Retooling Design and Development

3rd Additive/Aerospace Summit
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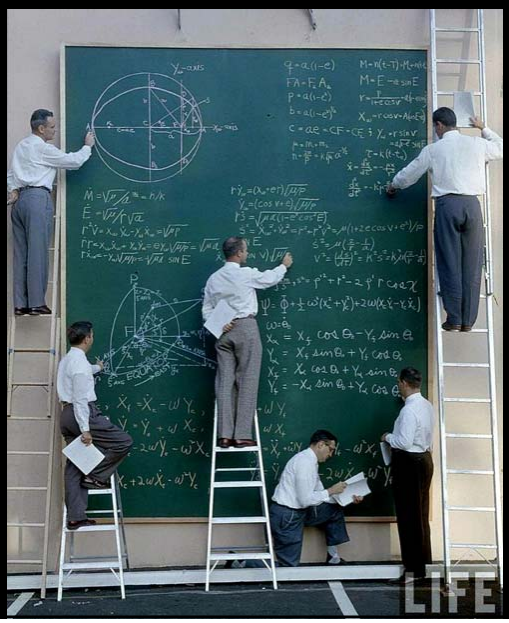
Engineering Director

Key Knowledge Gaps and Risks

- **Available requirements will not mitigate AM part risk to a level equivalent to other processes for some time to come. Known Unknowns needing investment:**
  - Unknown failure modes :: limited process history
  - Open loop process, needs closure or meaningful feedback
  - Feedstock specifications and controls
  - Thermal processing
  - Process parameter sensitivity
  - Mechanical properties
  - Part Cleaning
  - Welding of AM materials
  - AM Surface improvement strategies
  - NDE of complex AM parts
  - Electronic model data controls
  - Equipment faults, modes of failure
  - Machine calibration / maintenance
  - Vendor quality approvals

Knowledge gaps exist in the basic understanding of AM Materials and Processes, creating potential for risk to certification of critical AM Hardware.

Design cycle and Risk Conundrum



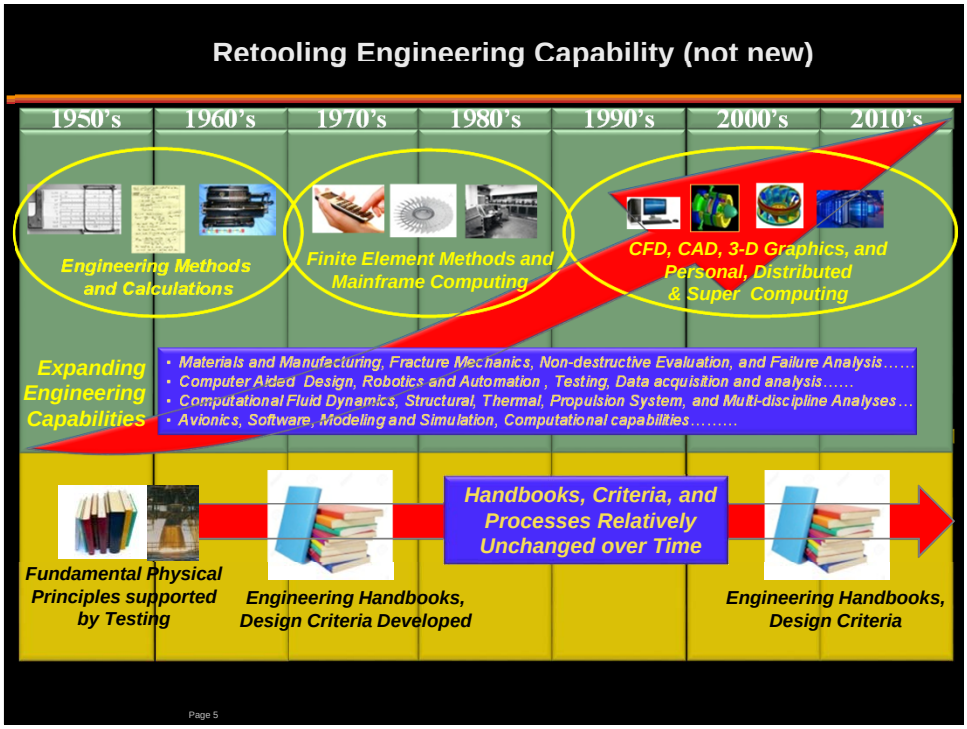
3

Critical Role of Testing

“One Good Test is Worth a Thousand Expert Opinions”
Von Braun

“One Good Failure is worth a thousand Successes”

