Future Challenges and Opportunities for Fatigue and Damage Tolerance of Aircraft Components

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REDAC Subcommittee on Aircraft Safety

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What Causes Failures?

Frequency of Failure Mechanisms *)

Failure Mechanism	% Failures *(Aircraft Components)*
Fatigue	55%
Corrosion	16%
Overload	14%
Stress Corrosion Cracking	7%
Wear / abrasion / erosion	6%
High temperature corrosion	2%

**) Source: Why Aircraft Fail, S. J. Findlay and N. D. Harrison, in Materials Today, pp. 18-25, Nov. 2002.*

- **Field Data Suggests that Fatigue is the Predominant Failure Mode in Service**
- ***Expect this trend to continue for metallic materials***

Emerging Technology Considerations

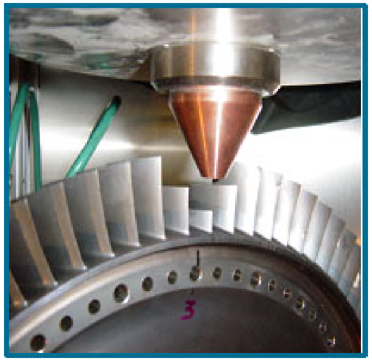
- **New material systems**
- **New manufacturing technologies**
- **Model-based certification**
- **Cradle-to-grave digital framework**

Motivation

<u>From the FAA Priority Initiatives</u>

"Risk-Based Decision Making: build on safety management principles to proactively address emerging safety risks…"

Additive Manufacturing (AM)
– A New "Disruptive" Technology




Additive manufacturing moves into the mainstream

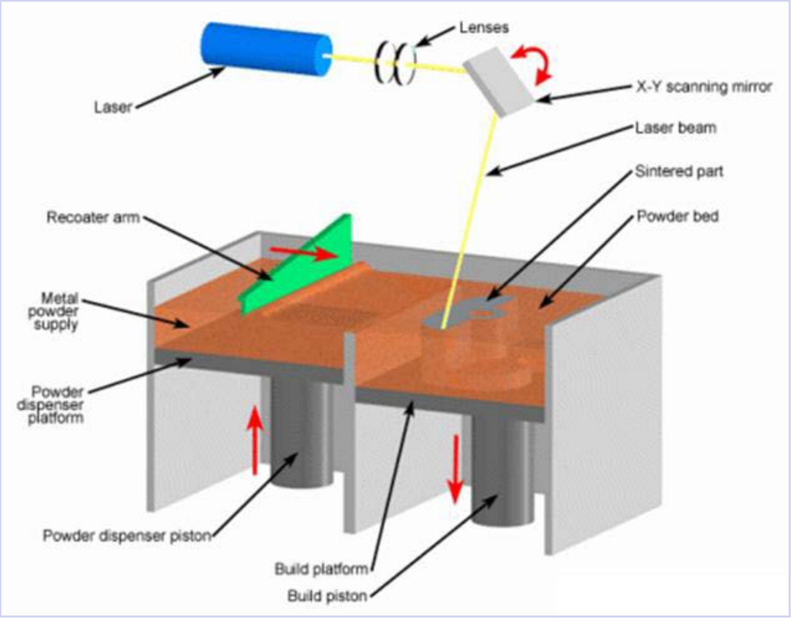
Kathleen Oldham and Chris Gravelle | April 10, 2014

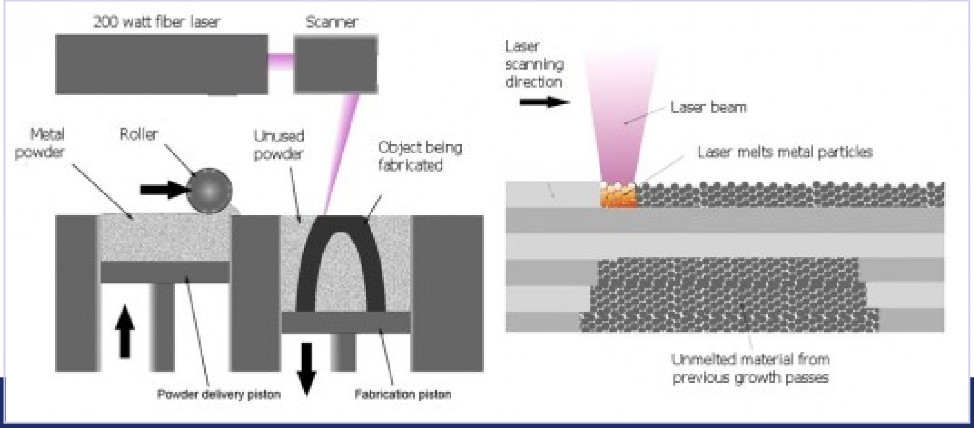
Bell Helicopter leverages 3D technology to drive efficiency and excellence.

