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What Do We Play?

- The Game is:
  - Multi-Decade, Massive, Complex System Conception, Design, Development and Operations
  - Targeted towards a hostile and unforgiving environment
  - With a gifted, diverse and distributed group of friends
  - With the goal of getting as far off the planet as possible
- The Rules are:
  - Physics / Teams / Process / Science / Story
  - Time / Distance / Culture / Goals

Who Plays, The Goals

- Players:
  - Government
    - We will be buying large systems
    - DoD more than NASA of course, but the principles are the same
  - Industry
    - Design – A lot of simulation based cooperation
    - Development – A lot of simulation based cooperation
    - Manufacturing – We have work to do
- Goals:
  - Share some of what we (NASA) have done
  - Elicit and get help with the next steps

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Things We Do

- We Model
  - We represent the **thing** we want to study
  - With as much detail as is necessary for that study
- We Simulate
  - We represent **behavior** of the thing(s) we want to study
  - With as much detail as is necessary for that study
- We Decide
  - We look at the things, and how they behave, **determine** the next step(s) and **communicate** the results of the study
  - With as much detail as is necessary for that study

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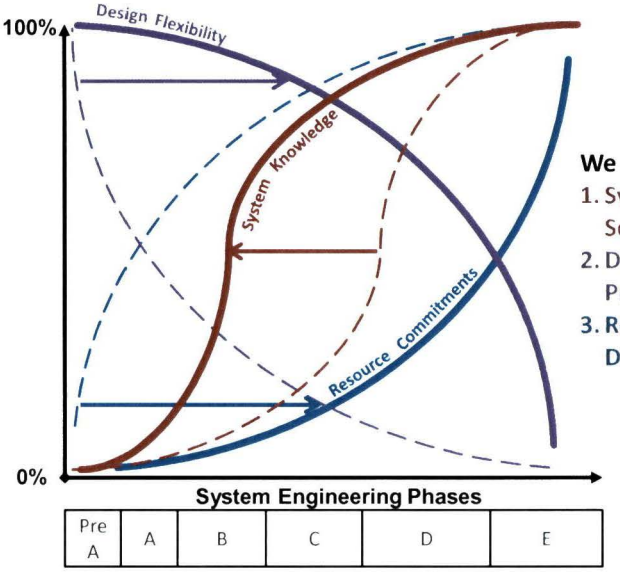
Things We Want



We All Want:

1. System Knowledge Sooner
2. Design Flexibility Preserved
3. Resource Commitments Delayed

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Simulation Helps Us Get Them

NASA / INCOSE System Engineering Phases

Pre A	A	B	C	D	E

Simulation Based Concepts

Simulation Based Designs

Simulation Based Products

Sustainable Systems

***And**, along the way we create artifacts that we can share, that increase understanding and allow us to access additional expertise*

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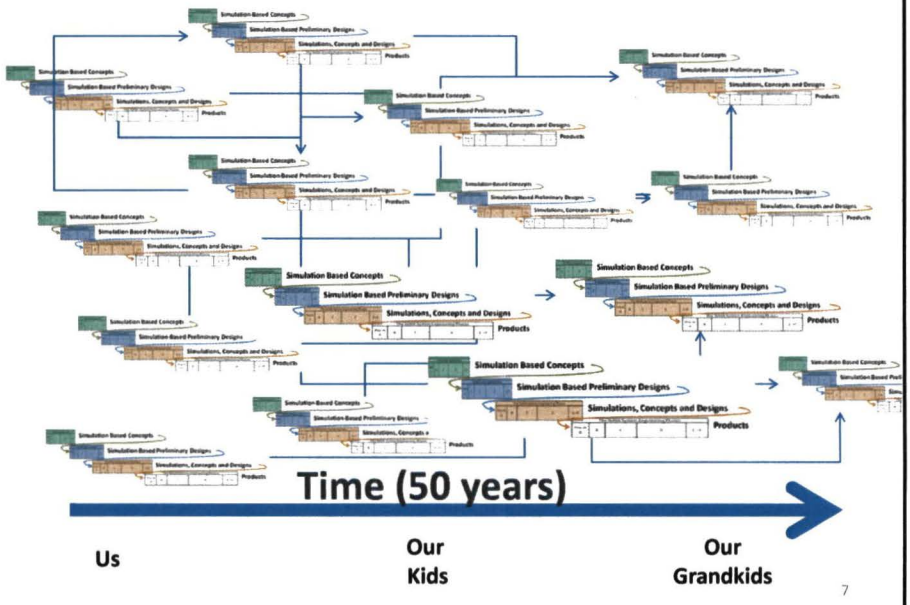
But, Multi-Decadal & Interdependent is Hard



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We know a Bit About Simulation Tools and Technologies

Constellation

Modeling and Simulation

Some Constellation Data

- Constellation was made of multiple Projects
  - That needed to be able to work together for 50+ years
- Simulation was a massive team that shrank massively
  - 80 to 8, neither was a good number
- The Product Data Manager (PDM) was going to make everything work fine
  - Um, if you have a mess, and you automate it, you get a highly automated, high speed mess
- We Reorganized and built a new Simulation organization
  - I found out I was the leader in the roll out teleconference
  - I got a PDM with a Common Model Library

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We Did Have Some Things

- We looked at Constellation's Tools
  - We found where the Data and Information were stored
  - We mapped how both flowed through the system and identified how to get them out
  - We normalized them so we could share the Knowledge
- We had distributed, physics based simulations
  - Could share data across the country
  - First internally, in Modeling and Simulation Labs (MSL) #1
    - A full mission flight simulation from Kennedy to ISS
  - Then externally, in Virtual Mission (VM) #1
    - MSL # 1 plus the assembly, prep, paper processes and test phase
- It All Looked Like This…