4

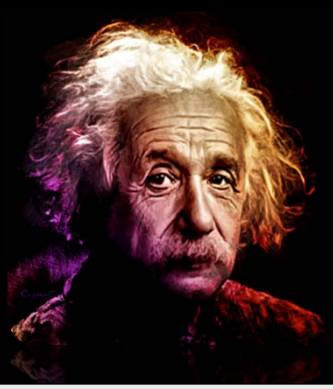

Retooling Engineering Capability (not new)
1950's
1960's
1970's
1980's
1990's
2000's
2010's
Engineering Methods and Calculations
Finite Element Methods and Mainframe Computing
CFD, CAD, 3-D Graphics, and Personal, Distributed & Super Computing
Expanding Engineering Capabilities
• Materials and Manufacturing, Fracture Mechanics, Non-destructive Evaluation, and Failure Analysis……
• Computer Aided Design, Robotics and Automation , Testing, Data acquisition and analysis……
• Computational Fluid Dynamics, Structural, Thermal, Propulsion System, and Multi-discipline Analyses…
• Avionics, Software, Modeling and Simulation, Computational capabilities……..
Handbooks, Criteria, and Processes Relatively Unchanged over Time
Fundamental Physical Principles supported by Testing
Engineering Handbooks, Design Criteria Developed
Engineering Handbooks, Design Criteria
Page 5

Tragedy triggers desire to control uncertainty

Our Challenge: Distinguish failure from tragedy

7

Natural Conflict- Innovation vs Certainty



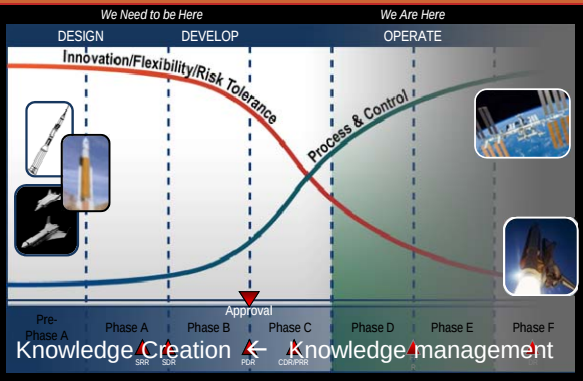
Hero Culture- Apollo 13
Failure is not an Option
Good, Bad, and Ugly
Missing Element

"We cannot solve our problems with the same thinking we used when we created them"
– Albert Einstein

Page 8

Development vs Operations Culture

- Risk Conundrum
- Multi-discipline Leaders
- Bust Stove-pipes
- Product over Process
- Safety Nets
- Fast Fail Philosophy
- Management Response



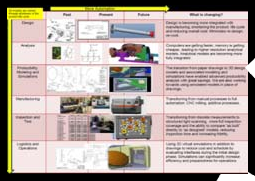
Technology is easy compared to culture change

Requires Resilience, Persistence- "Stick-to-it-tive-ness"

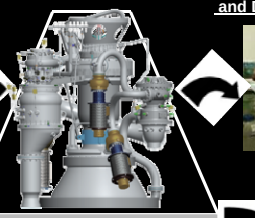
9

Embrace Possibility

Defining the Development Philosophy of the Future



"Smart Buyer" to Enable Commercial Partners and Develop Certification Requirements



