



Bildkorrelation zur Validierung der Finite-Elemente-Analyse mit Z88Aurora anhand einer Windkraftflügelstruktur

15. Bayreuther 3D-Konstruktuerstag

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Prof. Dr.-Ing. Frank Rieg



- Rechenkerne werden seit 1986 von Prof. Dr.-Ing. Frank Rieg entwickelt
- neueste Open-Source Version: Z88V14 OS
- seit 2009 Entwicklung einer grafischen Benutzeroberfläche am Lehrstuhl für Konstruktionslehre und CAD: Z88Aurora
 - neueste Version: V2a (nicht Open-Source)
 - Vollständiges FEA-Paket
 - Import von CAD-Dateien
 - 24 Elementtypen
 - 2 Free-Meshing Tools (Tetraedervernetzer)
 - Präprozessor (Randbedingungsangabe über GUI)
 - lineare, nichtlineare, thermische und Eigenschwingungssolver
 - Postprozessor und Exportfunktion

Entwicklung von Berechnungssoftware erfordert Validierung!

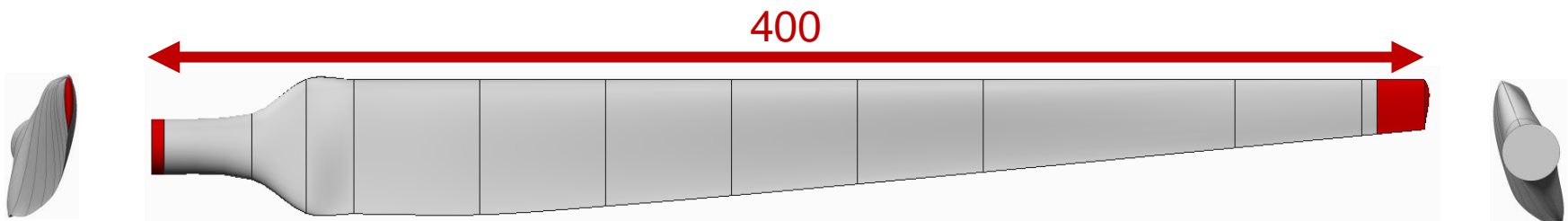


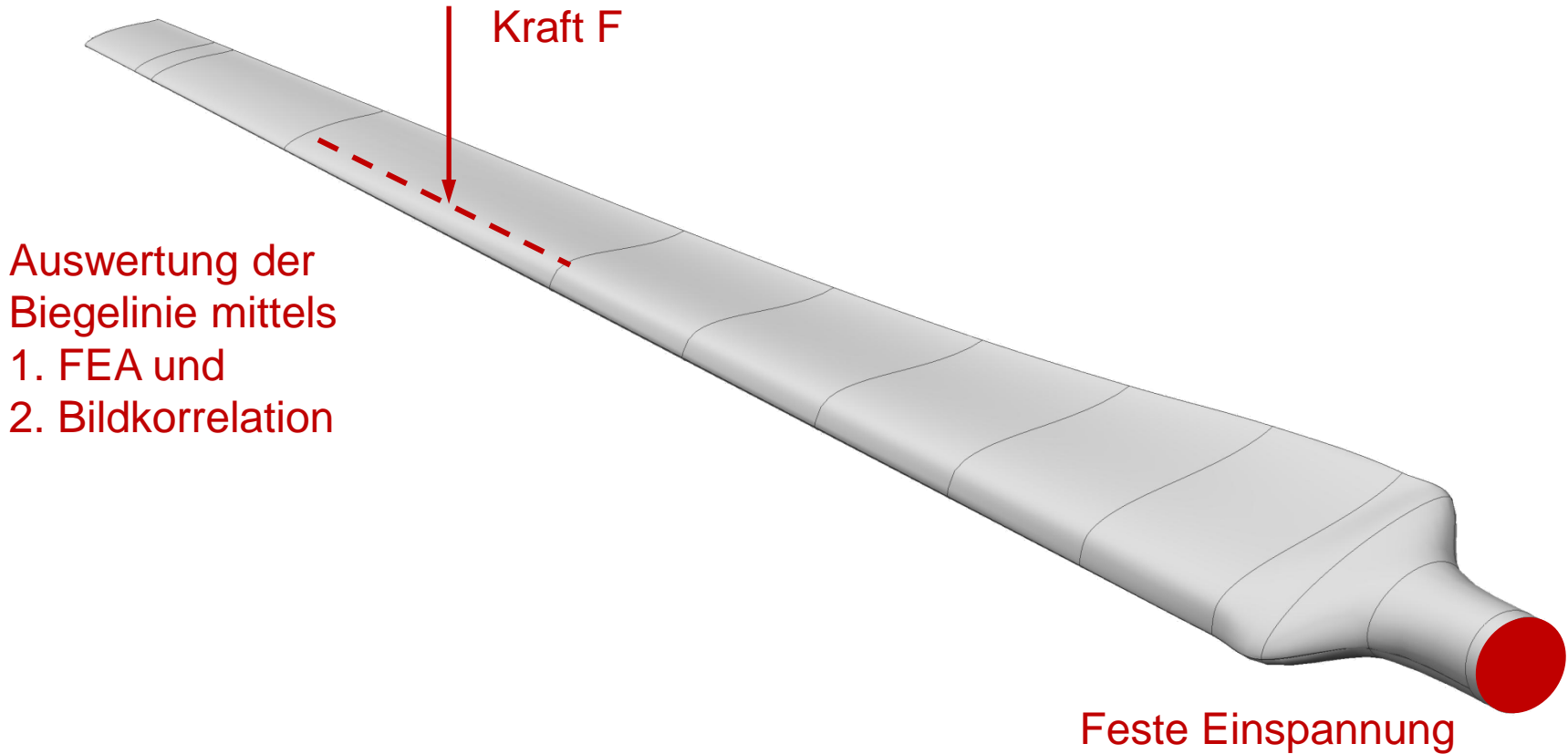
Verformungssimulation eines geometrisch komplexen Bauteils mit Z88Aurora und Validierung der Ergebnisse mittels Bildkorrelation

Auswahl Prüfkörper:

