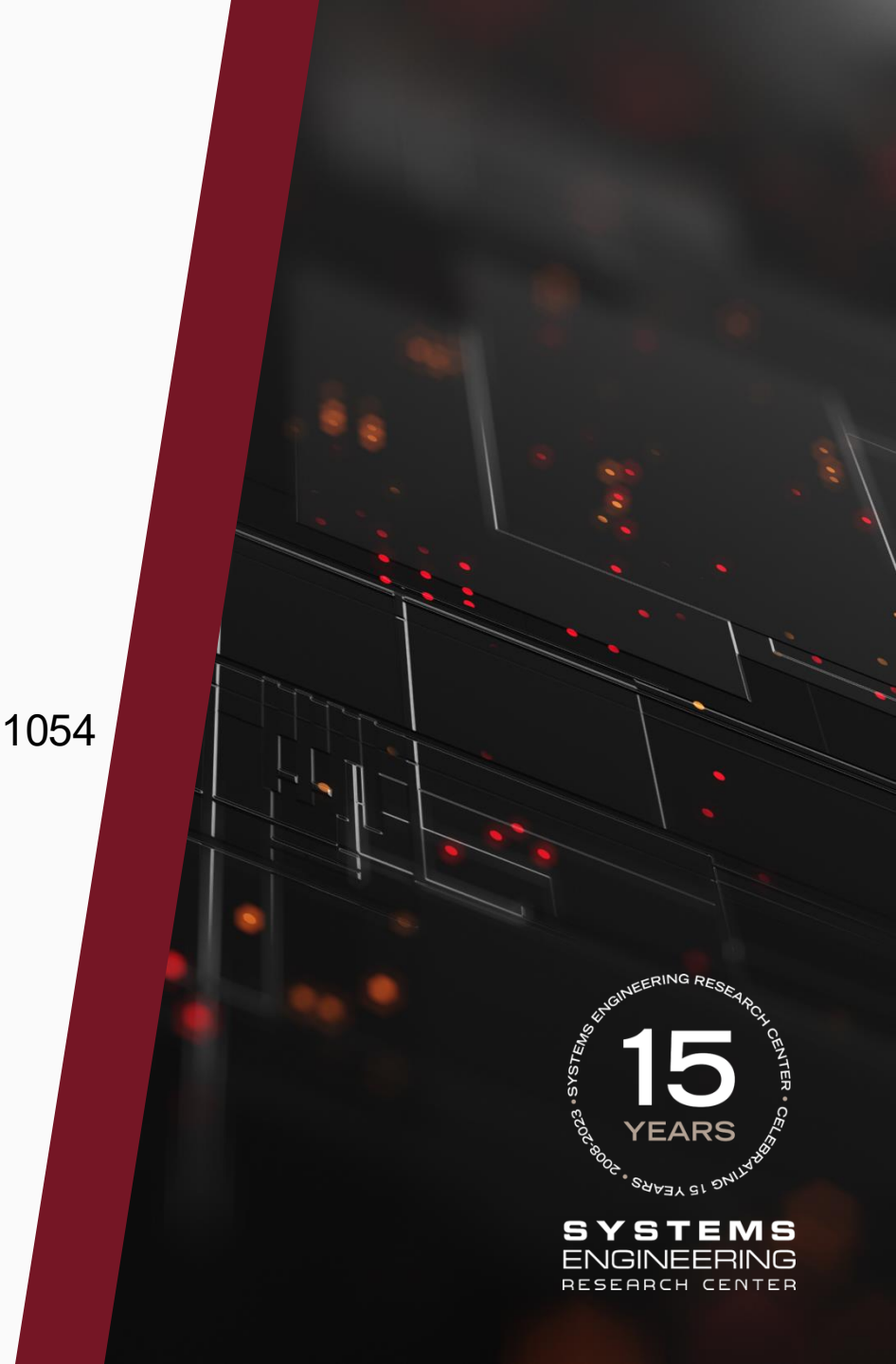
SERC RESEARCH REVIEW 2023 | NOVEMBER 15, 2023

A Decade of Digital Engineering Research

WRT-48/118/141/157170/195/1008/1036; WRT-168, ART-/002/022; WRT-1054
US Navy (NAVAIR), US Army Armaments Center, US Space Force