When design, manufacturing, and technology meet, the result is something straight out of a science fiction novel — a ready-to-use final

<u>Schematics of DMLS Process</u>

DMLS = Direct Metal Laser Sintering





PMA companies are likely to become early adopters

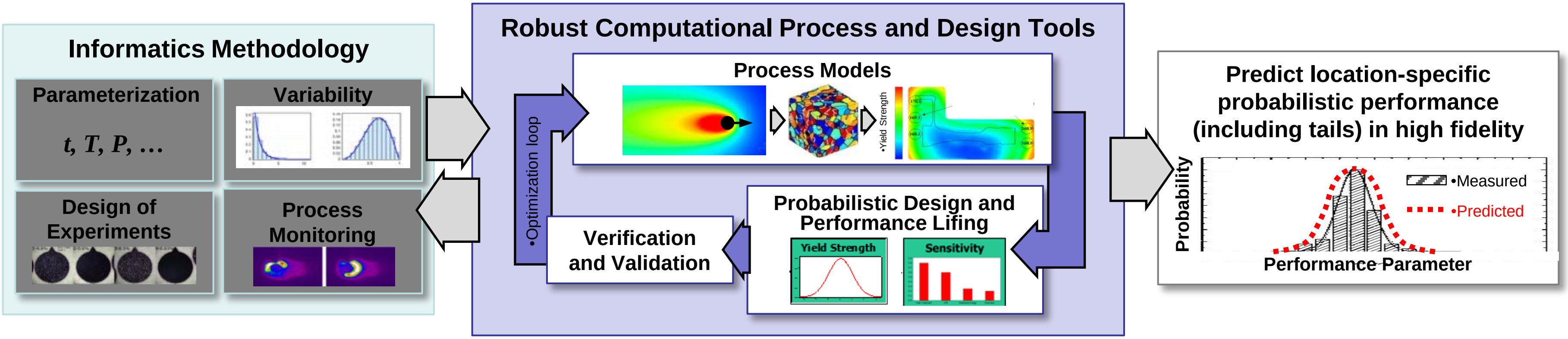
AM Challenges That Need to be Considered

"top five"

- **Variation in the types of AM equipment / processes and lack of standardization**
- **Limited understanding of acceptable ranges of variation for key manufacturing parameters**
- **Limited understanding of key failure mechanisms**
- **Lack of industry databases / allowables**
- **Development of capable NDI methods**
- ***OEM-proprietary vs. commodity type technology path***
- ***Level of criticality for initial applications***
- ***Use of AM by PMA industry***
- ***Potential export control considerations***

Open Manufacturing fundamentally changes how manufacturing variability is captured, analyzed and controlled

Courtesy of Mr. Michael "Mick" Maher, DARPA DSO



- Fully parameterize and monitor the factory-floor
- Capture probabilistic variability in laboratory and manufacturing environments

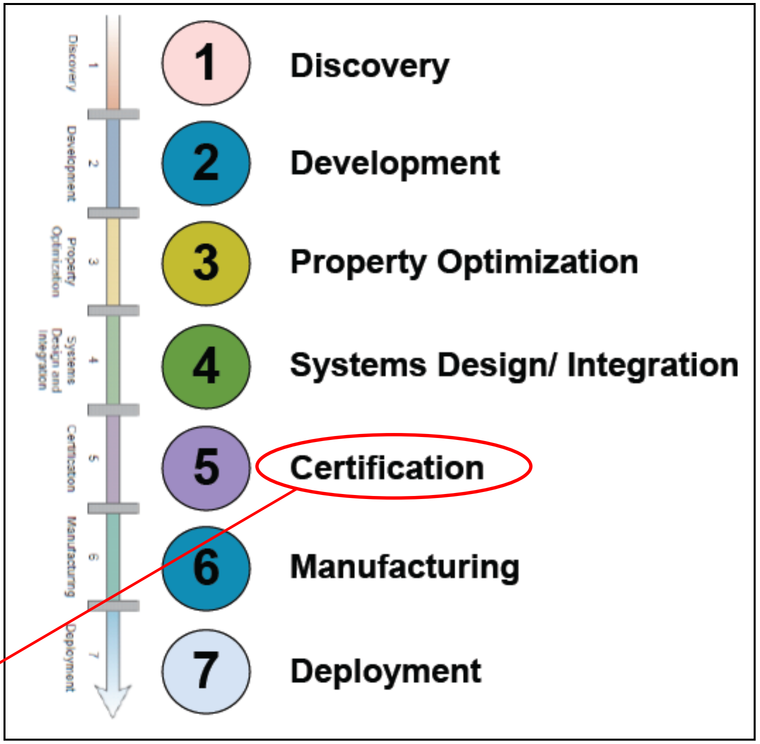
- Computational tools incorporate probabilistic variation into input parameters
- Rapid qualification schema that employ statistical methods for high-confidence prediction
- Rigorous model verification and validation
- Probabilistically predict location-specific process and part performance

