GO BEYOND

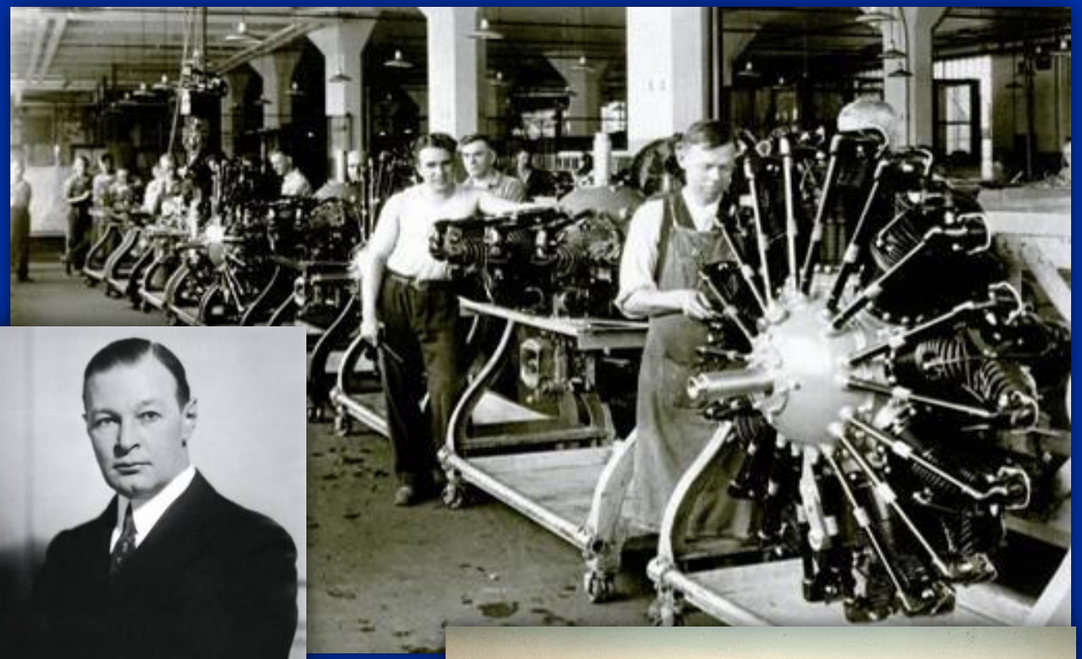
The Digital Thread

THE USE OF NON-CONTACT SCANNING FOR ADDITIVE MANUFACTURING

OCTOBER 2018

A UNITED TECHNOLOGIES COMPANY

Pratt & Whitney's history began in 1925…



Frederick Rentschler

…and continues

Pratt & Whitney Commercial Engines

Boeing 757

Airbus 320

Airbus 320neo

Mitsubishi MRJ

Boeing 767

Airbus 330

Bombardier C Series

Embraer 190/195-E2

Boeing 777

Airbus 380

Irkut MC-21

Embraer 175-E2

Mature

Geared Turbofan

Pratt & Whitney Military Engines

Tactical


Photo: Lockheed Martin

F-35 Joint Strike Fighter

F-22 Raptor

F-16

F-15

Mobility / Tanker

KC-46A Pegasus


Photo: Embraer

KC-390

C-17 Globemaster

B-21 Raider

Auxiliary Power Unit


Photo: Airbus

A400M Atlas

V-22 Osprey


Photo: Sikorsky

CH-53K King Stallion


Photo: Raytheon

Miniature Air Launched Decoy

Future Opportunities

Helicopters

Unmanned Aerial Vehicle

Adaptive Engine Technology Development

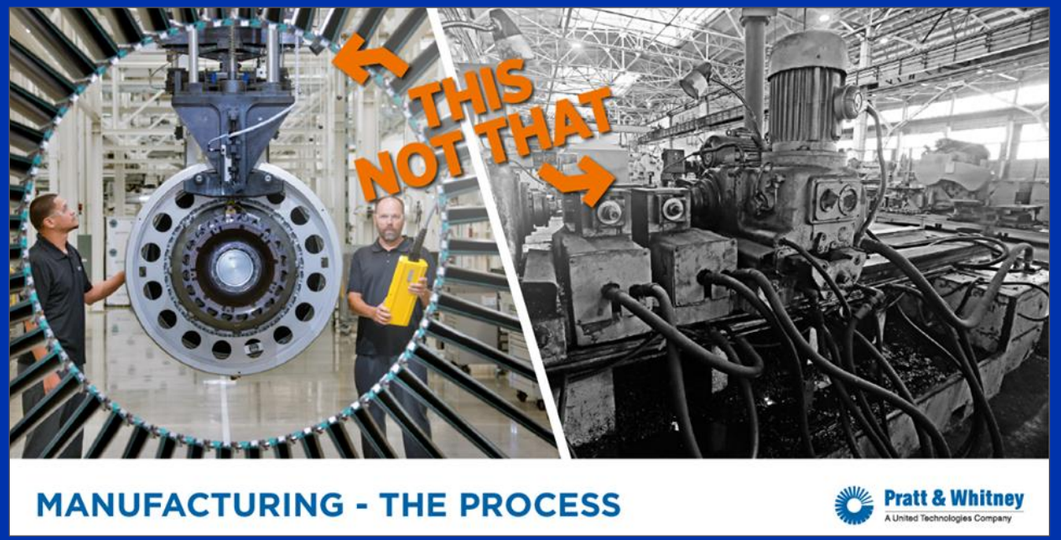

Photo: Lockheed Martin

F135 Fuel Burn Reduction

Pratt & Whitney Canada

Business Aviation	Regional Aviation	APU Segment	General Aviation	Helicopter Aviation	Aftermarket
 Embraer Phenom 300	 ATR 72	 Boeing 787	 Beechcraft King Air 350	 Leonardo-Finmeccanica AW169	 Customer First Centre
 Dassault F7X/F8X	 Bombardier Q400	 A380	 Pilatus PC-12NG	 Bell 429	 Maintenance, Repair & Overhaul

Pratt & Whitney Global Manufacturing



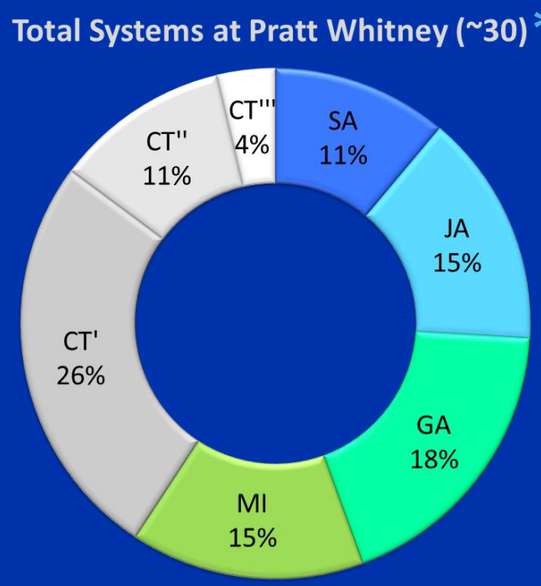
The world's first horizontal assembly lines — up to 50% more productivity

