DIGITAL TWIN SUMMIT
POWERED BY ASME

Gateway to the Future of Manufacturing & Autonomy!

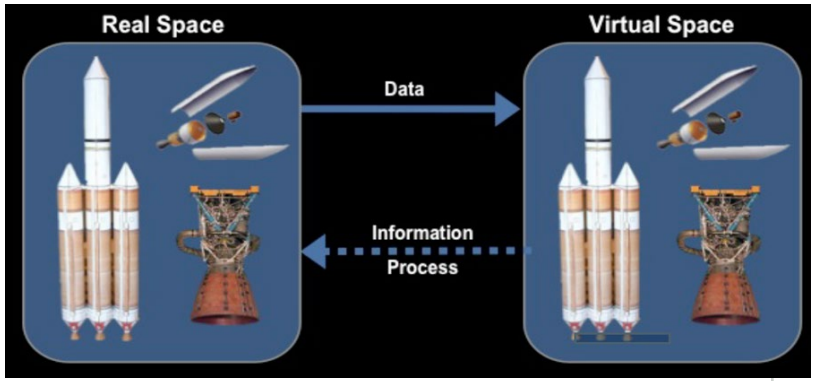
Digital Twins and Living Models at NASA

Presented by:
B. Danette Allen, PhD
Senior Technologist for Intelligent Flight Systems

03 November 2021

Digital Twins and Living Models at NASA

- Definition
- History
- Simulation
- Modeling & Simulation
- Digital Twins
- Immersion & Presence
- Living Models



Aeronautics Research

ESTO
EARTH SCIENCE TECHNOLOGY OFFICE

What is a Digital Twin?

A digital twin is a digital replica of a living or non-living physical entity, such as a manufacturing process, medical device, piece of medical equipment, and even a person... to gain insight into present and future operational states of each physical twin. – NIH-Interagency Modeling Analysis WG (2019)

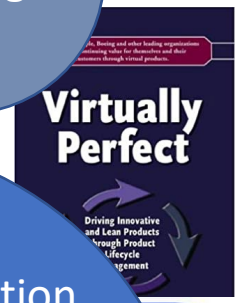
"A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" – TA 11 (2010)

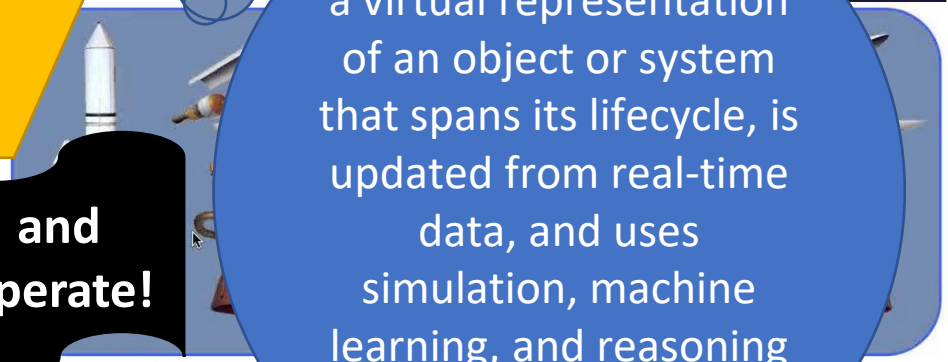
A digital twin is a virtual replica of an object, being, or system that can be continuously updated with data from its physical counterpart
– Purdy, MIT Sloan

Digital Twin - the application of interdisciplinary modeling and simulation across the product lifecycle. – John Vickers (2021)

The ultimate vision for the digital twin is to create, test and build our equipment in a virtual environment.
– John Vickers (2021)

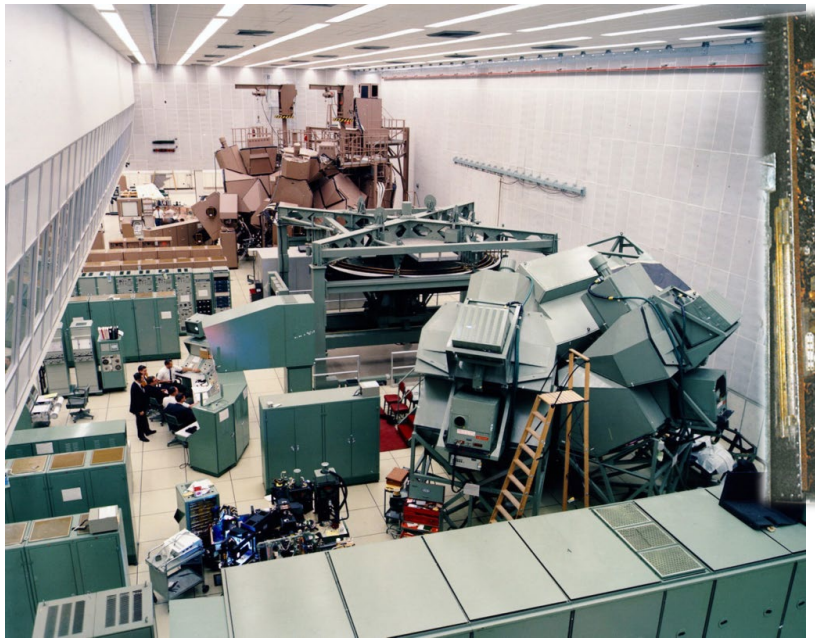
A Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin. – Michael Grieves and John Vickers (2002)

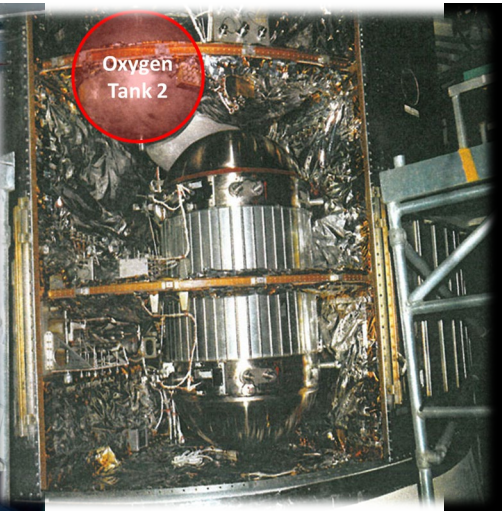


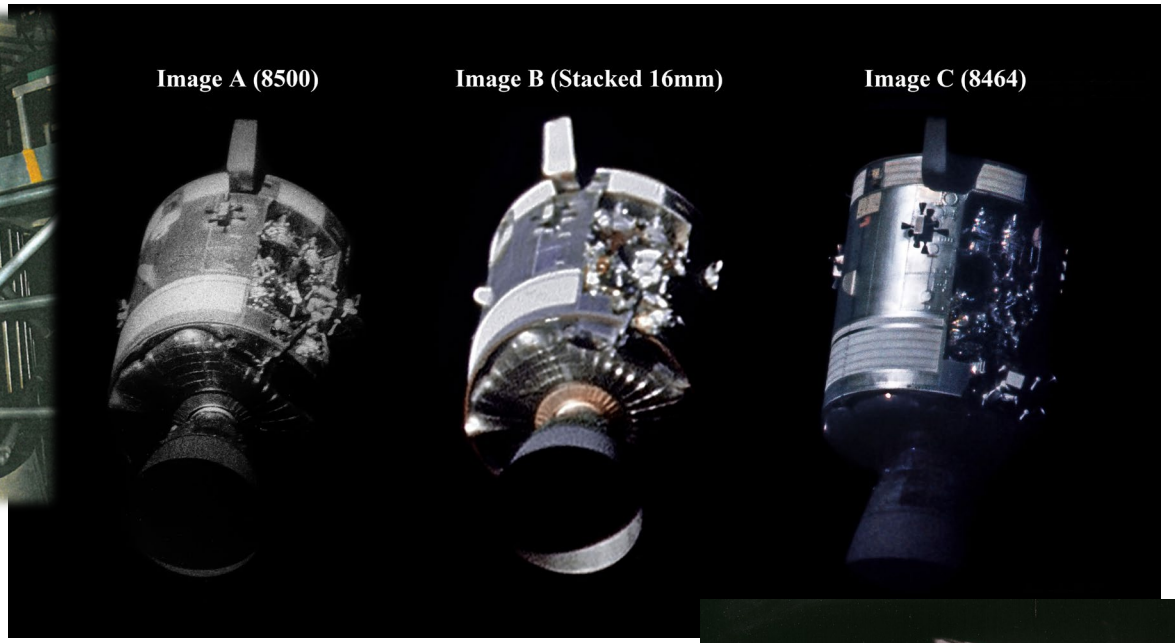


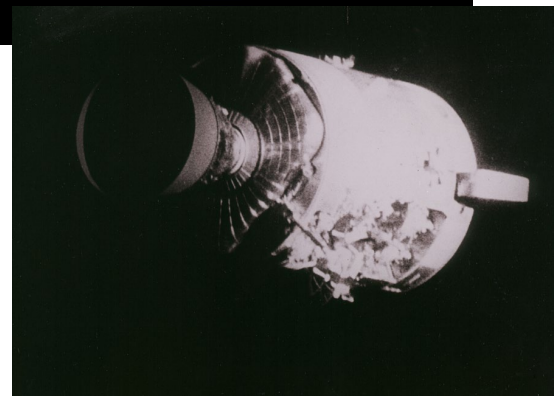
A Digital Twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help decision-making.
– IBM

The First Digital Twin: Apollo 13



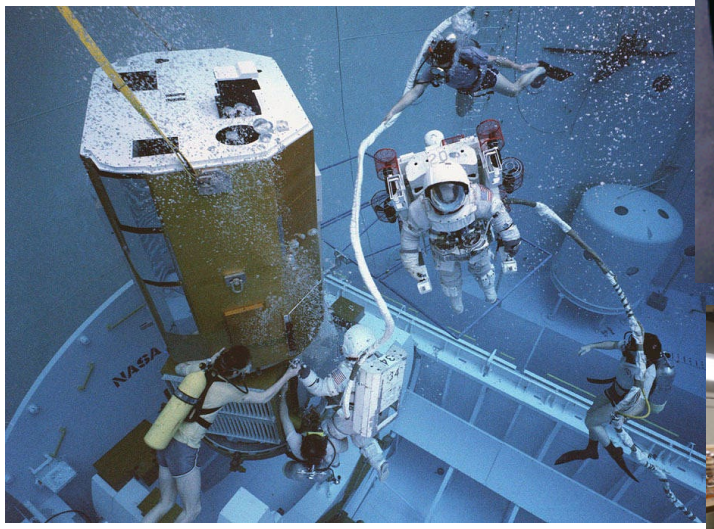


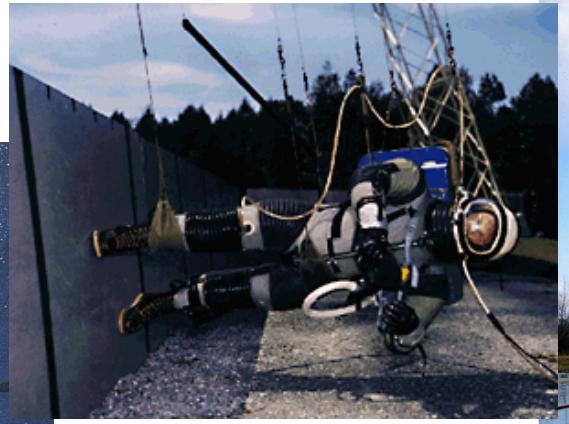


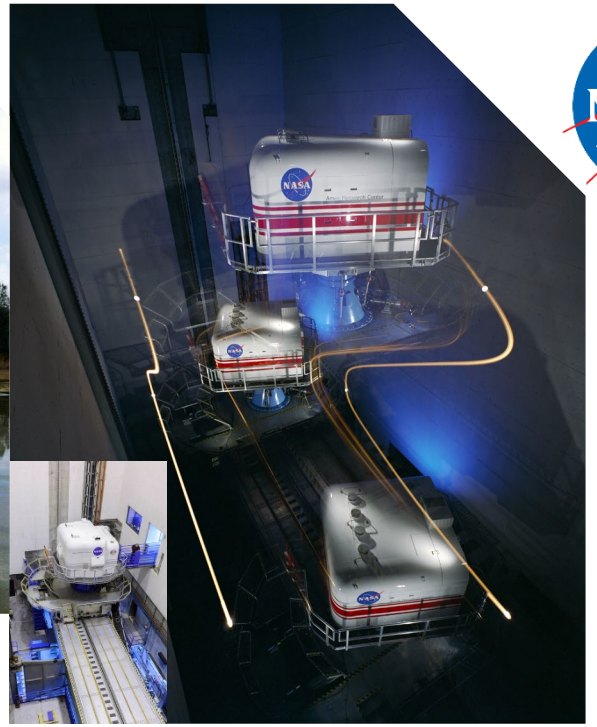


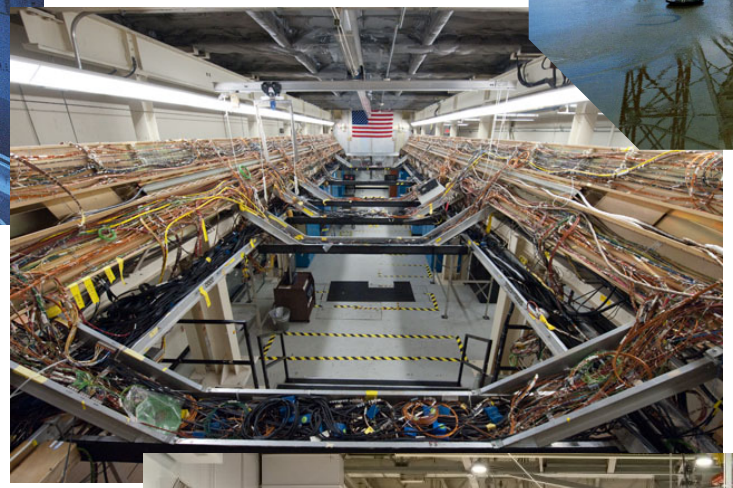
- 15 simulators were used to train astronauts and mission controllers
- Simulator → digital twin?
  - Adapted to match conditions of actual spacecraft
  - High fidelity model used to explore solutions and predict results