Dr. Mark Blackburn

STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY®



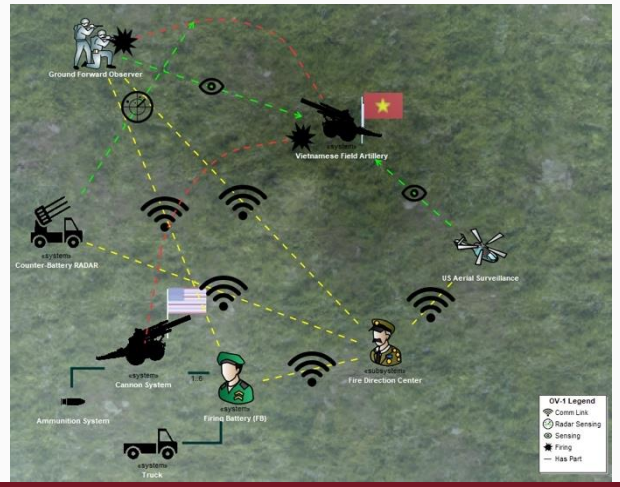
PRIMARY Research Sponsors

2013-2021

Skyzer Search & Rescue

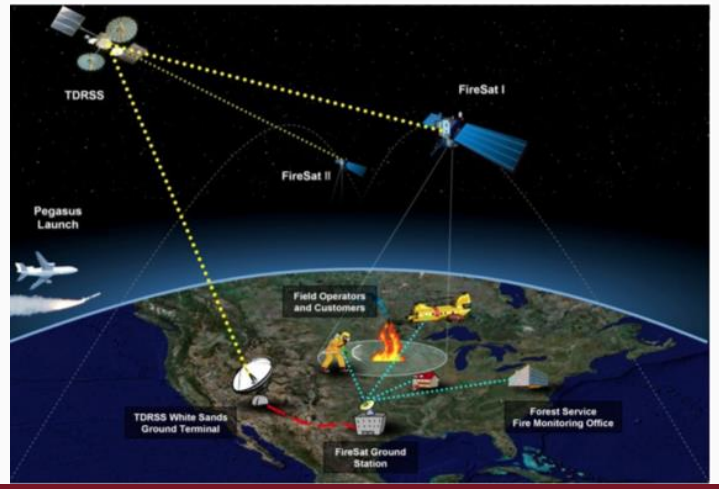
2016-present

Armaments Missions

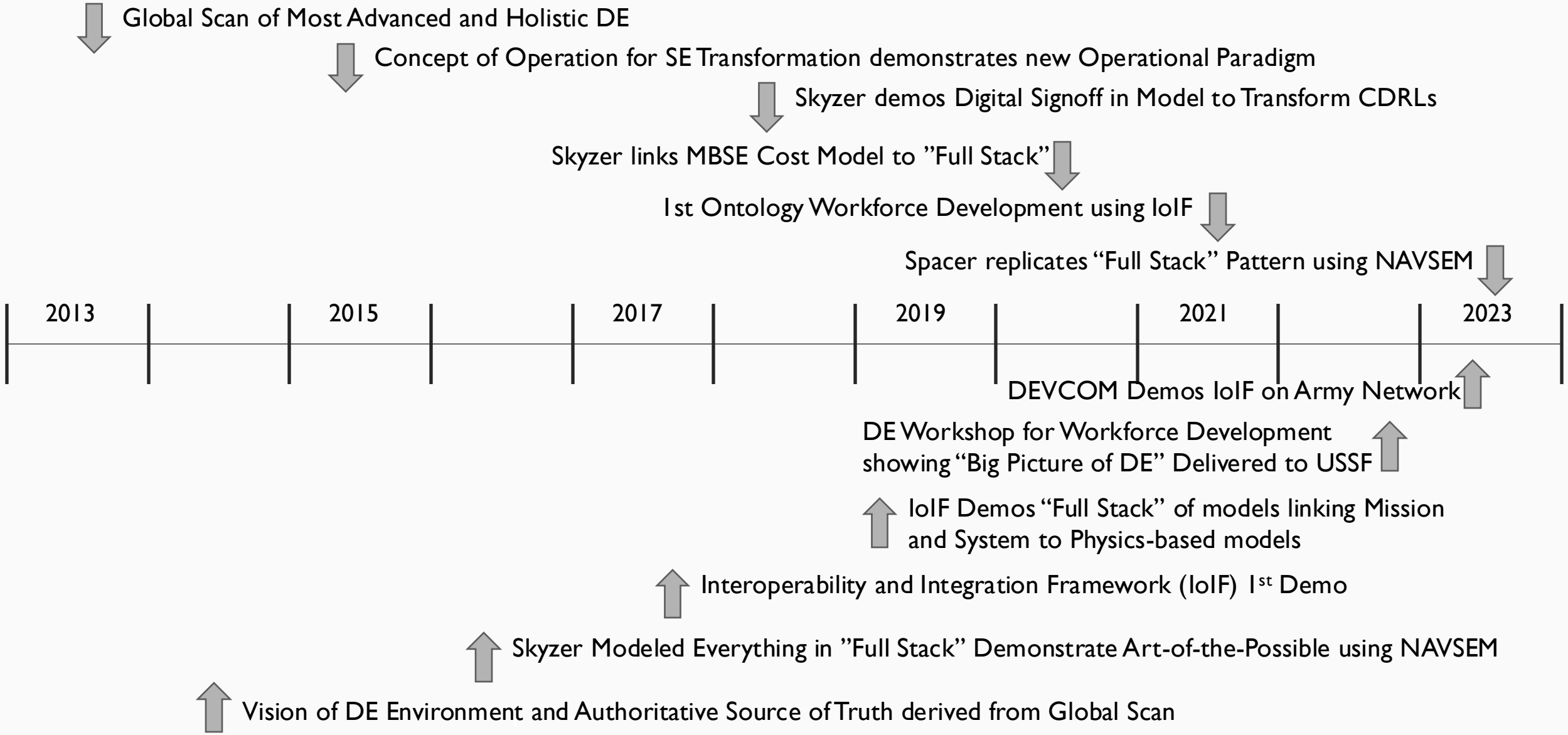


2022-2023

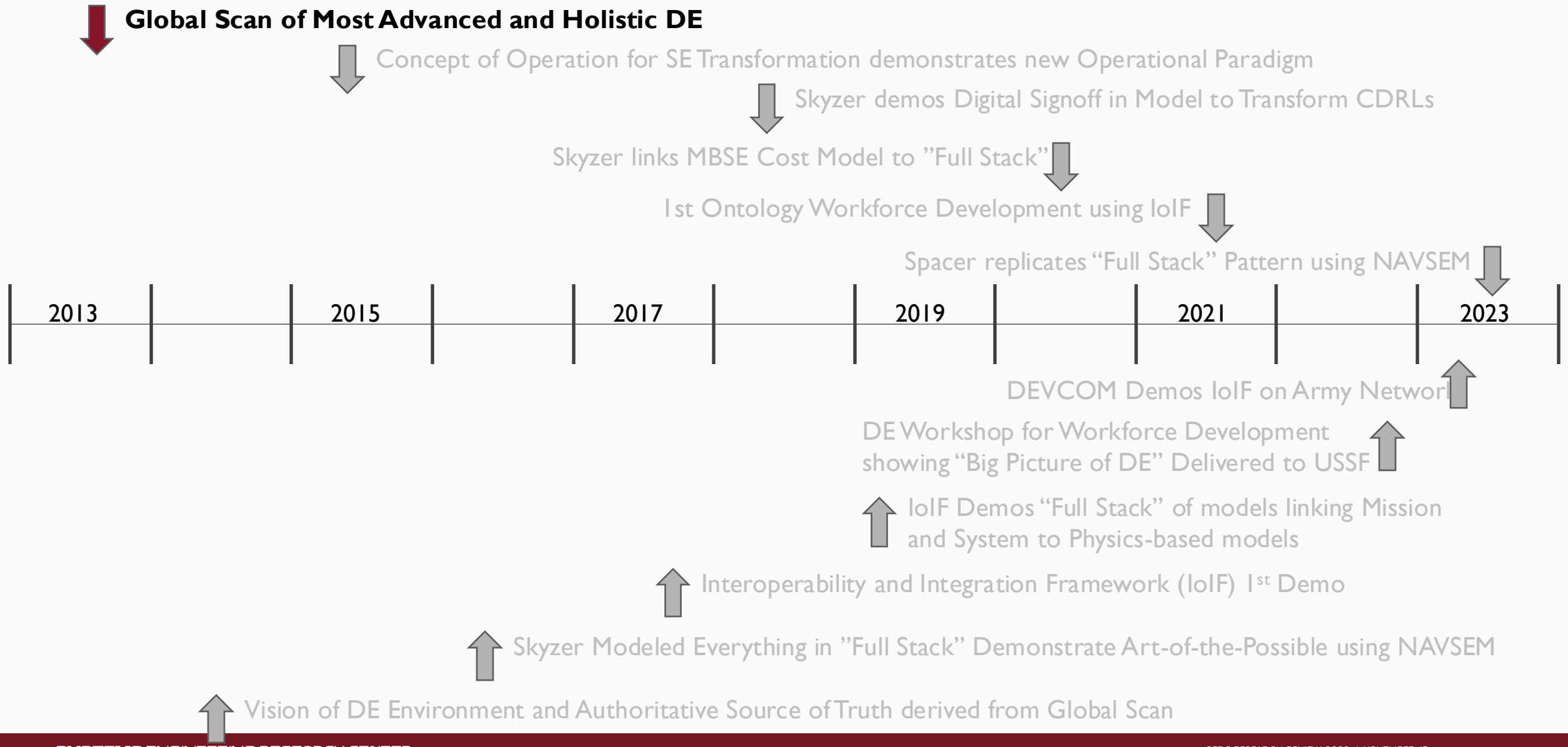
Spacer: FireSat



10 Years of DE Research, Experimentation and Demonstrations Outcomes (non-exhaustive)



10 Years of DE Research, Experimentation and Demonstrations Outcomes

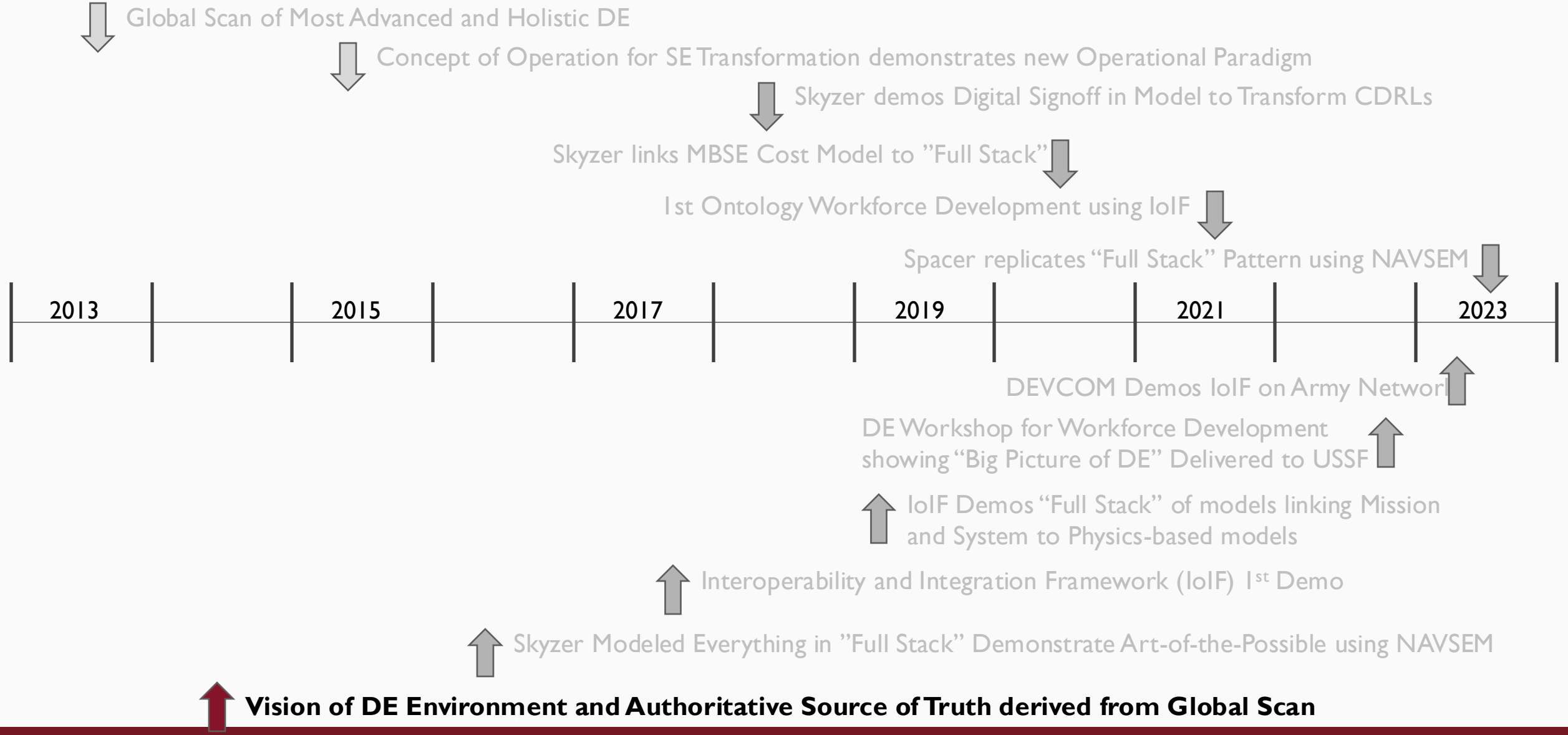


Global Scan of Most Advanced and HolistIC DE

1. Used discussion framework to survey government, industry and academia to quantify, link and trace realized modeling capabilities to NAVAIR Sponsor Vision
2. Goal was not to single out specific companies, rather in the aggregate answer the key question
   - Is it technically feasible (for NAVAIR) to have a radical transformation through model-centric engineering (now Digital Engineering) and reduce the time to develop large-scale air vehicle systems by 25 percent?
3. Discussions were open-ended, we asked:
   - Tell us about the most advanced and holistic approach to model-centric engineering you use or have seen used

- Spectrum of information was very broad; there really is no good way to make a comparison of over 30 different organizations

10 Years of DE Research, Experimentation and Demonstrations Outcomes



Leaders were Embracing Change & Adapting To Use Digital Strategies Faster Than Others

1. Enabling digital technologies are changing how companies are doing business using models-centric engineering (now Digital Engineering)
2. They use model-centric environments for customer engagements, and also for design engineering analysis and review sessions
3. They use commercial technologies and have developed a significant amount of infrastructure on their own
4. One company called it: **“our secret sauce”**

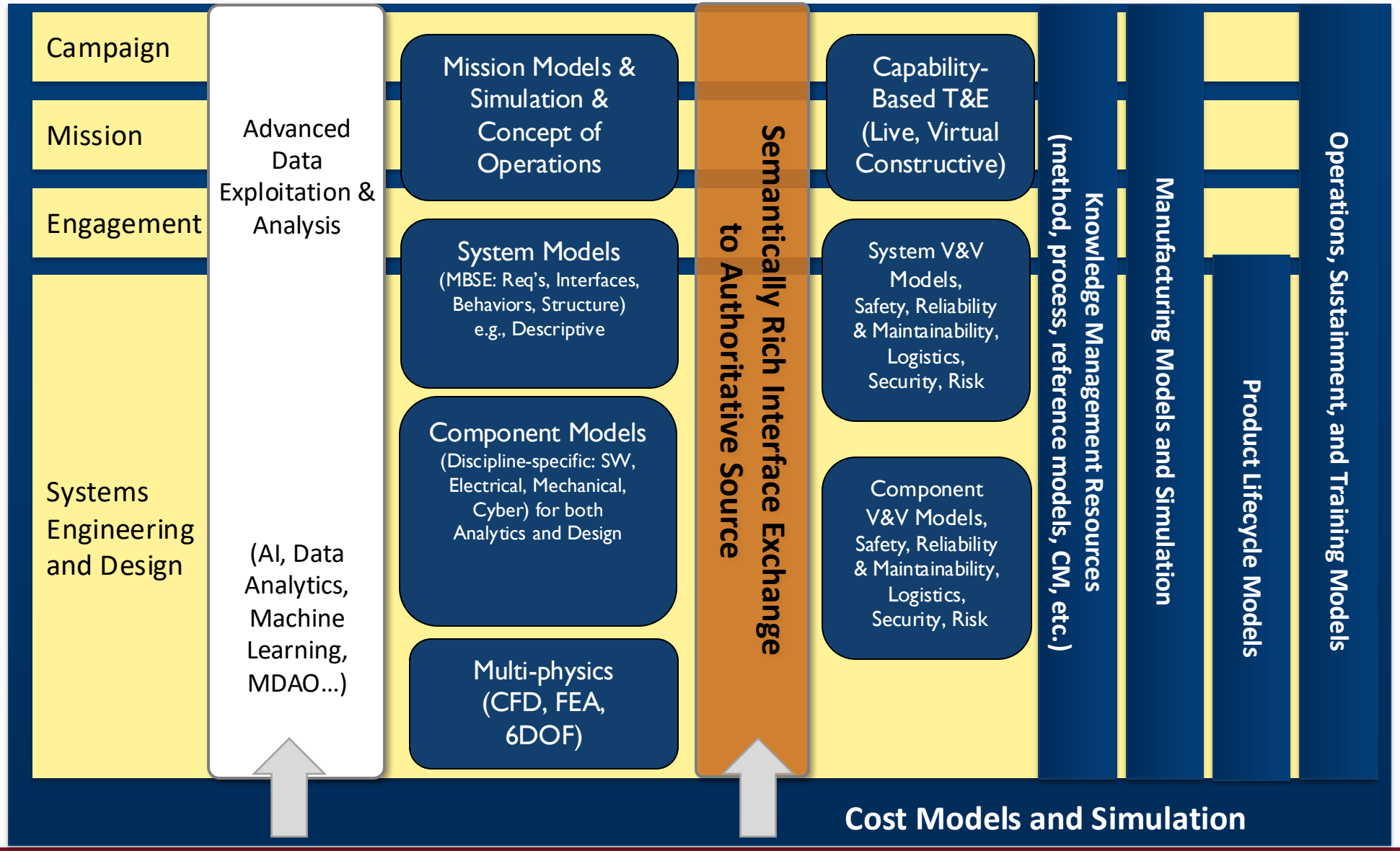
Are we nearing a tipping point driven by the Industrial Internet?

- We heard about mission-level simulations that are being integrated with system simulations, digital assets & products providing a new world of services

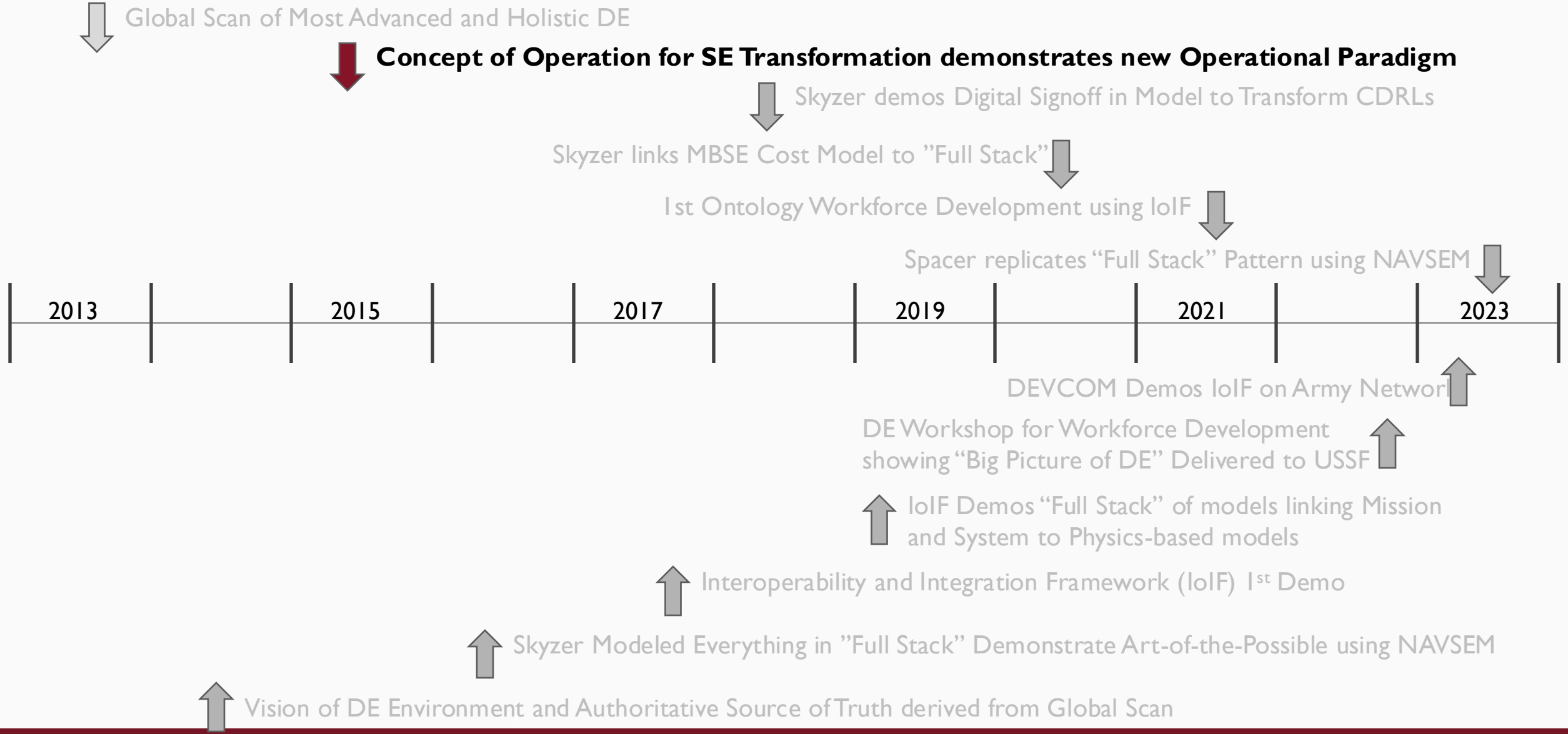
Holistic Model-Centric Engineering can Enable, But…