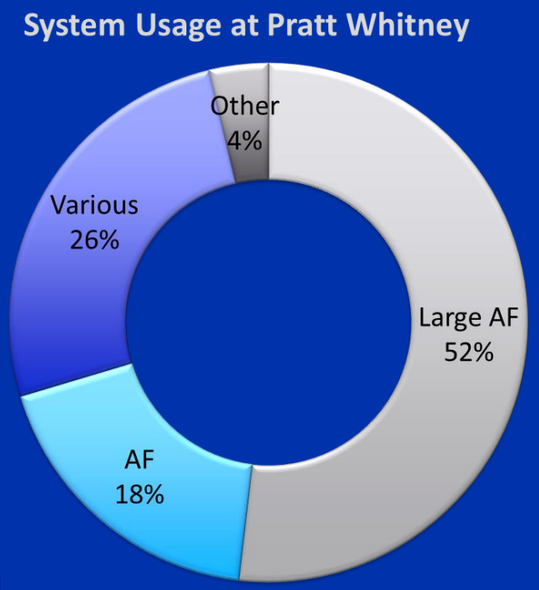
Intelligent manufacturing cells — closed loop machining, robotics, automated inspection

White/blue light quality techniques at sites worldwide — concurrent inspection and manufacturing

State of the art technology to produce advanced aerospace products

Use of Non-Contact Scanning at Pratt & Whitney





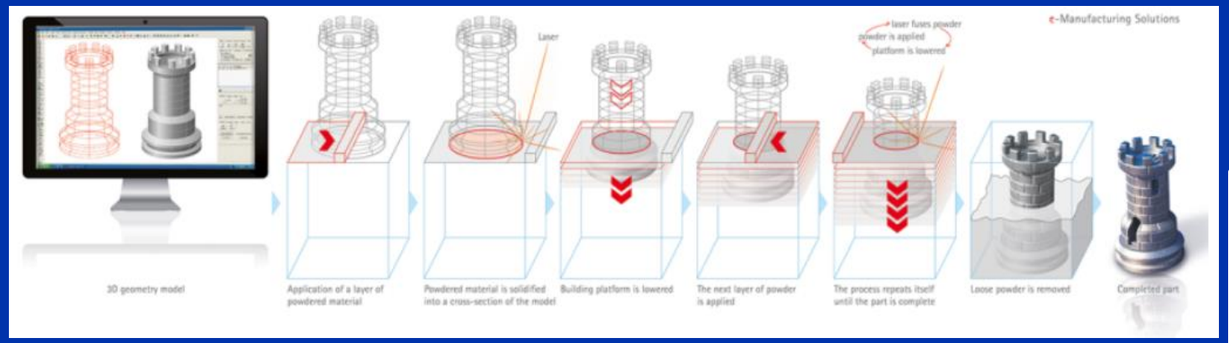
- Started in 2000
- 1st Production Approval in 2005
- Deployment into Supply Chain
- Multiple Uses
  - Airfoil
  - Root Cause
  - IP Investigations
  - Testing
  - Die Inspection
  - Nacelle Inspection
  - Quality Control
  - Process Improvements

*Powder is Still A Problem

What is Additive Manufacturing

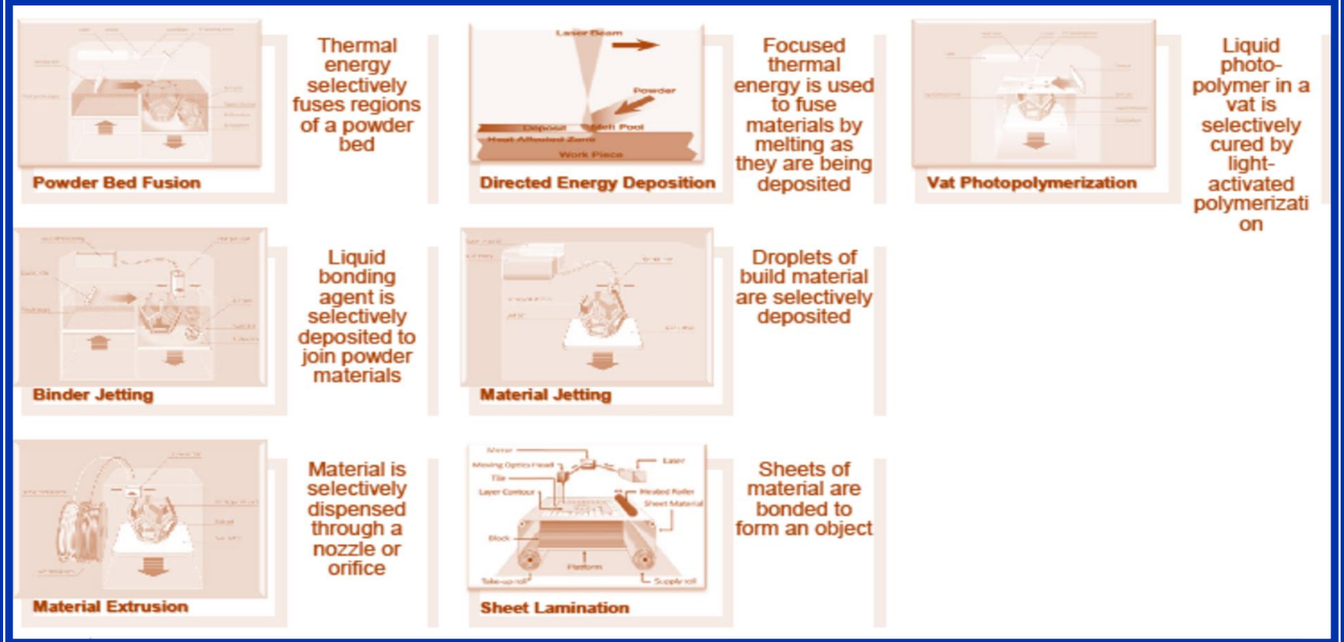
Processes that enable complex 3D shapes

Start: 3D Modeling → **End: Finished Product**



Additive manufacturing is a CAD-driven, layer by layer, building process that can produce components in polymers or metallic materials.