- **Framework for rapid qualification**
- Build confidence in new technologies
- Identify bounds of process window
- Optimize and control processes

Material Genome and ICME

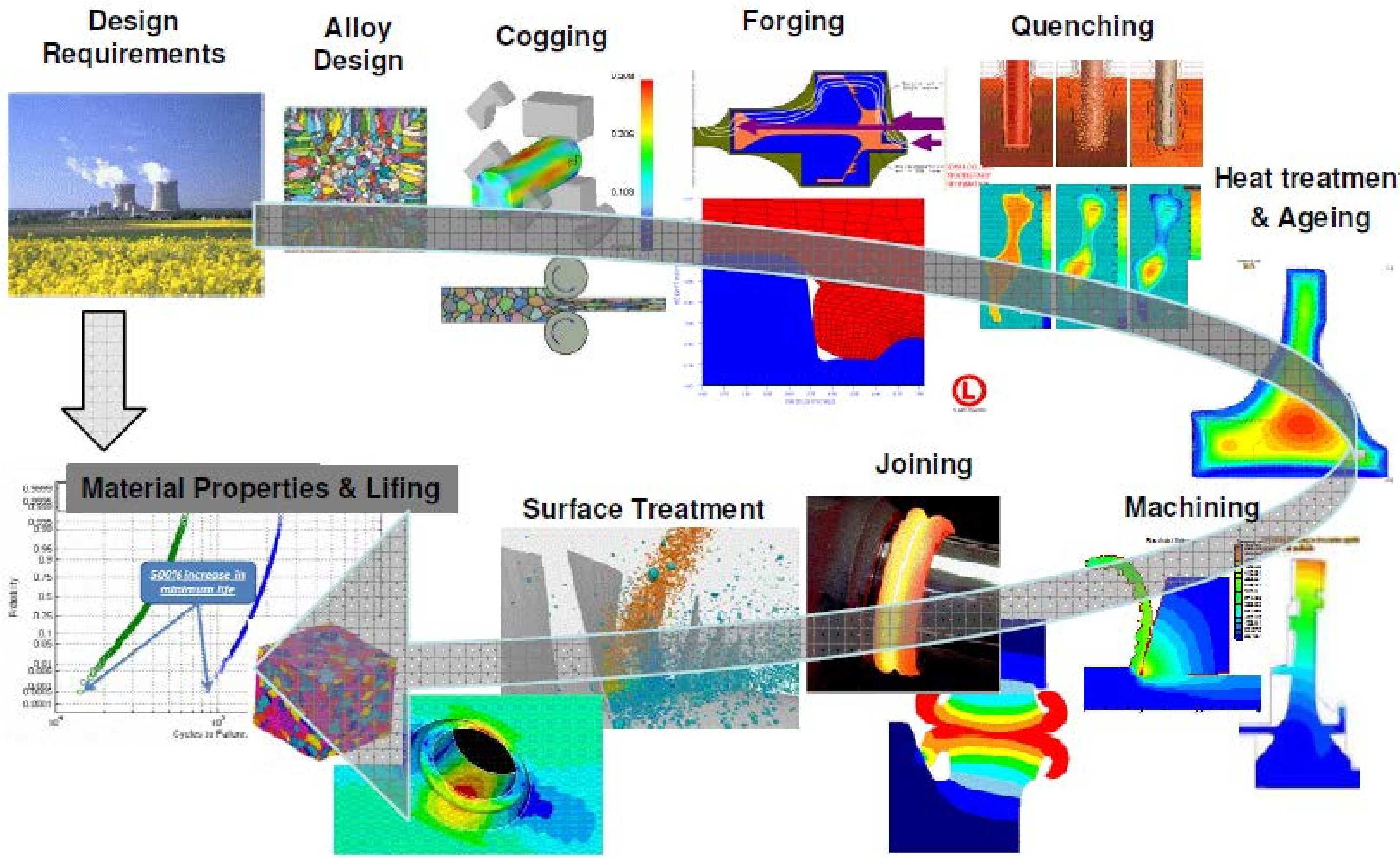
- "A multi-stakeholder effort to develop an infrastructure to accelerate advanced materials discovery and deployment in the United States".
  - Vision: "… to discover, develop, manufacture, and deploy advanced materials at least twice as fast as possible today, at a fraction of the cost".