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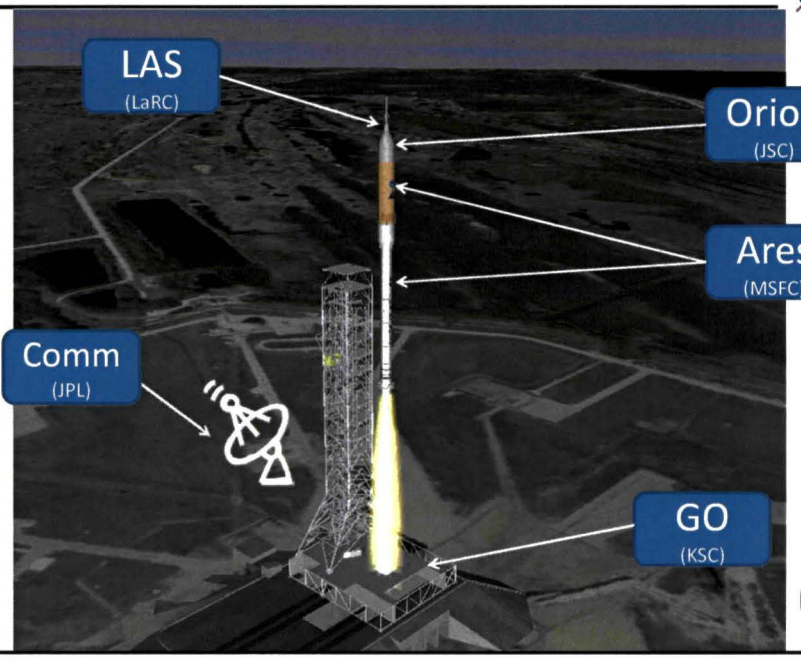
MSL 1, VM 1, Ares 1 Launch



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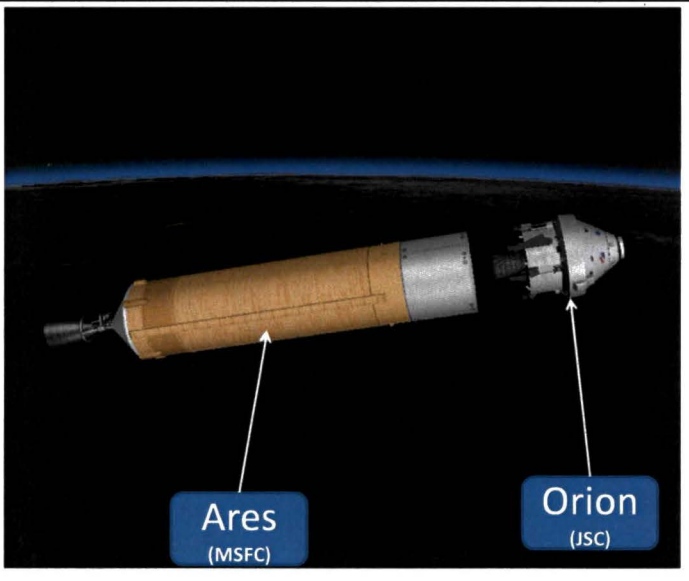
Upper Stage / Orion Separation



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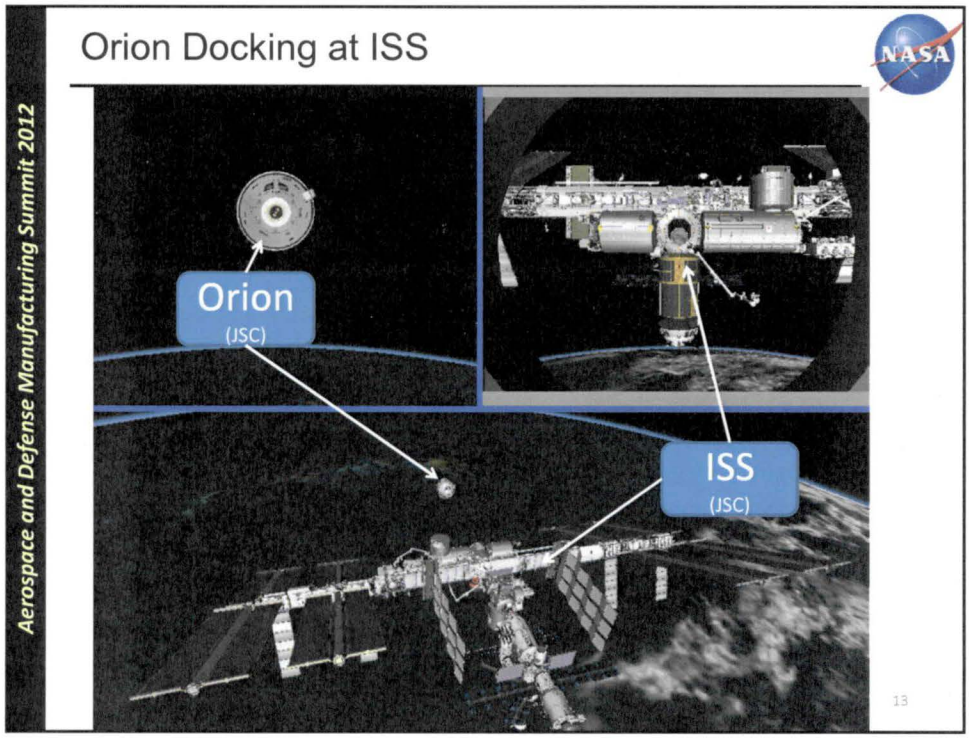
Orion Docking at ISS
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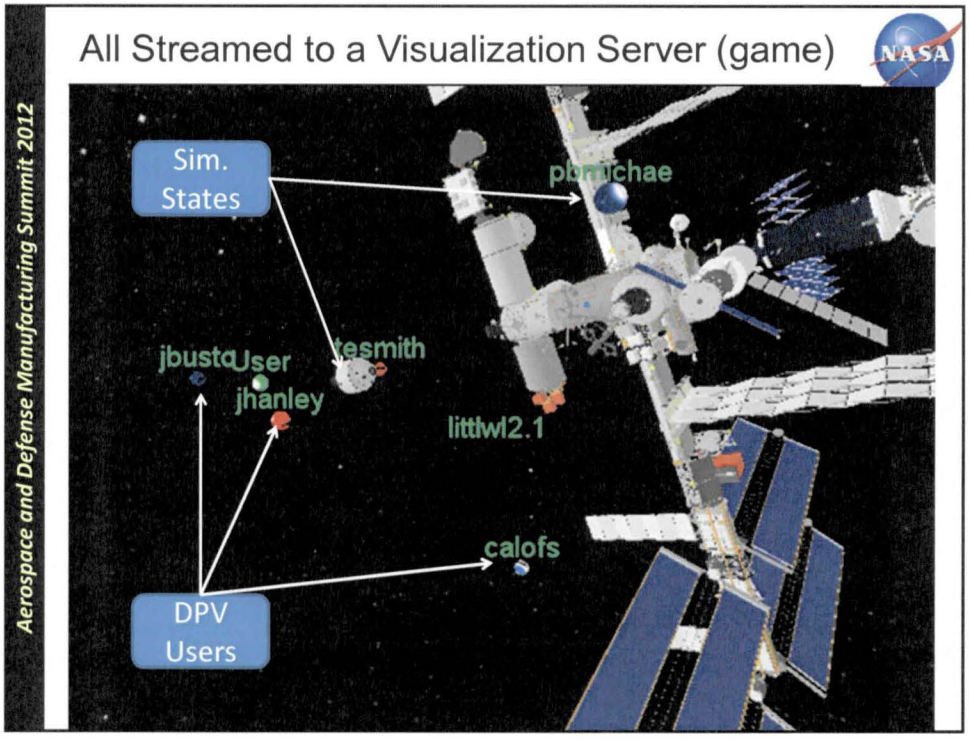
Orion
(JSC)
ISS
(JSC)
13