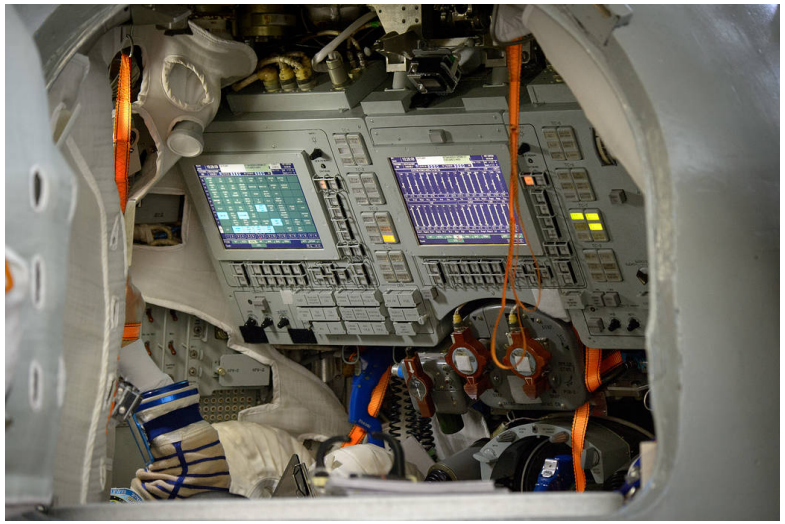
Simulation











Space Technology Systems

TX11.3.2 Integrated System Lifecycle Simulation
- Model and simulation interface specifications
- Federated simulations
- Enterprise-level modeling and simulation repositories
- Digital thread

TX11.3.3 Model-Based Systems Engineering (MBSE)
- Multi-Domain Modeling (MDM) Frameworks
- High-Performance Simulations (HPS)
- Adaptive Model Updating (ADU) Toolset
- Onboard predictive physics-based vehicle simulation
- Digital twin

Select Example Technologies

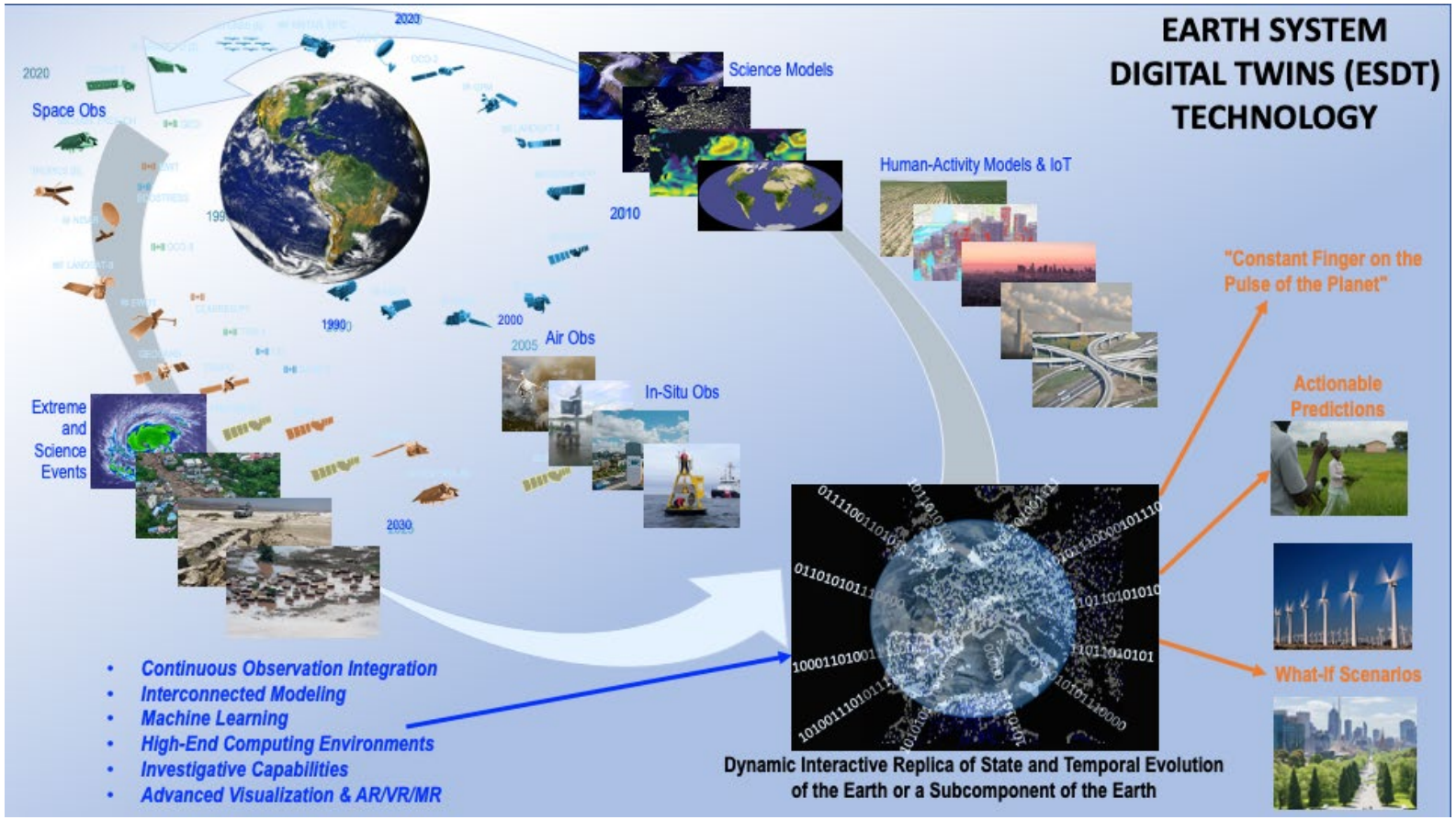
Earth Science Systems

NASA ESTO Advanced Information Systems Technology (AIST)

Earth System Digital Twins (ESDT) Thrust

- an interactive and integrated multidomain, multiscale, digital replica of the state and temporal evolution of Earth systems. It dynamically integrates:
  - relevant Earth system models and simulations;
  - other relevant models (e.g., related to the world's infrastructure);
  - continuous and timely (including near real time and direct readout) observations (e.g., space, air, ground, over/underwater, Internet of Things (IoT), socioeconomic);
  - long-time records;
  - analytics and artificial intelligence tools.

Earth Science Systems

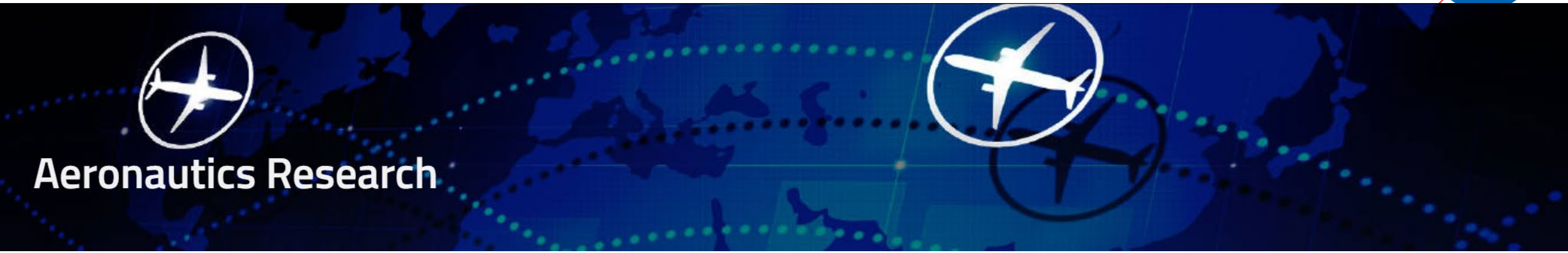


ROSES-21, A.46
"Advanced Information Systems Technology"

- Released 02 July 2021
- Two (2) sub-element Topic Areas;
  1. Early-Stage Technology (EST)
  2. Advanced and Emerging Technology (AET) in 3 sub-areas:
     a. New Observing Strategies (NOS)
     b. Analytic Collaborative Frameworks (ACF)
     c. Earth System Digital Twins (ESDT)

Credit: Jacqueline Le Moigne

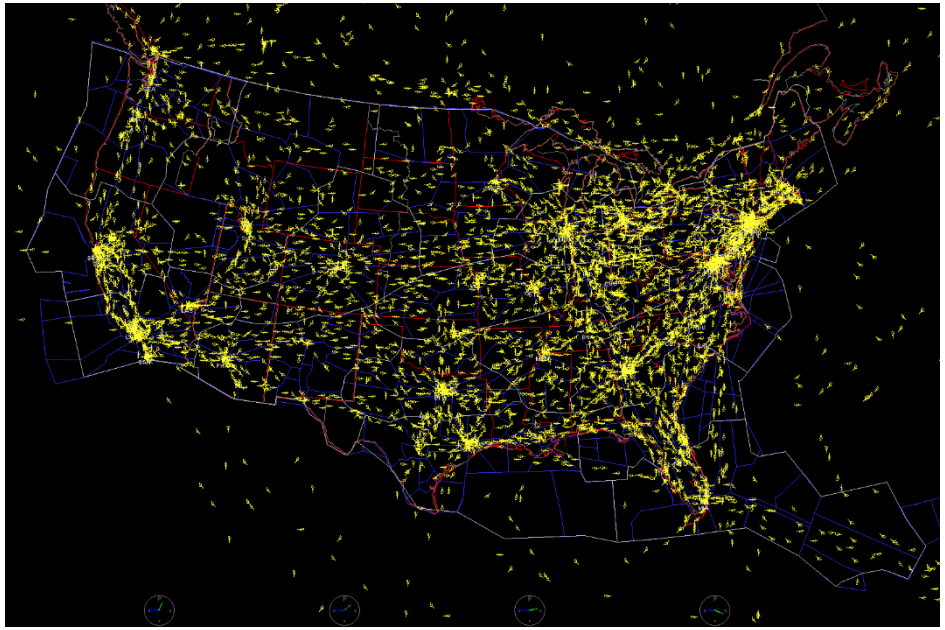
Aviation Systems



NASA ARMD has decades of experience developing advanced airspace capabilities that rely on simulations and field integrations.

Dedicated to agency goals of increased digital transformation and continually developing enhanced capabilities.

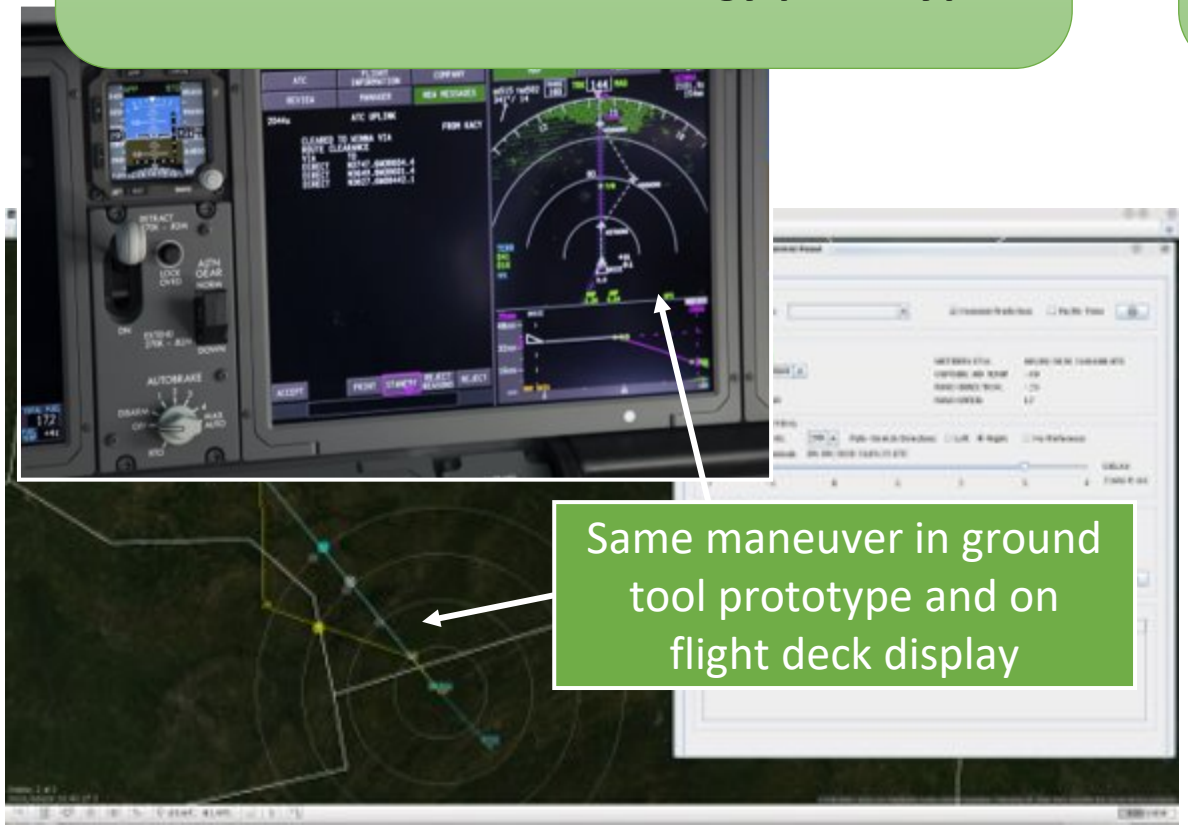
- SMART-NAS / Advanced Testbed
- ATOL / AOL