Flügel einer Windkraftanlage

- Vollkörper aus Aluminium gefräst



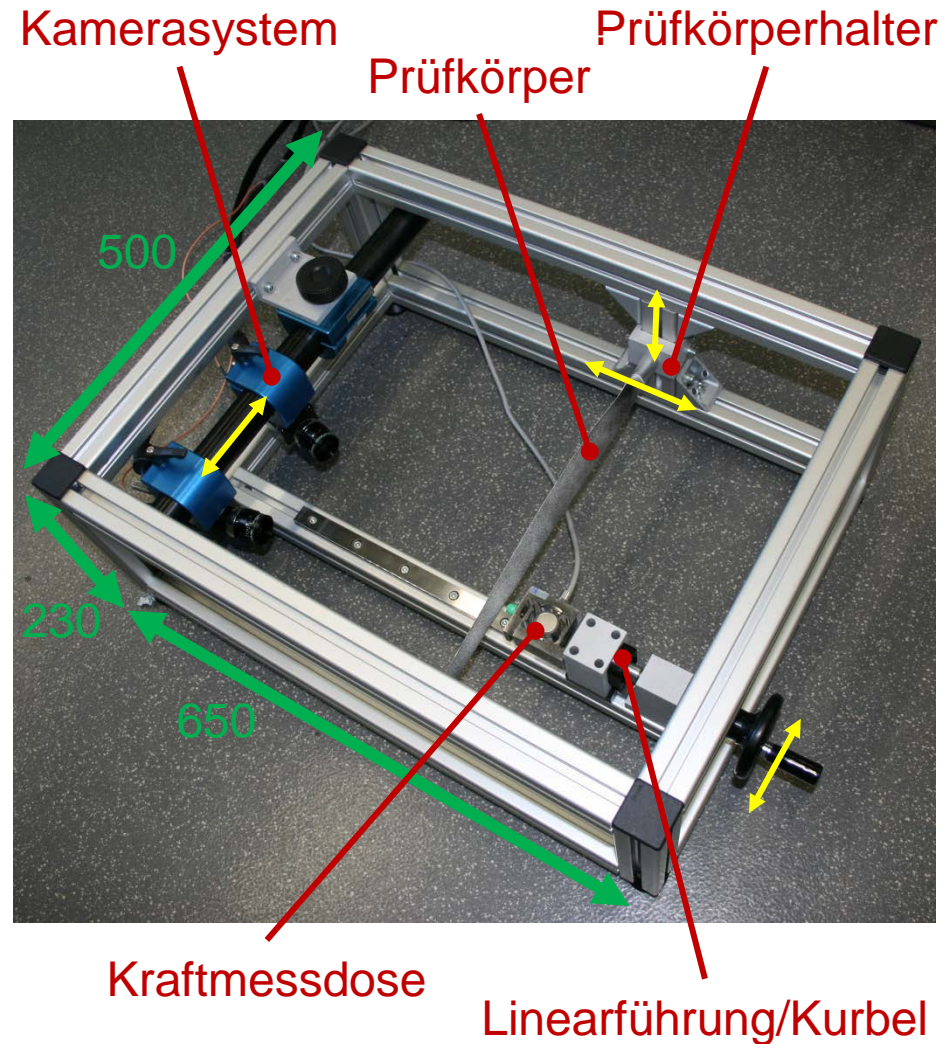


Versuchsaufbau

Prüfstand

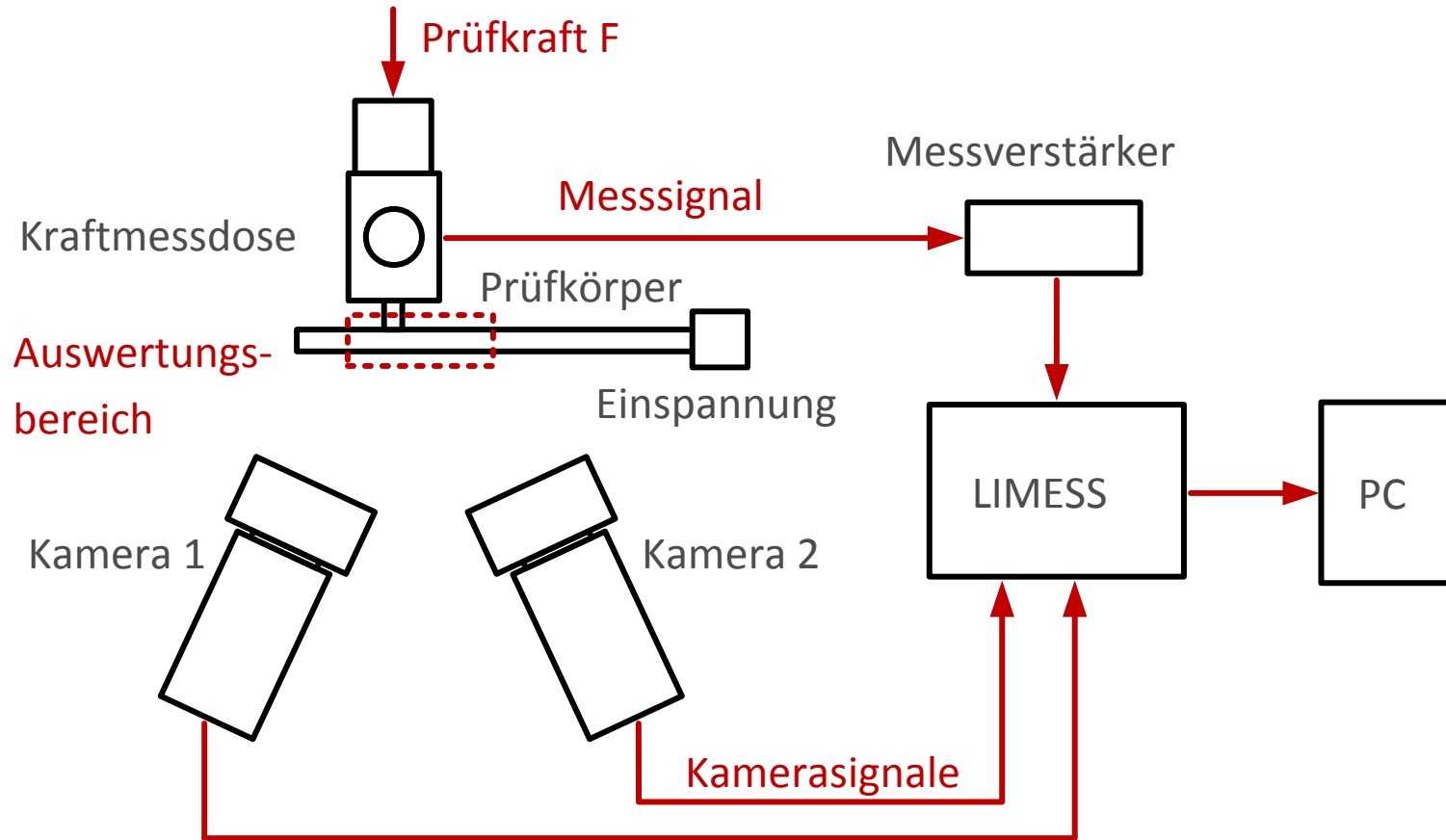


- Stereokamerasystem [LIM13]
- Verfahrweg Spindel: 50 mm
- Kraftmessdose: 500 N
- Anpassbarkeit an unterschiedliche Prüfkörpergeometrien





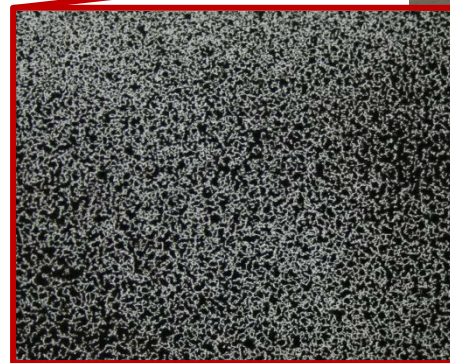
Schematischer Aufbau





Präparation des Prüfkörpers

1. Säubern und Entfetten des Aluminium-Rohlings
2. weiße Grundierung zur Erhöhung des Kontrastes
3. Auftragen eines unregelmäßigen, schwarzen Punktemusters



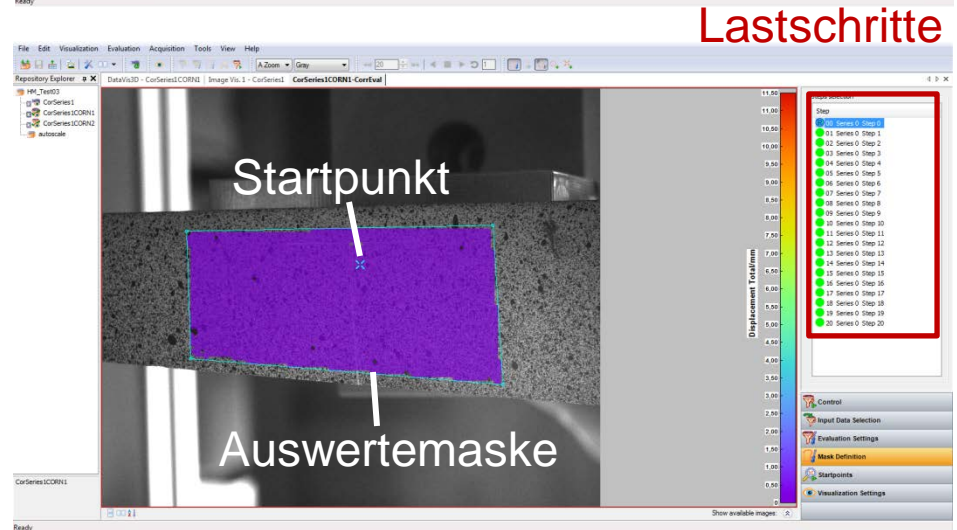
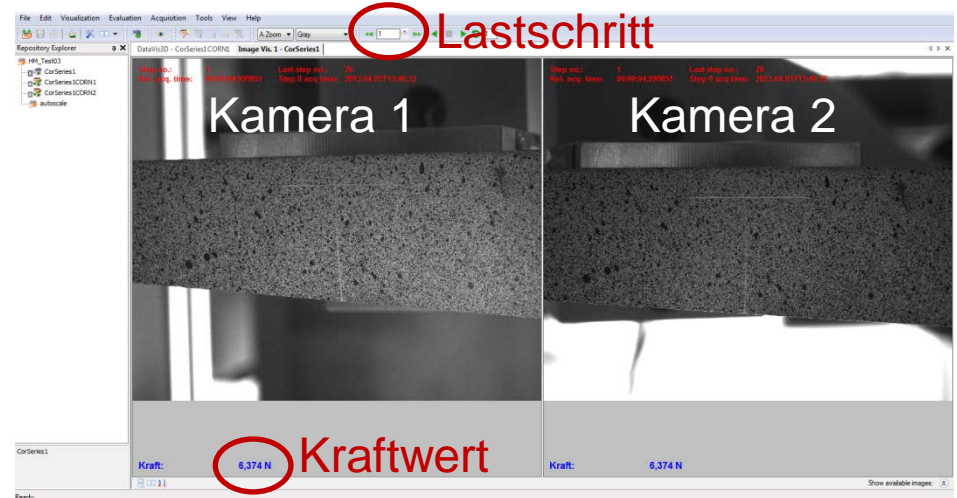
Versuchsdurchführung

Bildkorrelation



Durchführung

1. Aufnahmen von Stereobild und zugehörigem Kraftwert für jeden Lastschritt
2. Auswertungssoftware Istra4D [Dan13] berechnet aus dem Stereobild für jeden Lastschritt die Verschiebung innerhalb des Auswertebereichs





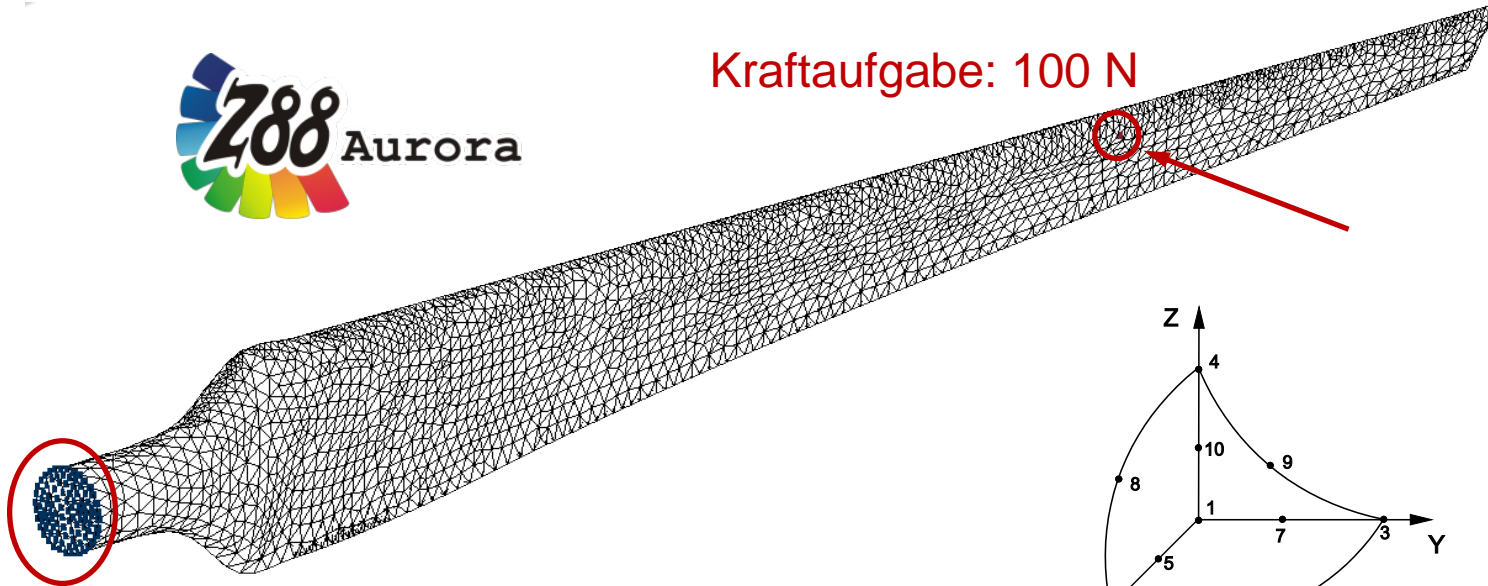
FEA-Model:

~ 37.000 Knoten

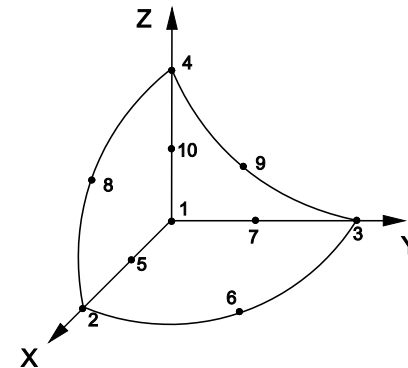
~ 22.000 Tetraeder (quadratisch/10 Knoten)