- Even if technically feasible, there are many changes that will need to be made for NAVAIR to adapt, adopt, transform, and work with contractors in radically different ways

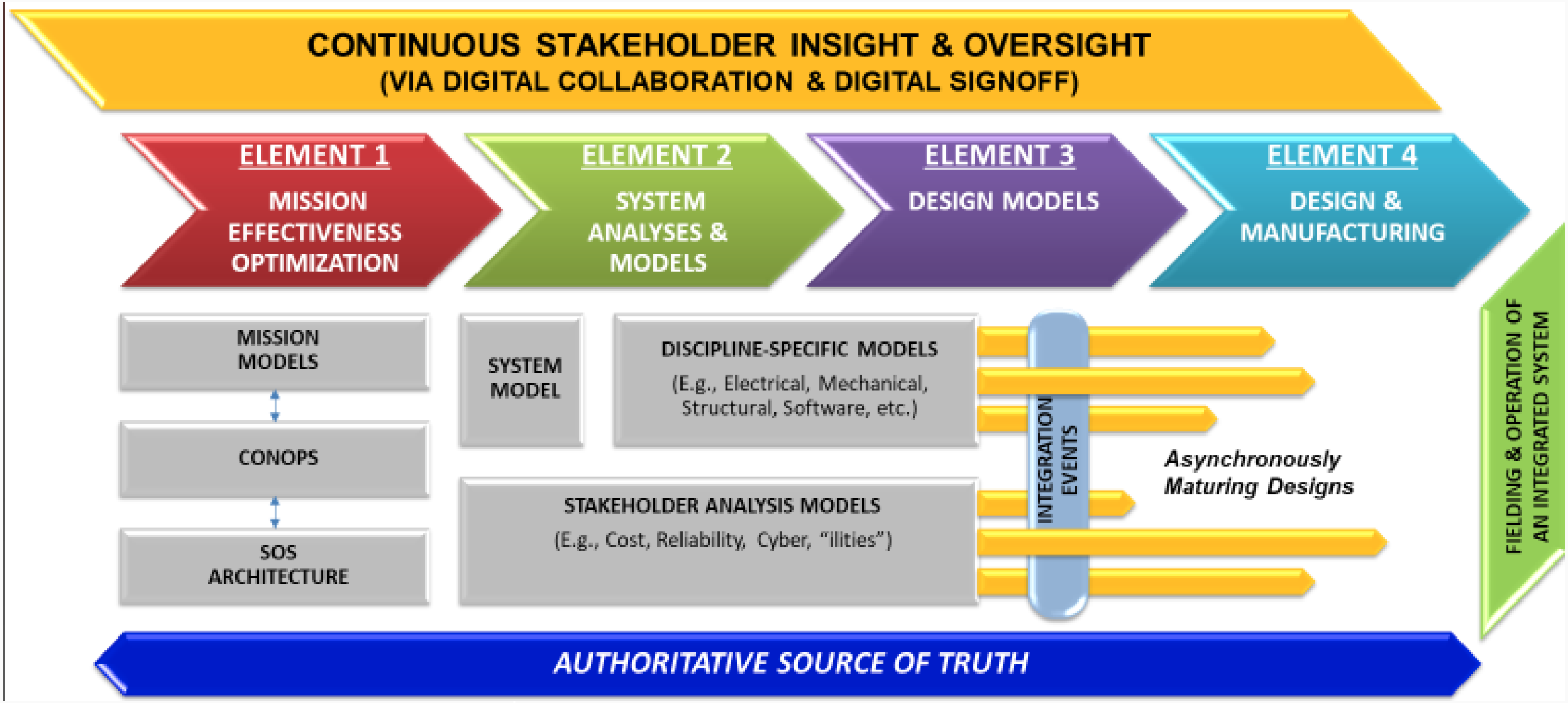
Notional: Reference Architecture for DE Ecosystem (not exhaustive)



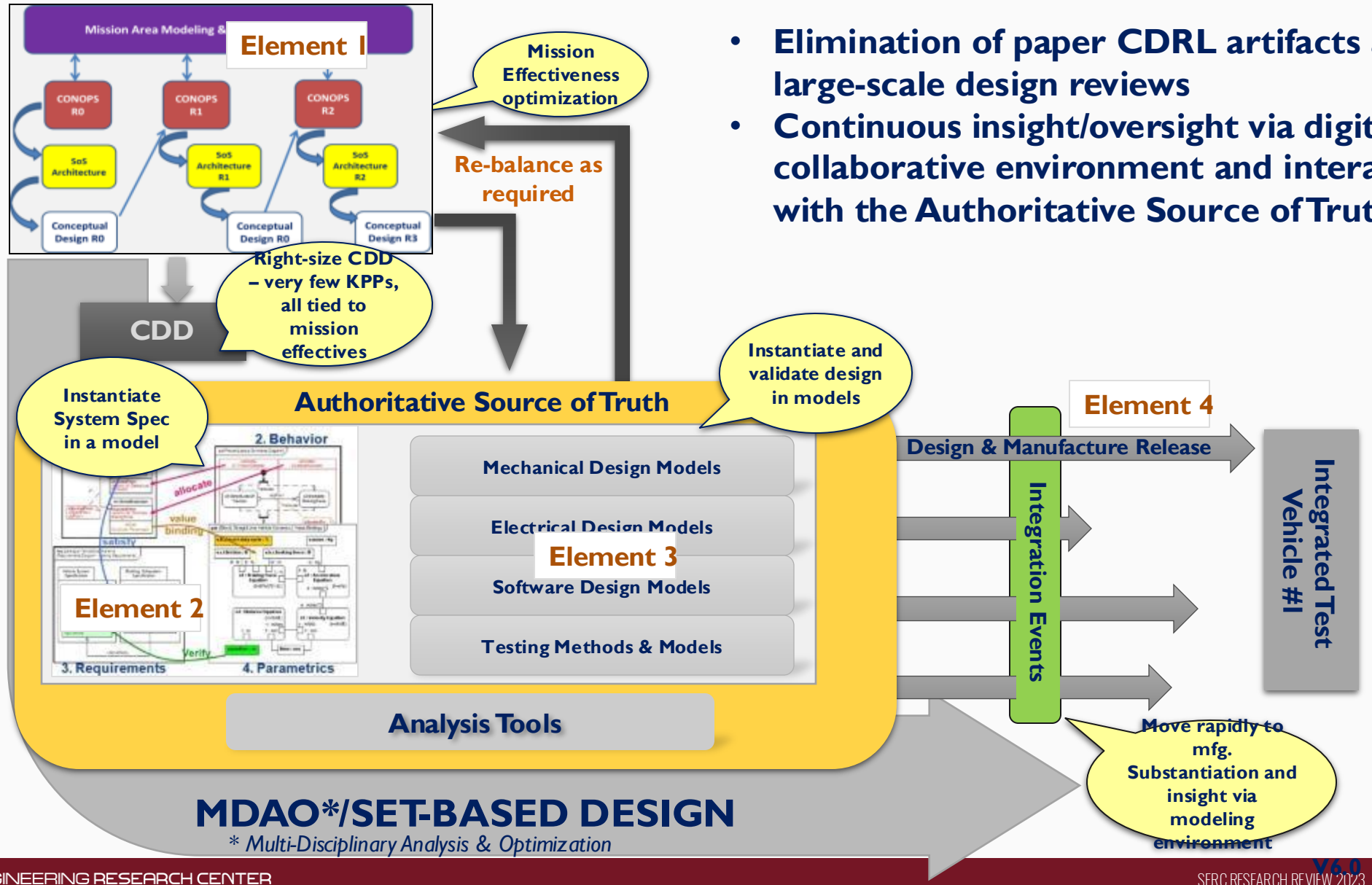
10 Years of DE Research, Experimentation and Demonstrations Outcomes



Concept of Operation for SE Transformation

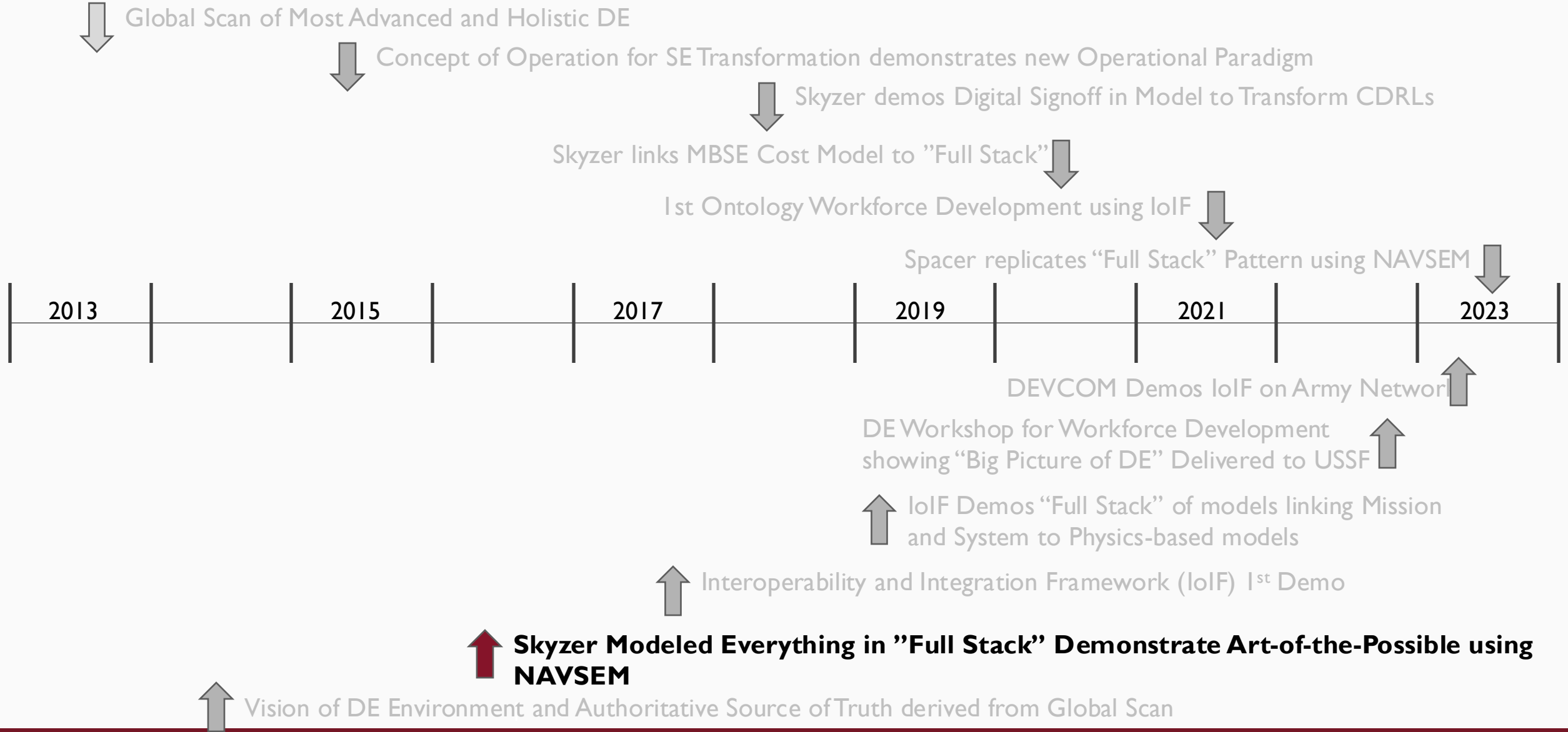


SET Framework for New Operational Paradigm for DE, Acquisition and Implementation



- **Elimination of paper CDRL artifacts and large-scale design reviews**
- **Continuous insight/oversight via digital collaborative environment and interaction with the Authoritative Source of Truth**

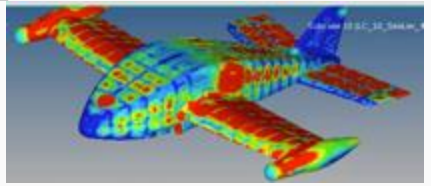
10 Years of DE Research, Experimentation and Demonstrations Outcomes



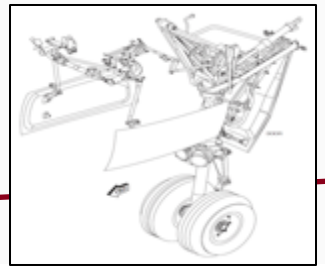
Skyzer "Full Stack" to Demonstrate Art-of-the-Possible using NAVSEM

Deep Dives by Phases

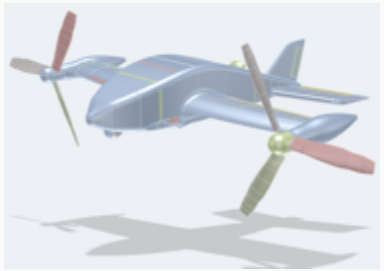
Graphical CONOPS Scenario: Search & Rescue Mission