Bridging the gap between the present and future projects that are coming

Building Foundational Industrial Base

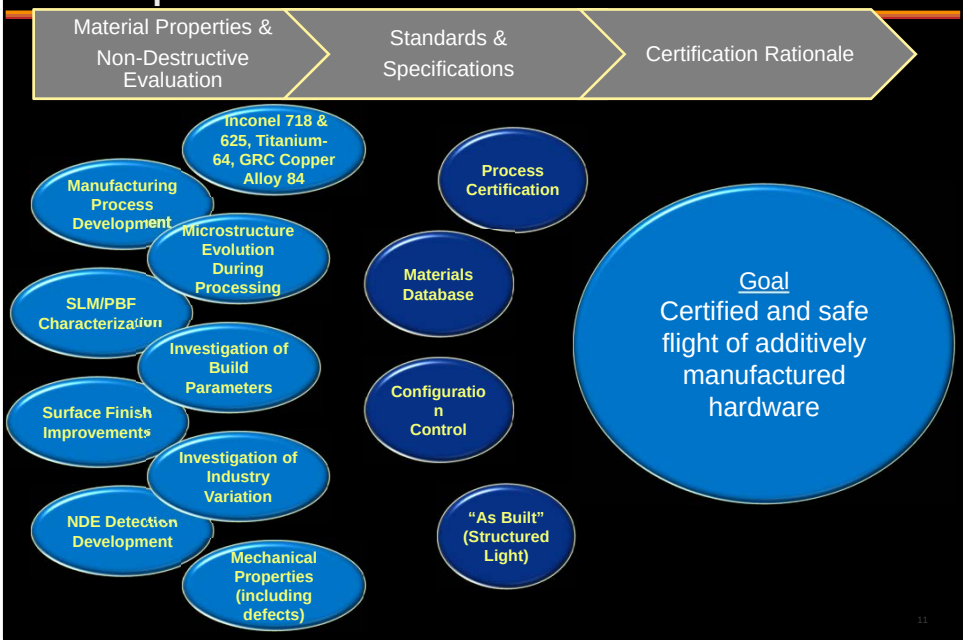
Stratasys
INCODEMA
LINEAR
RPM INNOVATIONS, INC.
Additive Manufacturing
DIRECTEDMFG

Enabling & Developing Revolutionary Technology for HEO missions

Transferring "Open Rights" SLM Material Property Data & Technology to U.S. Industry