Kraftaufgabe: 100 N



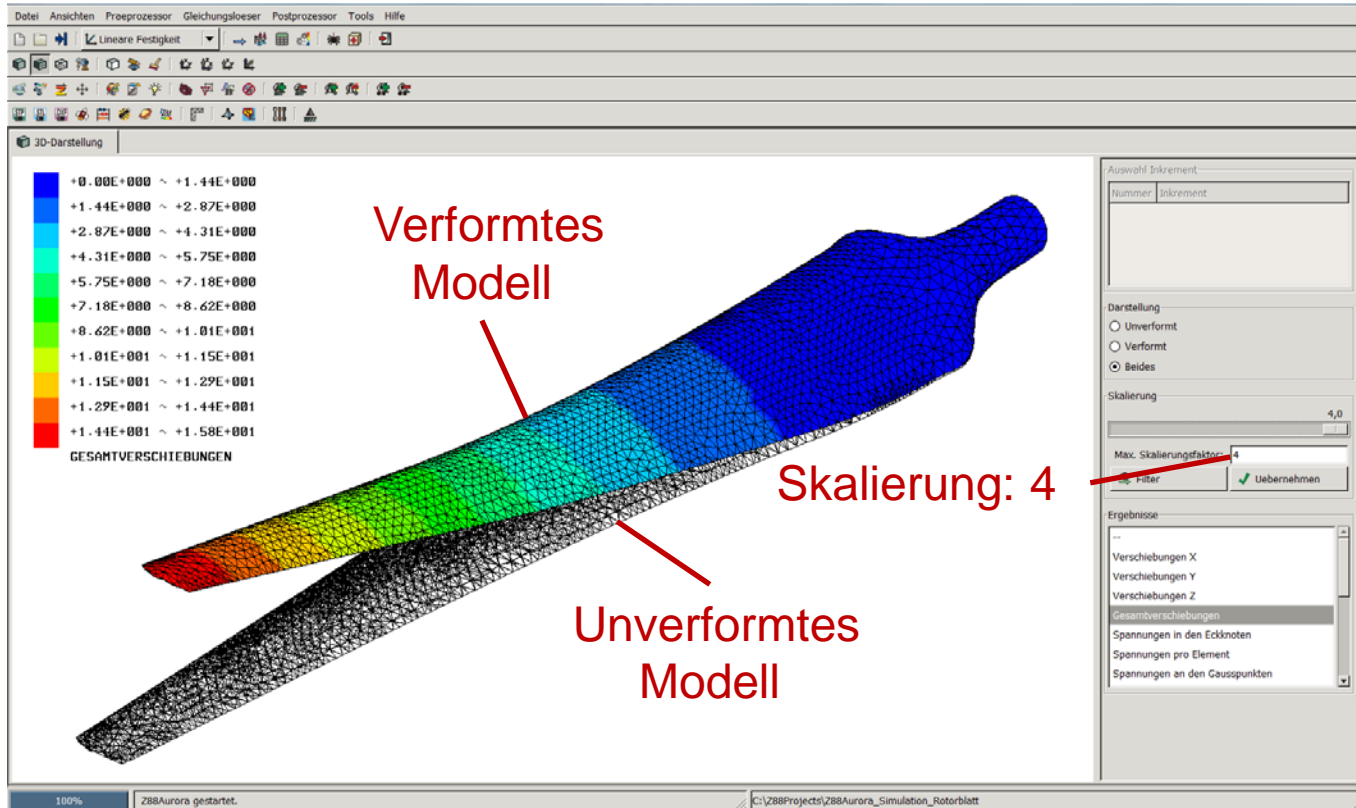
Feste Einspannung:
Verschiebungen in $x, y, z = 0$

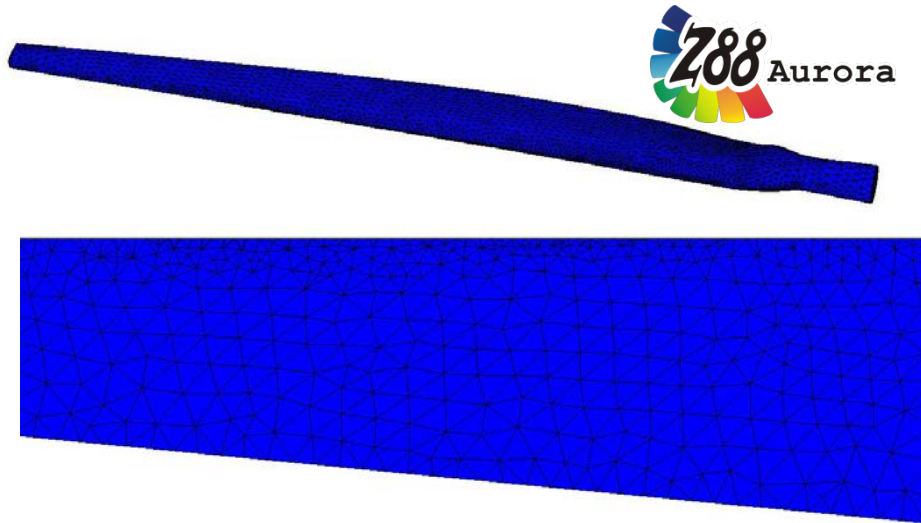


[RHA12]

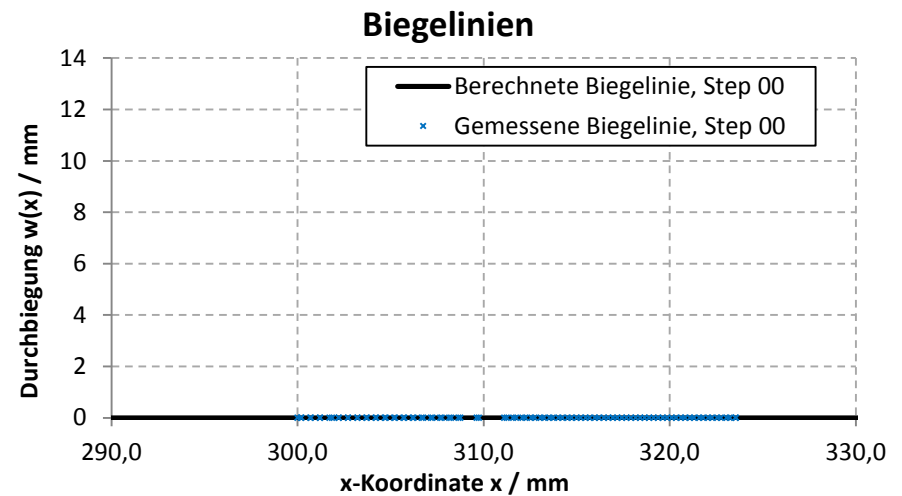
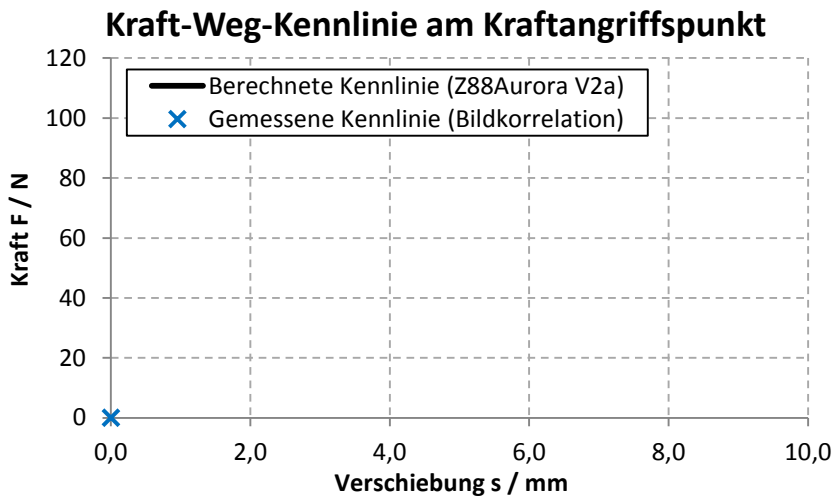
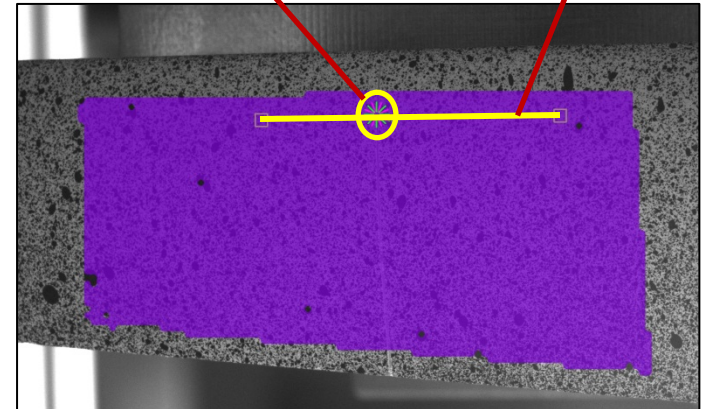