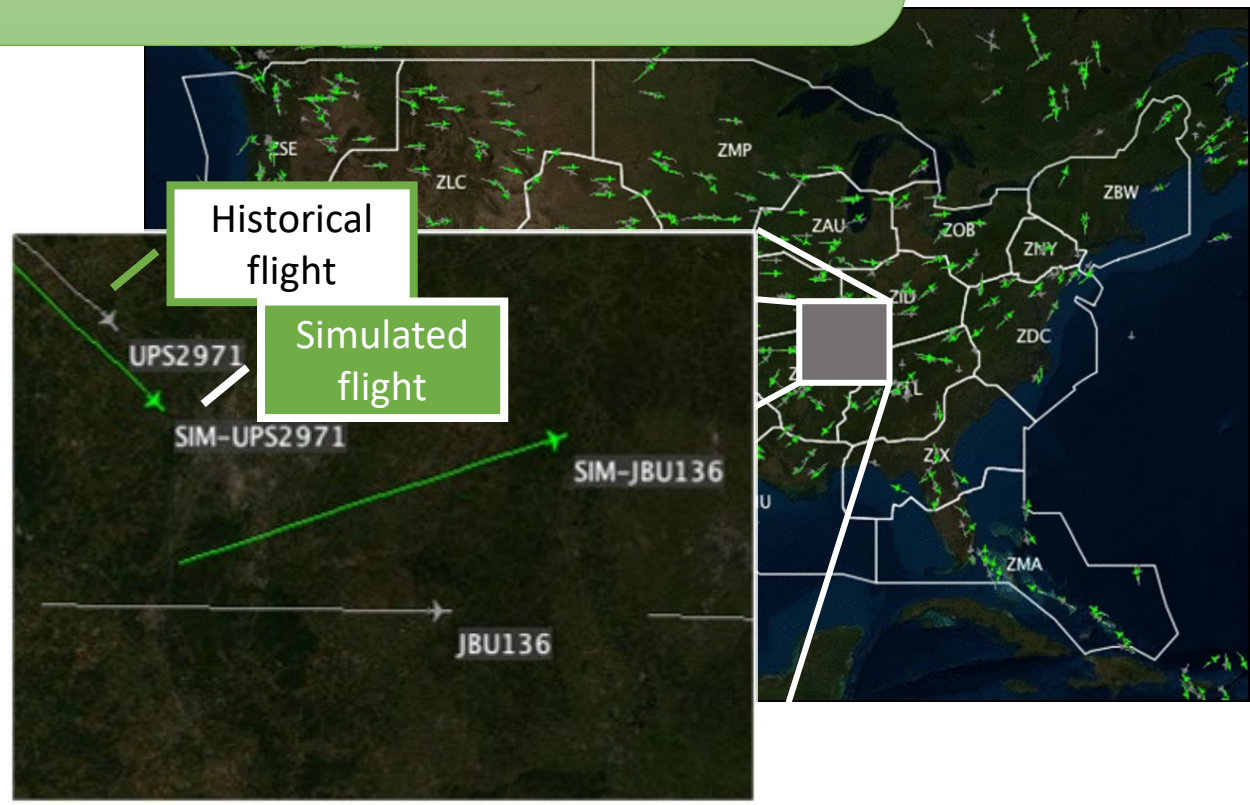
Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS)

Advanced Testbed

Advanced TestBed capabilities integrate disparate facilities and live flight-deck operations with simulated air traffic and advanced ATC technology prototypes



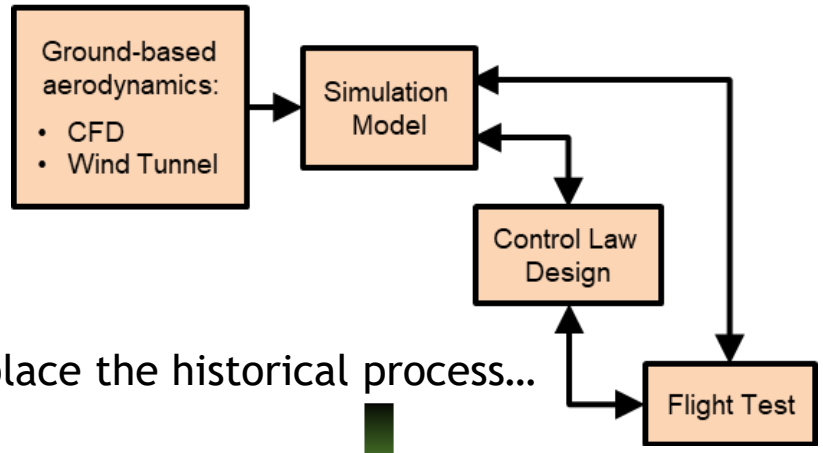
Large-scale simulations selectively replace historical flight operations with simulated autonomy-driven agents to reveal emergent system behaviors



ATOL/AOL

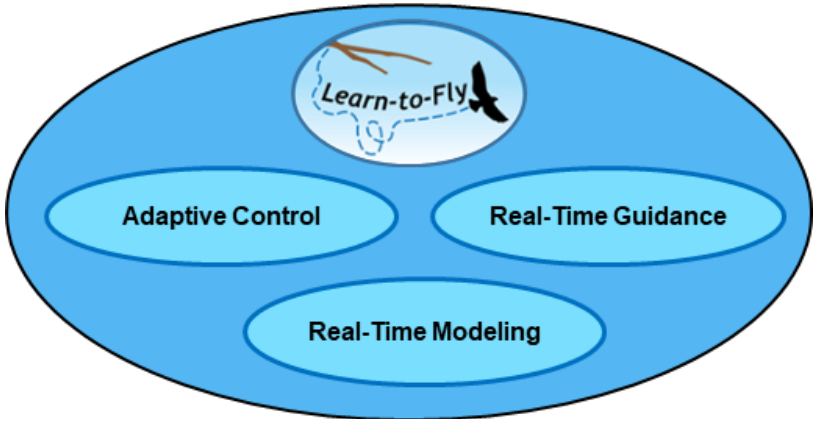
Air Traffic Operations Lab
Airspace Operations Lab

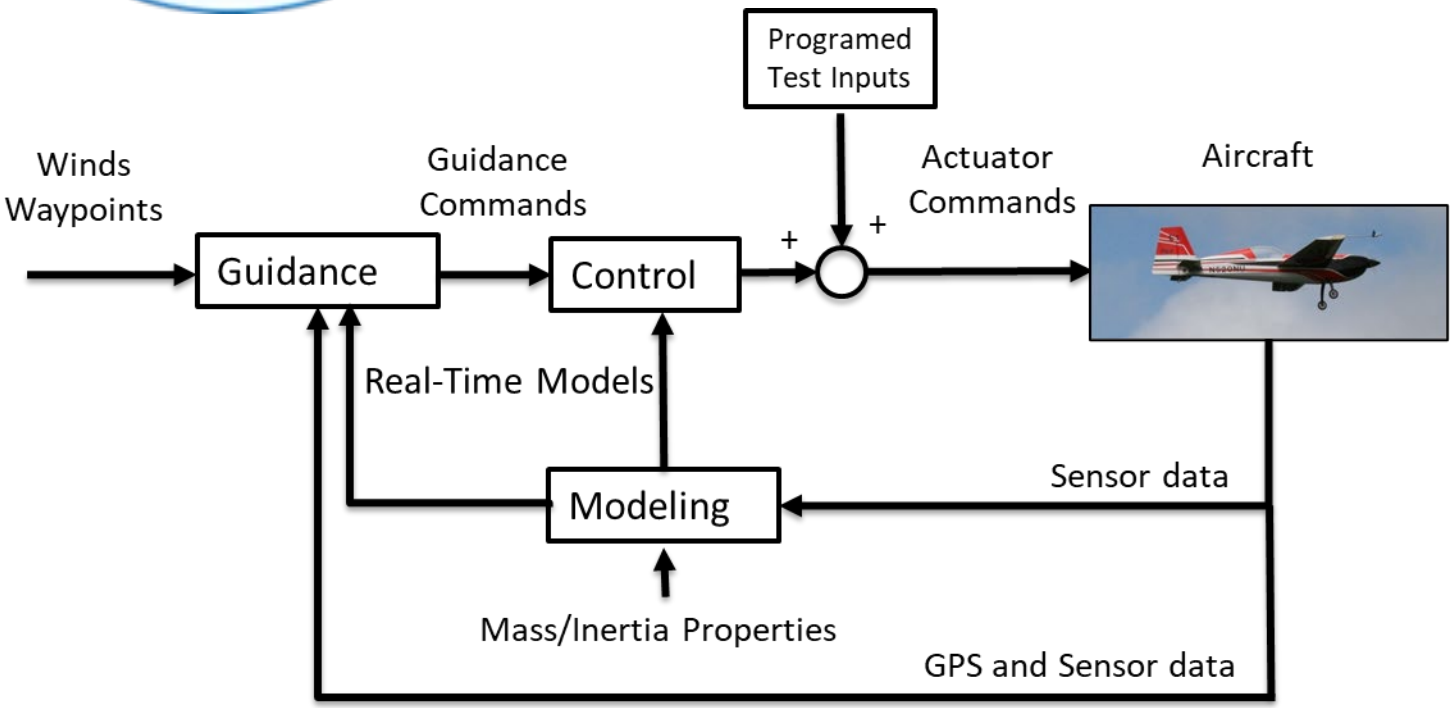
Learn-to-Fly



Replace the historical process…

With a new paradigm



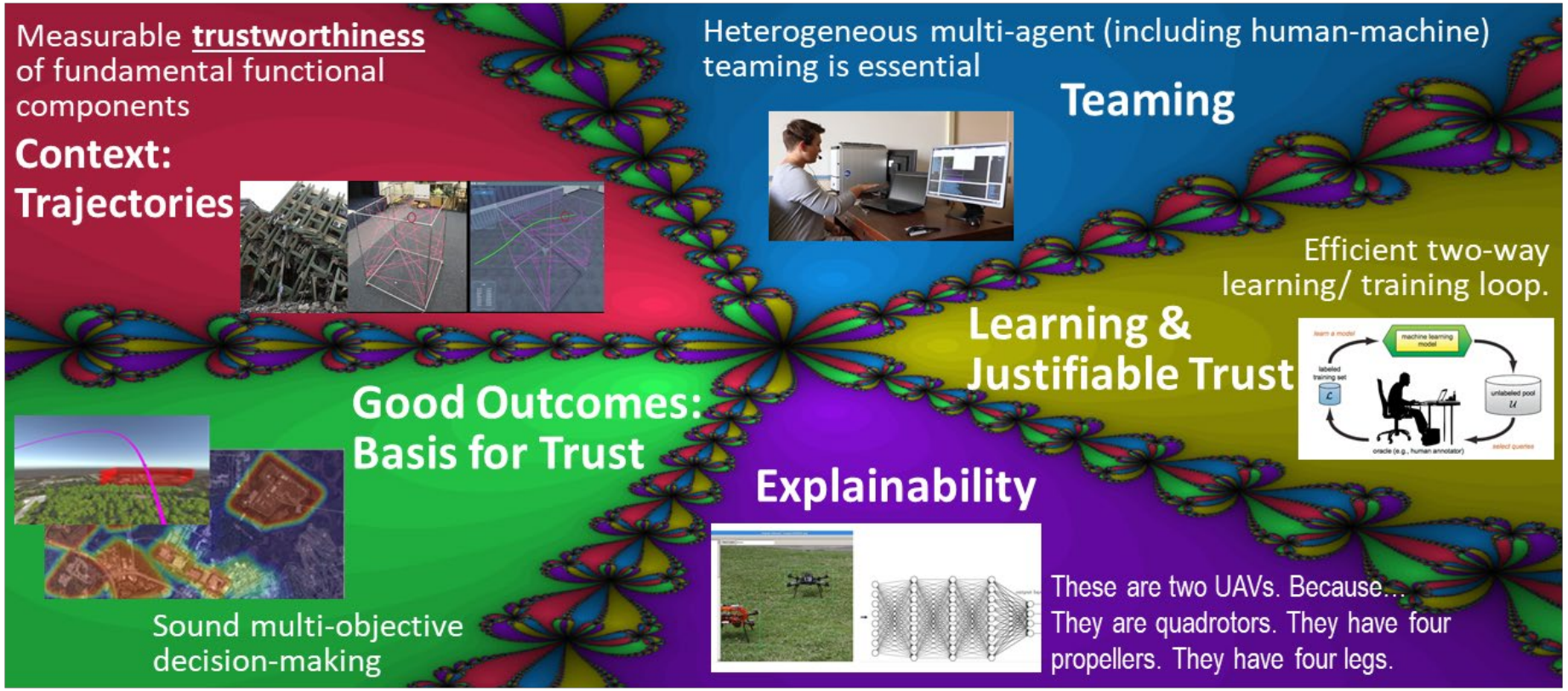


Digital Twin

The ATTRACTOR Challenge

Build a basis for certification of autonomous systems via establishing (1) metrics for trustworthiness and trust (2) in multi-agent team interactions, (3) using AI explainability and (4) persistent modeling and simulation, in the context of (5) mission planning and execution, with (6) analyzable trajectories.