All Streamed to a Visualization Server (game)
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Sim. States
pbruchae
tesmith
jbustoUser
jhanley
littlwl2.1
calofs
DPV Users

Did It Work? YES!

- We had:
  - Distributed Simulation and Visualization, Common Data Formats, Centralized Storage, Royalty Free Tools, Common Interfaces and were close to voluntary Program wide data integration
- Along the way:
  - We performed Program wide simulations, with real physics
  - We performed simulation based Program integration (the bolts)
  - The results were preserved in a Distributed Visualization System we could share with partners and friends while preserving their IP
- Within a year we had
  - Demonstrated simulation based program integration
  - Taught teams how to share their knowledge
  - Royalty free tools, with standard interfaces, that preserved IP
  - Constellation was Cancelled

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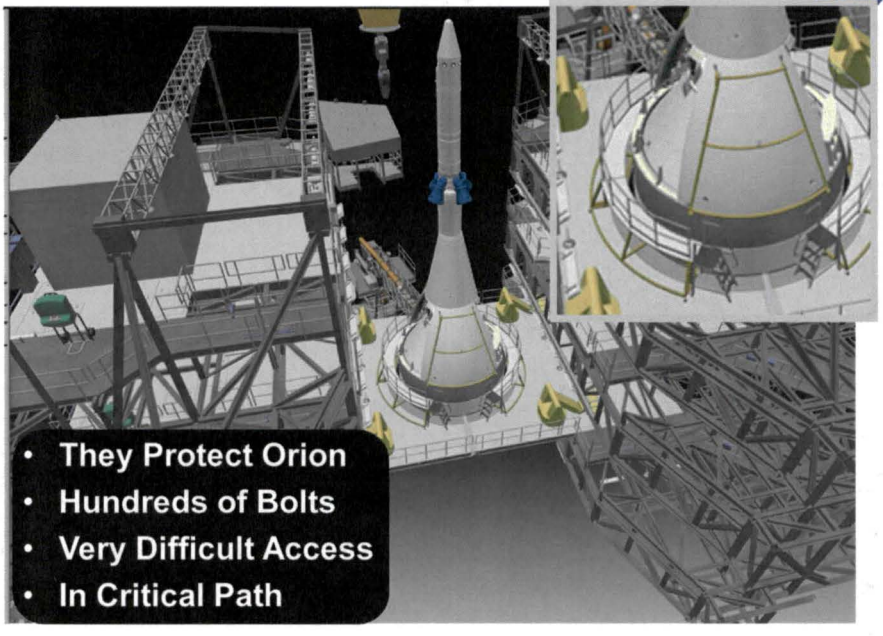
A Orion Simulation
Ogive Panel Installation

CxP Ground Operations Project
Modeling and Simulation

Install Ogive Panels in VAB



- They Protect Orion
- Hundreds of Bolts
- Very Difficult Access
- In Critical Path

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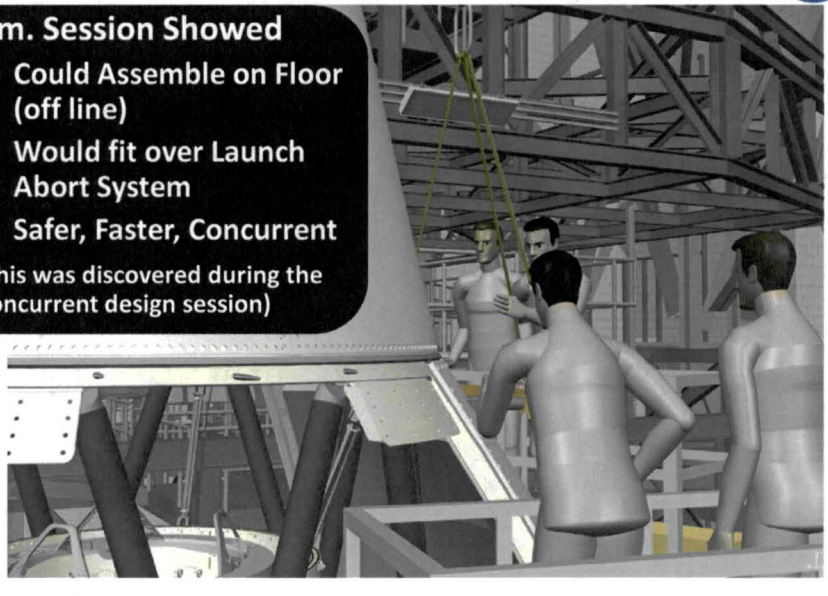
Ogive Human Factors Detail (Delmia)

Sim. Session Showed

- Could Assemble on Floor (off line)
- Would fit over Launch Abort System
- Safer, Faster, Concurrent

(this was discovered during the concurrent design session)



Did It Work? YES!