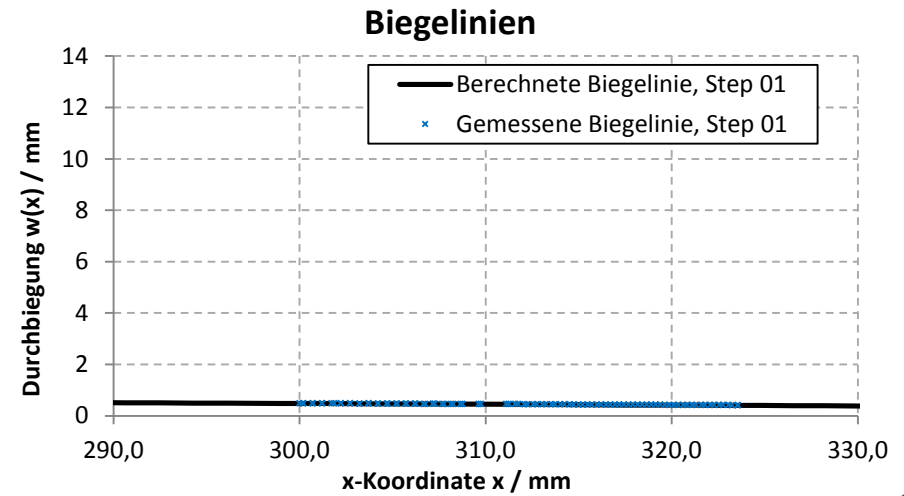
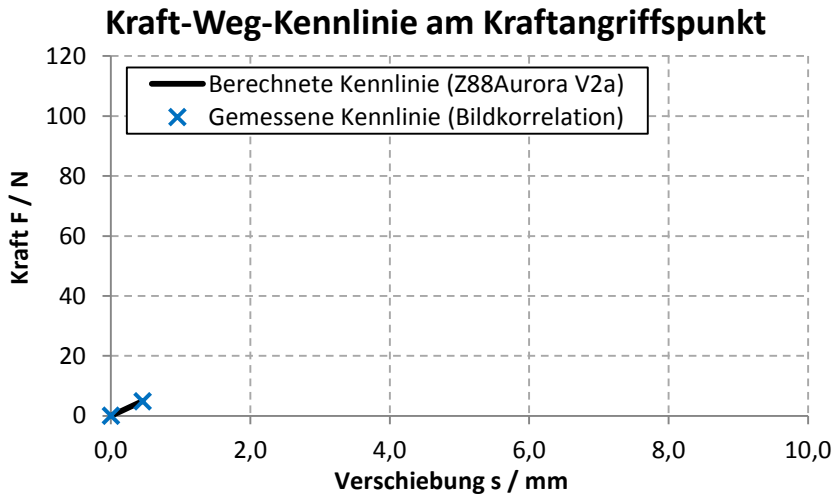
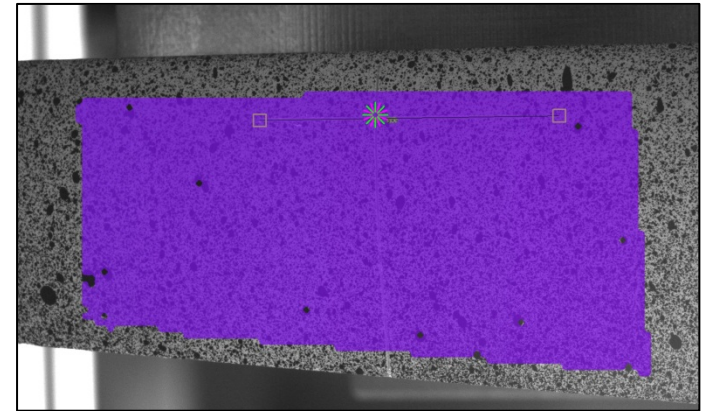
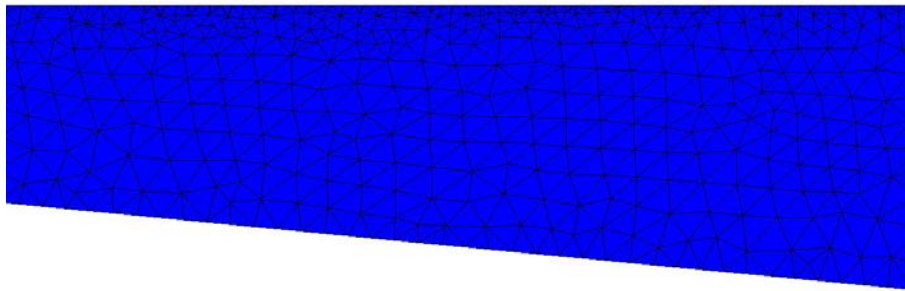
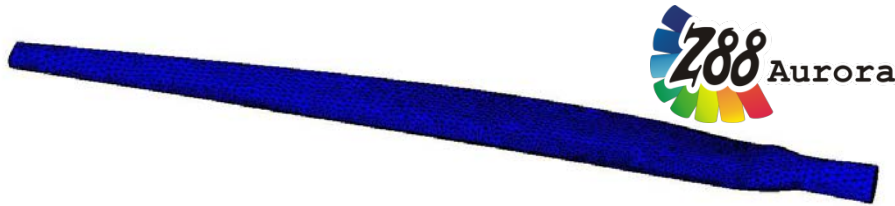
Gesamtverschiebungen

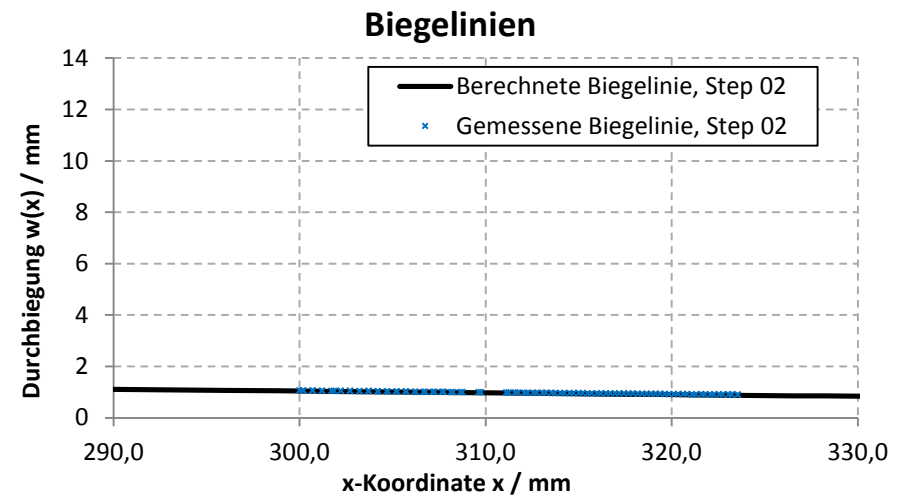
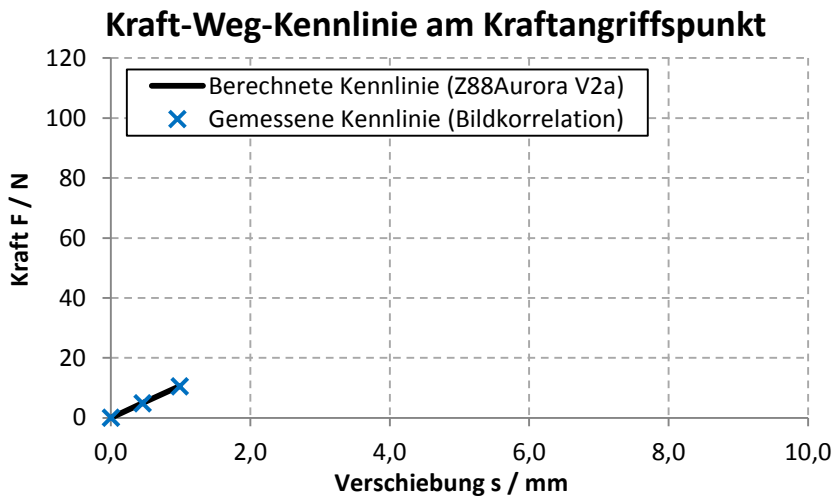
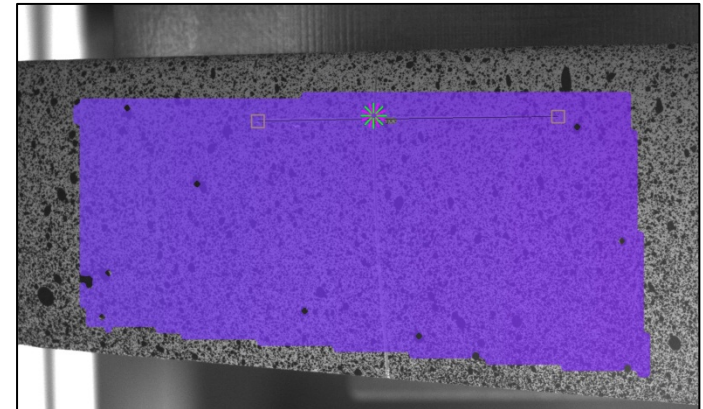
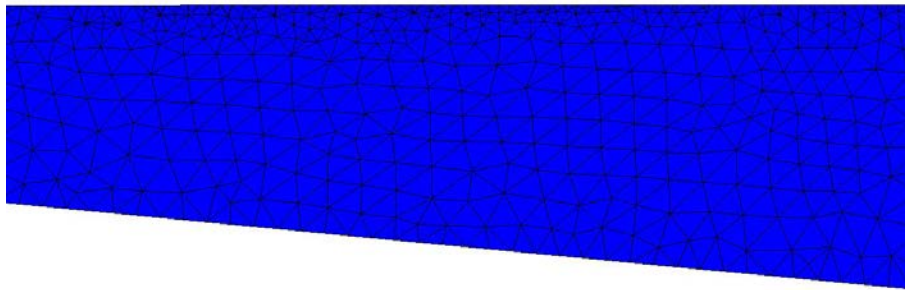
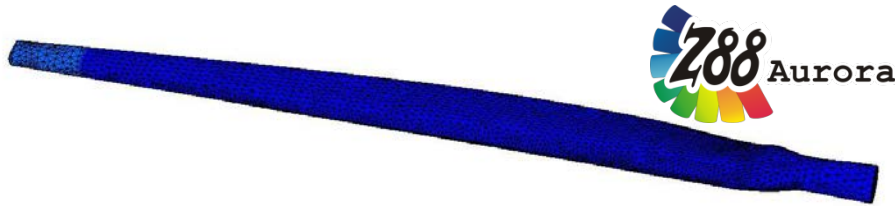