Multidisciplinary Components of Complex Multi-agent Systems



Persistent ModSim

Build a basis for certification of autonomous systems via establishing
(1) metrics for trustworthiness and trust (2) in multi-agent team interactions,
(3) using AI explainability and **(4) persistent modeling and simulation**, in the context of
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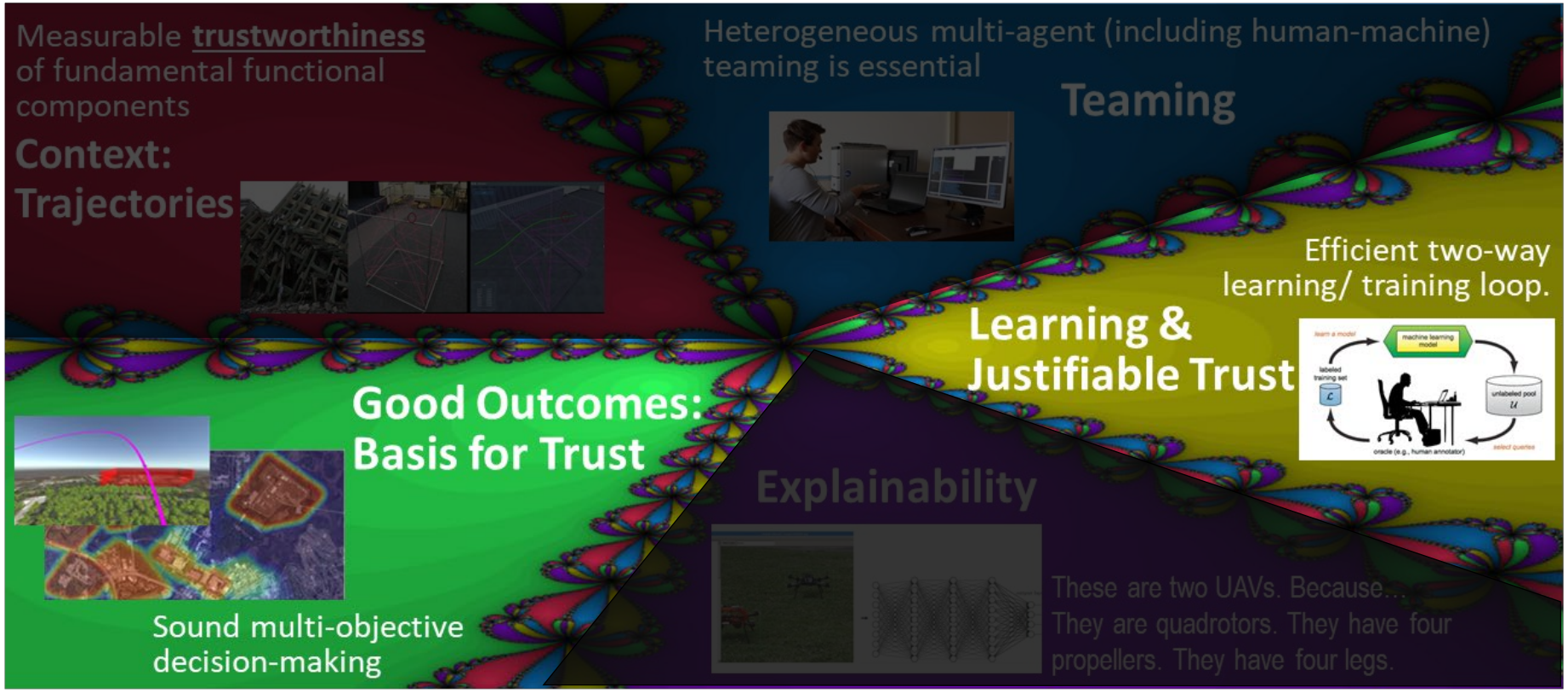
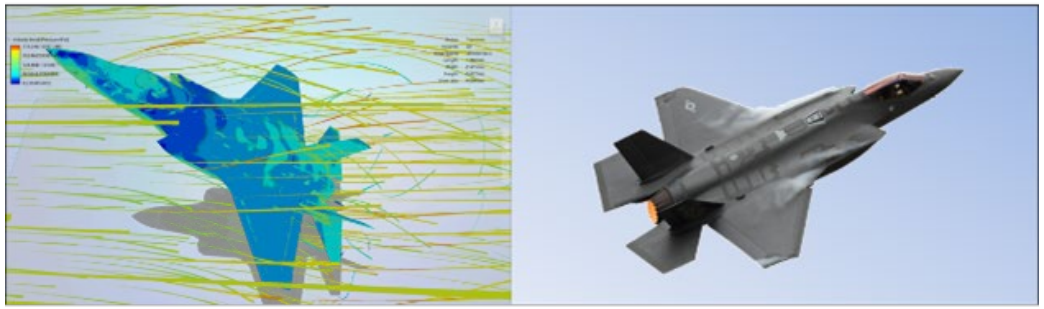
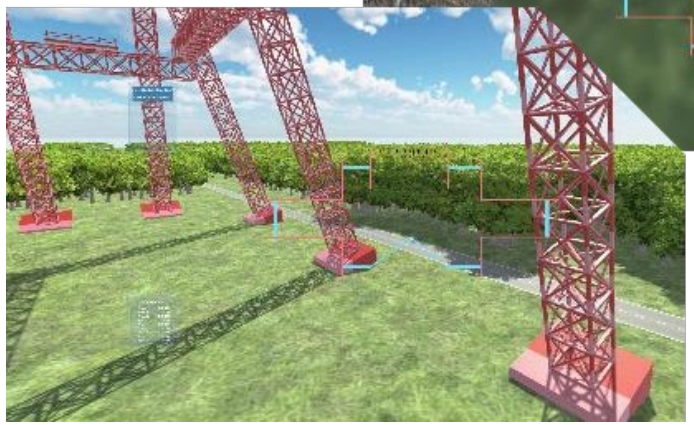
Multidisciplinary Components of Complex Multi-agent Systems



Persistent “TwinSim”



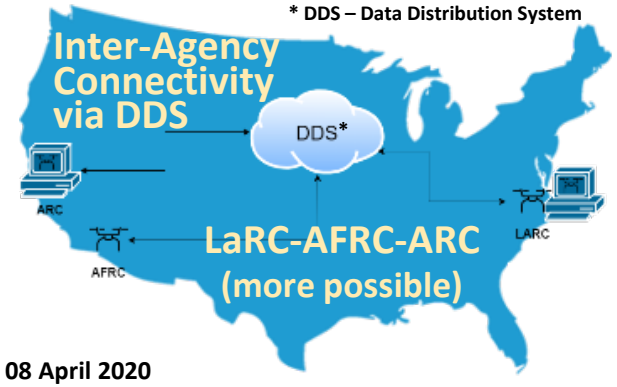
Digital Twin Artifacts/Environments



Credit: Natalia Alexandrov

“Digital Twin” Ecosystem

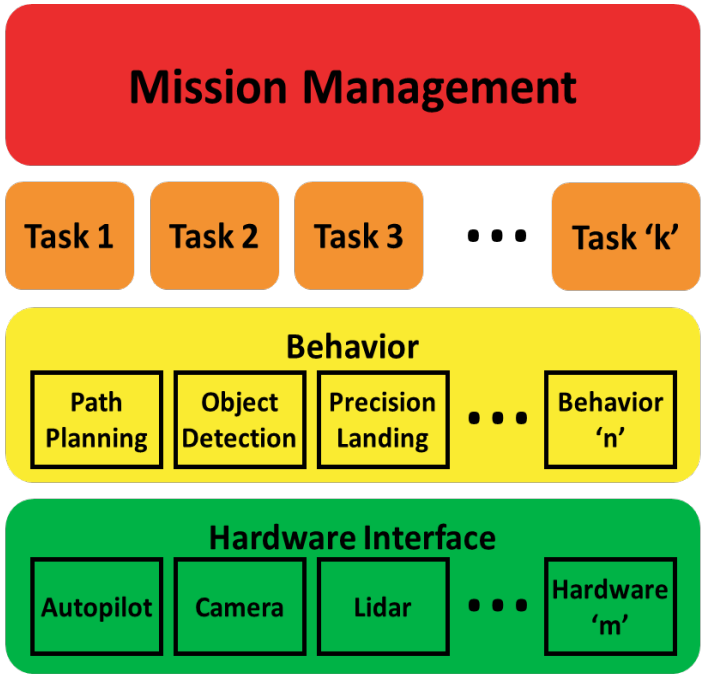
Persistent "TwinSim" → Operations



08 April 2020

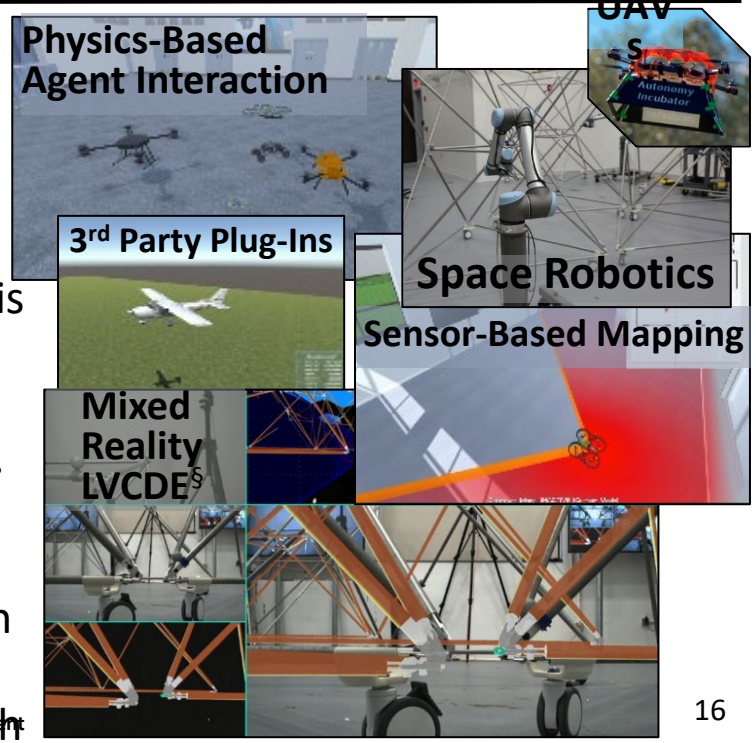
Autonomous Entity Operational Network (AEON)

- AEON is an architecture framework for sim-to-flight.
- AEON is a suite of libraries and self-contained applications supporting myriad features of critical autonomous capabilities.
- The AEON Framework is modular and easily extensible by developing new nodes to add system capabilities.



Baseline Environment for Autonomous Modeling (BEAM)

- Unity-based persistent sim that uses AEON and other frameworks
- Single- and Multi-Agent
- Mixed Reality for Data and Performance Analysis
- Multi-user with optional dependency on central servers. Also standalone.
- Modular plug-in capability
- Common communication interface (DDS) to support external research

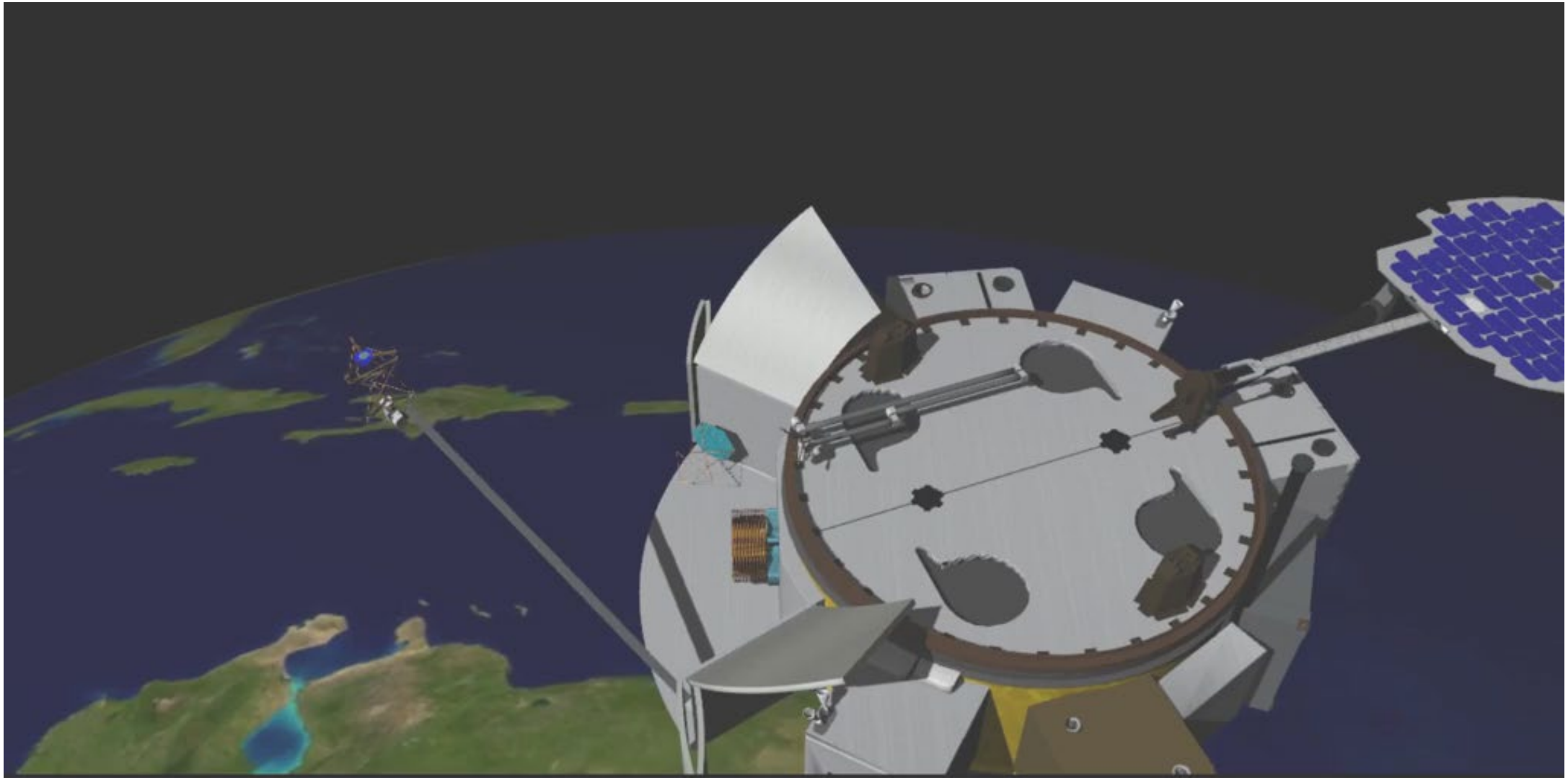


§ LVCDE – Live Virtual Constructive Distributed Environment

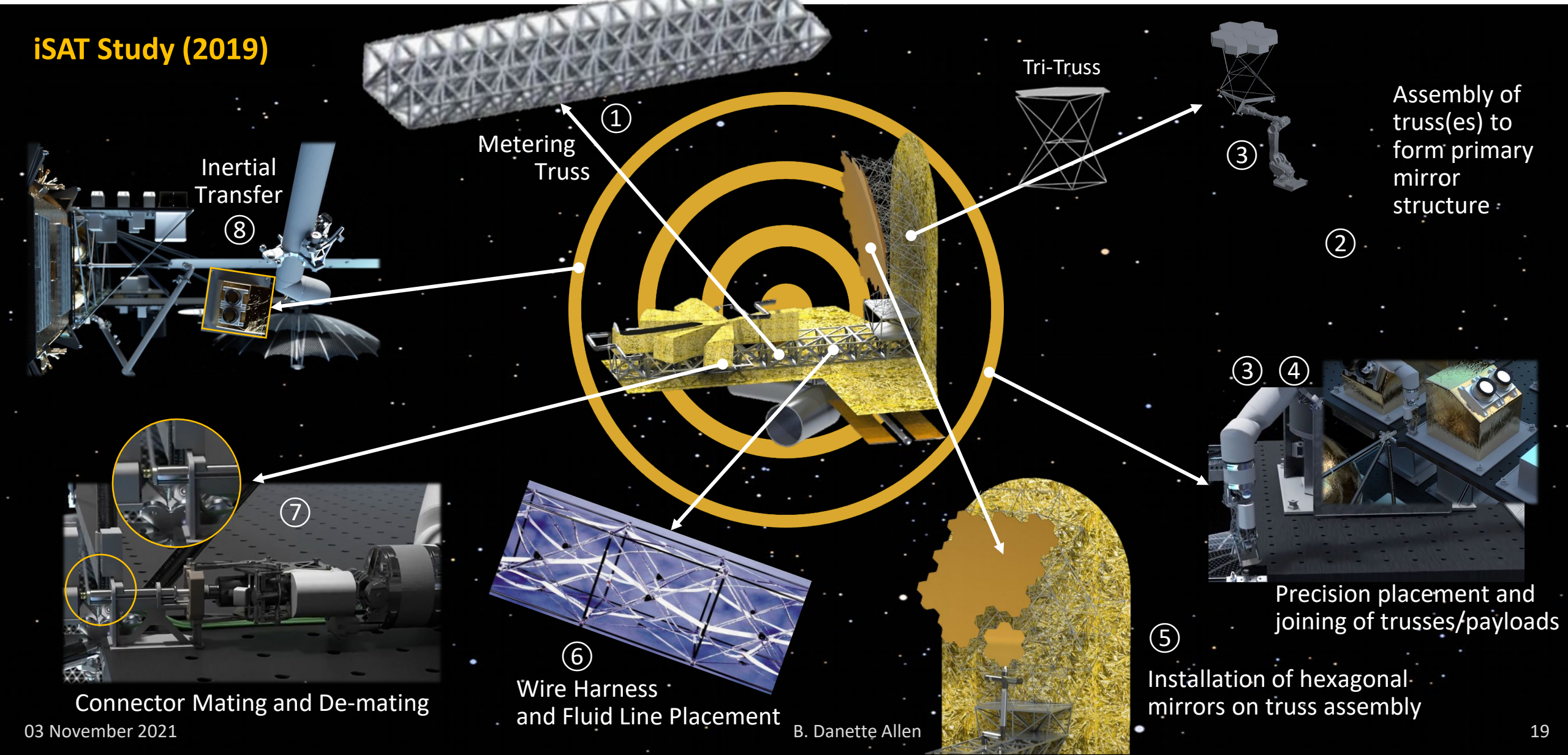
Presence

- *Presence* is a psychological state of *being there*, so in other words it describes *subjective* side of VR experience
- *Immersion* is a description of *human-made technology* that this experience is conveyed through — in other words it describes the *objective* side of VR experience.