ASTM F42 -- 7 categories of additive



25 Years of AM history at P&W

AM at PW is an Evolutionary Development, but Revolutionary in its Applications

Resin & Wax Stereolithography

1989 1st P&W machine

Supported structures

Powder Based Non-metallic

Nesting

Unsupported structures

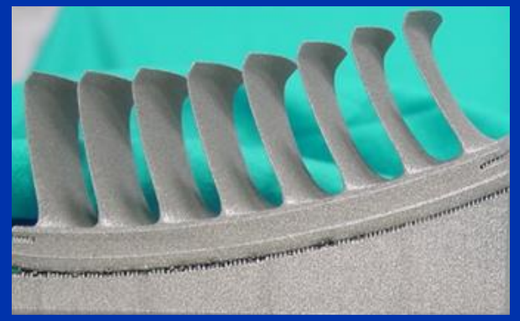
Tooling, prototypes

Powder Based Metallic

Prototype

Medical grade

Powder Based Aerospace Metallic



Development

Tooling

Production

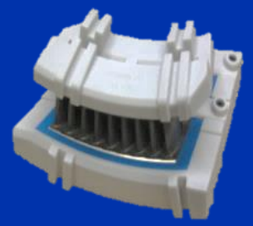
1980's 1990's 2000's Today

Use of Additive At PW

Mature

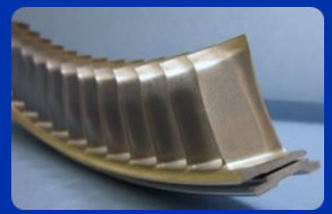
Polymer tooling
Demonstration hardware
Visual Aids



Expand & Leverage

Demonstration hardware
Rig & test hardware
Production hardware
Tooling
Certification




Develop

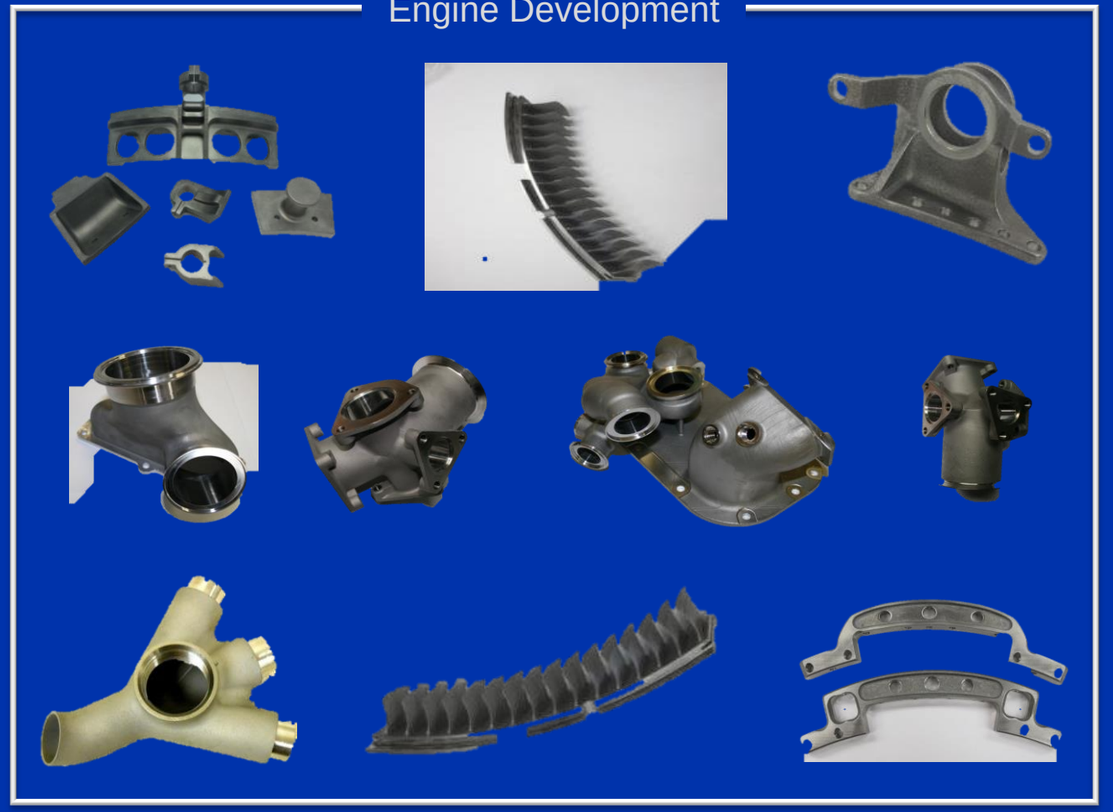
Design system
Process control capability
Material characterization data


Our Metals Experience

Visual

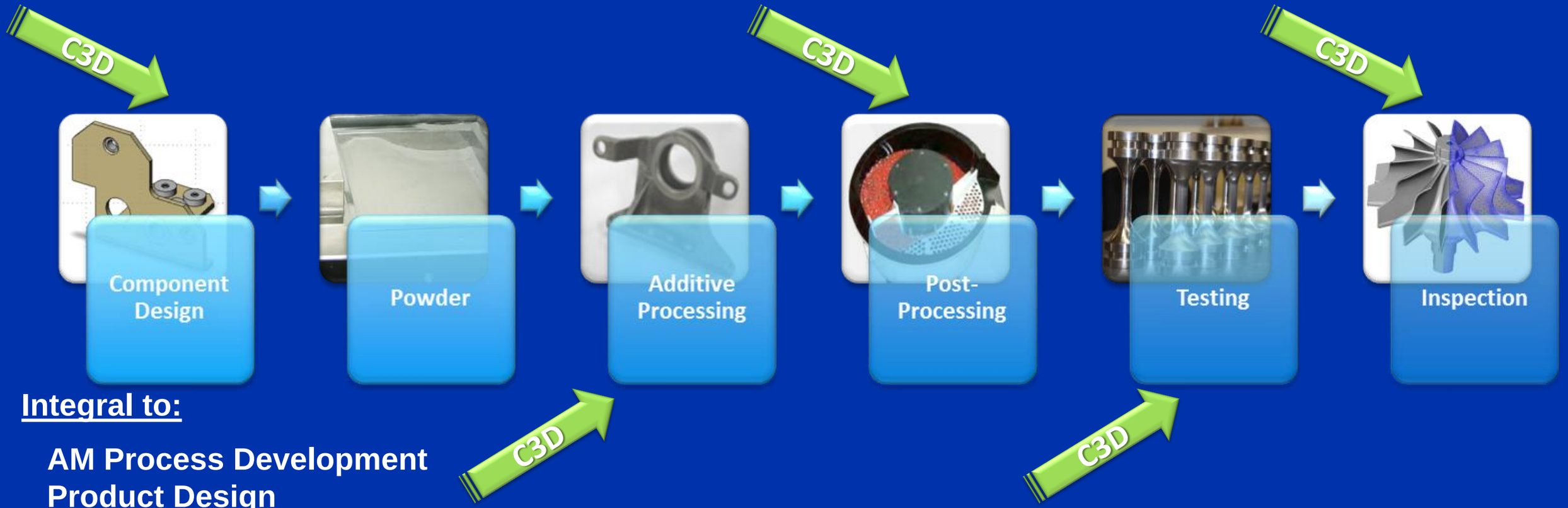
Rigs & Testing

Engine Development



Over 3,000 metal parts builds experience and knowledge

How do these two Merge (Digital Thread)