P1: Multi-physics



P2: Airworthiness

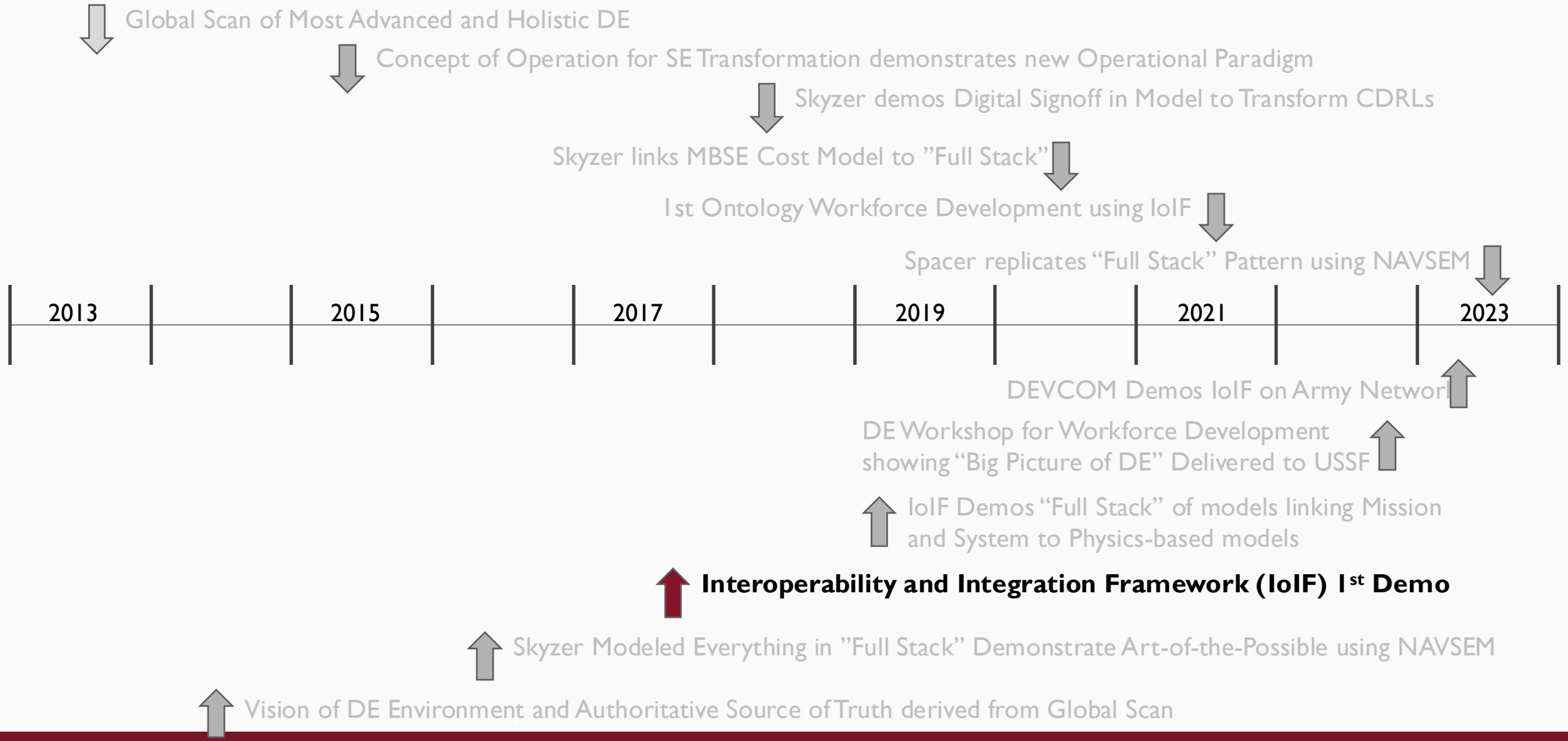


P3: Cost Modeling

Performance constraints force Multi-physics Design considerations– similar to Bell Eagle Eye

Doing Everything in Models to Demonstrate Art-of-the-Possible

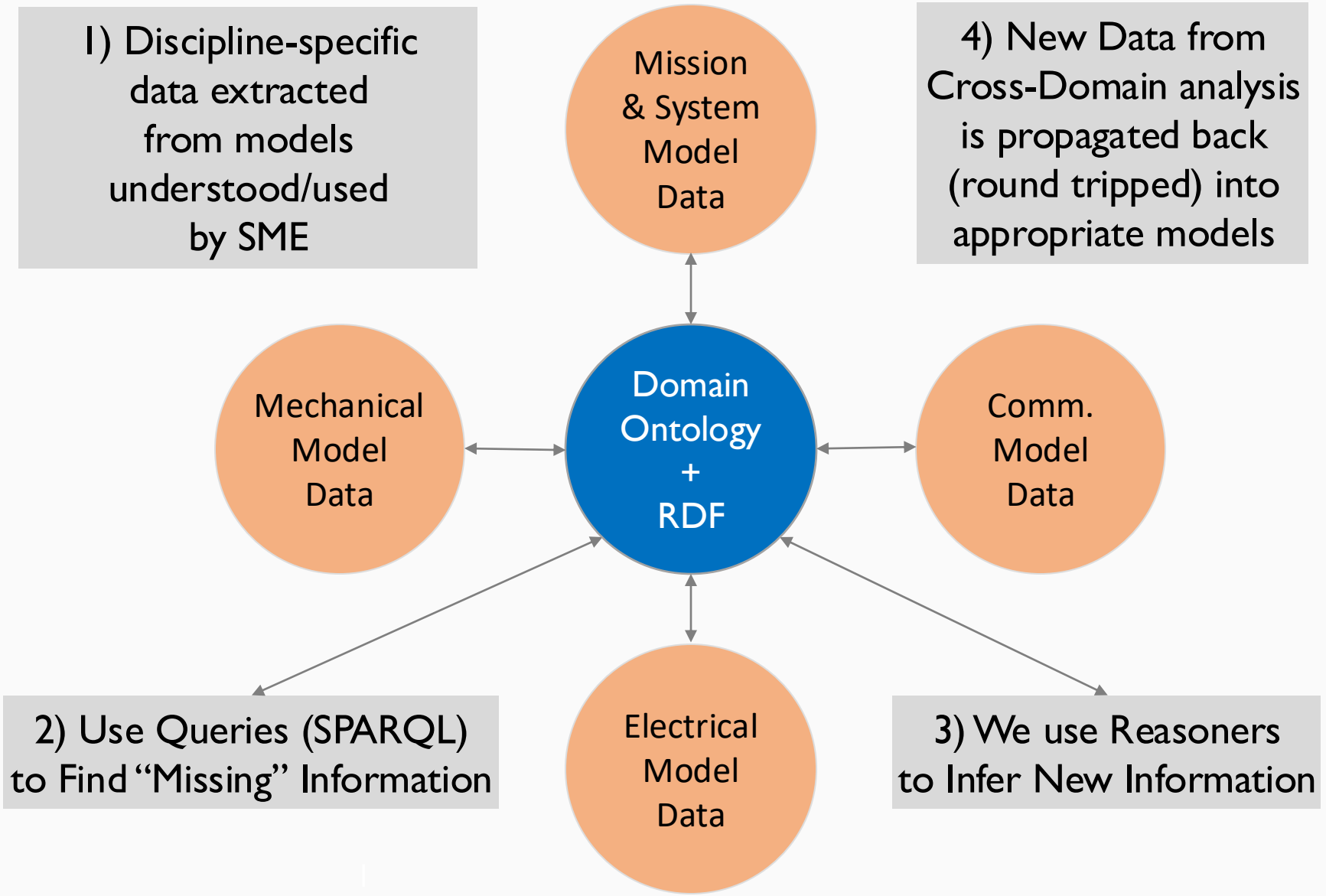
10 Years of DE Research, Experimentation and Demonstrations Outcomes



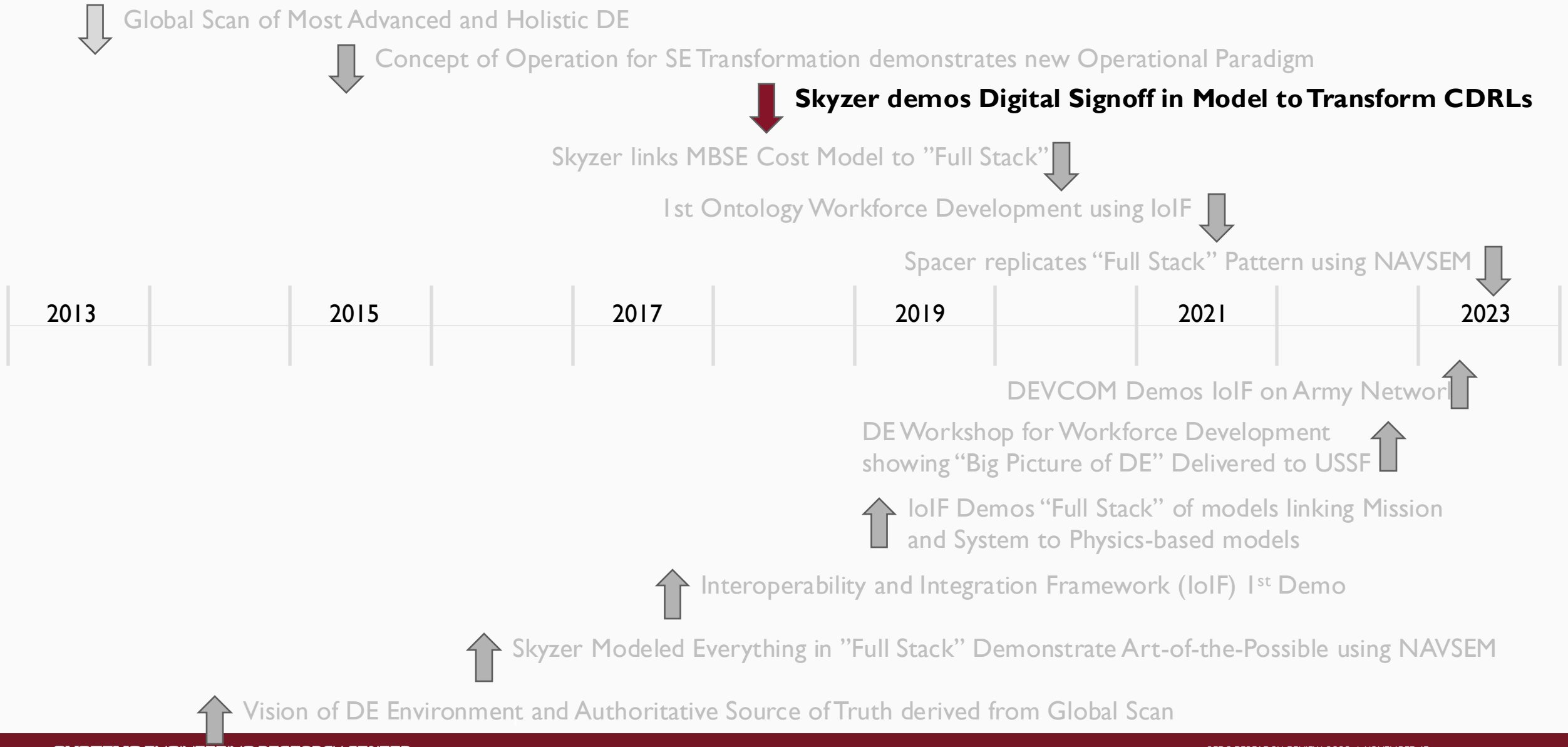
Interoperability and Integration Framework (IoIF)

1. IoIF is a framework to integrate data across disparate tool chains that were not designed to communicate with each other
2. Ontologies provide means of interoperability to map data between tools
   - Ontology-aligned data is graph-based and can evolve vs. databases that might need to redo schema for new version of tools and data
   - Ontologies are (usually) tool agnostic, and may be extended to new domains and applications
   - Need for evolution more critical as Digital Twins evolve over long life cycle
3. Ontologies provide knowledge representation that is foundational for AI / ML and intelligent agents
4. Ontologies are understandable by humans and machines using precise semantics
5. Formalizes domain knowledge to support a shared conceptualization of a domain

Data Across Disciplines Linked & Mapped to Computationally-Enabled Domain Ontologies