- We had:
  - The Vehicle Assembly Building, Mobile Launcher and Ares 1 all in one simulation, down to the lights, hand railings and fire system
  - Pulled multiple disciplines into the same room to concurrently design and review systems and processes
  - New concepts that reduced risk, schedule and cost
- Along the way:
  - We included Operations, Design, Development, Planning and the associated Program leadership
  - We demonstrated value of a dedicated Simulation or CAD Integration team and started a "by the pound" service subscription model

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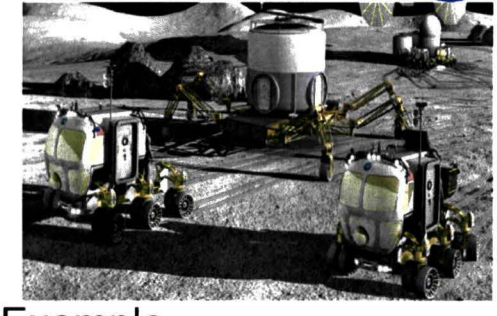


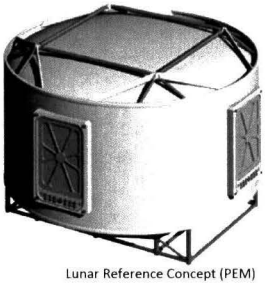
Exploration Systems Example
The Habitat Demonstration Unit

Exploration Habitation Project

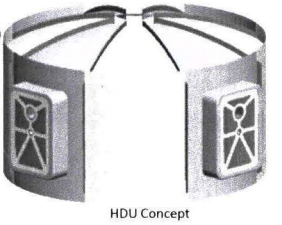
Modeling and Simulation

HDU Overview

- Vision
  - Develop, integrate, test, and evaluate a Habitation prototype to better understand mission architectures, requirements and operational concepts
- Timeline
  - Project Kick-off: **June 2009**
  - Shell: October 2009 – April 2010
  - Systems Integration: **April – August 2010**
    - 10 Month Build, 4 Month Integration
  - Field Test at Desert RATS September 2010
- Participation
  - Jointly managed and built across 3 Time Zones with subsystems from 7 Centers



Lunar Reference Concept (PEM)



HDU Concept

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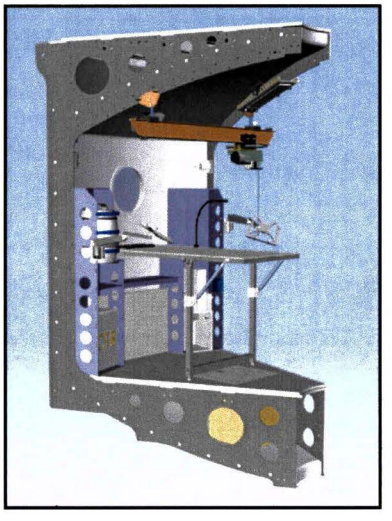
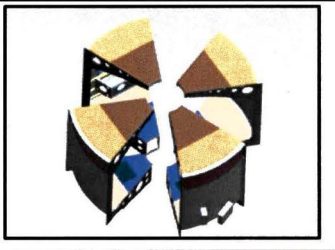
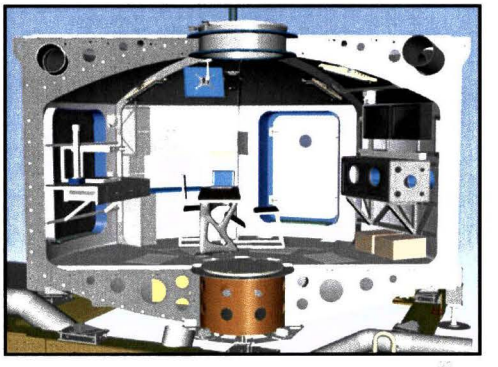
CAD Based Integration - Interior







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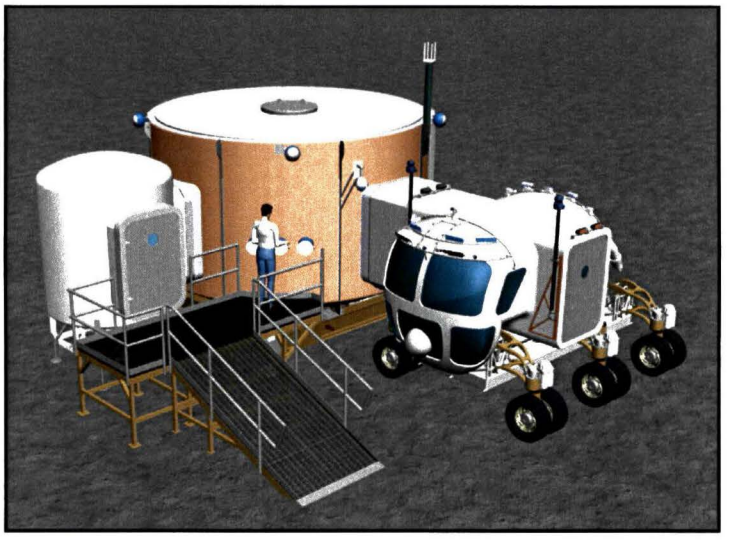
CAD Based Integration - Exterior



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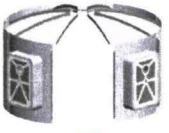
Concept Realization (15 Months to Field)



