Reverse Engineering Methodology for Free Form Components and Internal Features -Aerospace Applications-

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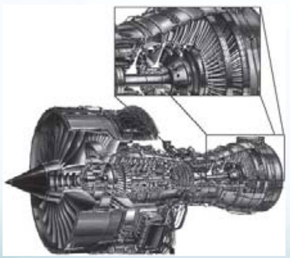
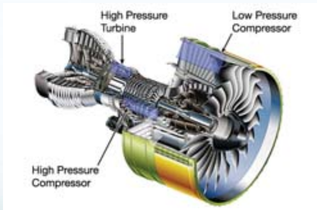
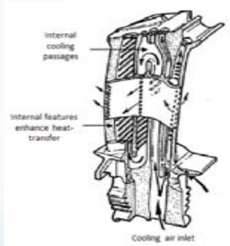
Common aeronautic components difficult to cut



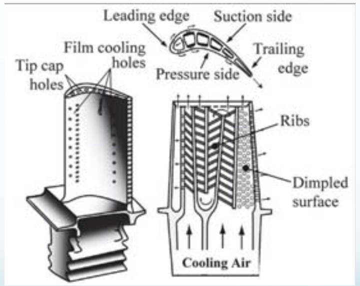


Courtesy of Rolls Royce UTC at the University of Nottingham

Internal geometric features in aeronautic components



Courtesy of EDC of the University of Cambridge



Courtesy of Tokio University of A&T Thermal Fluids Engineering Lab

Properties of Nickel Alloys

- Melting Temp. 1455°C unalloyed
- Young Modulus~ 240Gpa (Steel 210 Gpa)
- Density 8.9 g/cc (steel 7.8 g/cc)
- Tensile Strength 100-1410 Mpa

Difficult for processing
Low Machinability

Reverse Engineering for Aeronautic Components

"Producing a copy of the original part in order to generate a reconstructed 3D model"

Used for:

- Conceptual and functional design.
- Rapid maintenance operations.
- CAD/CAM/CAE

Advantages:

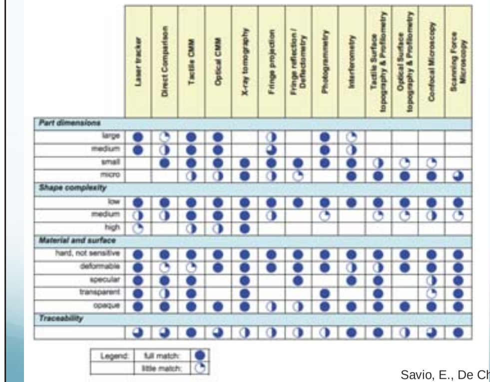
- Generation of 3D models when blue-prints are not available.
- Reduction of reconstruction time of 3D models (1/3 of time used with blue prints)

Reverse Engineering for Aeronautic Components

- Common Specifications of Aeronautic Components, suitable for RE
  - Tight tolerances.
  - Freeform surfaces.
  - Extreme working conditions (1,500 C)
  - Internal cooling blades (1,000 C)

Courtesy of Honeywell Aerospace Chihuahua

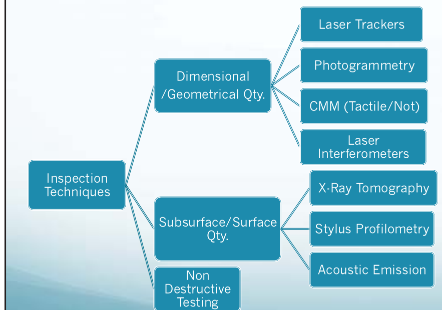
Metrology techniques for RE



Courtesy of Faro

Savio, E., De Chiffre, L., & Schmitt, R. (2007). Metrology of freeform shaped parts. *CIRP Annals-Manufacturing Technology*, *56*(2), 810-835.

Metrology Techniques for RE



Arámbula, K., Siller, H. R., De Chiffre, L., Rodríguez, C. A., & Cantatore, A. (2012). Evaluation of metrology technologies for free form surfaces.*International Journal of Metrology and Quality Engineering*, 3(01), 55-62.

Permisible Errors and Costs

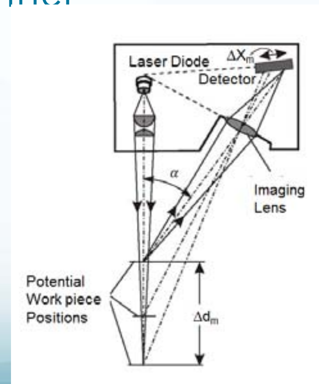
Size	Name and subsystem	Aprox, measuring length	CMM cost and MPE	Photogrammetry cost and MPE	Computed Tomography cost and MPE
Extra large	Fiixed and moveable wing structures	10000 mm	750000 USD 100 μm (volumetric) [11]	230000 USD 400 μm [12]	N/A
Large	Skin pannel section	1000 mm	680000 USD 90 μm (volumetric) [13]	230000 USD 100 μm [12]	N/A
Meso scale	Carbon heatpack (aircraft brakes)	750 mm	365000 USD 4 μm [14]	200000 USD 50 μm [12]	720 000 USD 20 μm [15]
Meso scale	Turbine blades	500 mm	98055 USD 4 μm [16]	155000 USD 20 μm [12]	720000 USD 10 μm [15]
Microscale	MK66 rocket nozzlz	70 mm	98055 USD 3 μm [16]	160000 USD 10 μm [12]	240000 USD 5 μm [17]

Courtesy of Faro

Arámbula, K., Siller, H. R., De Chiffre, L., Rodríguez, C. A., & Cantatore, A. (2012). Evaluation of metrology technologies for free form surfaces. *International Journal of Metrology and Quality Engineering*, *3*(01), 55-62.