10 Years of DE Research, Experimentation and Demonstrations Outcomes



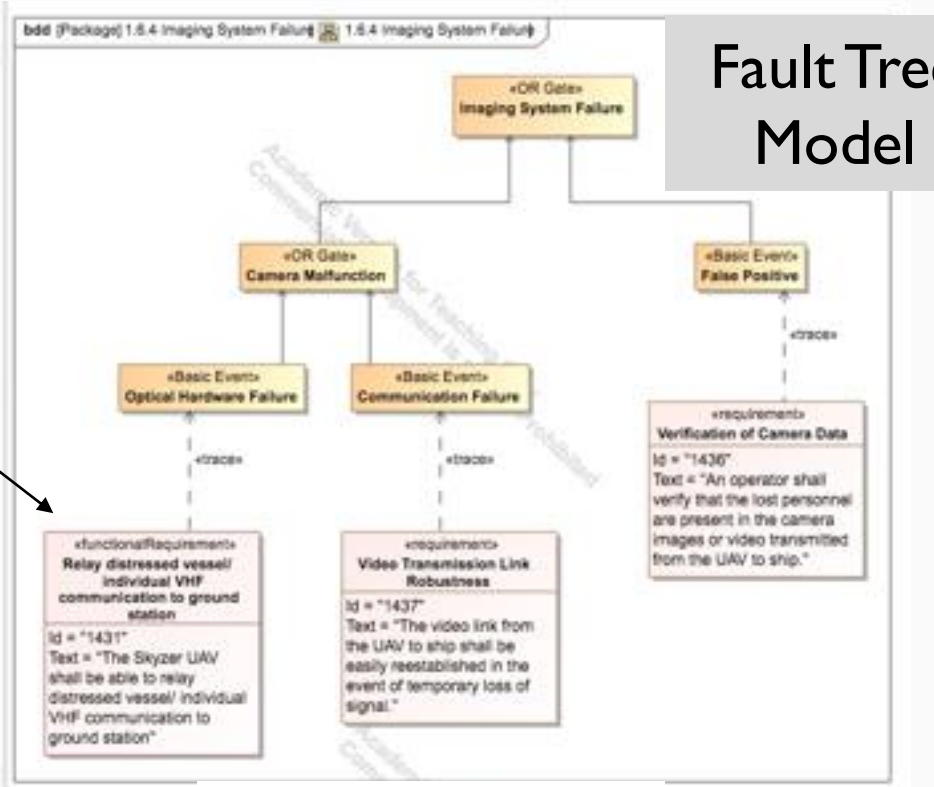
Skyzer demos Digital Signoff in Model to Transform CDRLs

1. Digital Signoffs provide a means to continuously and asynchronously approve developed model artifacts that comply with recommended methods for MBSE
2. Digital Signoffs provide a means to transform from traditional document-based reviews and signoff processes by locating signoff with modeling artifacts that satisfy analysis or design criteria
3. Digital Signoffs can be approved by Subject Matter Experts (SME) directly in web-based browsers (e.g., View Editor) reducing the need for SMEs to have expertise in a model-authoring client (e.g., Cameo/MagicDraw)
4. Digital Signoffs are template-based allowing for tailoring e.g., two approvals
5. Digital Signoff measures & metrics can be collected automatically
6. Demonstrated using Skyzer, including support for Source Selection
7. Skyzer is also being used in the updated DE Curriculum by Defense Acquisition University (DAU)

Digital Signoffs are Template-based & Tailorable to Subject Matter Experts

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Mitigation Requirement to address Basic Events that could lead to Mishap for the Hazard



Fault Tree Model

9.2 System Failure Analysis Signoff

Last Modified: 5/13/20 9:36 AM by ben

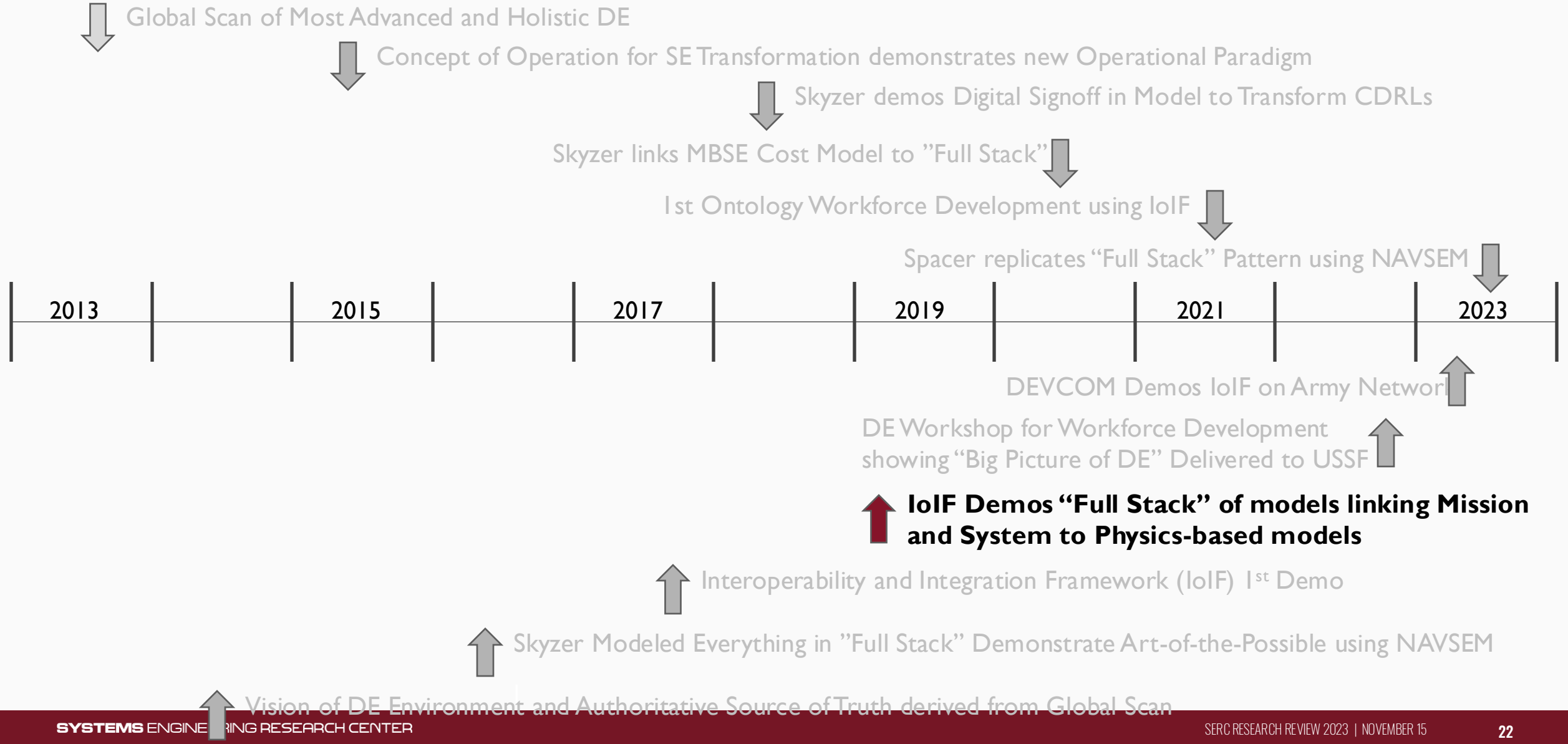
EXPORT CSV FILTER TABLE

Table 176. System Failure Analysis Signoff

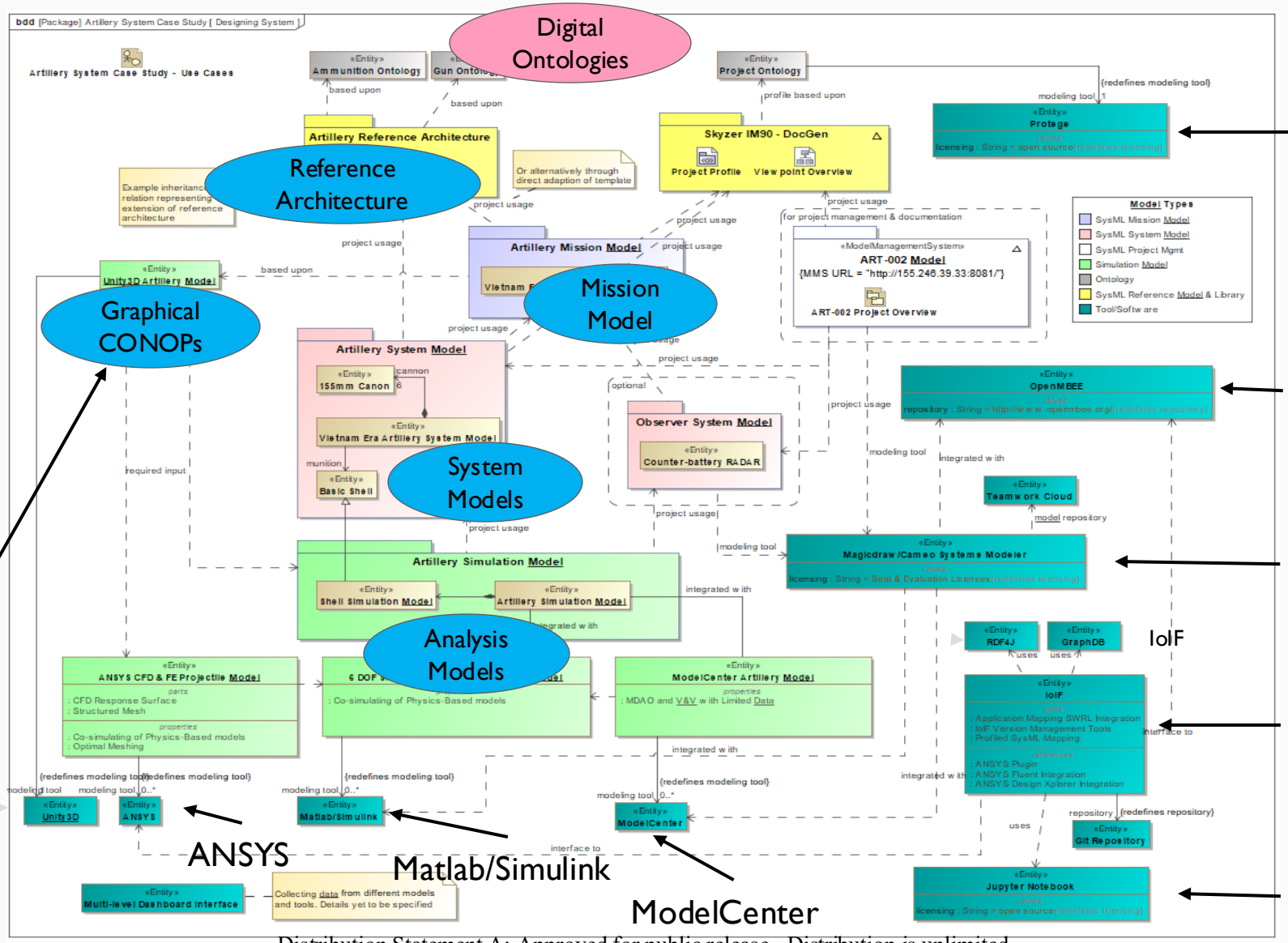
Approved Elements	Approval Status	Approved By	Completeness	Probability	Impact	Comment
3.9 Fault Tree Analysis	Value : rejected ADD	Adam Baker	Value : 75 ADD	Value : 25 ADD	Value : 75 ADD	may need an extra basic event added

Fault Tree analysis is the <u>Model Artifact</u> being assessed for a potential hazard, and assessment of Completeness, Probability and Impact is captured with Approval Status for Digital Signoff by SME