Concurrent Design Lessons

- CAD integration rapidly grew to system simulation, then concurrent development
  - Concepts were matured in design sessions
    - Concept developed, "model" updated, package base lined
    - Design completed, "model" updated, systems built
    - Multiple Centers, Teams, Projects, Time Zones and Budgets
- Success not just because of Simulation
  - Leadership prioritized decisions such that time critical elements were decided on first
    - Even if only allocations
  - Simulation Screen Shots became a key communication path
    - Timely, Enhanced Understanding, Converged Ideas

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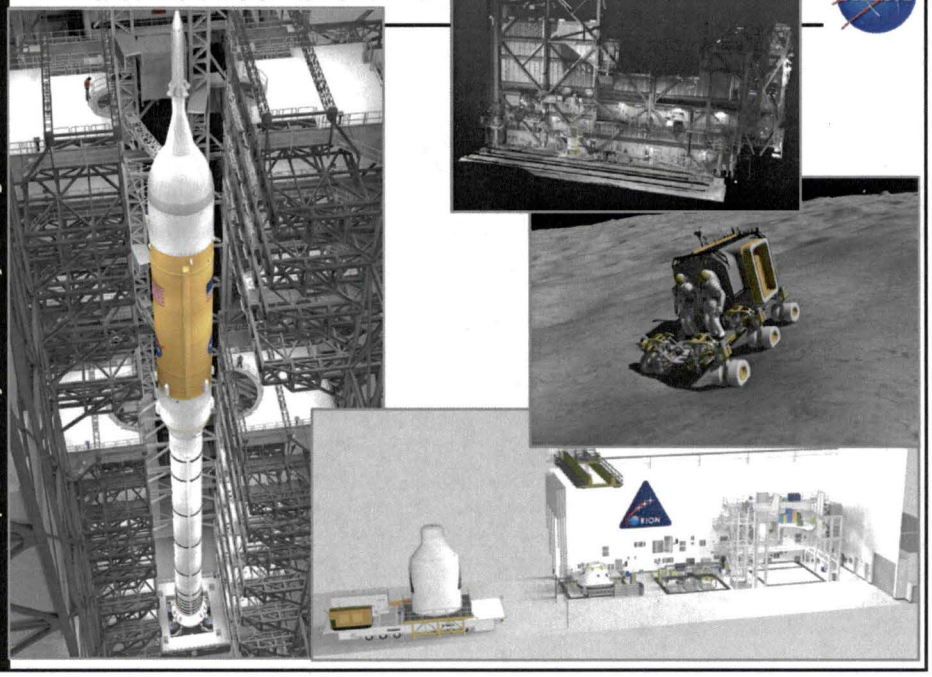
So, Altogether

- We had:
  - Common Data Formats, Centralized Storage, Concurrent Design, Free Tools, Common Interfaces, Voluntary Data Integration and the results preserved in a Distributed Visualization system
  - The ability to share data and decisions with partners and friends while preserving IP
- And, we had a Simulation based integration service available for purchase "By the Pound"
  - 1986 to 2006 (Gov. computers, software and scanners)
    - Reduced system costs from $1M to $250K
    - Reduced cost of a simulation minute from $90K to ~$5
    - Increased ROI from 6:1 to 200+:1
  - 2006 to Present (Vendor computers, software and scanners)
    - Simulation development is $150 an hour, or still about $5 a minute
    - And, not my $250K systems anymore ☺

And It Looked Like This



Next Problem(s):

- How to share our information with manufacturers
  - Without providing an unfair advantage
  - So you can tell me what I should really be doing
  - And, without going to jail
- How to get manufacturer information
  - So I can include it in the decision process
  - And, preserve your intellectual property
- Or, how to find out I could use a #42 widget from a ship or submarine or plane to meet my need

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Today's Goals Were To:

- Share:
  - Successes and Benefits realized due to opening the design table to Operations teams
- Begin to Create:
  - A way to re-achieve those Success and Benefits by doing the same with Manufacturing Teams
    - Planners, Engineers, Technicians, Managers, Stewards, Leaders
- Keep the lawyers really bored
  - By protecting everyone's IP
  - By ensuring a level playing field
  - By playing nice across time and space

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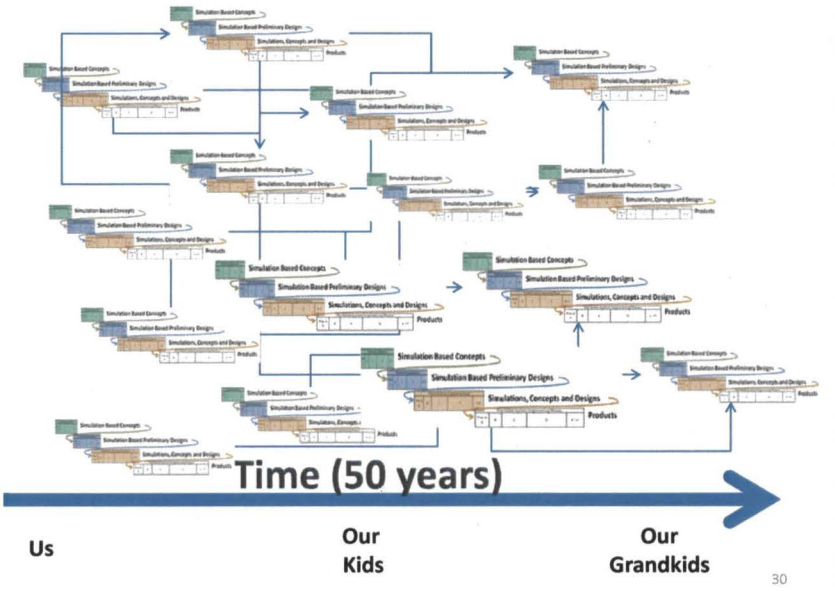
Remember This?