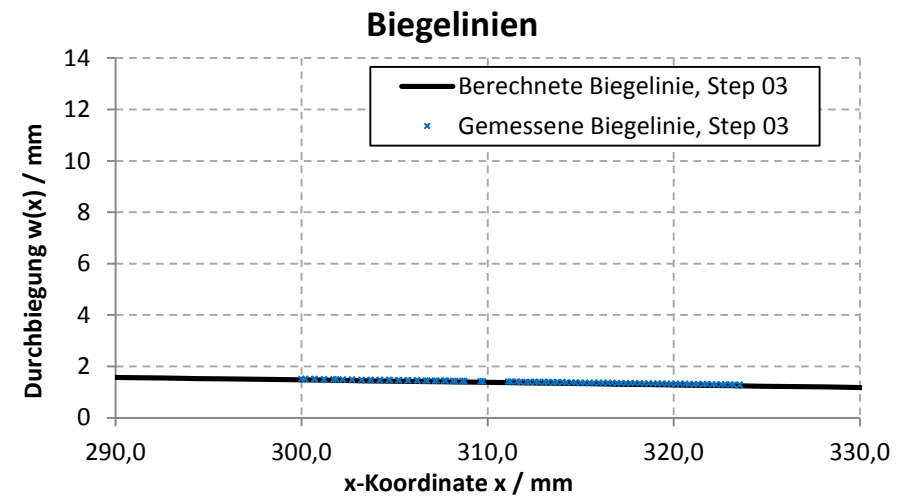
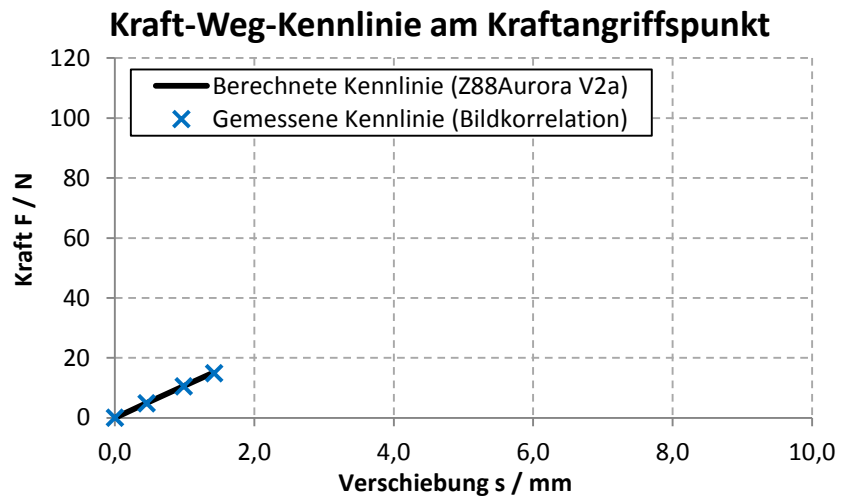
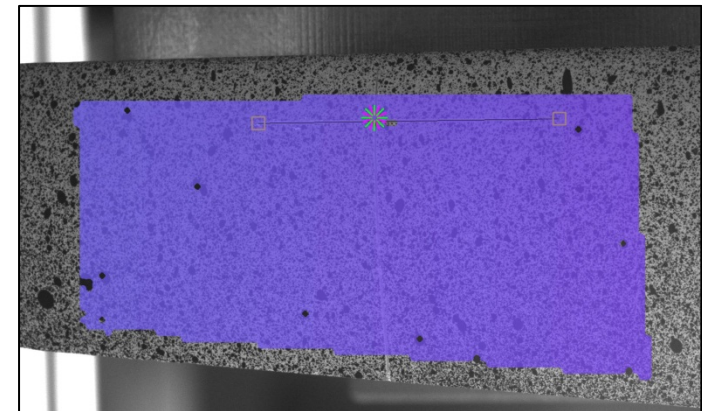
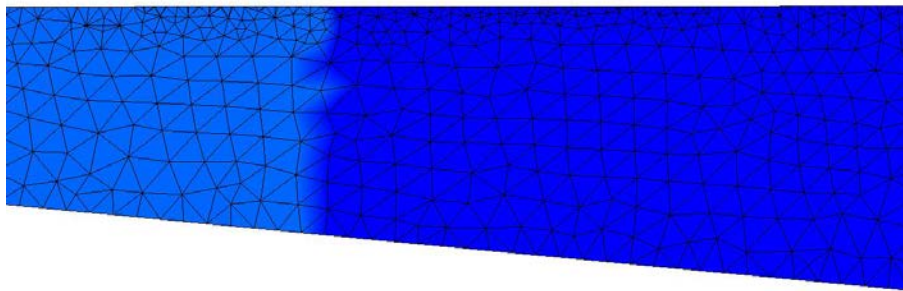
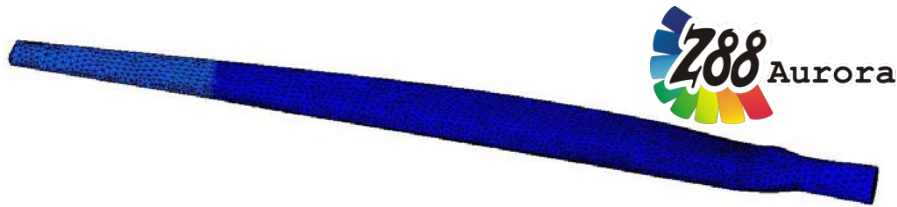


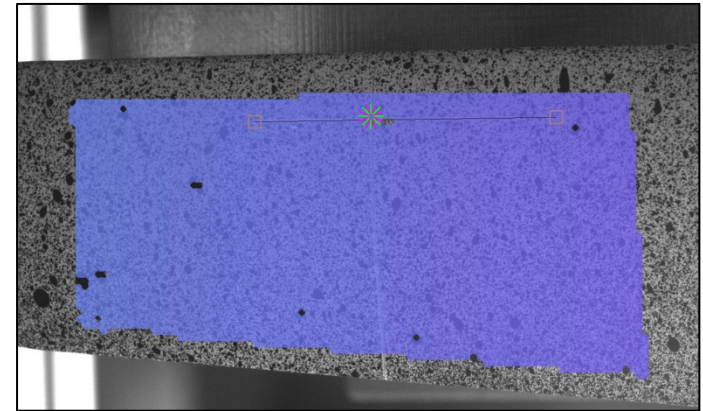
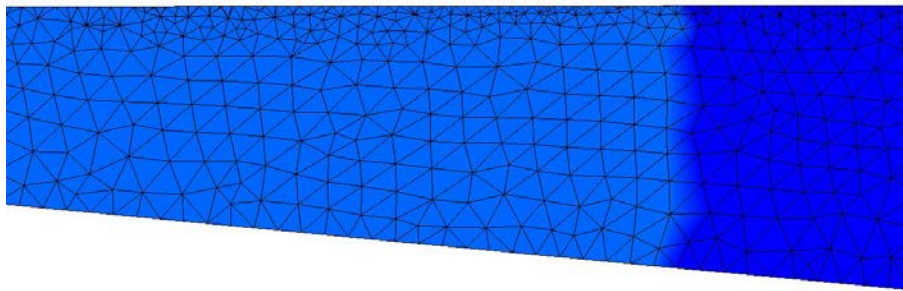
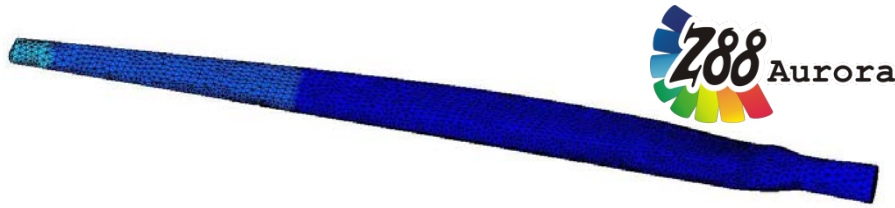
Kraftangriffspunkt Biegelinie