10 Years of DE Research, Experimentation and Demonstrations Outcomes



“Full Stack” linking Mission and Systems to Physics-based Models



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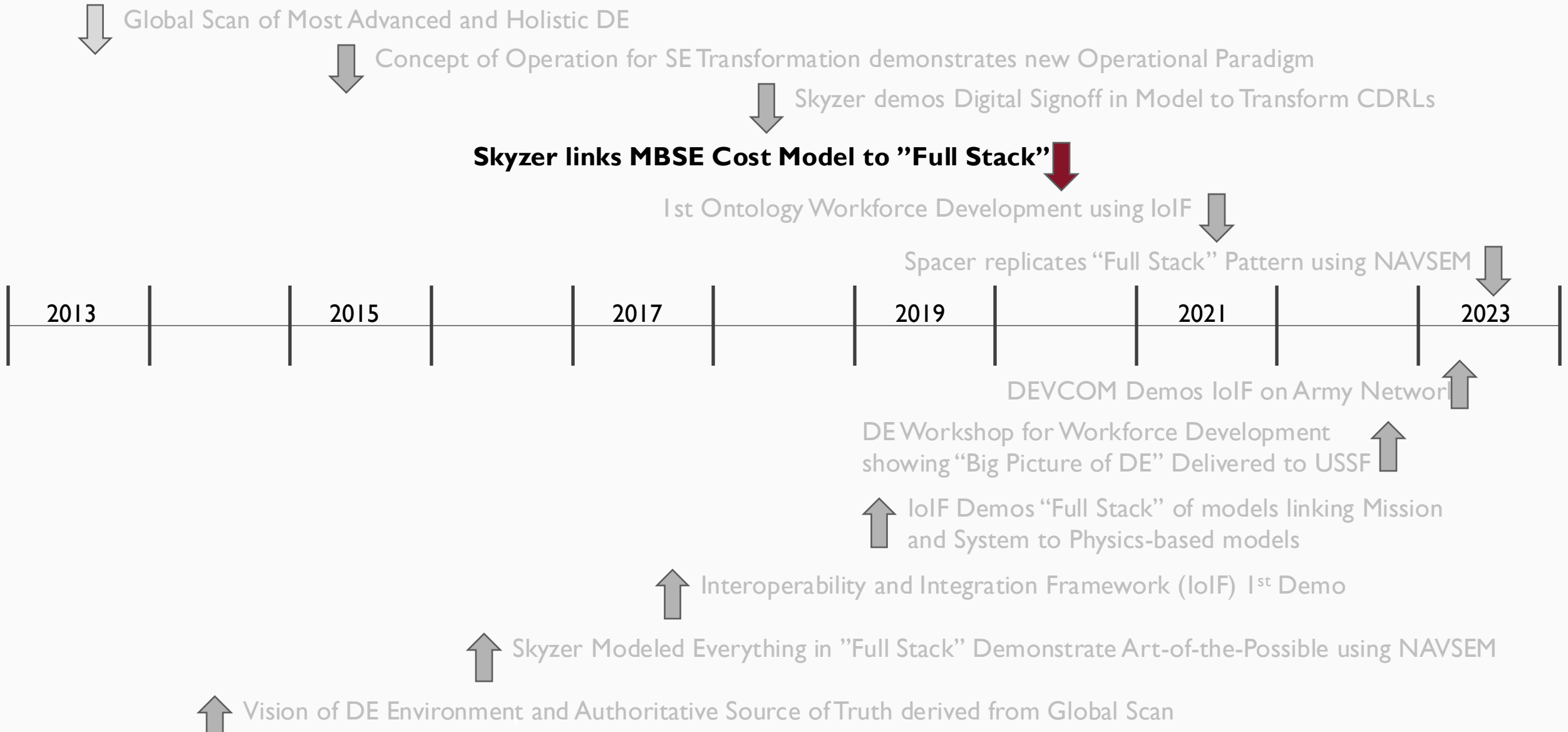
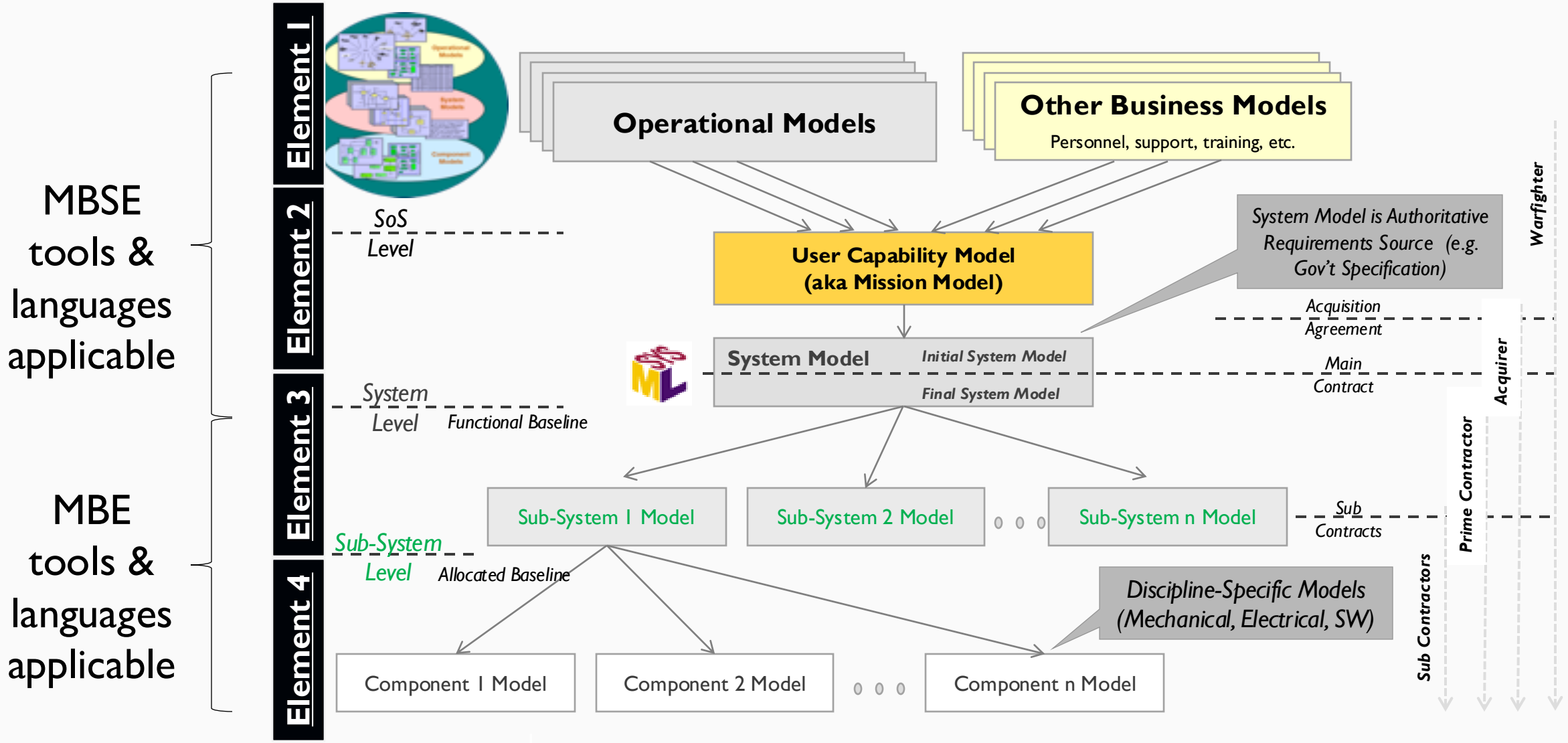


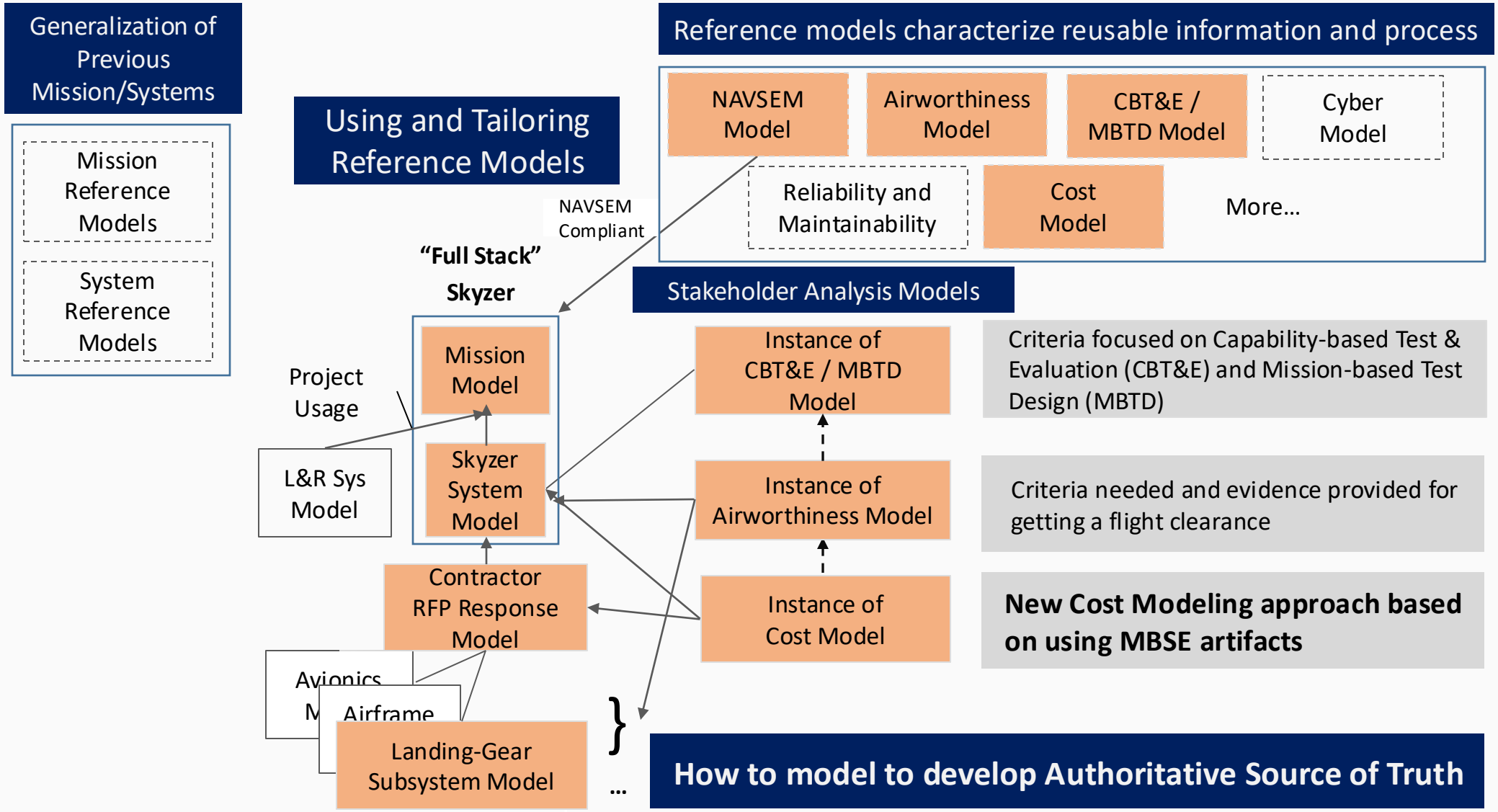
Skyzer links MBSE Cost Model to ”Full Stack”

1. Skyzer was modeled using the NAVAIR Systems Engineering Method (NAVSEM)
2. NAVSEM specifies process (what) and artifacts (how) for mission, system and subsystem models
3. NAVSEM also defines Stakeholder Analysis Models [SAMs] (e.g., Cost, Airworthiness [how to get flight clearance] derived from MilStd documents (e.g., MilStd 881F for Cost Model)
4. Skyzer links Mission, System & Contractor RFP technical models
5. Skyzer links SAM models to technical models
6. For Cost Model, we only add cost items if they are in the technical models
   - For example: Skyzer is a UAV, so there are no cost items related to a Pilot

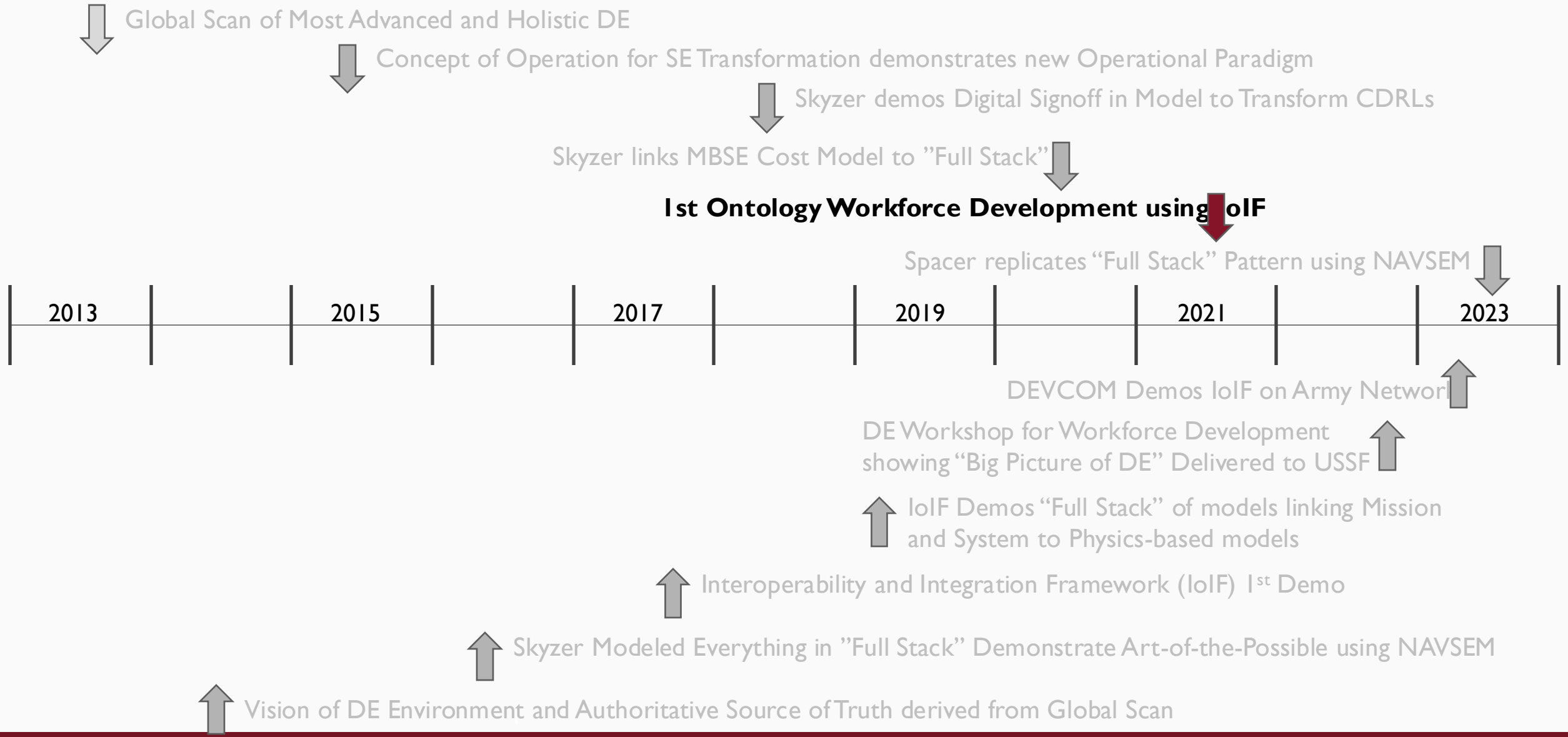
Skyzer Demonstrates Modeling at Different Abstraction Levels