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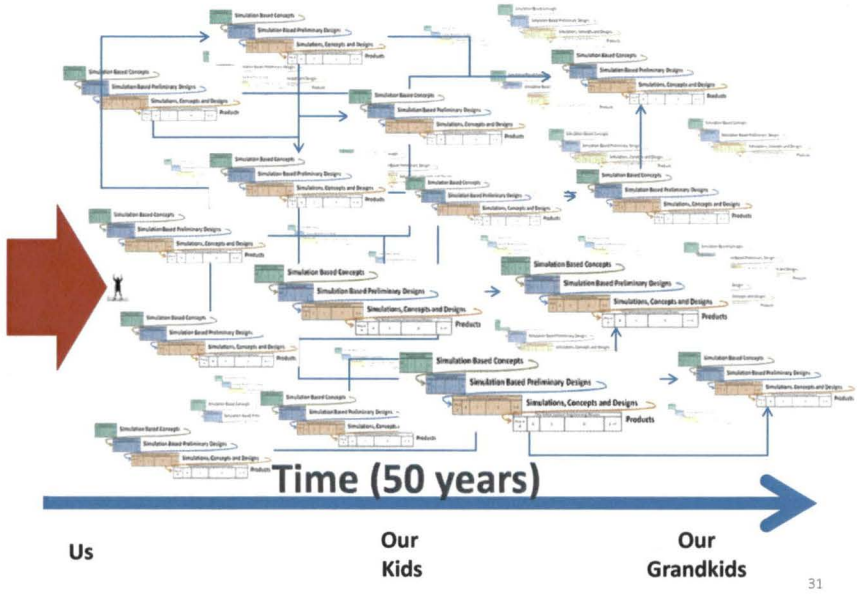
We Are Here



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Thank you

mike.conroy@nasa.gov

Backup Data

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I Think

- I can share some information with all manufacturers
  - If it can really go to everyone and it is efficient to use
  - And, if I actually know what is useful to share
    - **"what I plan to do" and "what I plan to do it with"?**
- I can get information from manufacturers
  - If I understand and can preserve their IP
  - And, if I actually know what is useful to get
    - **"relevant systems" and "production figures of merit"?**
- And then, I can add it all together such that
  - We design, build and deploy the most efficient, effective and buildable systems ever conceived
  - And the lawyers and the procurement people approve

Looking Forward (2030's)

- Workers will be younger than systems they are building
- Tools and Technologies change every few years
- Information created will be needed in 2060
- They need information from 2010
- The project team spans 11 time zones and 4 languages
- Model Re-Use and MBSE are going to save us
  (Just like PDM/PLM made it all better back in the 2020's)

- We really need to learn to Re-Use models starting Now!
  - So they can fit in the future above

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So, I Know:

- There are common goals across all projects
  - We want to know more, earlier in the lifecycle
  - We want to preserve our design flexibility until the last moment
  - We want to delay our resource commitments, at least until we know what we really need

- We have has some success
  - Design, development and operations teams at the table
  - With simulation based information and enabling processes
  - Can dramatically shorten design cycles and reduce costs

- There are open seats at the table and some challenges
  - We are missing people that actually create what we will use
  - We are missing a way to talk to them

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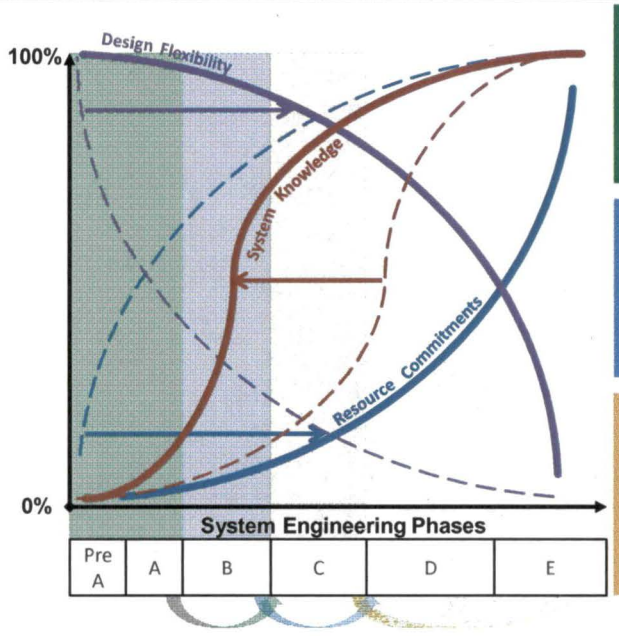
Because it Enables…



Simulation Based Concepts, ideas and Architectures Lead to…

Simulation Based System Designs that then Lead us to…

Simulation Based Integration and Operations,

And, that gets us…

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First, We What Did We Really Have

- Core and Common elements across the projects
  - *Knowledge*: Decisions, Experiences, Expertise
  - *Information*: Reports, Recommendations, Rationale
  - *Data*: Numbers, Pictures, Models, Equations
- Knowledge is hard to share
  - It is in peoples heads; they are attached to them
- Data is fairly easy to share
  - Just record it; lots and lots of disks
  - Finding it later is another matter (common model libraries)
- Information is somewhere in the middle
  - It requires data, but also a lot of other stuff

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But,
We Have a Lot Left To Learn

Time and Space are Huge
- 50 to 100 years
- Planets, Countries, Partners

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Going Forward

- Just wanting to meet huge new challenges is not enough
  - We must learn how to start meeting them today
    - With our partners, **whomever they are, wherever they are**
  - We must enable our children to finish tomorrow
    - Simple and persistent mechanisms to communicate with them **whenever they are**
- We must Learn how to Play Nice, Together, Across Space and Time

NASA Integrated Model-centric Architecture (NIMA) Initiative

Model Use and Re-Use Team
(Playing Nice with Models)

The Roles (Palyers? Positions?)