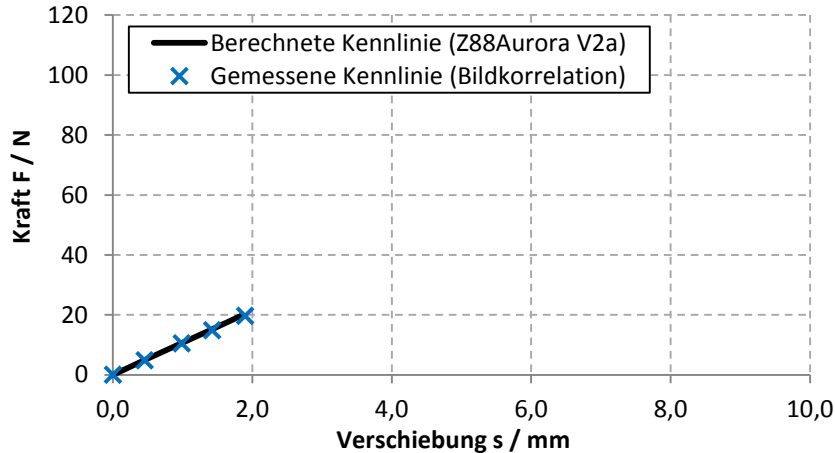




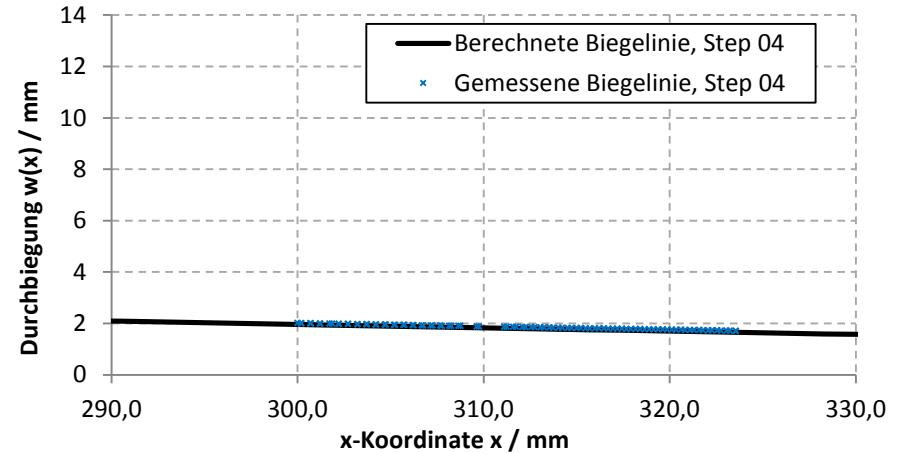


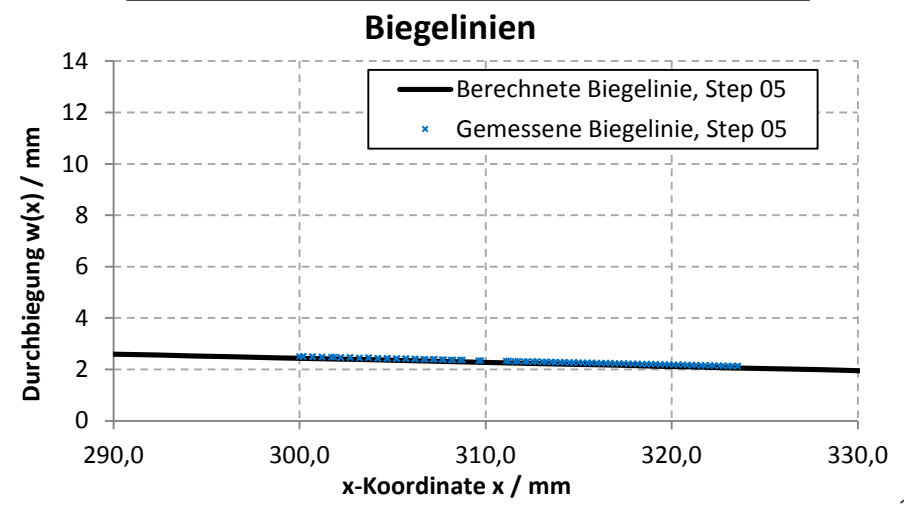
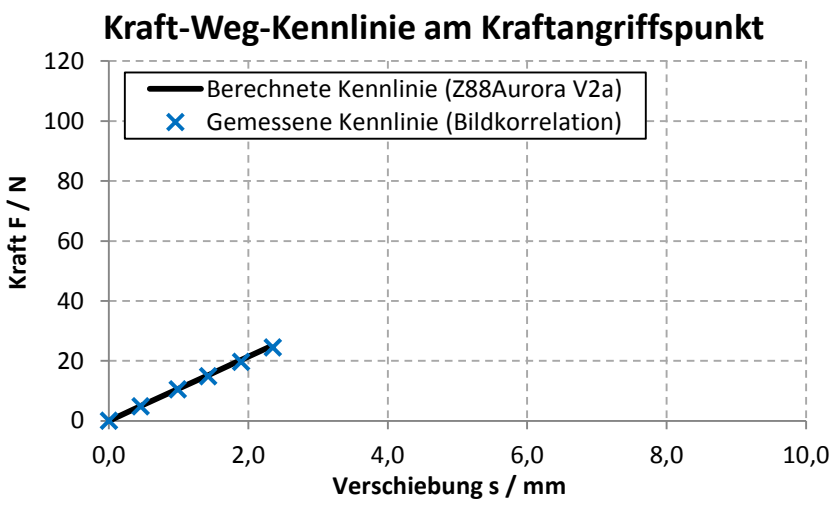
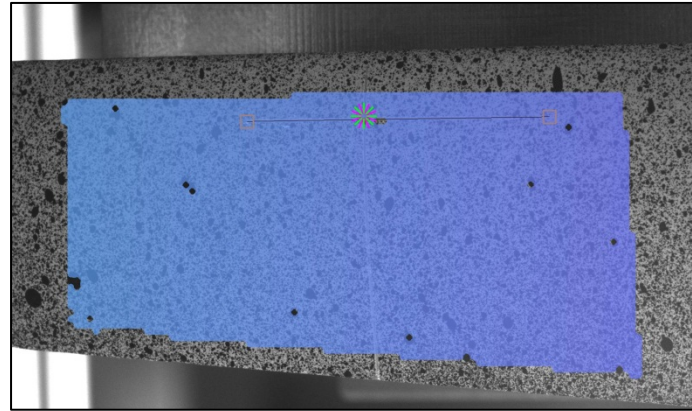
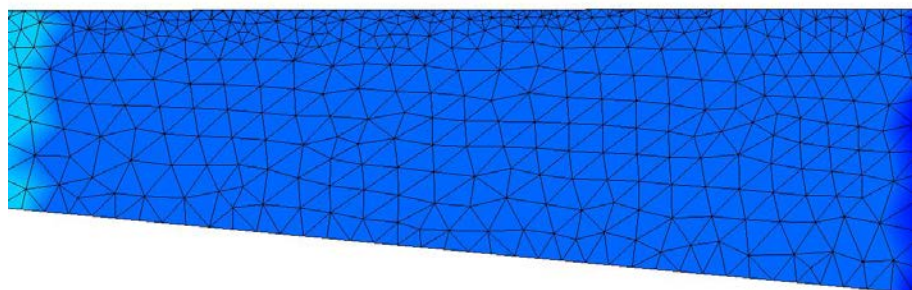
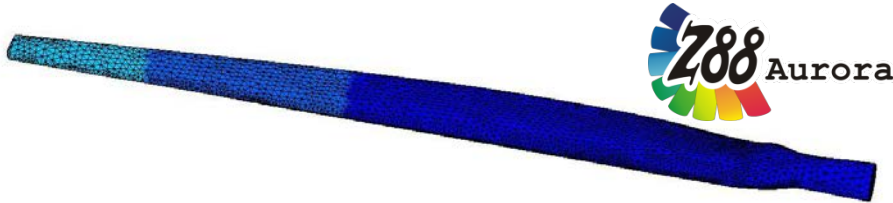


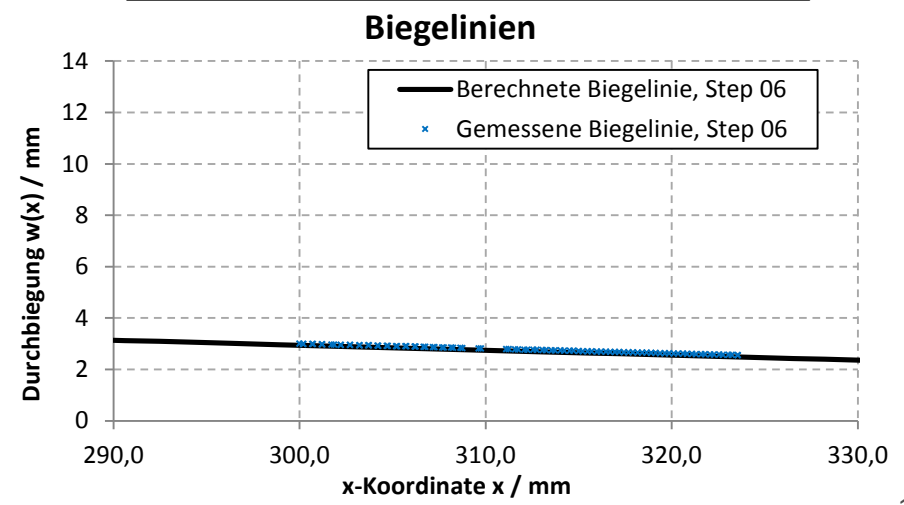
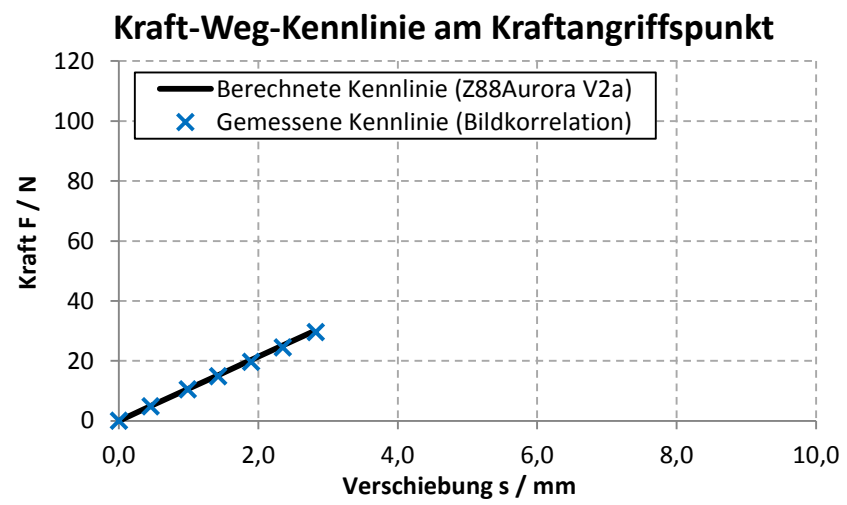
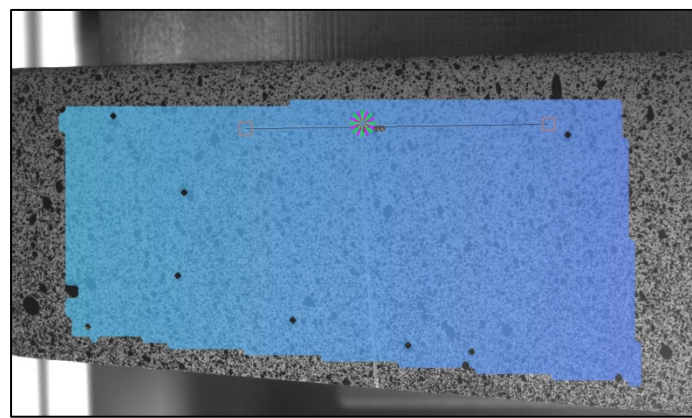
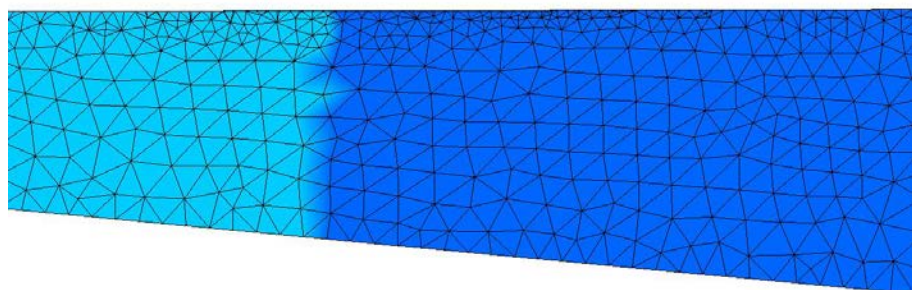
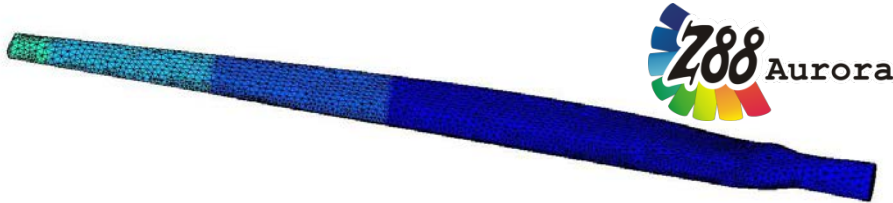
Kraft-Weg-Kennlinie am Kraftangriffspunkt