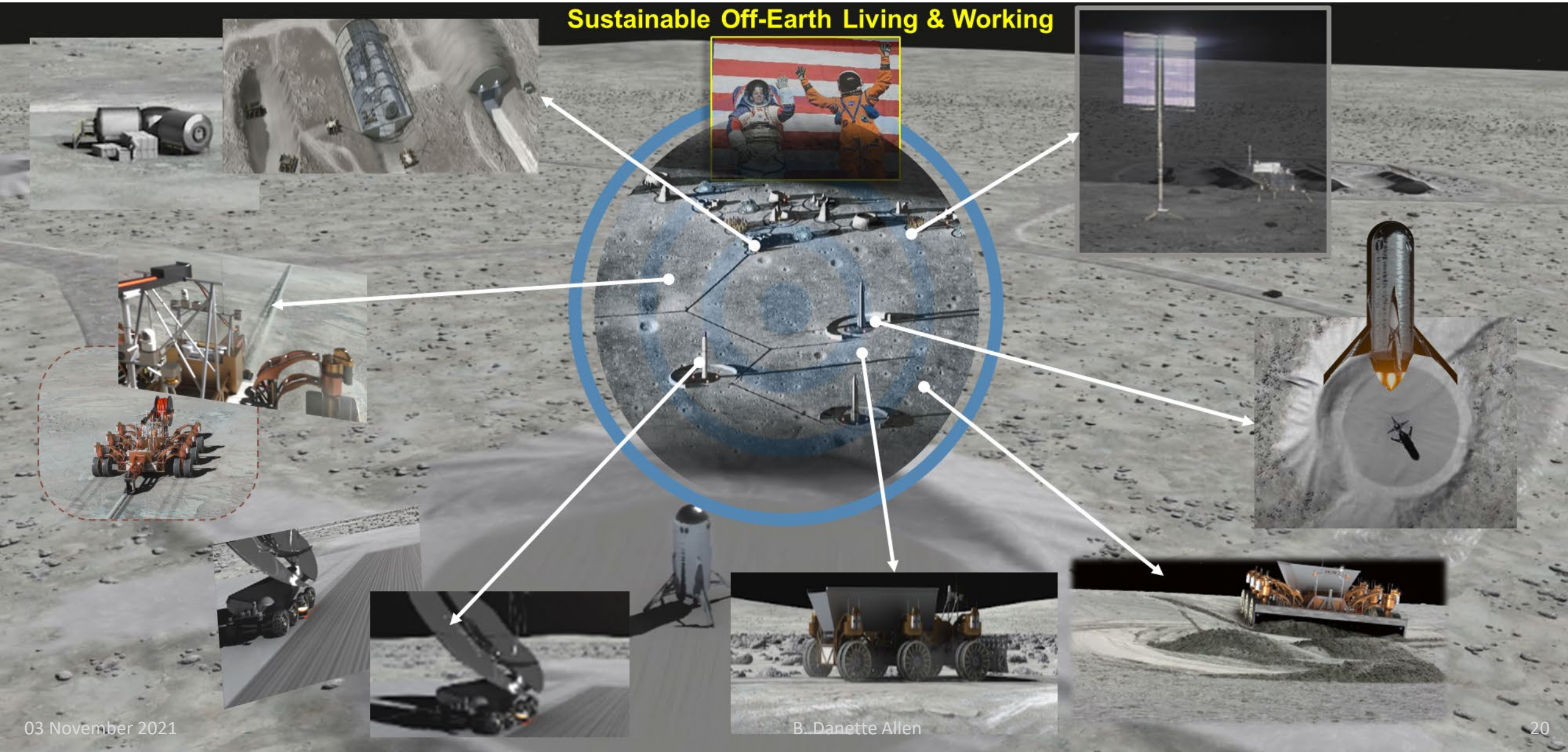
In-Space Assembly



Autonomous In-Space Assembly

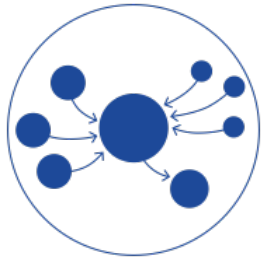


Autonomous On-Surface Assembly



In Conclusion: Living Models
"Digital Twin" Ecosystems

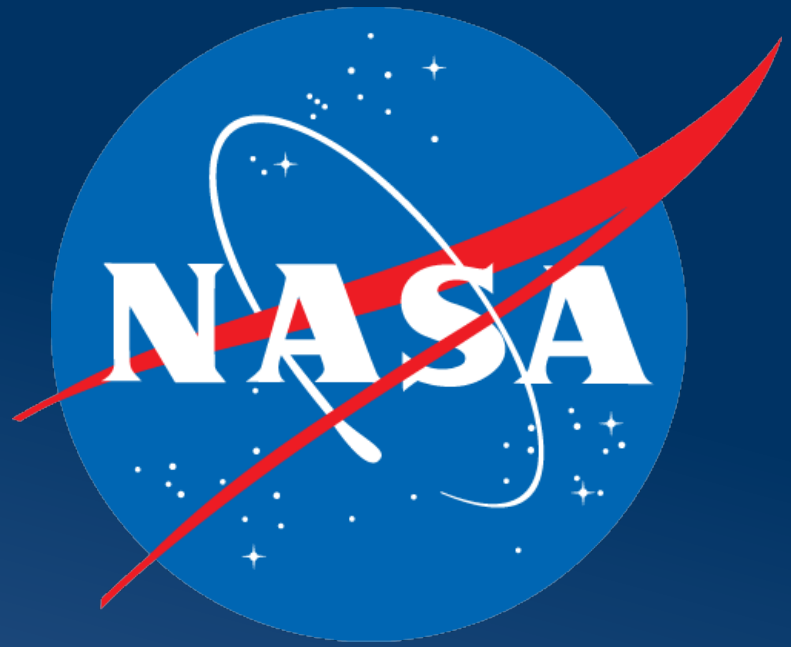
- Definition
- History
- Simulation
- Modeling & Simulation
- Digital Twins
- Immersion & Presence
- **Living Models**



?

- **"Digital Twin" Ecosystems**
  - Fidelity
  - Co-evolution
  - Verification & Validation
  - Reliability – How many 9s?
  - Sim-to-Flight… to Operations!
  - Prognostics

Thank you



DIGITAL TWIN SUMMIT
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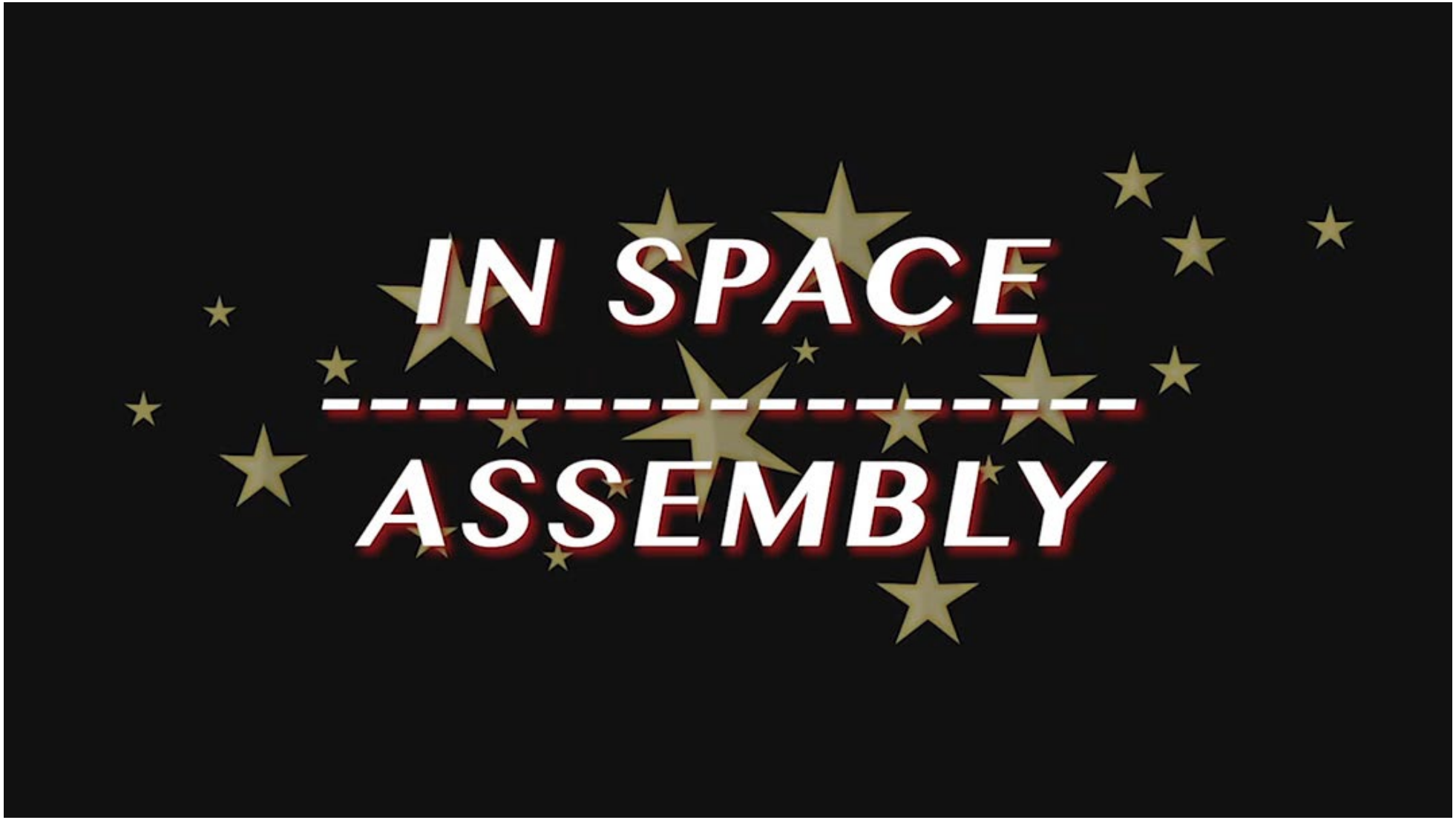
Autonomous In Space Assembly (ISA)



Digital Twin from Autonomous Excavation Team

- Construction
  - BIM - Building & Information Modeling
- Manufacturing
  - As build compensate for
- Simulation of conops to verify that design is meeting the intended requirements
- Little opportunity to be present on the moon (presence!)
  - Hugely valuable to provide opportunity for “visiting” the operational space n the lunar surface for operators, engineers, and maybe e public
  - Telepresence
- Modeling Methods for Lunar Regolith interacting with Excavation Implements and Design of such implements (Robert Mueller)
  - Construction machinery on the moon consists of two things (mobility + implement)
    - Interaction of wheels on regolith. Good body of knowledge
    - Reaction forces created by implement. Don’t know what input force is. Need to remove or “erase” forces like with RASSOR.
- Feedstock production
- Cadence!
- Launch and landing pads – produce rationale for when we need them… the timing. Need pad to land SAFELY.
- MMPACT - Surface texture transmogrifies. More than viz. Digital twin?

Natalia's thoughts

- One slide partition of the digital twin world and light it up piece by piece like I do
  - First, appeared for purpose of just the vehicle. Give a seminal reference. Started as digital twin of an aircraft. As A/C becomes more complex becomes harder to evaluate it flightworthiness, lifecycle, etc. wouldn't it be great to keep a digital copy for maintenance, etc.
  - Sim is way older than the vehicle
  - Given an idea of different qualities of modsim
  - Concept of digital twin is broader/expanded. Simulation of large systems of systems are not necessarily called digital twins but is analogous to having digital twins of the system → transition to ATTRACTOR
  - ATTRACTOR serves as small flexible test platform but has concept of sim-to-flight so it is both a platform for development and a platform that subsumes all of the transformation s that happen to the platform for while it is operating. Could have someone developing a piece of something in AEON BEAM. Someone else could be using it for flight and, without interfering with flight, someone could take the flying vehicles as the load for their testing system. Testing in real-time with operational vehicle
  - Vehicle → test system → sim-to-flight system → combined seamless developed to operation
  - SmartNAS, ATOL, others?
  - Sim vs digital twin.
    - Sim – run and see what happens
    - DT – connection to real operations and to use real operations as a load on the testing part
  - Event-based rather than vehicle-based for autonomy
  - Depends upon sensitivity of outcome of events to variables in the system. Could be state described by CDE, or, …
- At what point does a simulation become a digital twin? The significance of the effect that you are trying to model wrt to variables that you are interested inn. For instance, what the ICON guys do is going to eb dictated in anyway by the article model of the surface then putting an animation there doesn't make the system a DT because it lacks fidelity for the purposes of the operations. Is there a fidelity "slider" from sim to DT? Ask whether its meaningful to what you're predicating. It's a question of uncertainty and validation. Is it good enough to drive operations? A sim (like LITE) never changes. DT changes over time.
  - DT changing over time = persistent sim over life of asset or system. Co-evolution of digital artifact with physical artifact
  - Predictive
- Conclusion: identification of validation criteria for then is your DT good enough of a twin? Gravity variable is potentially a gamechanger. Lack of air (vacuum). Need serious thinking about what validation is.