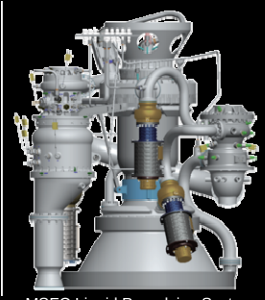
10

Fundamental Additive Manufacturing M&P Development at MSFC



MSFC's Parallel AM DDT&E and Materials Efforts


In Space ISS experiment


MSFC Liquid Propulsion System

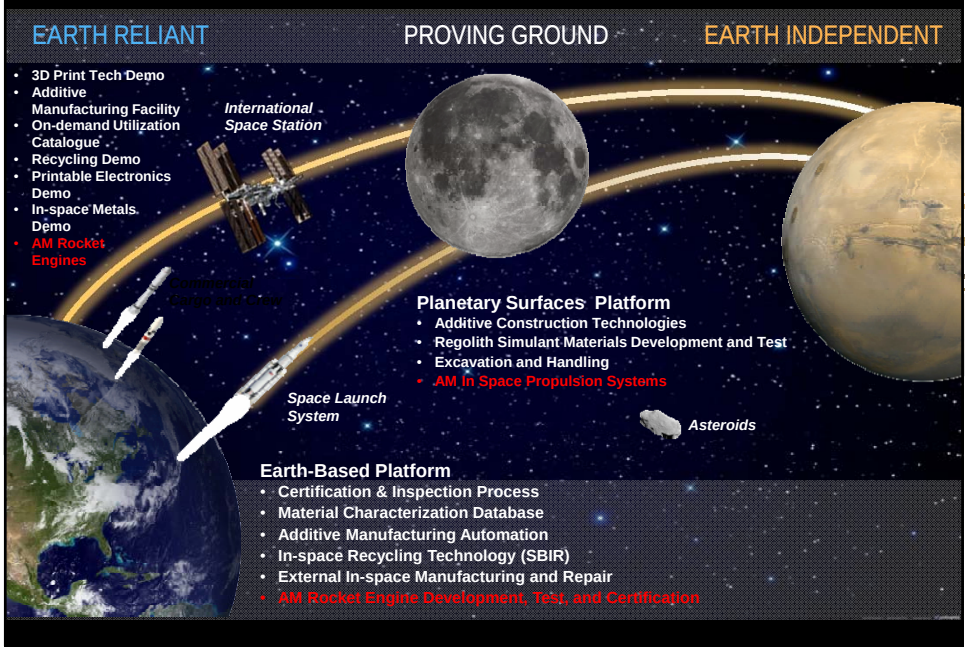

AM Liquid Hydrogen Turbopump


Full Scale Injector Water Flow

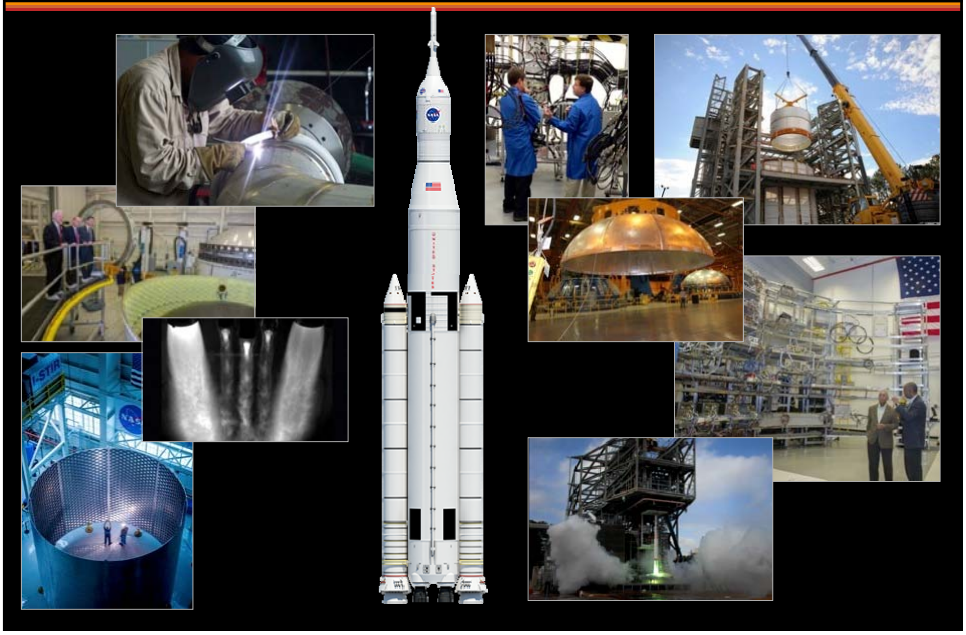

Technology demonstration parts


Subscale injector test

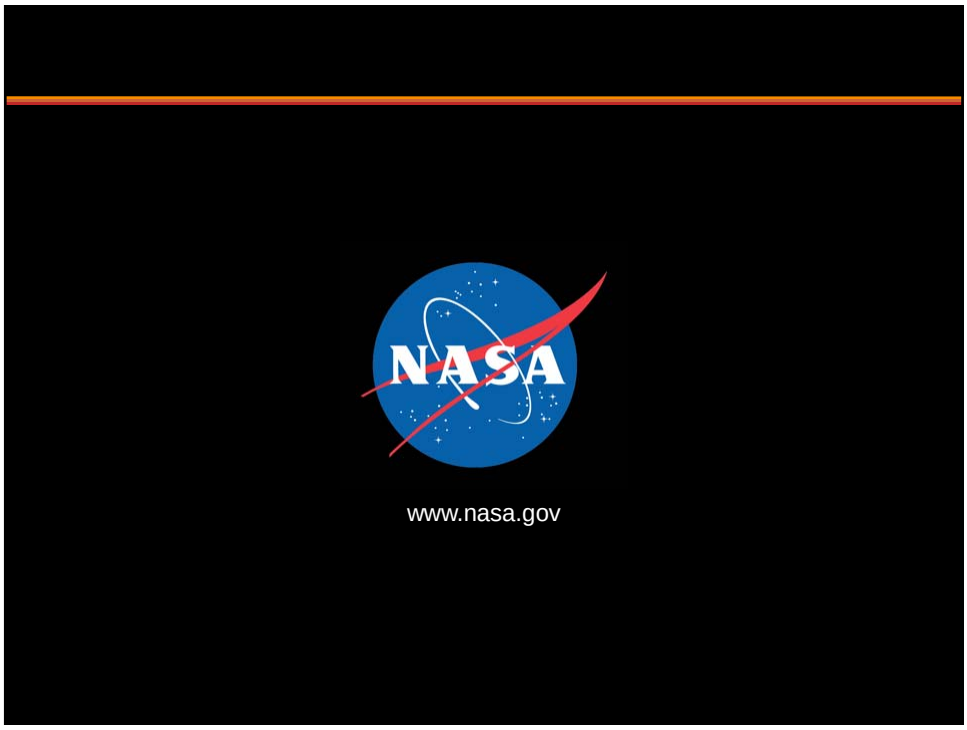
Path to Exploration



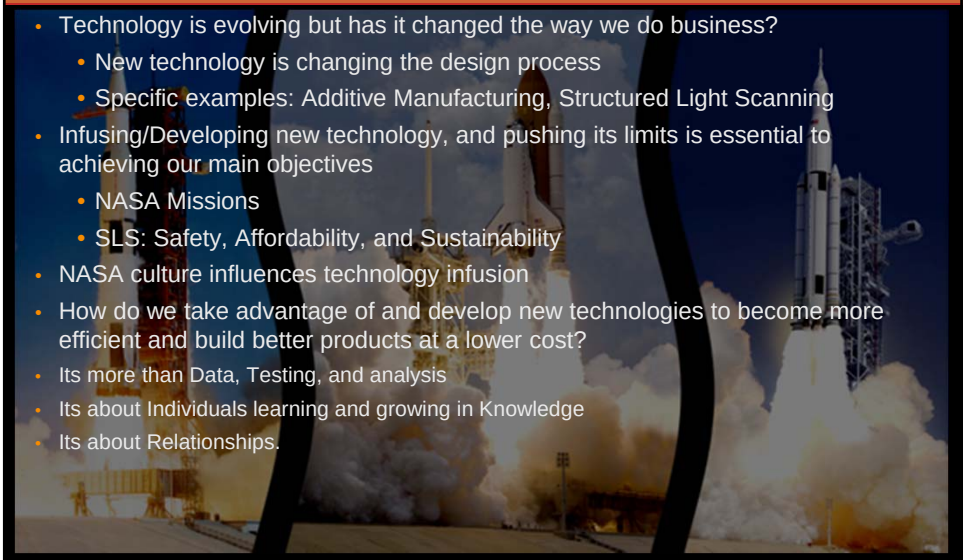
Real Hardware for Human Exploration




This Inspired several Generations


NASA
www.nasa.gov

Incorporating Technologies



- Technology is evolving but has it changed the way we do business?
  - New technology is changing the design process
  - Specific examples: Additive Manufacturing, Structured Light Scanning
- Infusing/Developing new technology, and pushing its limits is essential to achieving our main objectives
  - NASA Missions
  - SLS: Safety, Affordability, and Sustainability
- NASA culture influences technology infusion
- How do we take advantage of and develop new technologies to become more efficient and build better products at a lower cost?
- Its more than Data, Testing, and analysis
- Its about Individuals learning and growing in Knowledge
- Its about Relationships.

17