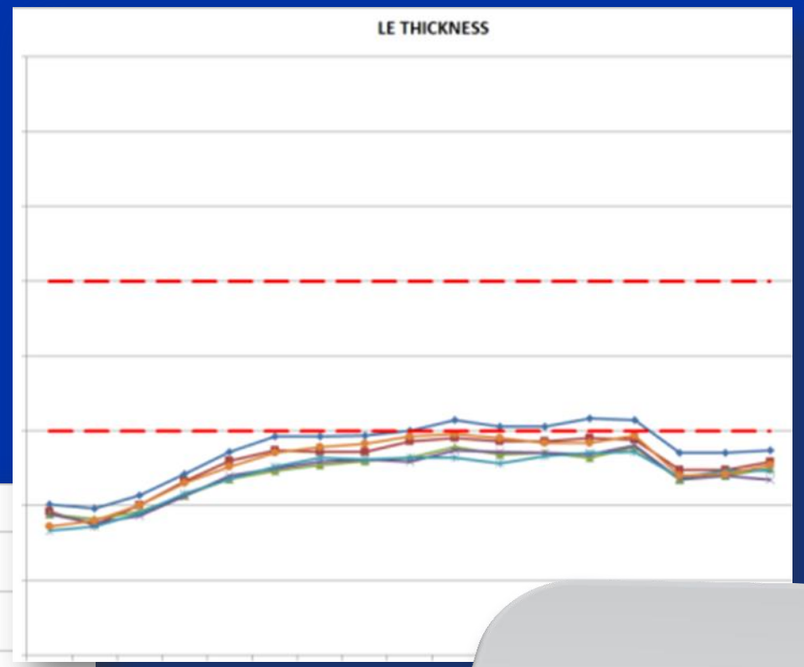


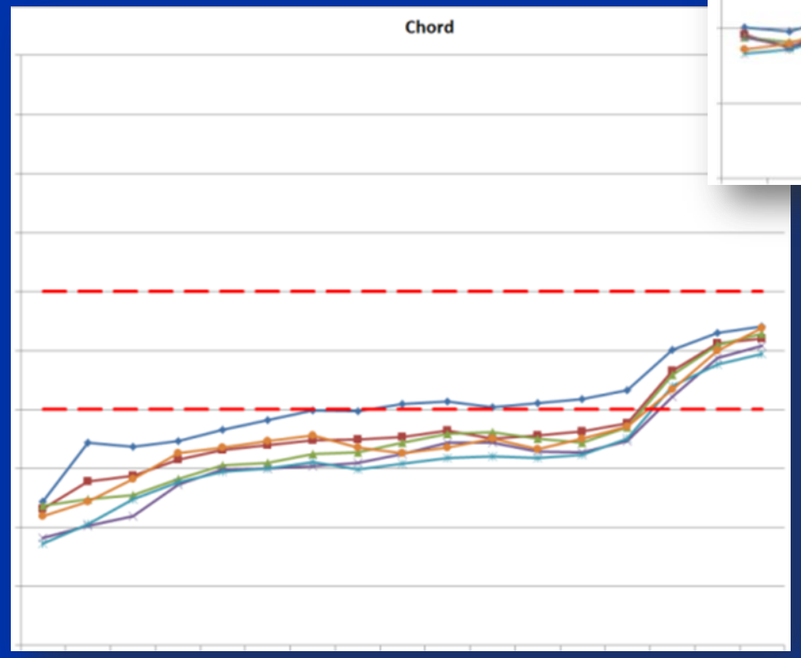
Integral to:

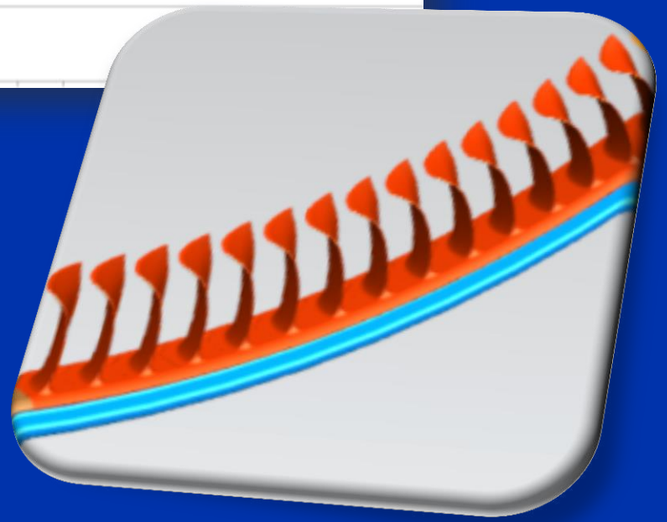
AM Process Development
Product Design
Overall Process Development
Material Testing
Quality Assurance

Measurement of Airfoils (Not Simple 2D)

- 7 to 13 Airfoils
- ~13+ Sections
- >120 Points
- >10 Minutes (Msmnt Only)
- Significant Post Analysis







Distortion in Additive (Not Simple 2D)

- One of several challenges in Additive Manufacturing
- Very Difficult to Predict
- Directly Effects Final Part Acceptance
- Could Effect Material Property