Digital Twin

Smart-NAS Project

Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS)

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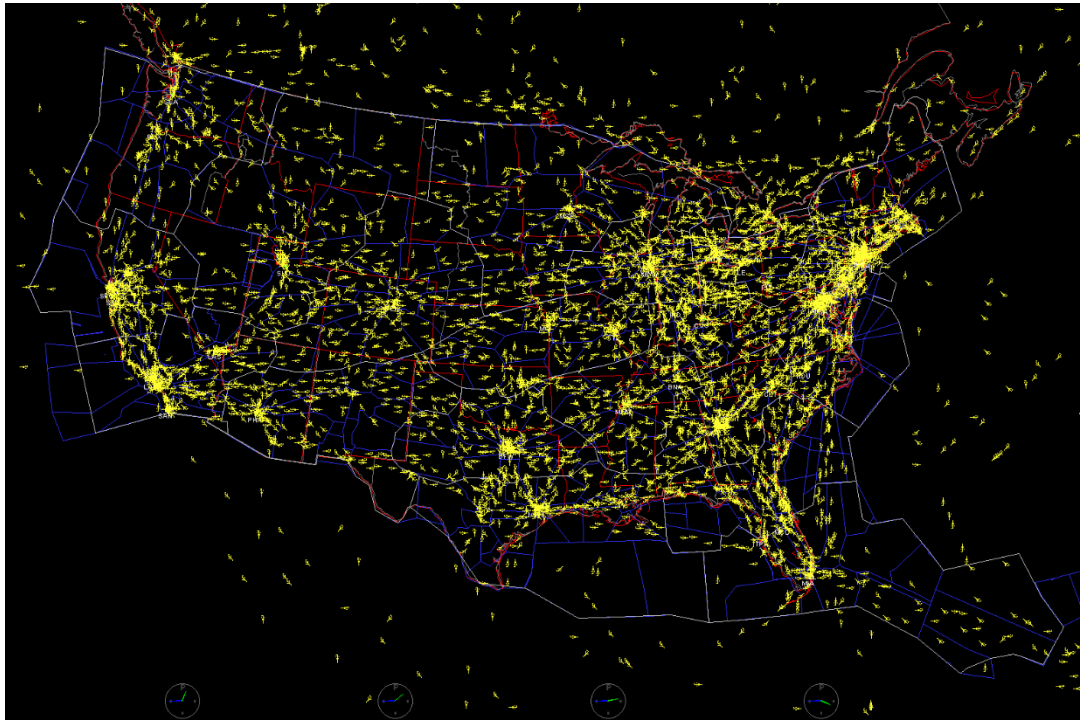
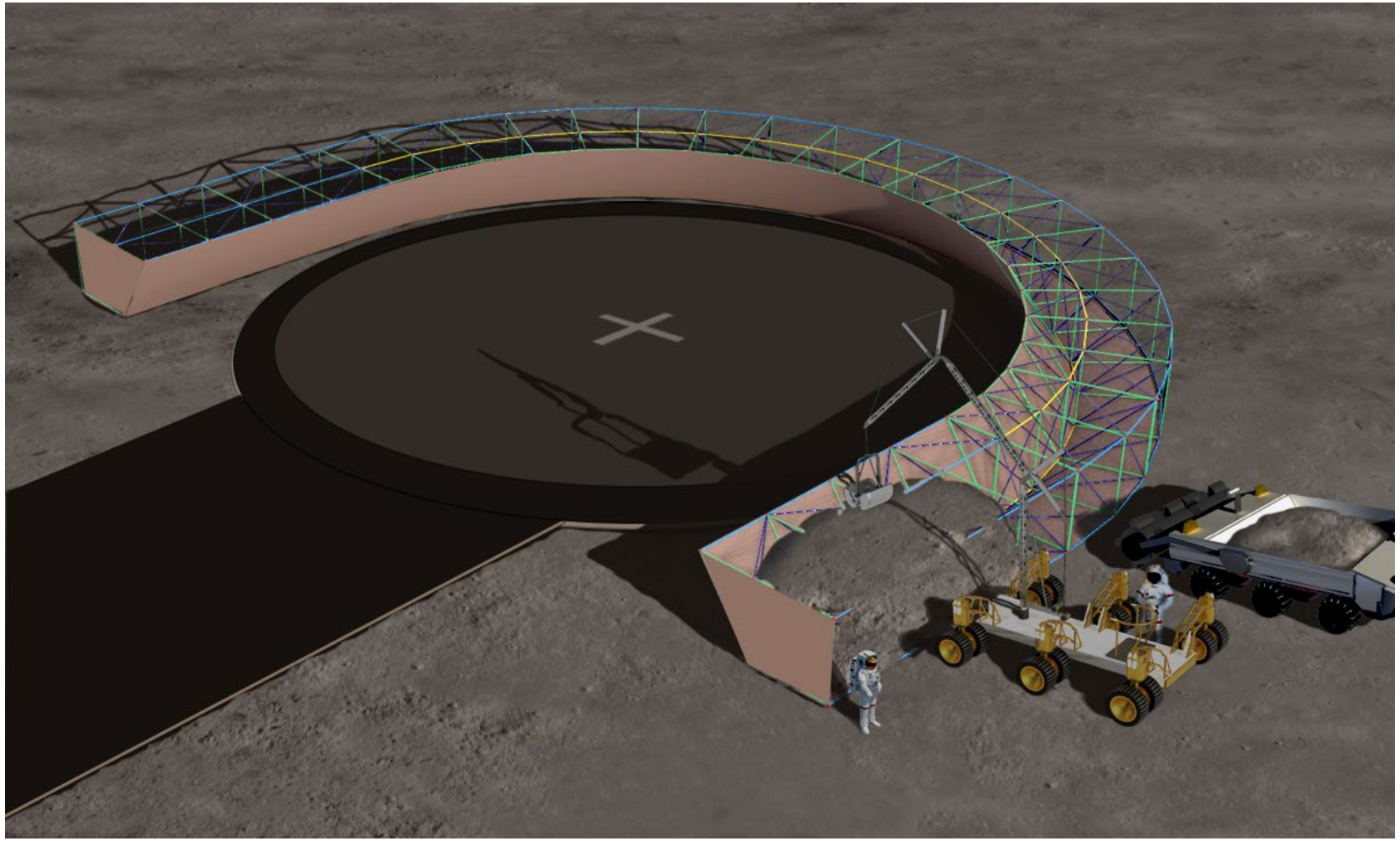
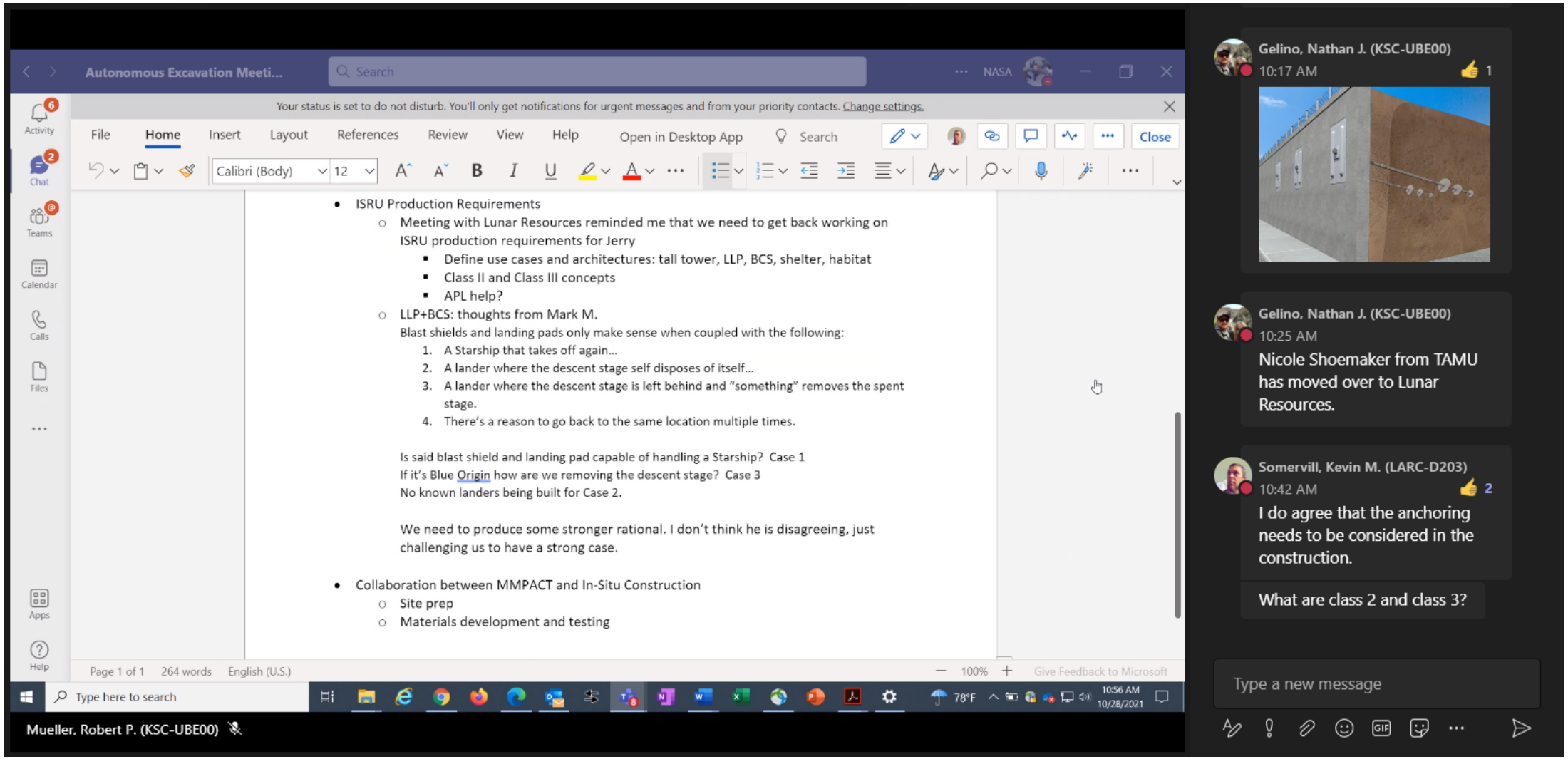


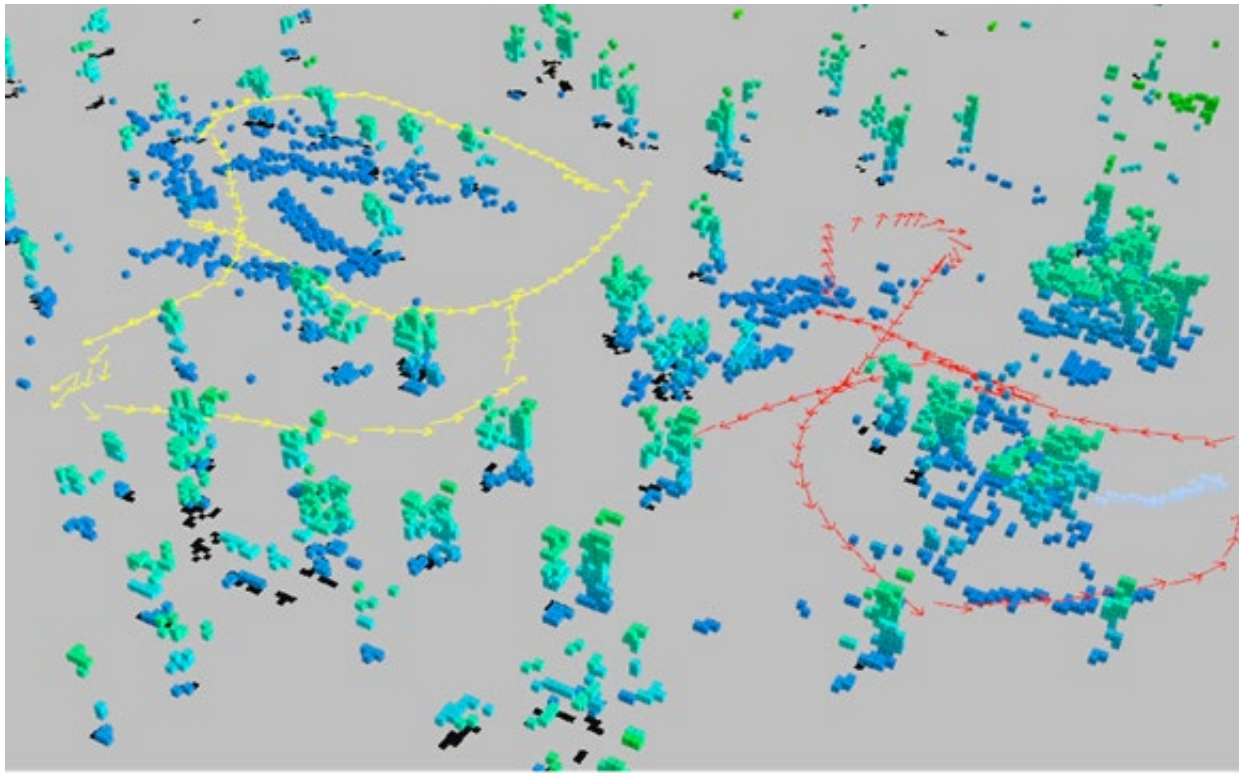
Blast Shield Concept (MarkH & BillD)