- Executive:
  - Mission, Policy, Partnerships, Resource Plans, Goals
- Architecture Development:
  - Concepts, Partnerships, ConOps, Milestones, Parametrics, Cost
- Program Development:
  - Systems, SoS, SysML, IRDs, Milestones, ConOps, MBSE, Cost
- Project Development:
  - MBSE, Requirements, Design, ConOps, ICDs, Cost, Schedule
- Engineering:
  - Design, Systems, Procedures, Cost, Schedule, Mass, SW, Stuff

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Some Rules

- Communication Methods
  - Role Above = Customer = Provider of $$ and Goals
  - Role Below = Supplier = Provider of Stuff that Works
  - You must to Customer in their language
  - You can talk to the Supplier in your language
    - But you need to make sure they understand
- Scope or Span of Vision
  - Each Role has norms that must be respected
    - organizational physics, motivation, rewards
  - You can look across multiple roles, but to see successfully, you must acknowledge and honor local norms

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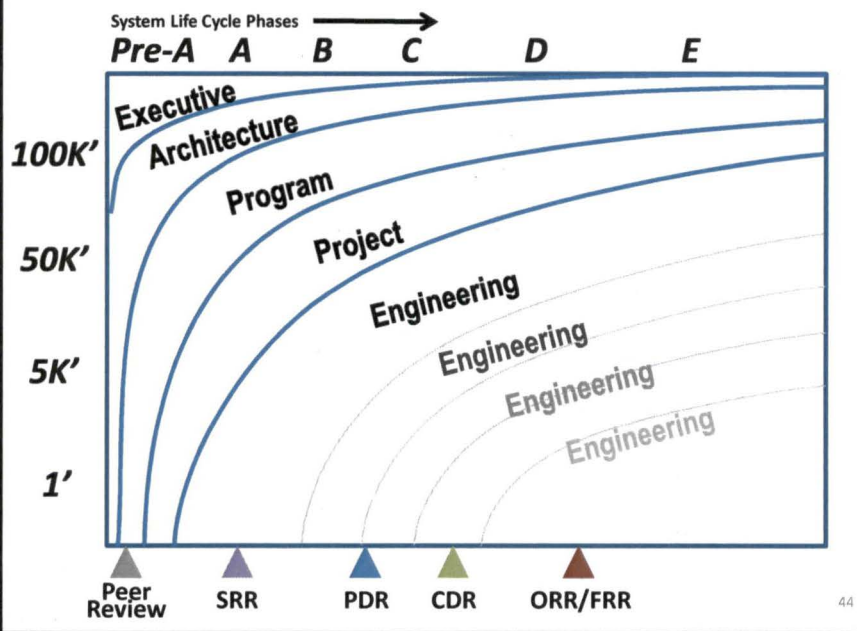
Boundaries and Gates (for the Field)



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Portfolios Change Over Time

Role:	Starts With, Heavily Involved:	Moves To, Recieves from Others:
Executive	Early Artwork, Sketches, Goals (pictures, simple spreadsheets)	Parametric Data, System Simulations (system simulations, cost / performance models)
Architecture	Early Concepts, System Segment Simulations, Parametric Data (pictures, animations, tables)	Architecture Models, System Sims (SysML, lifecycle simulations, cost / performance analysis)
Program	Early System Models, Program Simulations, Scenarios (spreadsheets, animations)	Program/Cost/Performance Sims (SysML, program models, discrete event simulations)
Project	Early Concepts, System Simulations, Parametric Analysis (databases, SysML models)	System Simulations, Process Simulations, Design Visualization (MBSE, PM software, DES, Catia)
Engineering	Concepts, Sub-System Simulations, Parametric Data, SysML (concept sketches, requirements)	CAD/CAE, PDM/PLM, System Sim. (Pro-E, Windchill, Catia, Unigraphics, DOORS, Cradle, FEA, ..)

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Some Methods and Patterns to Organize Things

From NIMA Use and Re-Use

Data Methods and Tools

- Data Organization
  - I need a place work, with my team structure, with my options, studies, options and alternatives.
  - I need a place to release it, in the project or product structure, to my parents or my children, with appropriate indicators for credibility of that information.
- Data Sharing
  - I share data with my Customers. I get it from my Suppliers, integrate the results, add value and give it to them.
  - I share data with my Suppliers. I get it form my Customer, decompose as necessary, and give it and any additional data to them.

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Process Patterns (Decomposition)

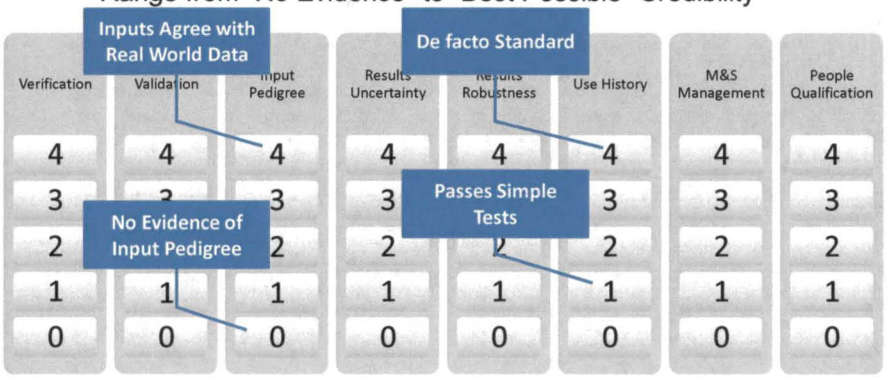
- Leadership
  - Creates and shares the architecture, con-ops, scenarios, decompositions and plans
- System Engineering
  - Leads the MBSE effort, decomposes and owns the system model, system requirements and stands up the PDM
  - This is a Critical Art with few masters
- Engineering
  - Creates relevant system and sub-system models, assigns work, decomposes and composes information and controls tasks
- Everyone
  - Shares data up and down, with associated credibility information and complying with project guidelines, methods and tools