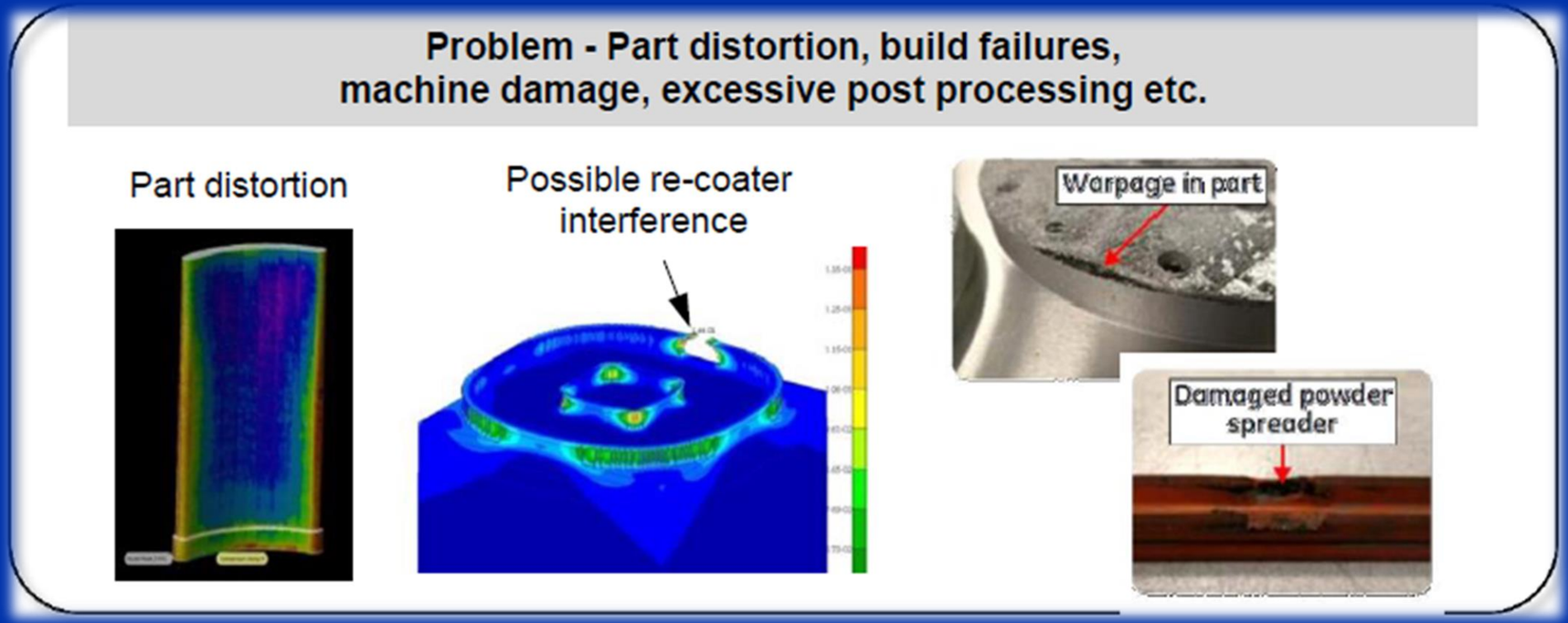
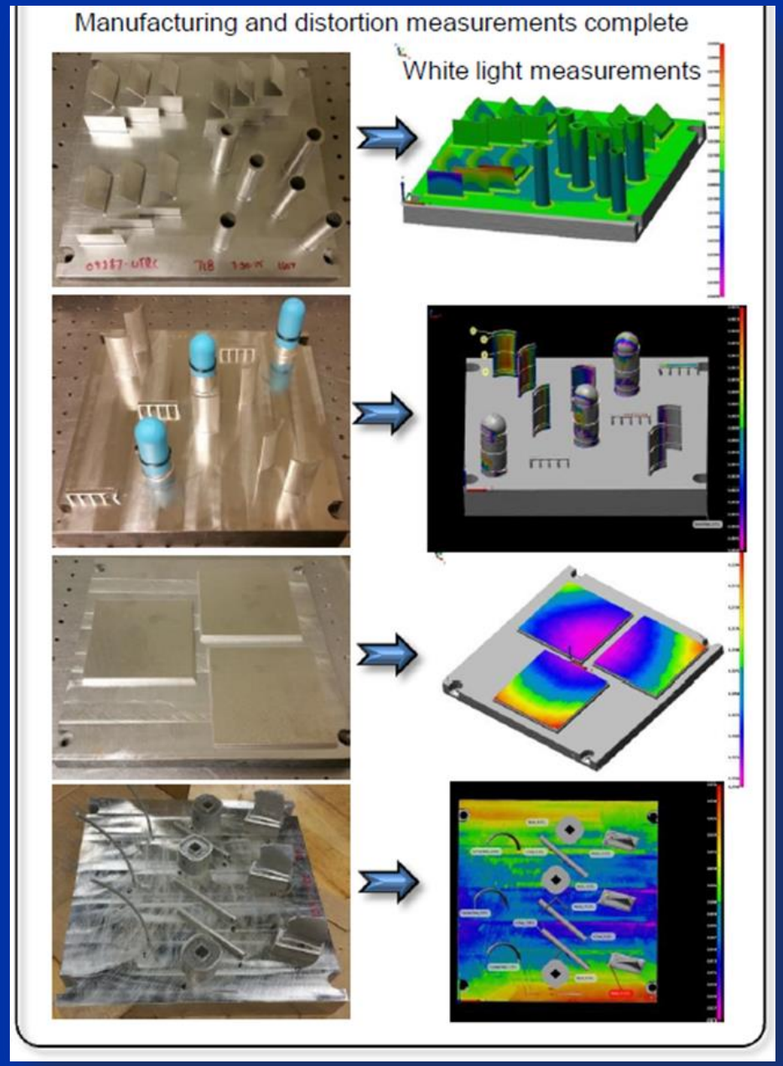


Photo courtesy America Makes (NCDMM)

Understanding Distortion

- **Fundamental Research for the Process**
- **Start with Simple Shapes**
- **Still Significant Amount of Data**
- **Used by Leaders in Additive Manufacturing**



4026.001 - Development of Distortion Prediction and Compensation Methods for Metal Powder-Bed Additive Manufacturing

(Report Released: 8 / 2017, Revised 11/2017)

Submitted by: GE Global Research Center (GEGRC)