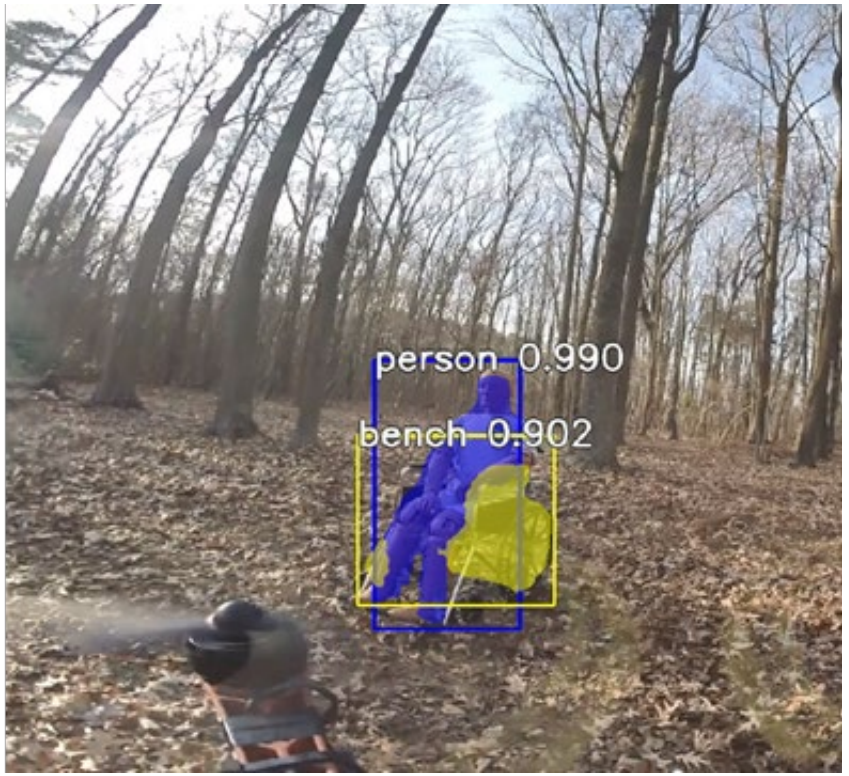


Digital Twin from Autonomous Excavation Team

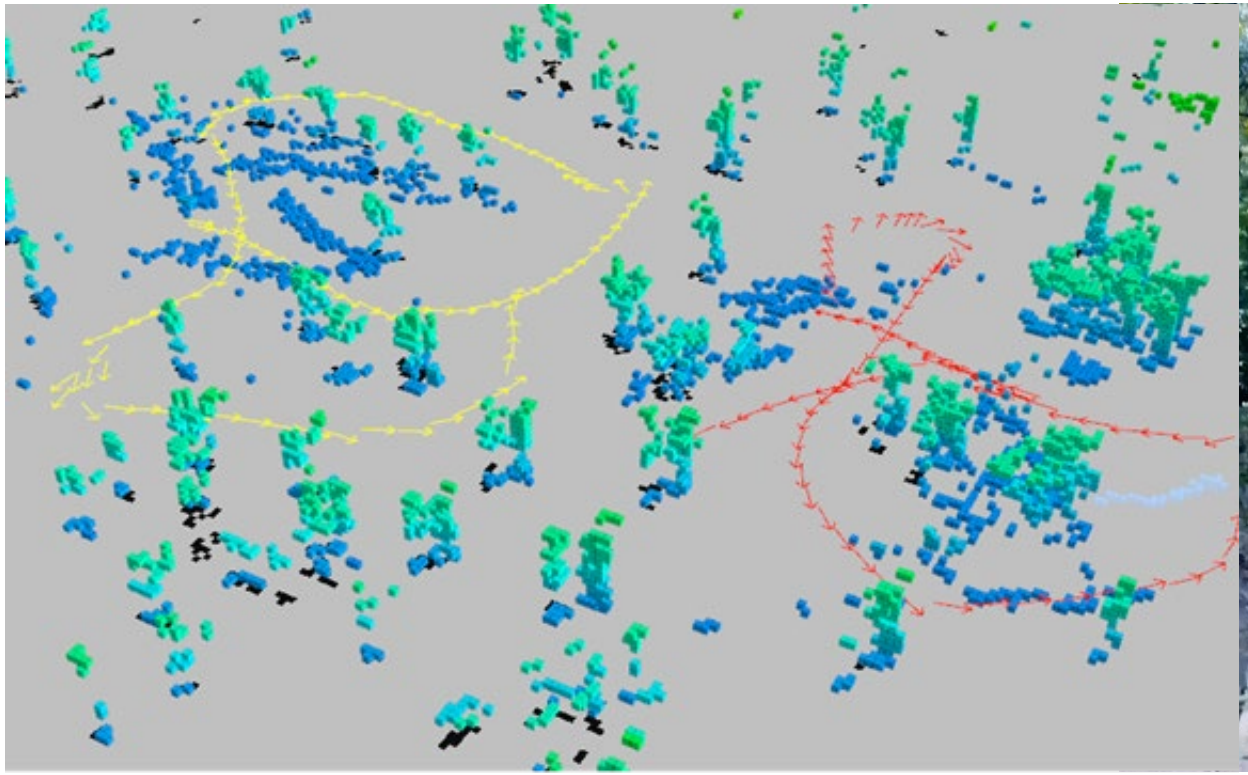


ATTRACTOR DRM:
Search & Rescue Under the Canopy

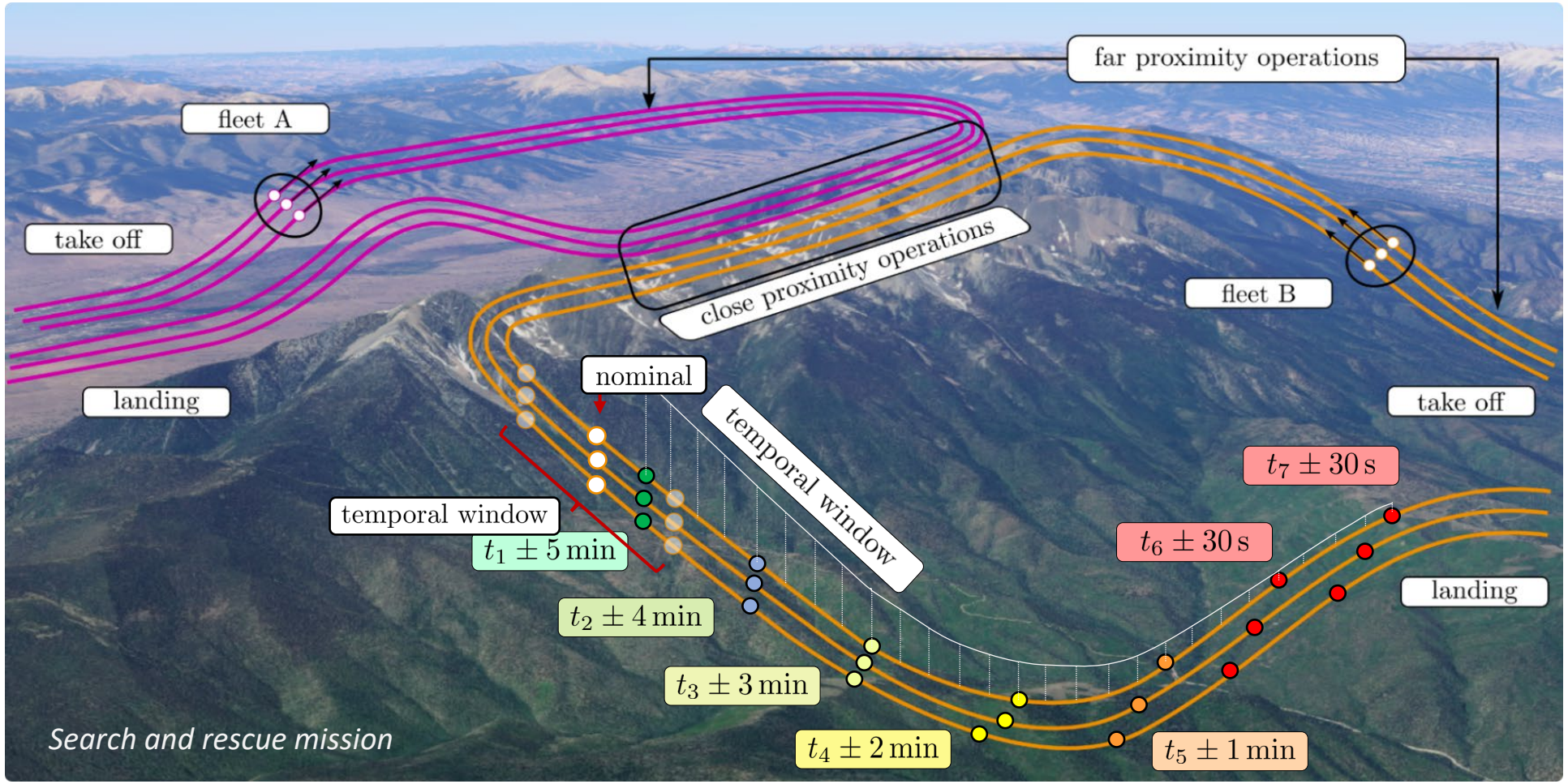




ATTRACTOR DRM:
Search & Rescue Under the Canopy

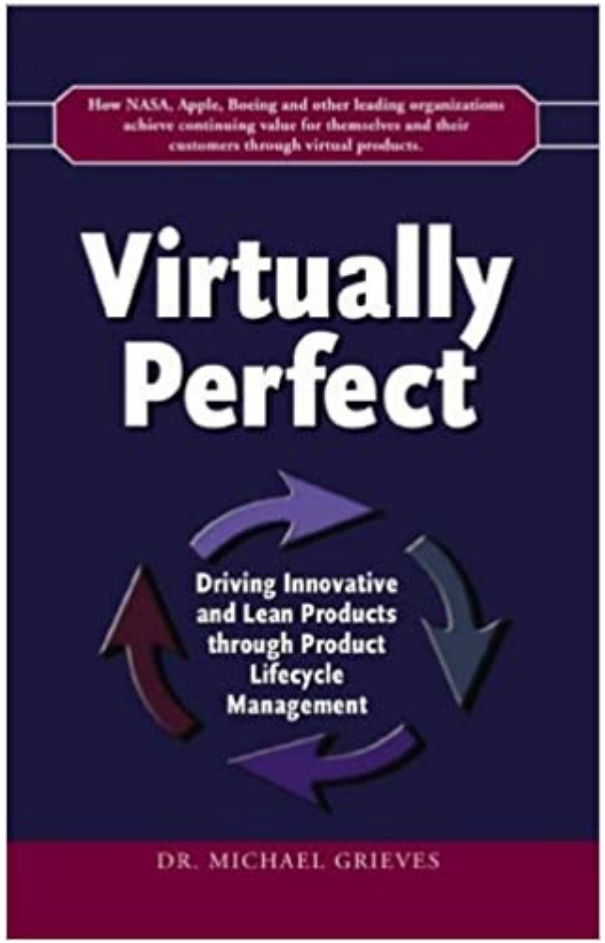


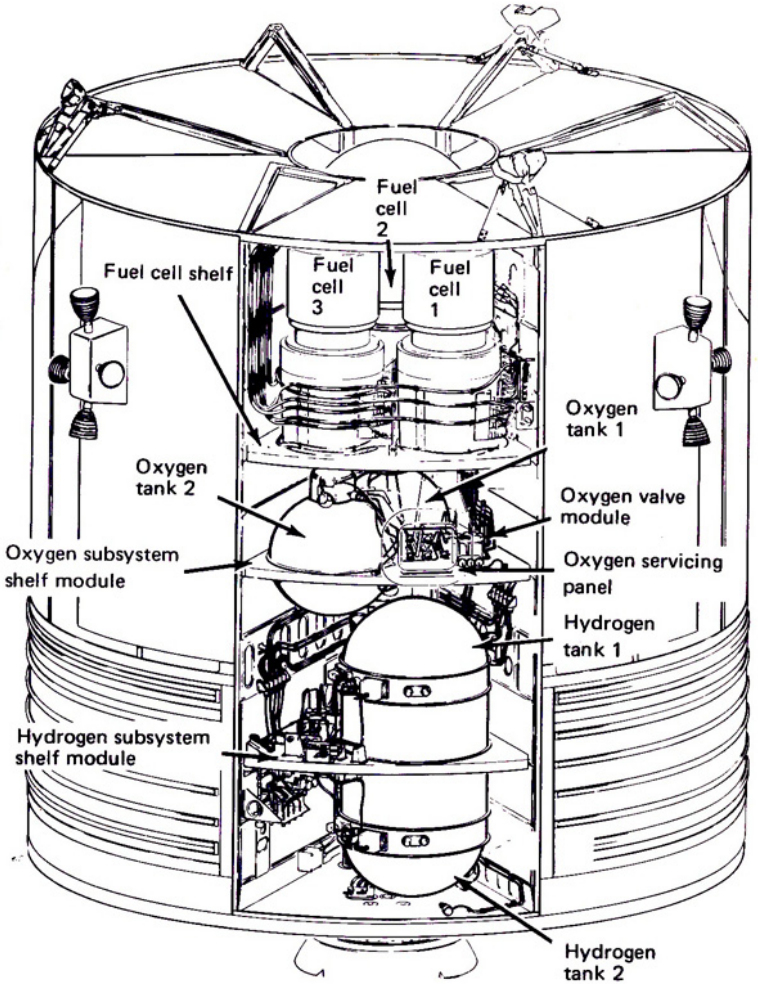
ATTRACTOR DRM: Search and Rescue (SAR)