Optical Scanner

- Advantages
  - Fast data acquisition when compared with CMM (200pts/s vs 25,000 pts/s)
- Disadvantages
  - Issues with accuracy/uncertainty
  - Workpiece preparation (3-5μm coating)



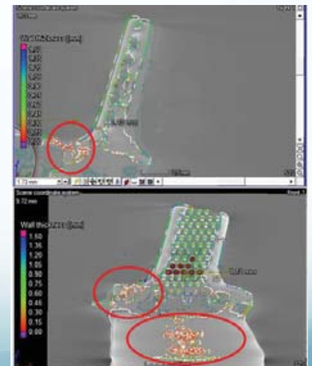
Coordinate Measuring Machine

- Advantages
  - Reliable Inspection with well known standards
  - Low Uncertainty
  - High Traceability
- Disadvantages
  - Tactile sensitivity
  - Rigid components
  - Low productivity

Courtesy of Carl Zeiss

Computerized Tomography (CT)

- Advantages
  - Internal features reconstruction
  - Non Destructive Internal Inspection
- Disadvantages
  - Dispersion/Beam hardening
  - Lack of international standards.



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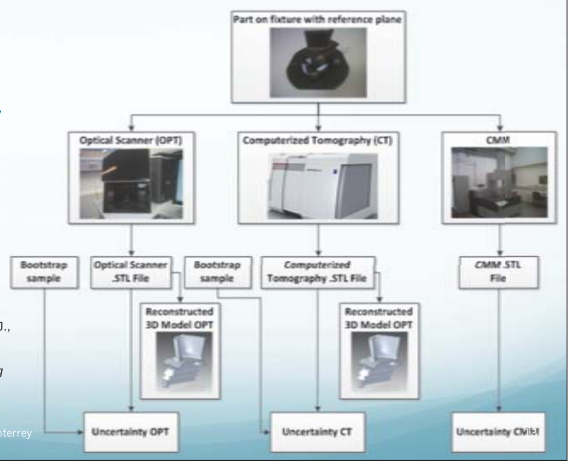
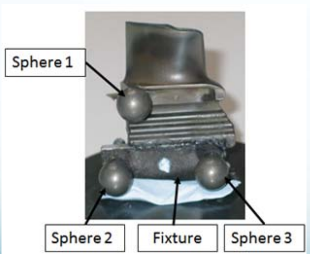
Proposed Methodology



Gameros, A., De Chiffre, L., Siller, H. R., Hiller, J., & Genta, G. (2015). A reverse engineering methodology for nickel alloy turbine blades with internal features. *CIRP Journal of Manufacturing Science and Technology.*

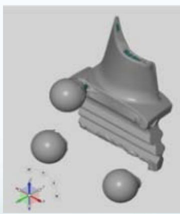
Experimental Procedure

- Optical Scanner



3Shape optical scanner, model Q800

Setup →



Mesh used for RE

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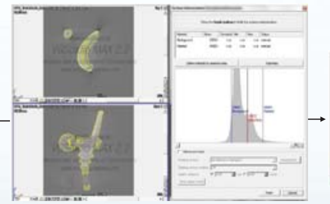
Experimental Procedure

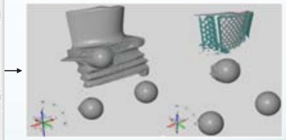
- CT Scanner

Carl Zeiss METROTOM 1500

Setup



Surface determination



Mesh used for RE

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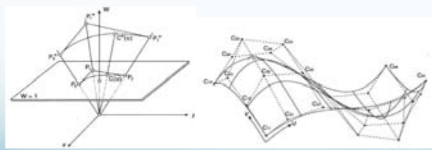
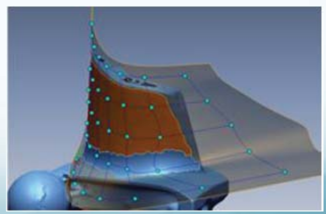
Experimental Procedure

- Point triangulation (*stl)
  - Numerical representation
- Construction of analytical equations (Bilinear surface elements)
  - Generated in the form of NURB surfaces