Ade Makinde & Prabhjot Singh

NCDMM
NATIONAL CENTER FOR DEFENSE MANUFACTURING AND MACHINING

America Makes

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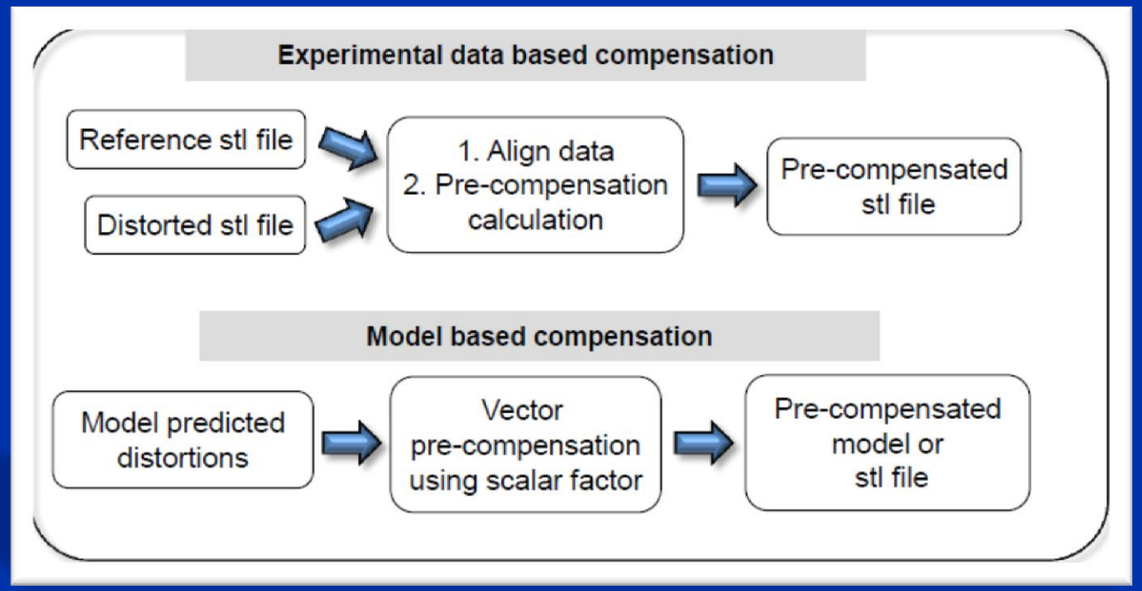
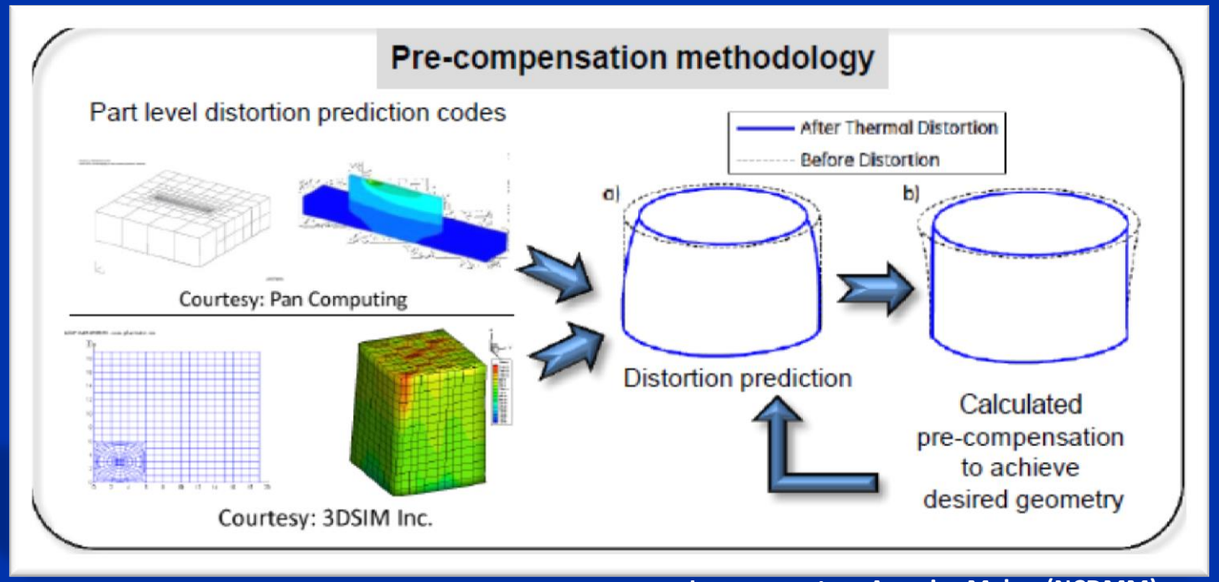
Images courtesy America Makes (NCDMM)

Accounting for Distortion



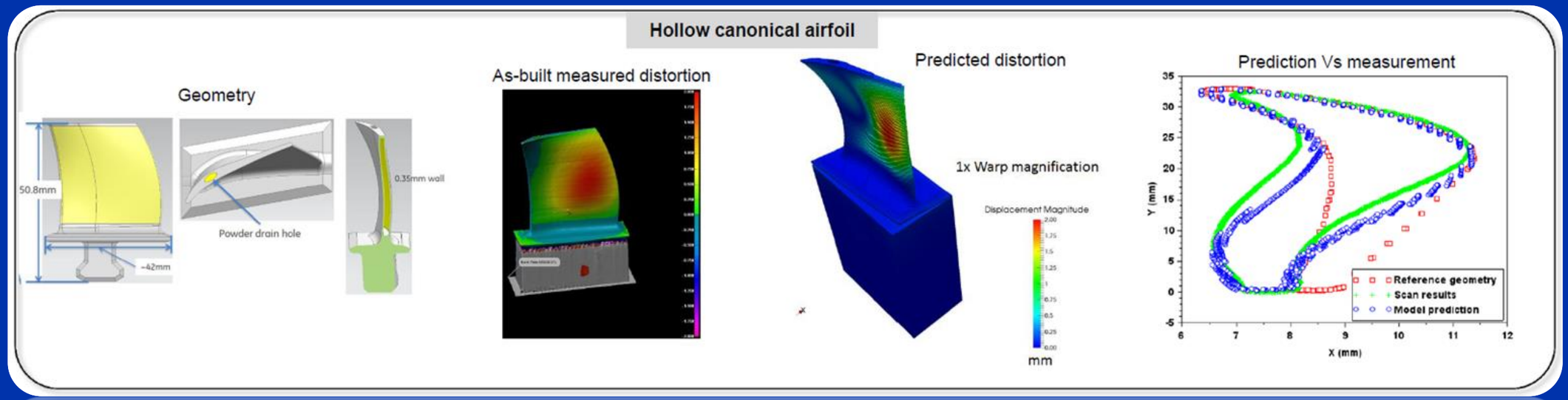
- **Experimental and Model Based Paths**
- **Validation of Model**
- **Key to Cost Effective Product**
- **Non-Contact Minimizes Iterations**



Imagescourtesy America Makes (NCDMM)