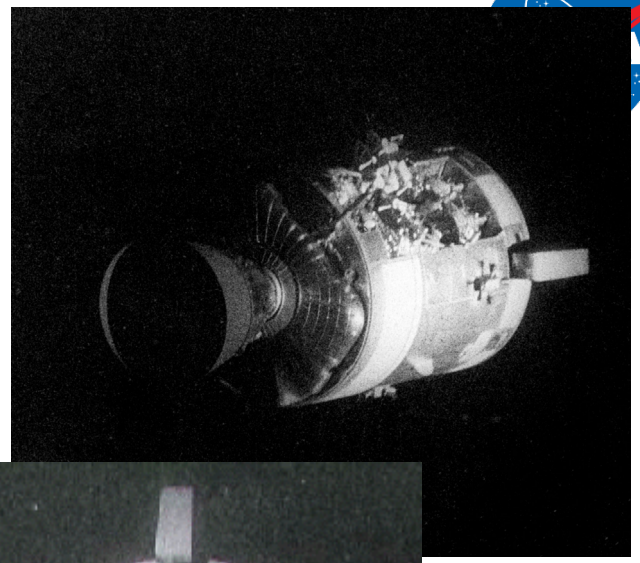


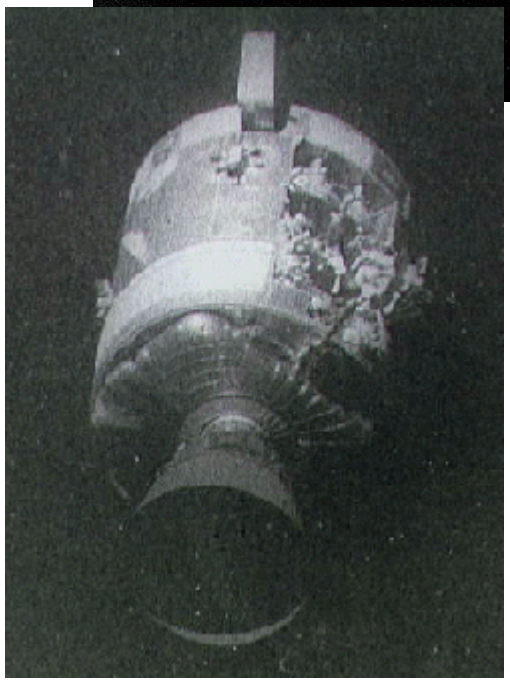
Mission Planning – Temporal and Spatial Coordination

Graphics

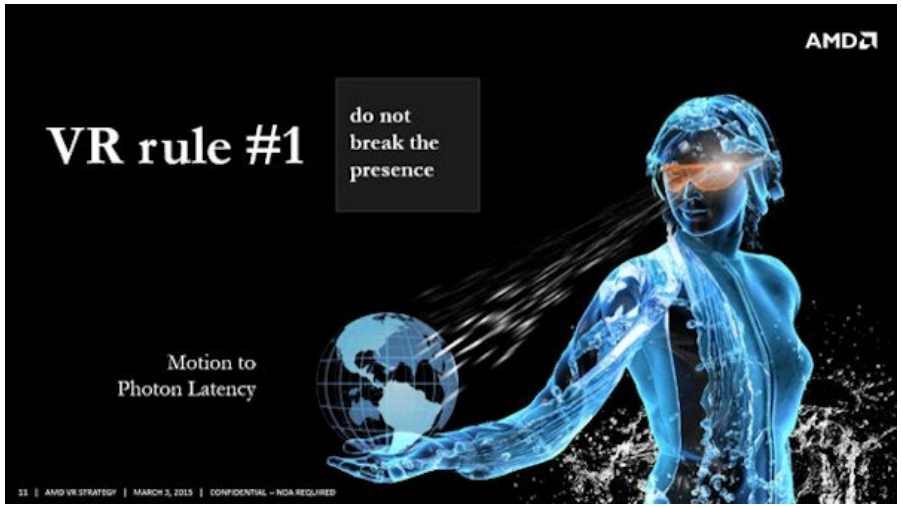

How NASA, Apple, Boeing and other leading organizations achieve continuing value for themselves and their customers through virtual products.
Virtually Perfect
Driving Innovative and Lean Products through Product Lifecycle Management
DR. MICHAEL GRIEVES


Fuel cell 2
Fuel cell shelf
Fuel cell 3
Fuel cell 1
Oxygen tank 1
Oxygen tank 2
Oxygen valve module
Oxygen subsystem shelf module
Oxygen servicing panel
Hydrogen tank 1
Hydrogen subsystem shelf module
Hydrogen tank 2






Oxygen
Tank 2

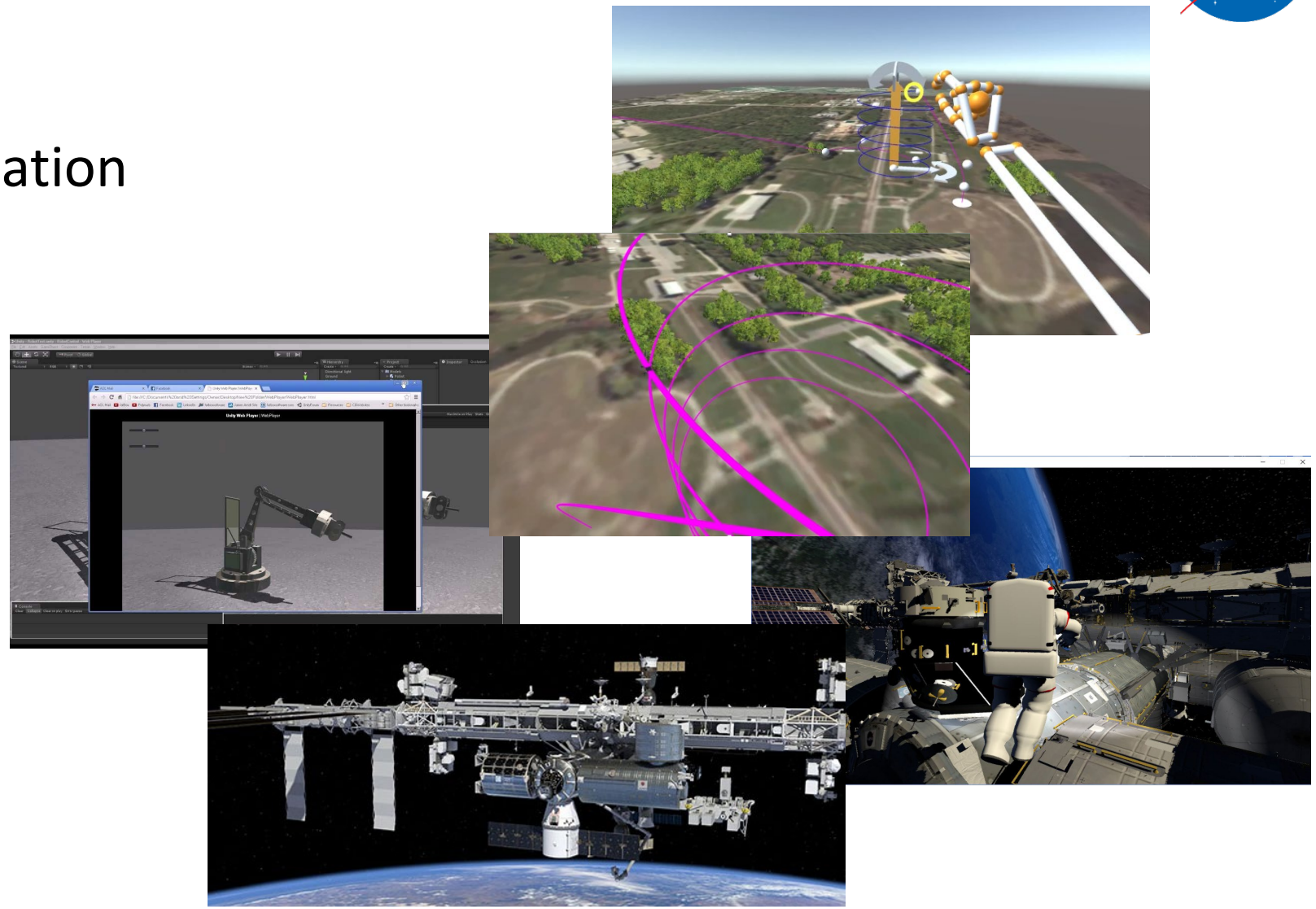

AMD
VR rule #1
do not
break the
presence
Motion to
Photon Latency

Retaining Wall (NathanG)

- Wall wants to fall over to the left
- On earth, drive rods or cables into soil with backing plate
- Self-reacting structure to hold retaining wall up
- Structure is filled in from the right to the left
- An energy push from off screen to the right would make it fall

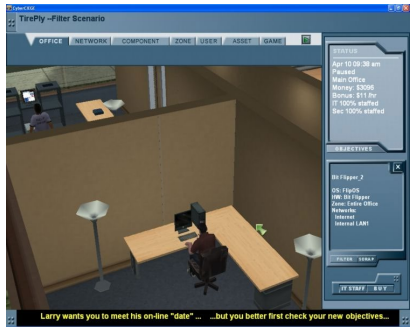
Modeling & Simulation of Autonomous Systems

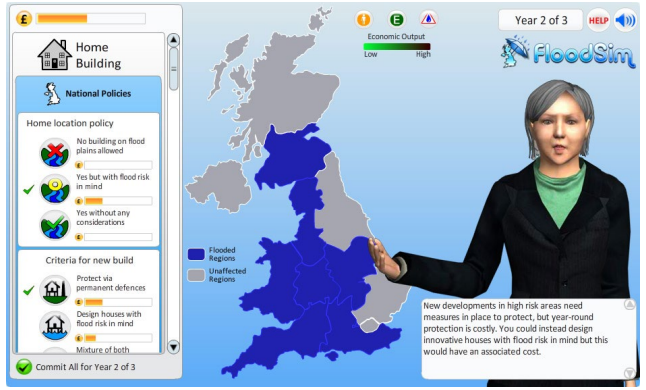
- Game development application
  - Distributed environment
  - Cross-platform
  - VR applications
- Supports
  - Robot animation
  - Physics engines
  - Persistent World

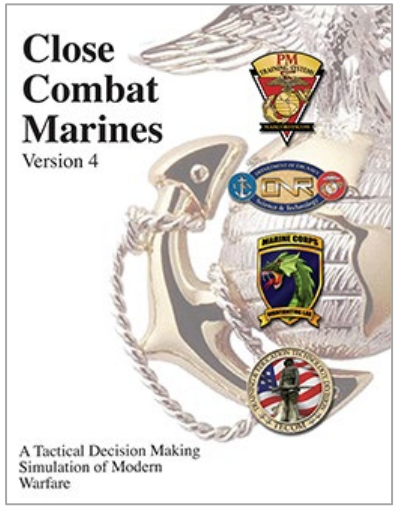


Serious Gaming

- Simulations of real-world events or processes designed for the purpose of solving a problem
- Examples
  - Floodsim (UK)
  - Food Force (UN)
  - Close Combat (Marines)
  - CyberCEIGE (NPS)
  - World Without Oil
  - X Plane
  - ATTRACTOR





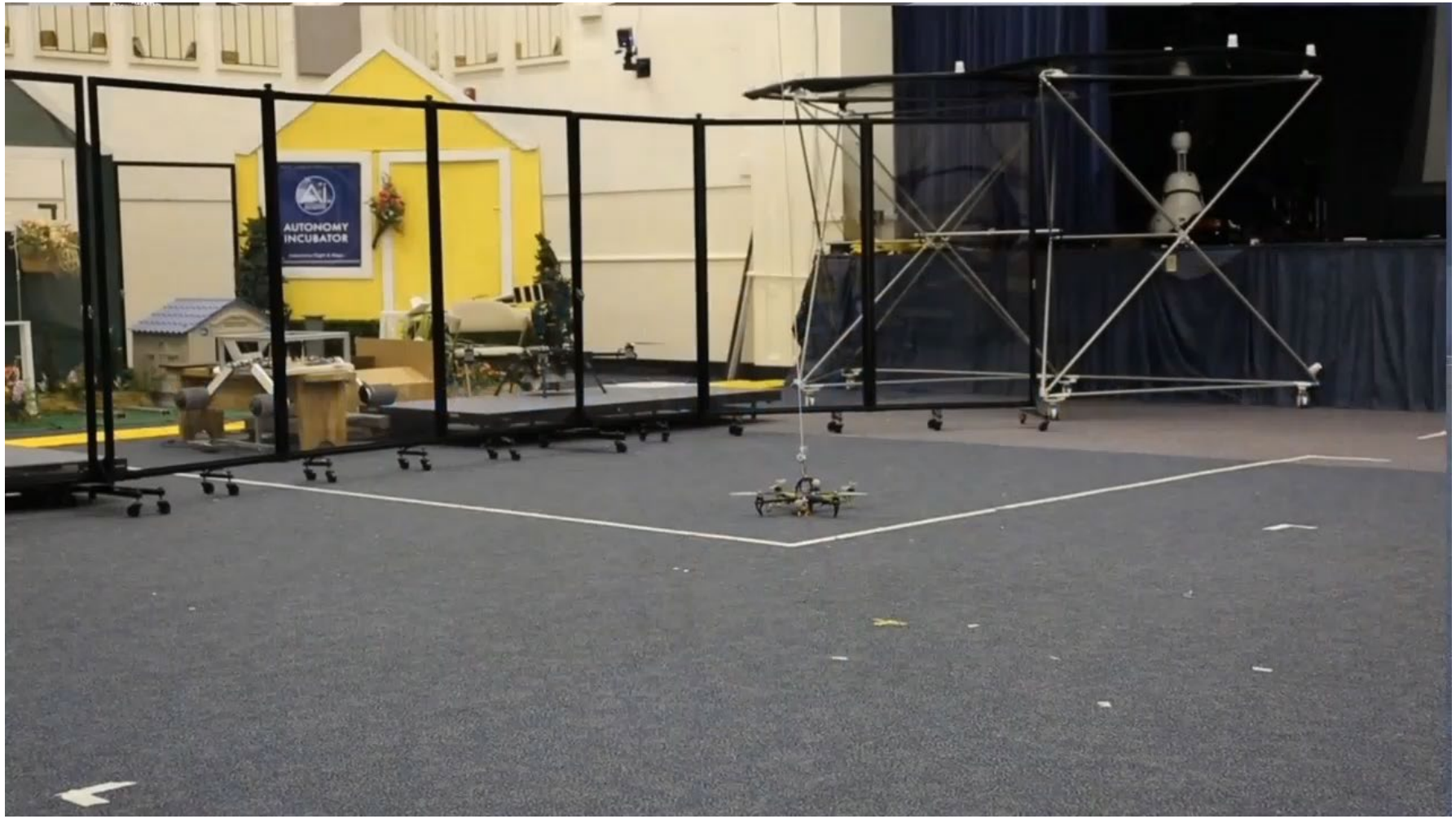


MMORPG for Autonomous Systems
Massively Multiplayer Online Role Playing Games

Evolution of Massively Multiplayer Games (l to r): Dungeons & Dragons, Second Life, World of Warcraft)

Participants create characters, infrastructure, and vehicles in Minecraft

An Idea is Born



Human Exploration Systems

NASA ARMD has decades of experience developing advanced airspace capabilities that rely on simulations and field integrations.

Dedicated to agency goals of increased digital transformation and continually developing enhanced capabilities.

- SMART-NAS
- ATOL/AOL