Sun-Solar System Connection	Aeronautical Technologies	Education	Nuclear Systems
Large Deployable Lightweight Apertures				●			No Data Available	●	●			No Data Available	
System/Instrument Design and Performance		●	●	●				●	●	●			●
On-Board Processing		●							●				
Mission Planning, Impact, and Operations	●	○	●	○	●	●		○	●	●			
Space Environment Effects	○	●	●		●	●		○	●	●			
Spacecraft Design and Broad Applicability		●			●	●				●	●		●
In Situ Exploration and/or Sample Return	○	●	●										
Science Needs		●	●	●		●		●	●	●			
Engineering Analysis and Design Needs			●		●	●			○	●	○		●
Planetary Environment, Protection Habitability	○	●	●		○				●	●			
Data Synthesis, Analysis, and Visualization			●	○					●	●			
Navigation and/or Formation Flying		●	●	●	●			●	●	●			●
Telecommunications (Deep Space)		●	●		●	●		○		●			●
Materials Science and Durability		●		●	●								
Robotics, Surface Terrains, and Mobility	○	●	●										
SRM Identification of AMSA Support	**None**	**None**	**Partial**	**None**	**None**	**Some**		**None**	**Major**	**Major**	**None**		**Some**

● Areas where SRMs either mentioned modeling or the topic area need in general

○ Gaps, where SRMs did not mention modeling, nevertheless modeling should be applied

View of AMSA support indicates if an SRM explicitly identified how the AMSA CRMs would aid their goals

Identified topics are based only on data within SRM documents

AMSA Relationship to SRMs

Advanced Planning & Integration Office

AMSA Identified Need 🟠
SRM Identified Need 🔵

Broad Topics Captured / SRM Teams	Lunar: Human & Robotic	Mars: Human & Robotic	Solar System Exploration	Search for Earth-Like Planets	Exploration Transport System	International Space Station	Space Shuttle	Universe Exploration	Earth Science & Apps. From Space	Sun-Solar System Connection	Aeronautical Technologies	Education	Nuclear Systems
Aero-assist, Aero-capture		🔵			🔵		No Data Available					No Data Available	
Human in-the-loop (EDL training, field experiments, virtual testbeds, flight tech.)	🟠	🔵			🔵	🔵					🟠		
Planetary Atmospheres and/or Interior			🔵	🟠					🔵	🔵	🟠		
In Space Propulsion and Transportation		🔵	🔵		🔵	🔵							🔵
Optical Systems			🔵	🔵				🔵					
Spacecraft /Aircraft System Validation	🟠	🟠		🔵					🟠		🔵		
Automated Rendezvous and Docking	🟠	🔵			🔵	🔵							
Safety										🔵	🔵		🔵
SRM Identification of AMSA Support	None	None	Partial	None	None	Some		None	Major	Major	None		Some

🔵 Areas where SRMs either mentioned modeling or the topic area need in general

🟠 Gaps, where SRMs did not mention modeling, nevertheless modeling should be applied

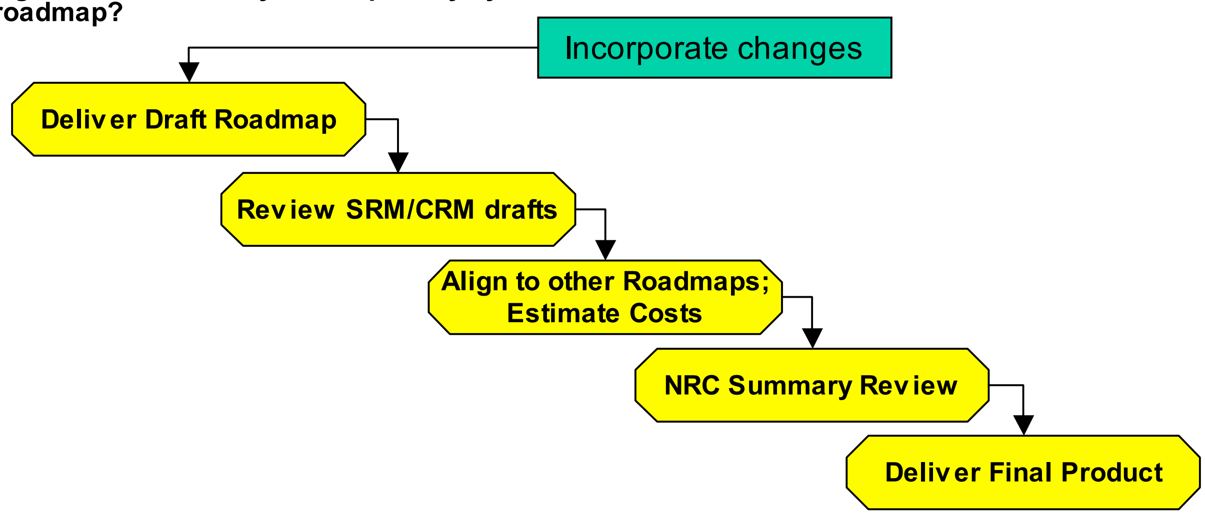
View of AMSA support indicates if an SRM explicitly identified how the AMSA CRMs would aid their goals

Identified topics are based only on data within SRM documents

Summary/ Forward Work

- Make changes to roadmaps based on verbal feedback from NRC review
- Receive the draft Strategic Roadmaps
- Review and Assess all applicable Strategic Roadmaps and their requirements for AMSA capability
- Make changes to AMSA roadmaps to ensure consistency with Strategic Roadmaps requirements
- Develop rough order of magnitude cost estimates for the AMSA Capability Roadmap
- Prepare for 2nd NRC Review which will focus on 4 additional questions:
  - Are there any important gaps in the capability roadmaps as related to the strategic roadmap set?
  - Do the capability roadmaps articulate a clear sense of priorities among various elements?
  - Are the capability roadmaps clearly linked to the strategic roadmaps, and do the capability roadmaps reflect the priorities set out in the strategic roadmaps?
  - Is the timing for the availability of a capability synchronized with the scheduled need in the associated strategic roadmap?

Remaining



Acronyms