Supporting Application Research

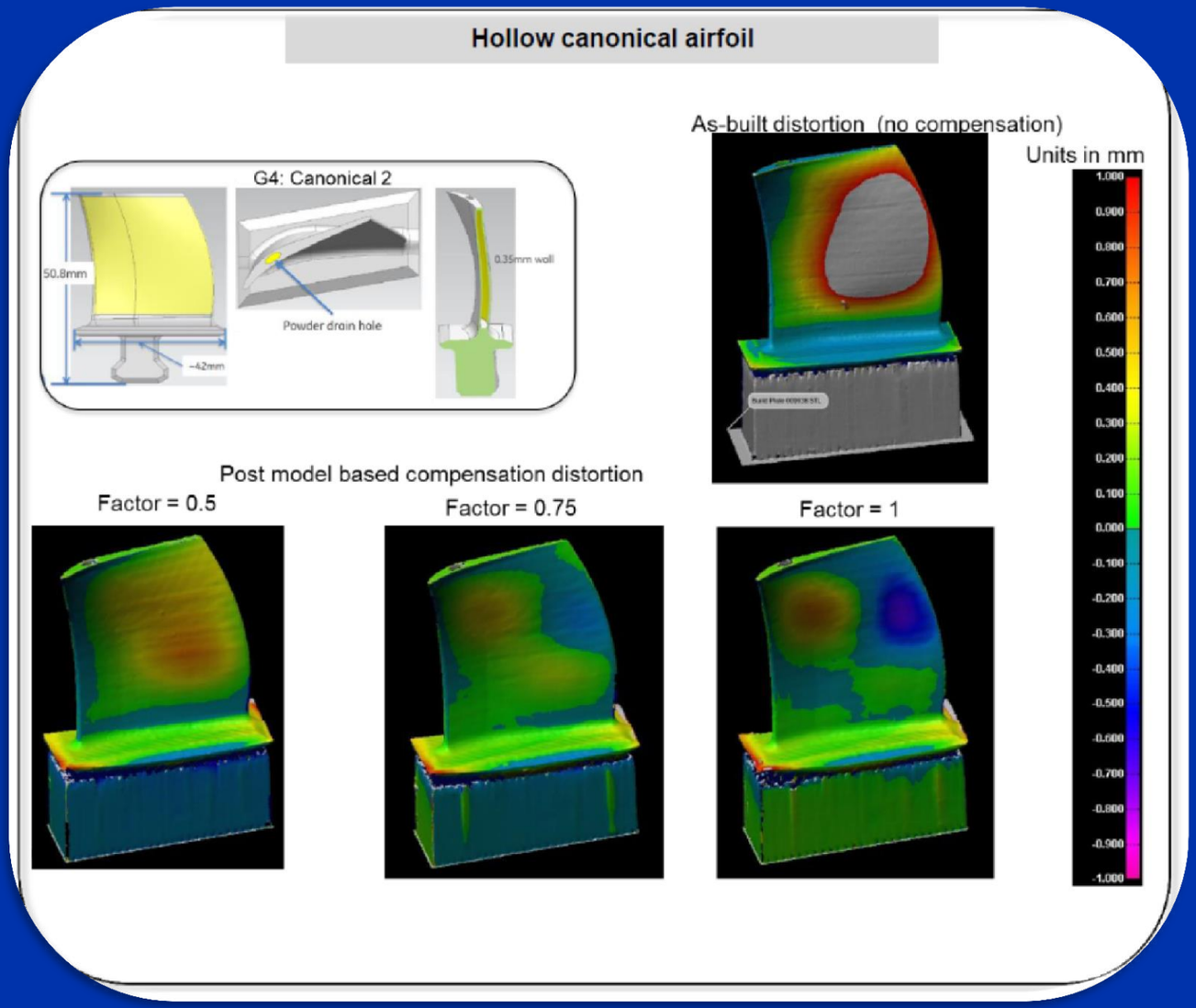
- **Process Development and Process Validation**
- **Accuracy of System Influences Success of Model**



Images courtesy America Makes (NCDMM)

Validating Limits

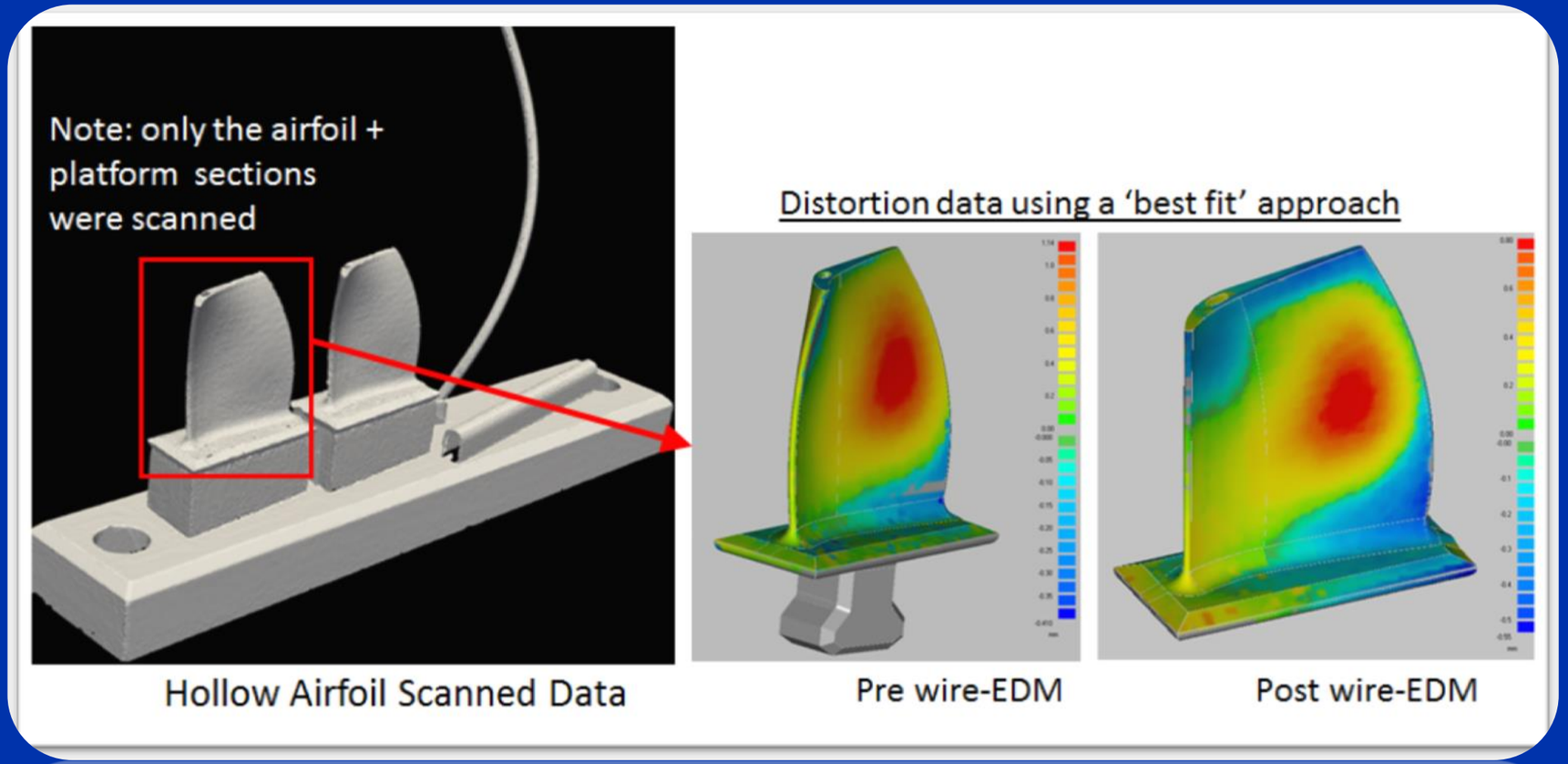
- **Verify Sensitivity**
- **Varied Process Parameters**
- **Robust Process Control Needed**



Images courtesy America Makes (NCDMM)