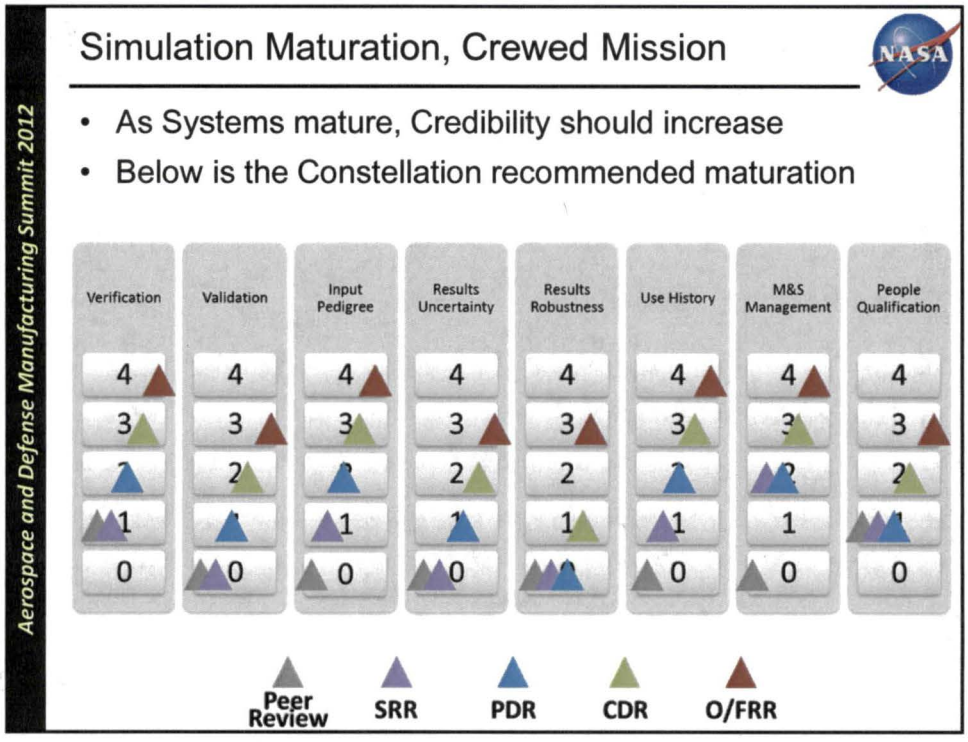
Process Patterns (Composition)

- Program / Project Manager
  - Identify goals and dates, products, expected credibility, integration / testing dates, artifacts and formats that will enable later information utilization
- System Engineer(s)
  - Create list of Review products that are necessary for the review
  - Lead Review and ensure necessary artifacts exist, are shared, and are preserved.
- Data Systems
  - Preserve the appropriate artifacts for existing use and re-use by future generations
  - With all the necessary supporting information that will be needed

Score Sheet

- To communicate the rigor, fidelity and pedigree of our work (Credibility), across distance and years
- We used NASA Standard 7009
  - 8 categories, 5 levels per category
  - Range from "No Evidence" to "Best Possible" Credibility

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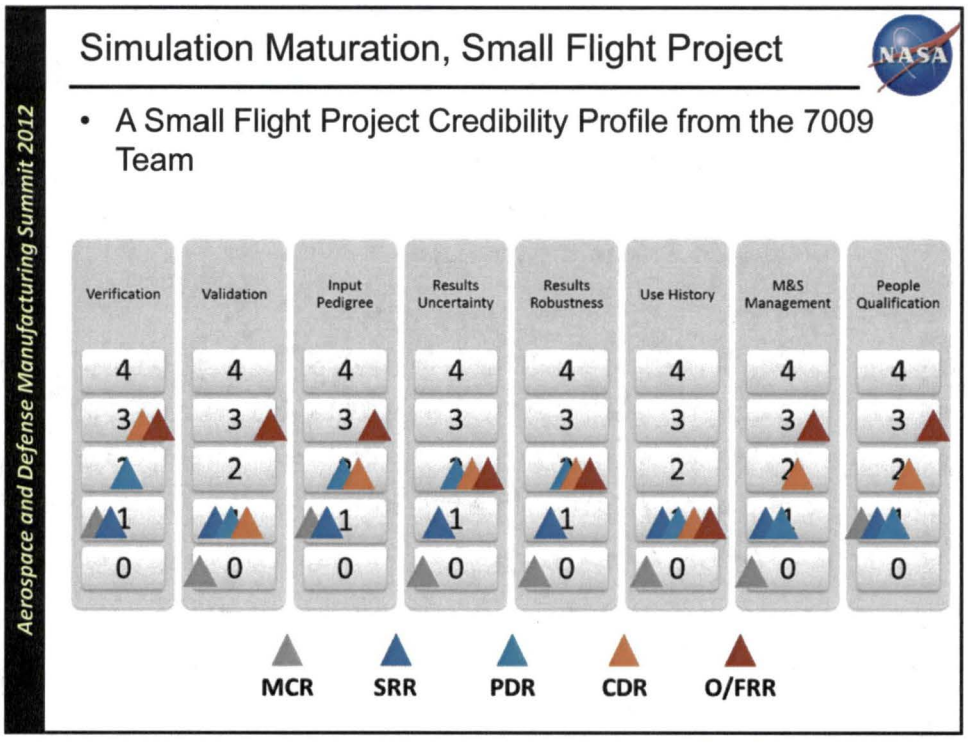
Simulation Maturation, Crewed Mission
NASA
• As Systems mature, Credibility should increase
• Below is the Constellation recommended maturation
Verification
Validation
Input Pedigree
Results Uncertainty
Results Robustness
Use History
M&S Management
People Qualification
4
3
2
1
0
Peer Review
SRR
PDR
CDR
O/FRR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Simulation Maturation, Small Flight Project
NASA
• A Small Flight Project Credibility Profile from the 7009 Team
Verification
Validation
Input Pedigree
Results Uncertainty
Results Robustness
Use History
M&S Management
People Qualification
4
3
2
1
0
MCR
SRR
PDR
CDR
O/FRR

NIMA, a year or so later…

- We have Roles, Rules
  - And understand some Temporal constraints
- We have Patterns we can share across teams
  - And ways to encourage following them
- We are Re-Looking at almost everything
  - Concept of Operations, Product Data Management, Product Lifecycle Management, SysML Tools, Data Architectures and all the supporting tools in a new light
  - We are still discovering new things we did not know
- We have an understanding of Projects vs. Initiatives
  - NIMA is definitely and Initiative. It lacks the focus, financing, and programmatic benefits of a Project. It means things will be slow.
  - But, I was there when the examples I shared were just Initiatives, and feel good about this one too