- *Integrated Computational Materials Engineering (ICME)* is an emerging discipline that aims ***to integrate*** computational materials science tools into a holistic system that can accelerate materials development, transform the engineering design optimization process, and unify design and manufacturing.



Tie-in with AIR Mission

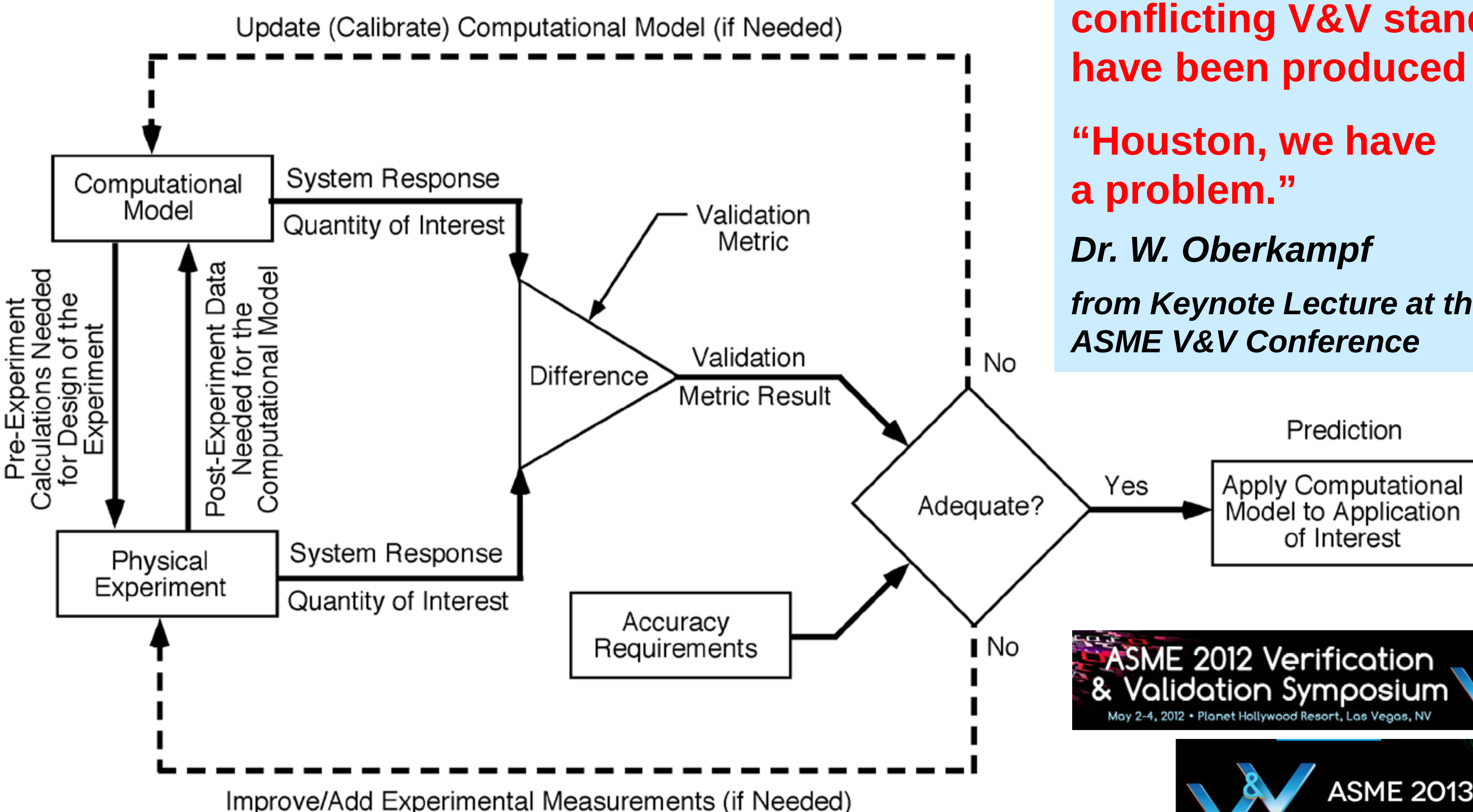
Notional ICME Framework for Forged Components



M. Glavicic et al., "Application of ICME to Turbine Engine Component Design Optimization", AIAA 2011-1738

Effective Use of Probabilistic and UQ Methods is Needed to Address These Risks

Models Verification and Validation (V&V) Framework



(from Oberkampf and Barone, 2006)

20 conceptually conflicting V&V standards have been produced

"Houston, we have a problem."