Alignments and Discovery

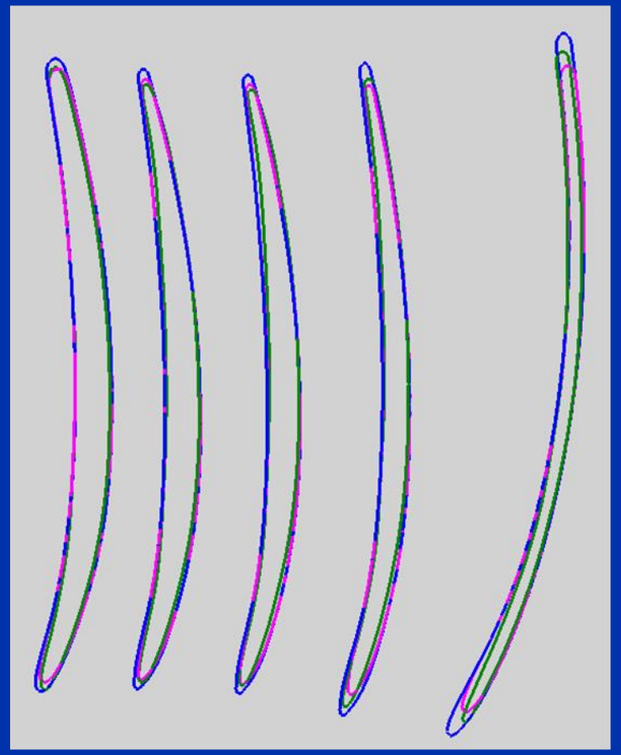
- **Inspection Strategy Key to Data Use**
- **Unexpected Results Discovered via Non-Contact**
  - **Residual Stress**
  - **In-Process Distortion**



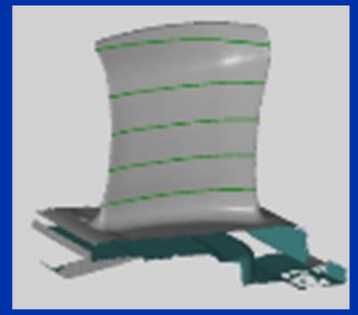
Images courtesy America Makes (NCDMM)

How We Brought It Together (Airfoils)

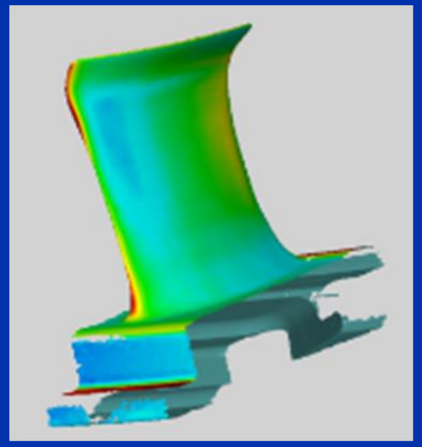
- **Method to Compensate Complex Airfoils**
- **Scripting Used to Automate Process**
- **Output Used in Other CAD Tools**

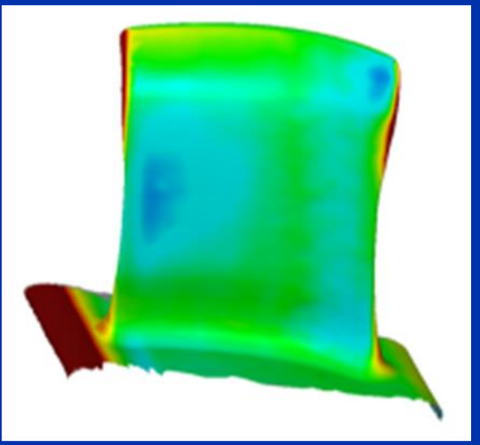


Purple is nominal CAD
Blue is build file
Green is Actual scan



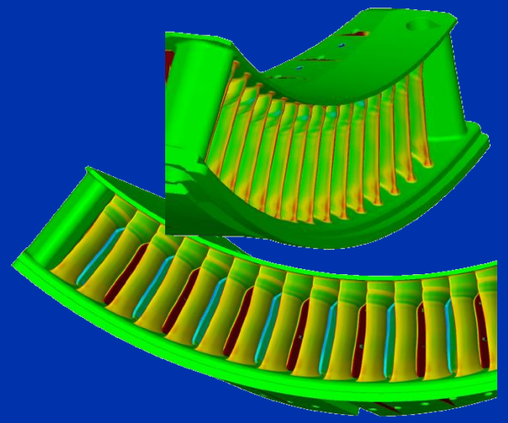
Section location

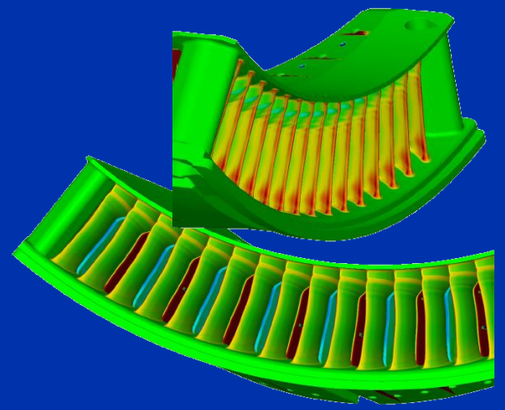


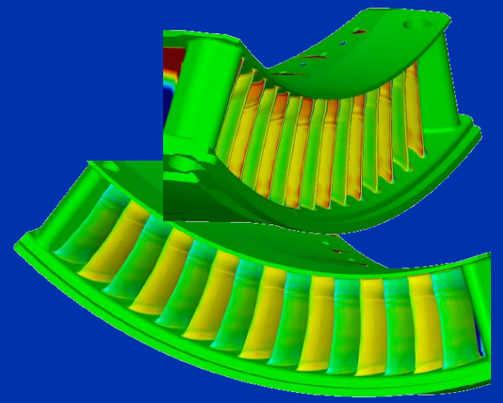


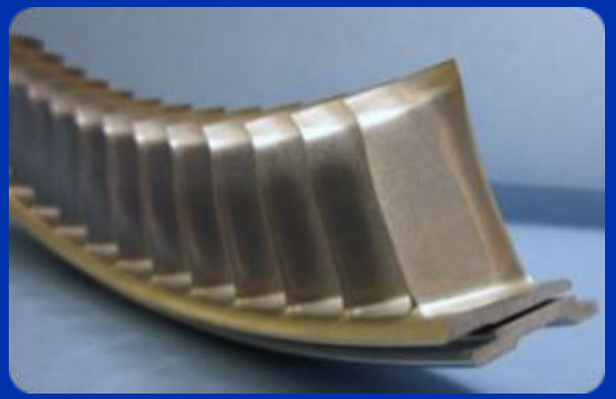
Actual to Nominal

Improving the Process









- **Process Sensitivity to Validate Input to Drive Output**
- **Automated Process**
- **Complete Each Cluster <10min**
- **Data Used as Input to Post Processing**
- **Process Used to Validate Post Processing**

GO BEYOND

Summary

- Pervasive Use of Non-Contact Scanning Within Pratt & Whitney
- Additive is Being Used Throughout Pratt & Whitney
- Digital Applications are Driving Advanced Digital Methods
- Non-Contact Inspection Key Enabler for Process and Tool Development for Additive Manufacturing

Pratt & Whitney

We believe that powered flight has, and will continue to, transform the world. So we work with an explorer's heart and perfectionist's grit to design, build, and service the world's most advanced and unrelenting aircraft engines.

To turn flight's possibilities into realities for our customers.