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Experimental Procedure

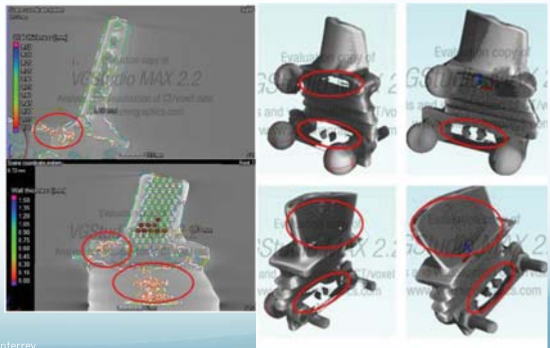
- Uncertainty Evaluation
  - Use of CMM measurements as reference
  - Use of Modular Freeform Gage for reference uncertainty

Uncertainty Component	Symbol	Type	Estimation
MFG Uncertainty	u_{MFG}	A	MFG Uncertainty
Repeatability	u_{CMM}	A	Repeated CMM measurements on MFG
Temperature	u_e	B	U-shaped distribution

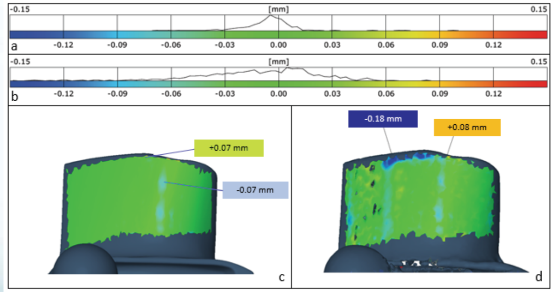
$$U_{REF} = k\sqrt{u_{MFG}^2 + u_{CMM}^2 + u_e^2}$$

Results and discussion

- Dispersion of measurements in CT
  - Use of aluminum box for filtering x-ray beam.
  - Surface determination procedure in 2 stages.
  - Part internal porosity



Results and discussion



Comparison of deviations values from CMM measurements and optical scanner (a and c) and comparison between CMM and CT scans (b and d).

Results and discussion

- Uncertainty estimation for MFG (Values in µm)

Uncertainty Component	Type	Estimation	Standard uncertainty
Calibration uncertainty of single objects	B	Calibration certificates	0.90
Uncertainty of the relative positions	A	CMM measurements	5.51
Combined standard uncertainty			**5.58**
Expanded Uncertainty (k=2), U_{MFG}			**11.16**

Results and discussion

- Uncertainty estimation for CMM (Values in µm)

Uncertainty Component	Type	Estimation	Standard uncertainty
MFG Uncertainty	A	MFG Uncertainty	5.58
Repeatability	A	Repeated CMM measurements	6.97
Temperature	B	U-shaped distribution	0.23
Combined standard uncertainty			**8.93**
Expanded Uncertainty (k=2), U_{REF}			**17.86**

Results and discussion

- Uncertainty estimation for optical scanner (values in µm).

Uncertainty Component	Type	Estimation	Standard uncertainty
Reference uncertainty	A	Reference uncertainty (CMM)	8.93
Repeatability	A	Bootstrap method	19.92
Temperature	B	U-shaped distribution	1.37
Combined standard uncertainty			**21.87**
Expanded Uncertainty (k=2), U_{OPT}			**43.70**

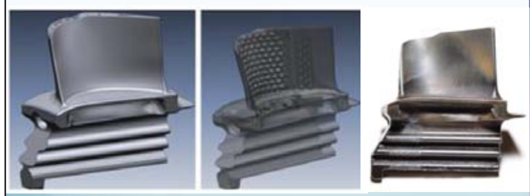
Results and discussion

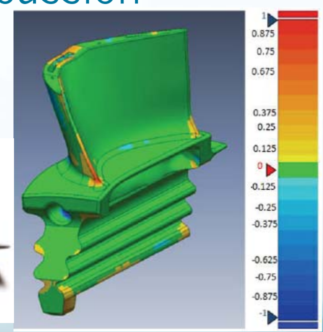
- Uncertainty estimation for CT scanner (values in µm).

Uncertainty Component	Type	Estimation	Standard uncertainty
Reference uncertainty	A	Reference uncertainty (CMM)	8.93
Repeatability	A	Bootstrap method	58.93
Temperature	B	U-shaped distribution	0.14
Combined standard uncertainty			**59.60**
Expanded Uncertainty (k=2), U_{CT}			**119.20**

Results and discussion

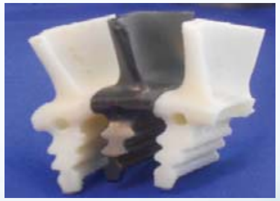
- Deviation of final model
  - Deviation in the range of +/-50 µm.
  - Sporadic Deviations in the range of +/-80µm.





Conclusions

- Total time for reconstruction: 45 hours (1/3 of reconstruction from blueprints)
- Is not recommendable to use the CT scans for the geometrical reconstruction of the external surface (Bigger uncertainty, poorer precision)
- The combination of Optical Scanner and CT Scanner for RE is very promising for the Additive Manufacturing of Aeronautic Components and freeform shapes with internal features.



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  - **Beca de sostenimiento CONACyT** (4.5 Salarios Mínimos).
  - Beca mixta para estancias en el extanjero
  - Participación en proyectos inspiradores y de alto impacto en ciencia y tecnología.
- Informes: hector.siller@itesm.mx

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Investigación que Transforma Vidas

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