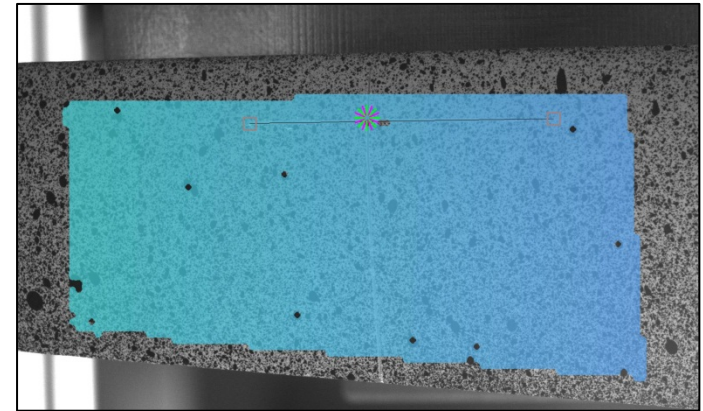
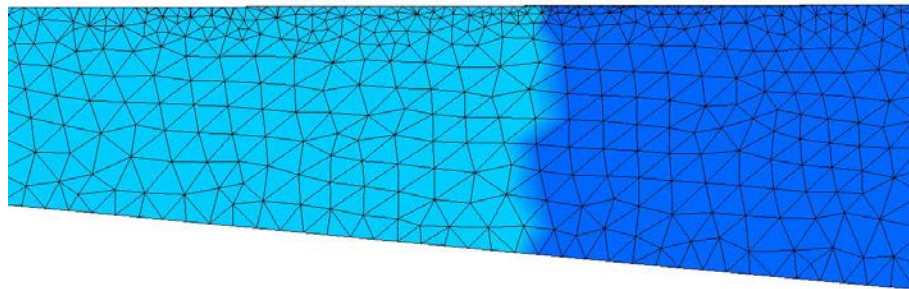
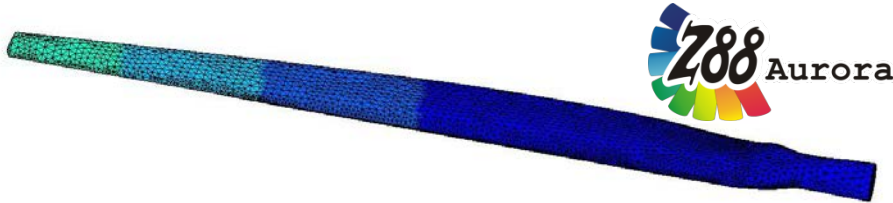


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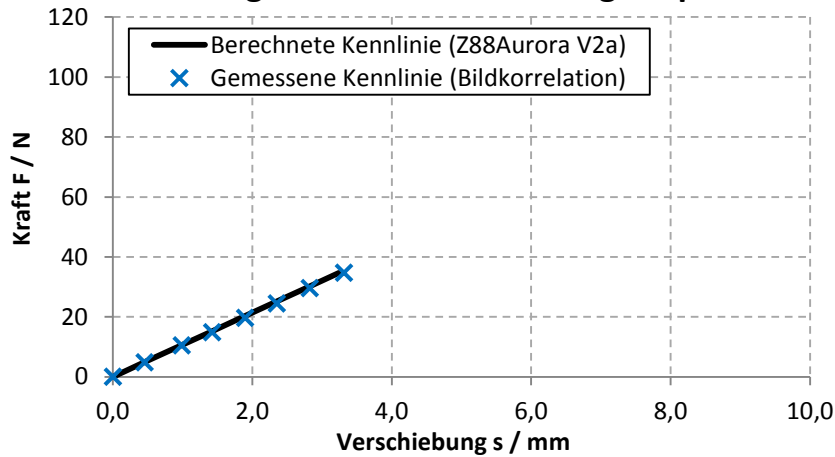




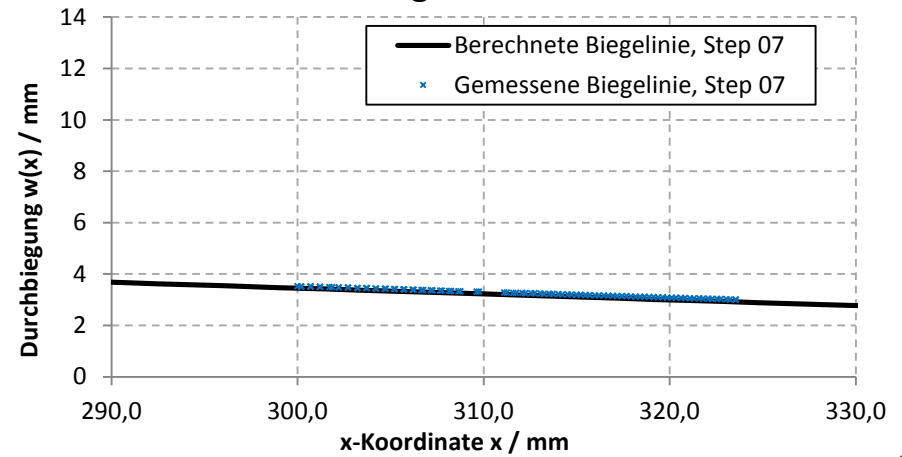


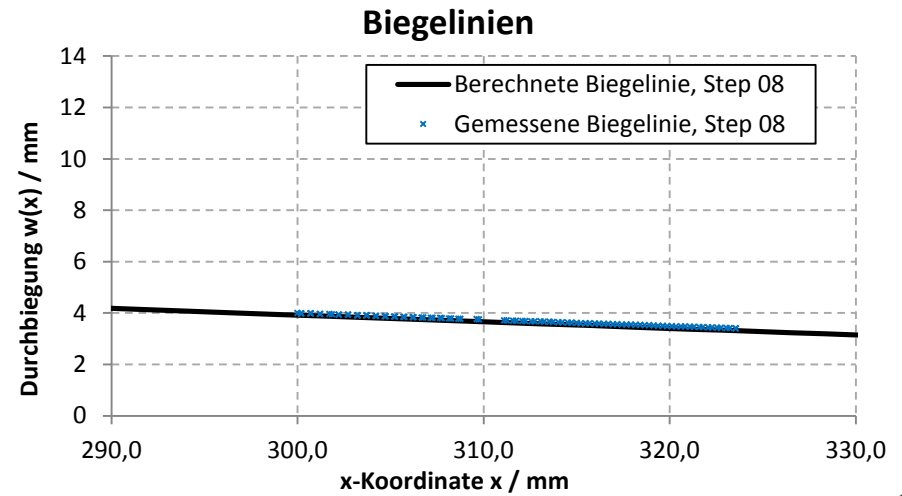
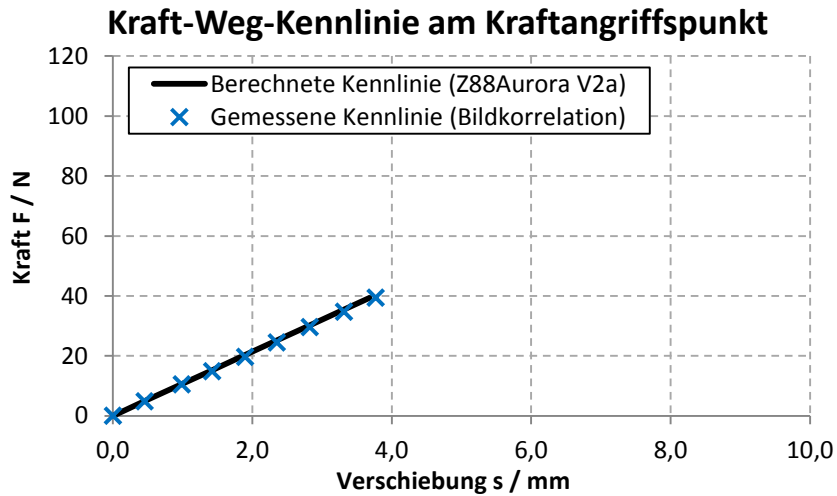
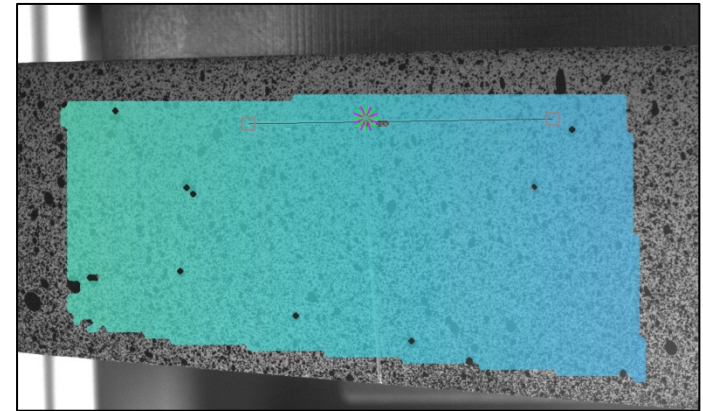
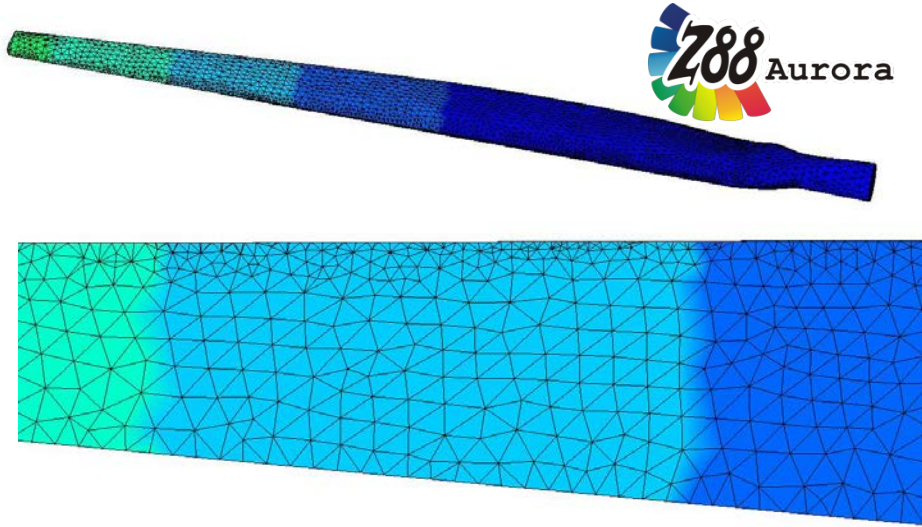