Dr. W. Oberkampf

from Keynote Lecture at the 2012 ASME V&V Conference

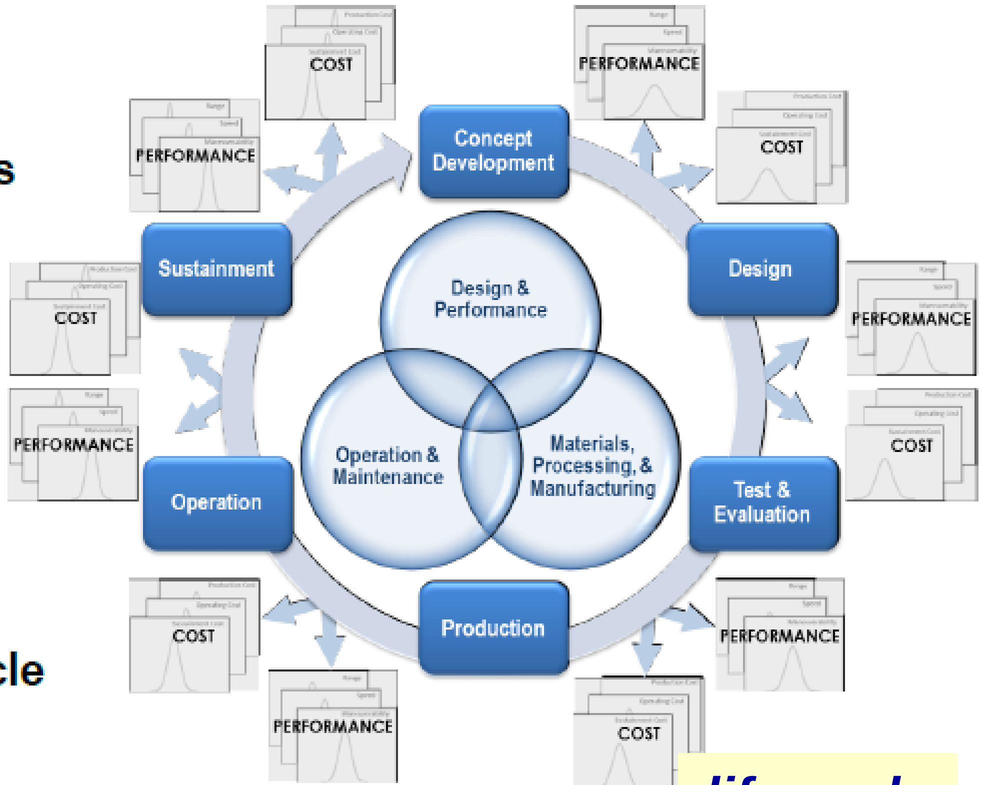

Verifica
Metho
Rec

Digital Thread Concept

Courtesy of Dr. R. Dutton, USAF

Main Goals:

- Use ALL AVAILABLE INFORMATION in analyses
- Use PHYSICS to inform analyses
- Use PROBABILISTIC METHODS to quantify program risks
- Close the loop & CONTINUALLY UPDATE throughout system lifecycle



Make ***INFORMED DECISIONS*** throughout ~~acquisition~~ ***life cycle***

AFRL 6

Challenges vs. Enablers

Increasing Use of "Process-Intensive" Material Technologies
(e.g. Additive Manufacturing, Composites)

Challenges

- **Identification and control of key process parameters**
- **Database generation**
- **Identification of failure modes**
- **Material "performance" models (e.g. lifing)**

Moving towards Models-Based Certification

Challenges

- **Domain of model's validity**
- **Does it capture key failure modes?**
- **What does it mean to validate a model ?**
- **Defining required level of testing**
- **Impact of variation**

Enablers

- **Development / Deployment of V&V Frameworks**
- **Probabilistic Methods and UQ**
- **Development and Maturation of Physics-based Models**
  - *Example: ICME*

Discussion

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