“Full Stack” of Skyzer Models Enables Acquisition Analysis



10 Years of DE Research, Experimentation and Demonstrations Outcomes



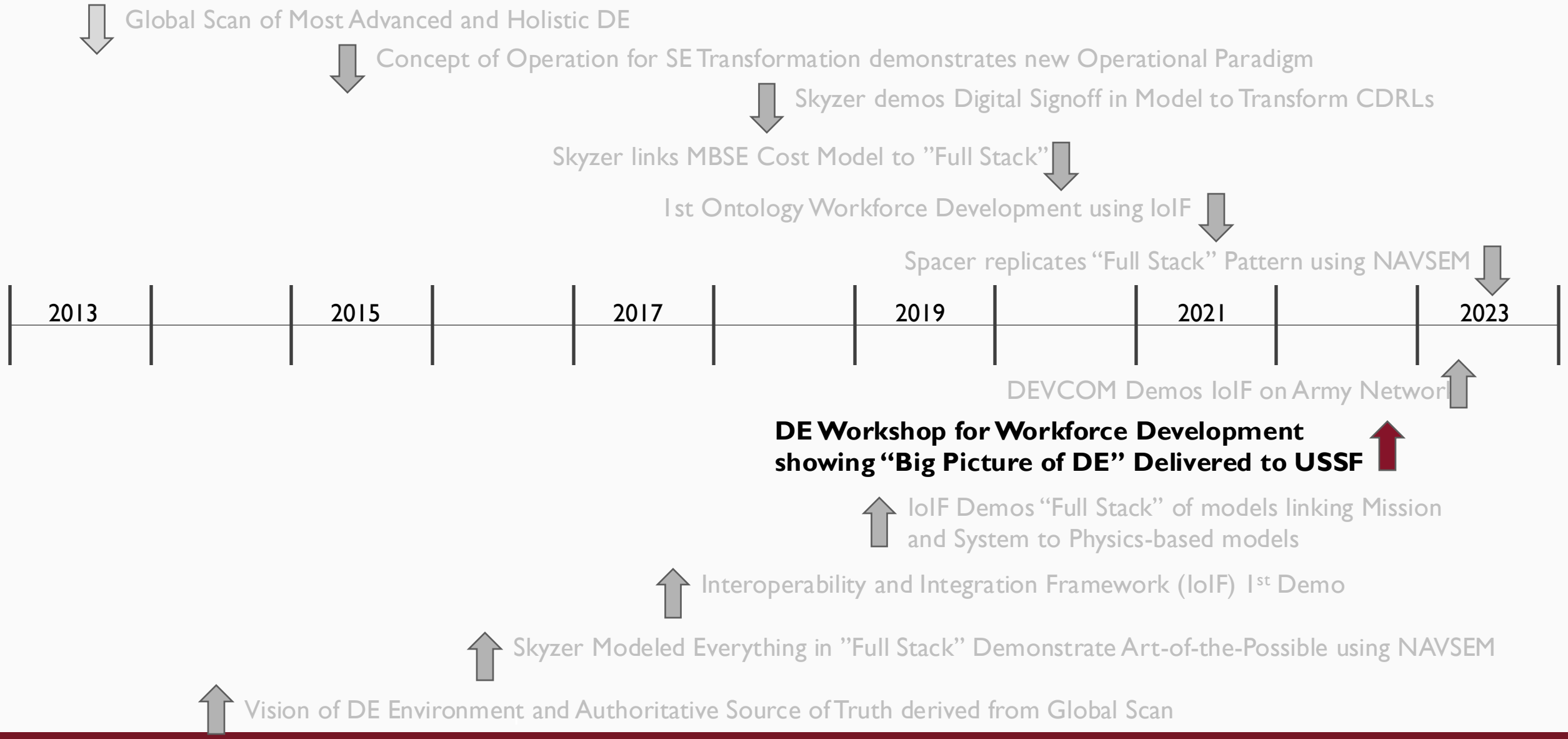
First Ontology Workforce Development using IoIF

1. The DoD Digital Engineering Strategy Goals include Workforce Development
2. First successful workforce development with IoIF started Feb 2021 and completed May 2021 using Cyber Use Case originally Modeled with US Navy
3. Includes 13 modules with hands-on exercises
4. Second successful workforce development with IoIF used case study for Distribution A Catapult projectile launcher started October 2022 and completed April 2023 – includes 14 modules
   - Successfully converted the Catapult SysML v1 models into the new proposed SysML v2 model and have developed two Flipbooks documenting the process and insights gained by the effort
5. Army allowed material to be provided to US Space Force and can be shared in new Digital Engineering Workforce Development Workshop

First IoIF Workforce Development using Cyber Use Case

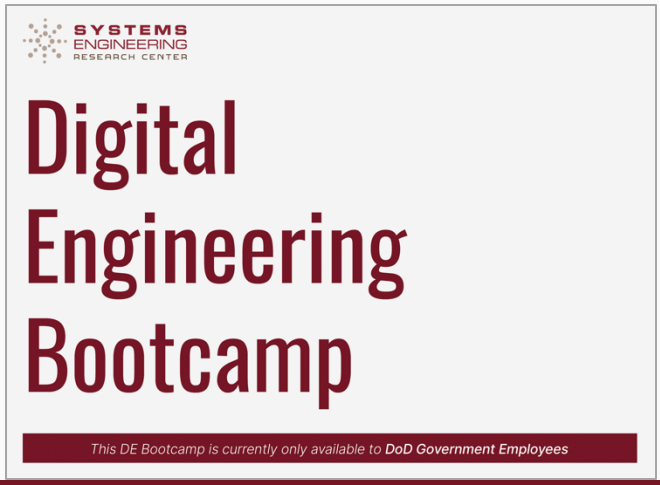
Duration (min)	Description	Attendees
45	Introduction and Course Overview (1300-1530)	Anyone
90	Fundamental Concepts for Using and Extending IoIF	Anyone
45	Case Study Overview (1400-1600)	Anyone
60	Computer System Model (SysML) for the Cyber Use Case	Developer
60	Ontology for the Cyber Use Case plus Vulnerability and Update SysML based on Ontology	Developer
60	Jupyter Notebook Workflow Creation for Executing Use Case	Developer
60	Using Assessment Flow Diagram for Trade Space Analysis	Developer
60	Tool Proxies: IoIF Services for Exchanging Data between IoIF and Tools	Developer
60	Cameo Collaborator	Developer
60	Advanced Topics: Ontology Theory and Practice (Upper Level Ontology – BFO)	Developer
60	Advanced Topics: IoIF Mapping Semantics	Developer
60	Advanced Topics: Semantics of IoIF Interfaces	Developer
90	Advanced Topics (AFD, Decision Framework, Model Management, Versions, & Branches, Mapping to Reference Architectures)	Developer

10 Years of DE Research, Experimentation and Demonstrations Outcomes

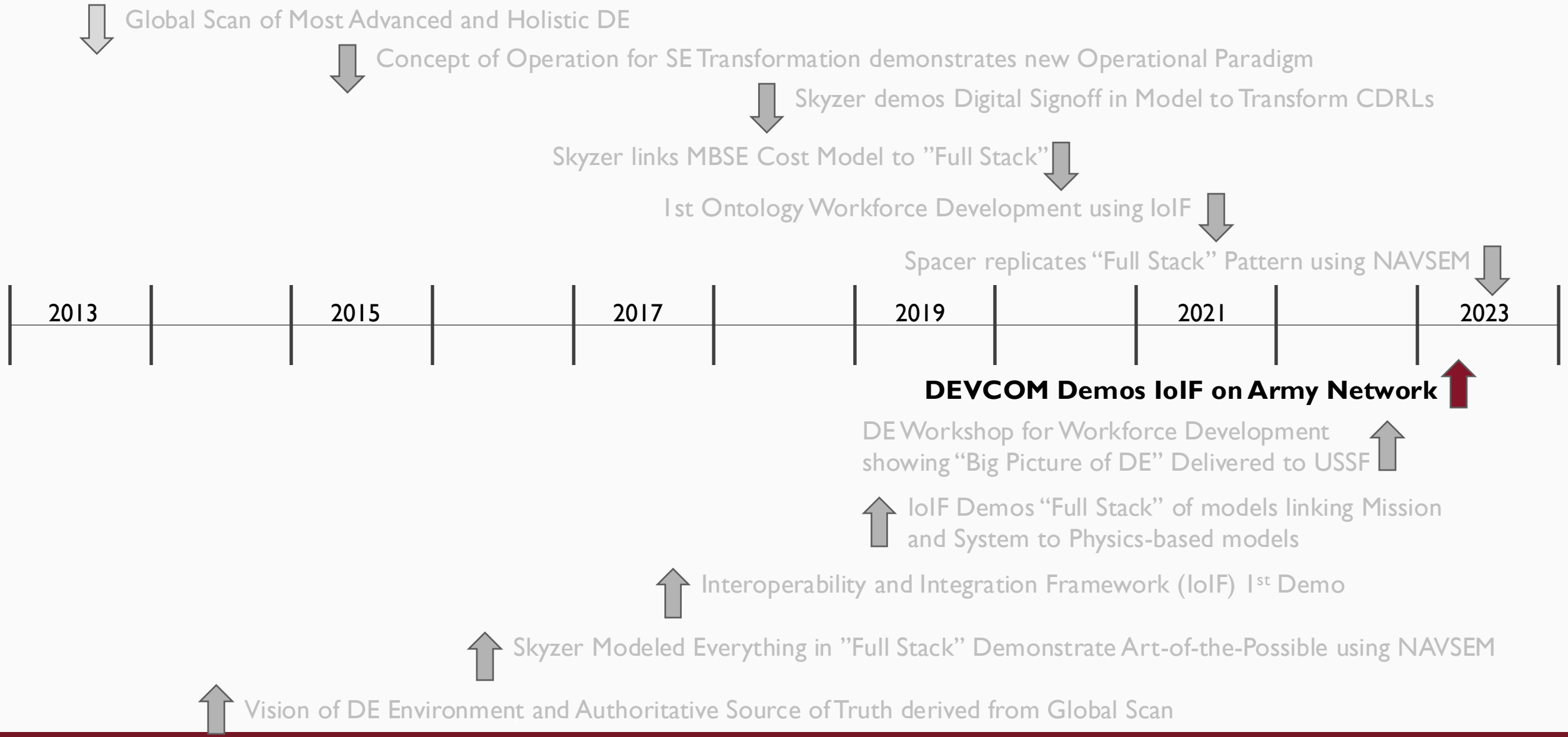


DE Workshop showing "Big Picture of DE" Delivered to US Space Force

1. US Space Force started the research task with primary objective to "Understand Big Picture of Digital Engineering" for Program Adoption
2. Wanted to understand DE Enabling Technologies extending prior research from NAVAIR Skyzer Surrogate Pilot and Systems Engineering Transformation
3. Wanted their own "Full Stack" of Models with a more space-relevant case study called "Spacer" using publicly available sources from FireSat/CubeSat
4. DE Flipbook – describing step-by-step process used to create Spacer
5. Transitioned much of the research effort using Spacer case study and supporting workforce development with Digital Engineering Workforce Development workshop
6. OpenMBEE plays role in workforce development and DE execution; enables people to be able to "read" model in web app called View Editor (www.openmbee.org)

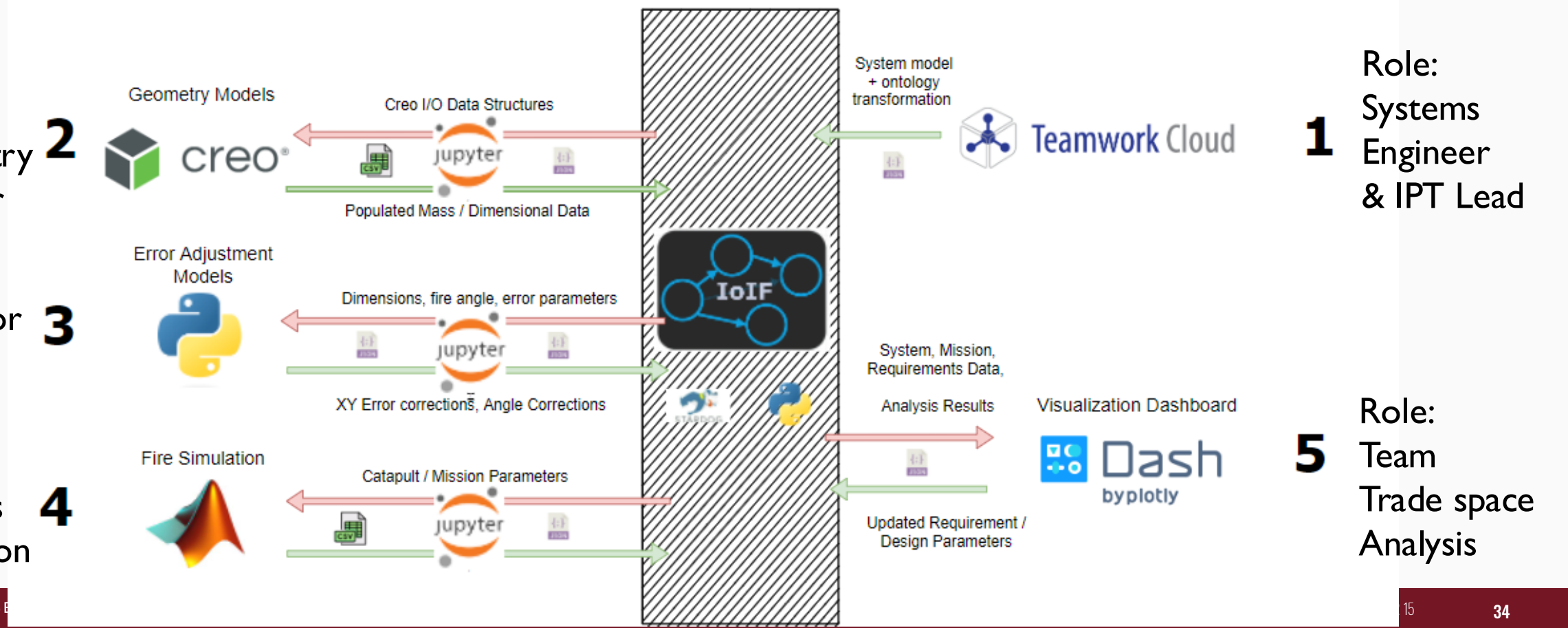


10 Years of DE Research, Experimentation and Demonstrations Outcomes



DEVCOM Team Demos IoIF on Army Network

- An objective of SERC Research is to Transition and enable sponsors to Execute on transitioned research
- DEVCOM successfully demonstrated to other Army Sponsors an Armaments Case Study and Workflow on Army computers and networks



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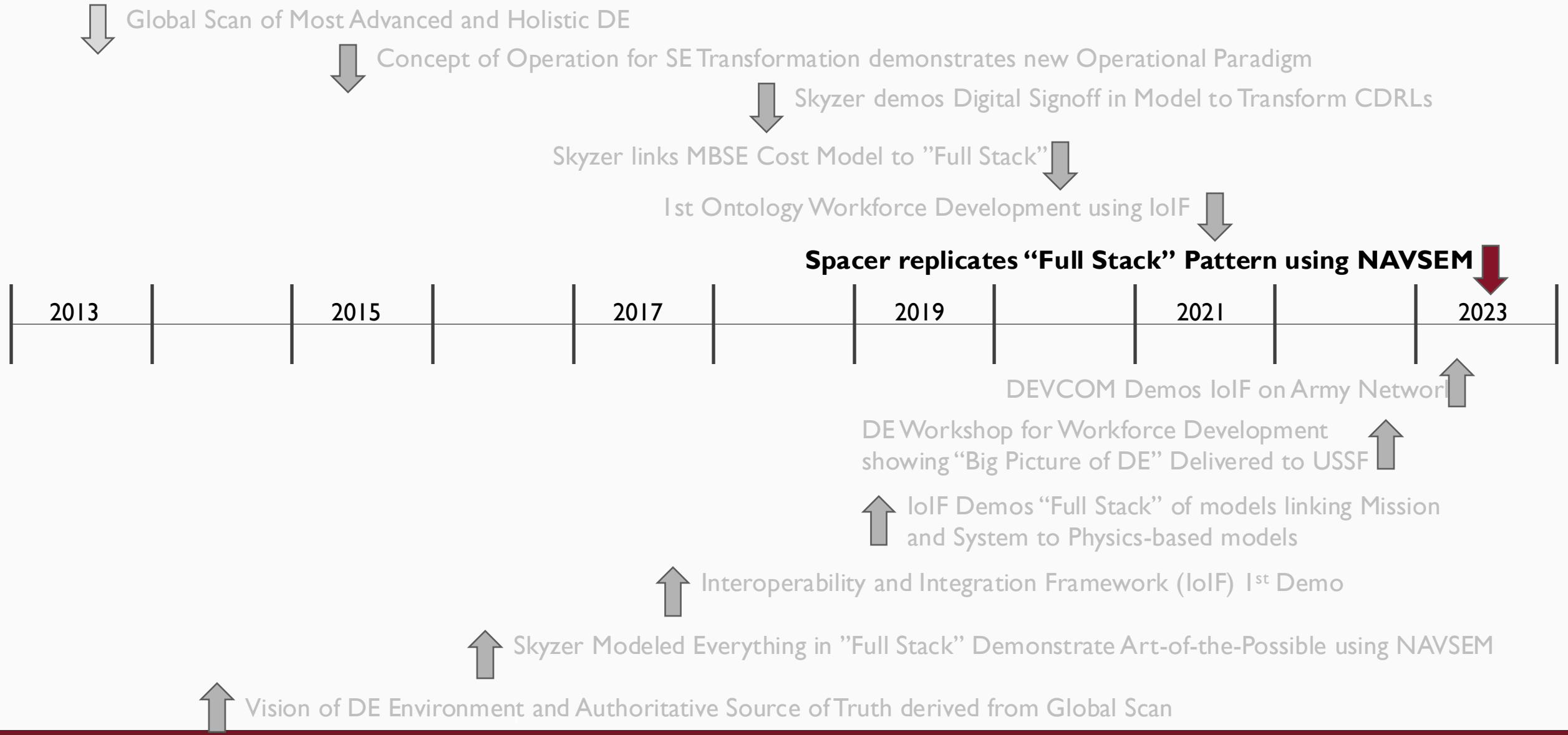


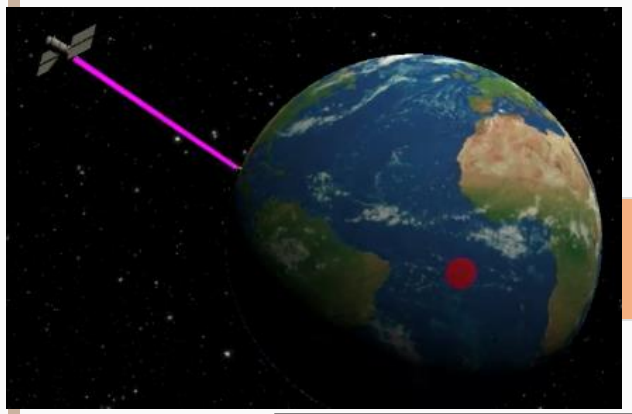
Spacer Replicates "Full Stack" Pattern using NAVSEM

1. Spacer was modeled to cover the five (5) major process steps of NAVSEM
2. A graphical CONOPs for a satellite monitoring system based on publicly available FireSat provided for a space-based case study
   - Graphical CONOPs is also part of an IoIF workflow
   - Cost model was also included in Spacer and documented in the Flipbook
3. All of the process steps and some sample artifacts are provided in a two-volume Flipbook
4. The modularization pattern for linking Mission, System, Contractor, subsystem, and Graphical CONOPs results in a "Full Stack" of models similar to Skyzer Surrogate Pilot

“Full Stack” of Spacer Use Cases & Models Enabling Acquisition Analysis

Using and Tailoring Reference Models

Graphical CONOPs derived from publicly available sources FireSat



Reference models characterize reusable information and process

Models are NAVSEM Compliant

NAVSEM Model | CBT&E / MBTD Model | Cyber Model | Reliability and Maintainability | Cost Model | More…

“Full Stack” Spacer

Mission Model

Ground System Model

Project Usage

Space Model

- Payload
- Guidance & Navigation
- Communication
- Etc.

Contractor RFP Response Model (1..*)

- Spacecraft Command
- Ground Equipment Control
- Communication
- Mission Data Processing
- Etc.

}

…

Stakeholder Analysis Models

Instance of Cost Model

Cost Modeling approach based on using MBSE artifacts (MilStd-881F)

How to model to develop Authoritative Source of Truth

Repeated the Concept like NAVAIR Skyzer as Spacer for Space Force

Discussion

Research Tasks and Collaborator Network

RT-48 (2013)
- Mark Blackburn (PI), Stevens
- Rob Cloutier (Co-PI) - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-118 (2014)
- Mark Blackburn (PI), Stevens
- Rob Cloutier - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-141 (2015)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Gary Witus – Wayne State

RT-157 (2016)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Roger Blake - Stevens
- Mark Austin – Univ. Maryland
- Leonard Petnga – Univ. of Maryland

RT-170 (2016)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Deva Henry - Stevens
- Paul Grogan - Stevens
- Steven Hoffenson - Stevens
- Mark Austin – Univ. of Maryland
- Leonard Petnga – Univ. of Maryland
- Maria Coelho (Grad) – UMD
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.

RT-168 – Phase I & II (2016)
- Mark Blackburn (PI), Stevens
- Dinesh Verma (Co-PI) – Stevens
- Ralph Giffin
- Roger Blake - Stevens
- Mary Bone – Stevens
- Andrew Dawson – Stevens (Phase I)
- Rick Dove
- John Dzielski, Stevens
- Paul Grogan - Stevens
- Deva Henry – Stevens (Phase I)
- Bob Hathaway - Stevens
- Steven Hoffenson - Stevens
- Eirik Hole - Stevens
- Roger Jones – Stevens
- Benjamine Kruse - Stevens
- Jeff McDonald – Stevens (Phase I)
- Kishore Pochiraju – Stevens
- Chris Snyder - Stevens
- Gregg Vesonder – Stevens (Phase I)
- Lu Xiao – Stevens (Phase I)
- Brian Chell (Grad) – Stevens
- Luigi Ballarinni (Grad) – Stevens
- Harsh Kevadia (Grad) – Stevens
- Kunal Batra (Grad) – Stevens
- Khushali Dave (Grad) – Stevens
- Rob Cloutier – Visiting Professor
- Robin Dillon-Merrill – Georgetown
- Ian Grosse – UMass
- Tom Hagedorn – UMass
- Todd Richmond – USC
- Edgar Evangelista – USC

RT-195 (2018)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Ralph Giffin - Stevens
- Benjamin Kruse - Stevens
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark Austin – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

WRT-1008 (2019)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- John Dzielski- Stevens
- Benjamin Kruse - Stevens
- Bill Rouse – Stevens/Georgetown
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.
- Alanna Carnevale (Grad) – Georgia Tech.
- William Stock (Grad) – Georgia Tech.
- Michael Szostak (Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark Austin – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

WRT-1025 (2020)
- Mark Blackburn (PI), Stevens
- Mark Austin (Co-PI) – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

ART-002 (2018) – ART-022 (2021/23)
- Mark Blackburn (PI), Stevens
- Dinesh Verma (Co-PI) – Stevens
- Kunal Batra – Stevens
- Mary Bone - Stevens
- John Dzielski, Stevens
- Steven Hoffenson - Stevens
- Steve Hespelt – Stevens
- Tom Hagedorn – Stevens
- Roger Jones – Stevens
- Philip Odonkor – Stevens
- Annie Yu – Stevens
- Benjamin Kruse – Stevens/VT
- Chris Snyder - Stevens
- Brian Chell – Stevens
- Chuck Colllard– Stevens
- Daniel Dunbar (PhD) – Stevens
- Josh Maccoby (PhD) – Stevens
- Renee Blatchley (PhD) – Stevens
- Maximillian Vierlboeck (PhD) - Stevens
- Andrew Underwood (Ungrad) – Stevens
- Benjamin Steinwurtzel (Ungrad)
- Ariela Litvin (Ungrad)
- Aughdon Breslin (Ungrad)
- Joshua Bernstein (Ungrad)
- Cory Phillipe (Grad) - Stevens
- Ian Grosse – Univ. of Massachucetts
- Doug Eddy – Univ. of Massachucetts
- Joe Gabbard – Virginia Tech
- Kyle Tanous– Virginia Tech
- Jared Van Dam (PhD) – Virginia Tech
- Kelsey Quinn (PhD) – Virginia Tech

WRT-1036 (2020)
- Mark Blackburn (PI), Stevens
- John Dzielski- Stevens
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Taylor Fields – Georgia Tech.
- William Stock (Grad) – Georgia Tech.
- Sahil Panchal – Georgia Tech
- Jake Sisavath – Georgia Tech
- Gabriel Rizzo – Georgia Tech

WRT-1054 (2022)
- Mark Blackburn (PI), Stevens
- John Dzielski- Stevens
- Tom Hagedorn – Stevens
- Steve Hespelt – Stevens
- Chuck Collard– Stevens
- Daniel Dunbar (PhD) – Stevens
- Kevin Morrill)– Stevens
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Taylor Fields – Georgia Tech.
- Adam Baker – Georgia Tech.
- Avik Banerjee – Georgia Tech.
- Vanessa J. Nuhn – Georgia Tech.
- Cole A. Sherling – Georgia Tech.

Thank you

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