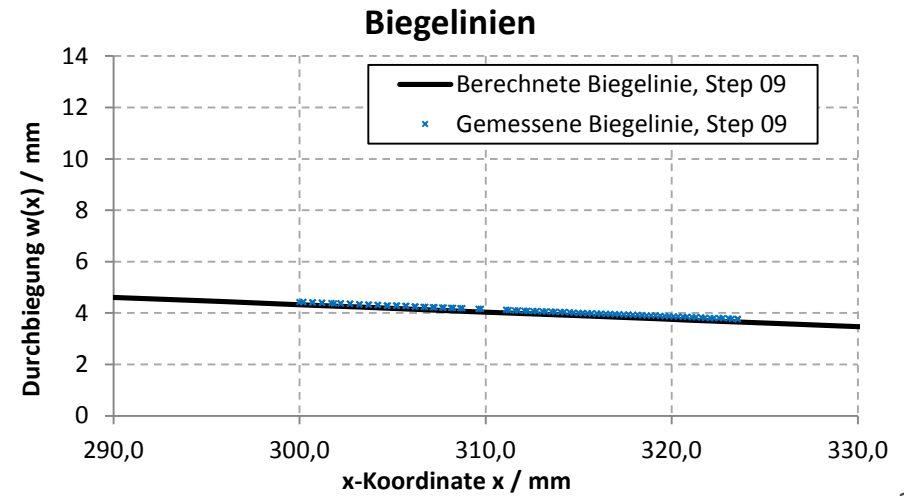
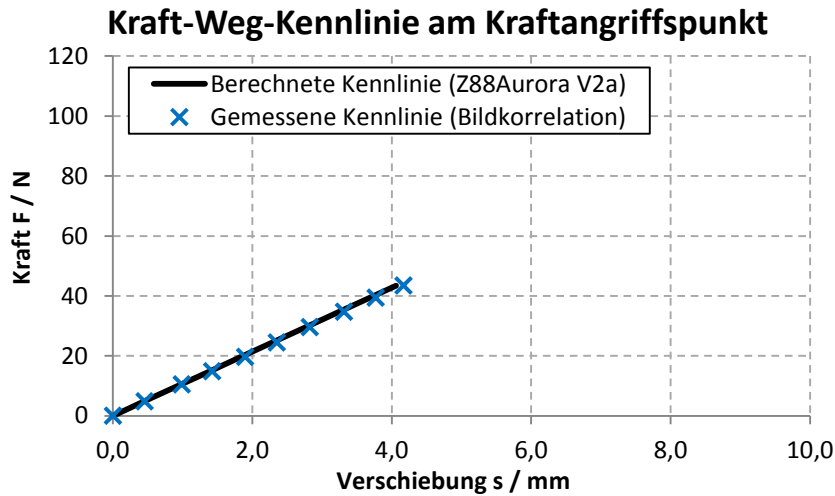
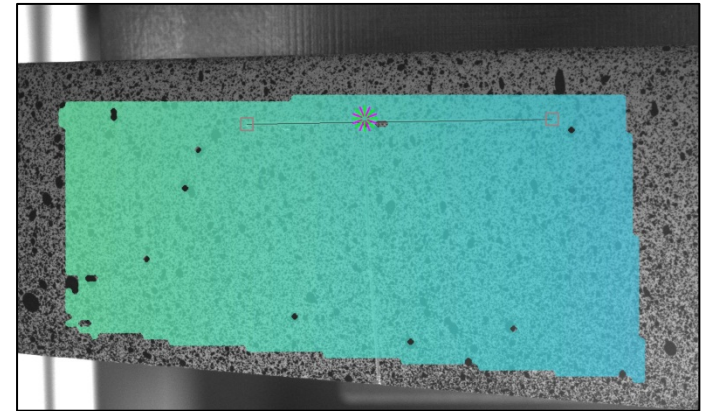
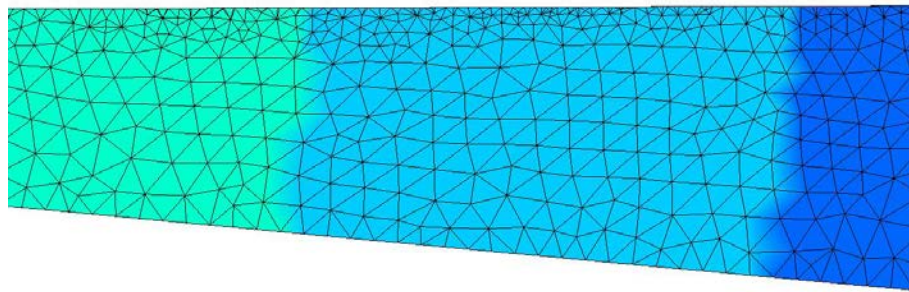
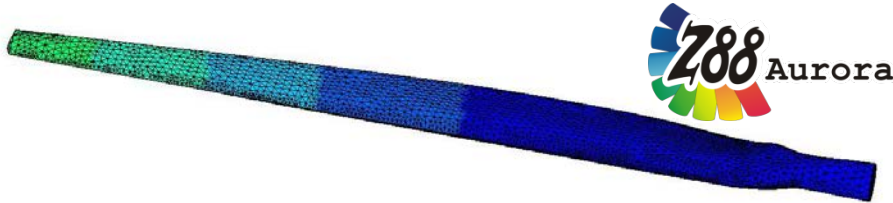
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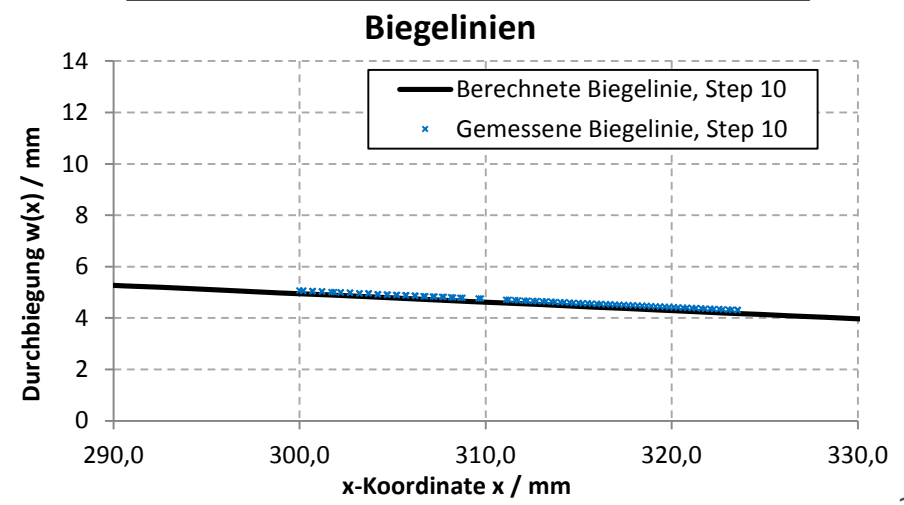
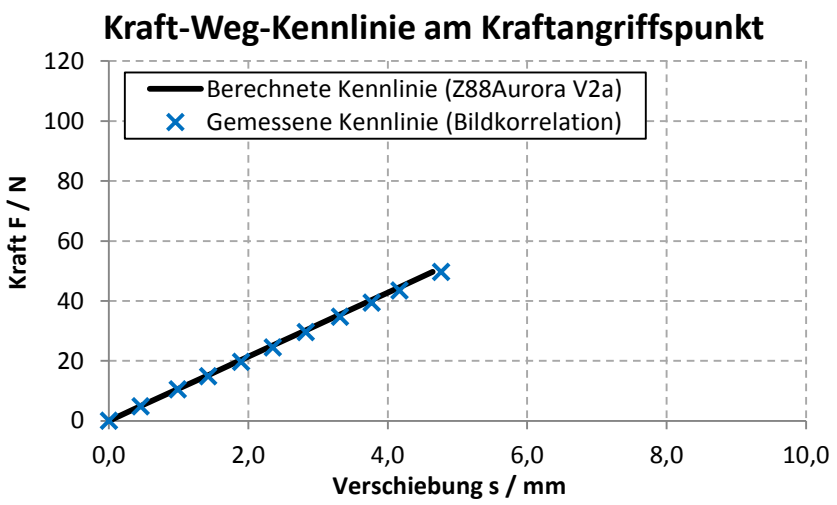
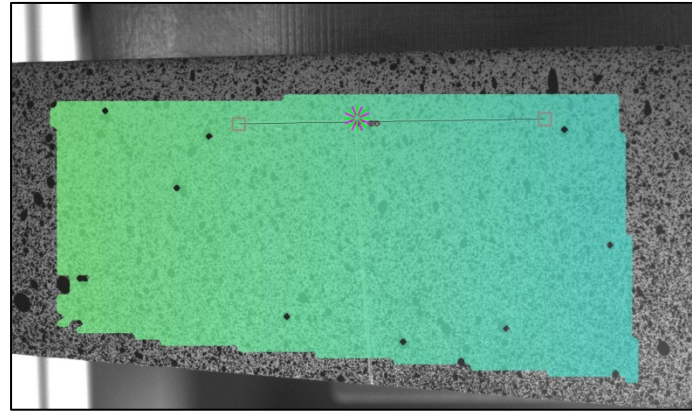
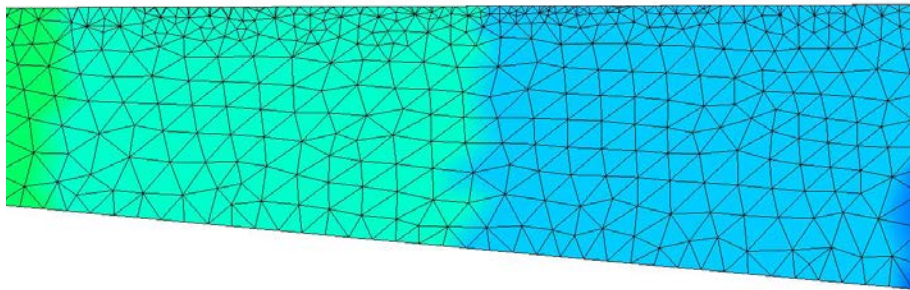
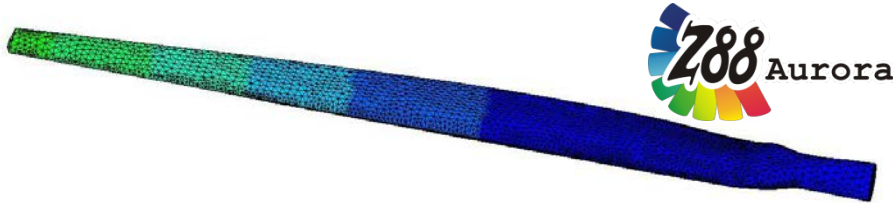


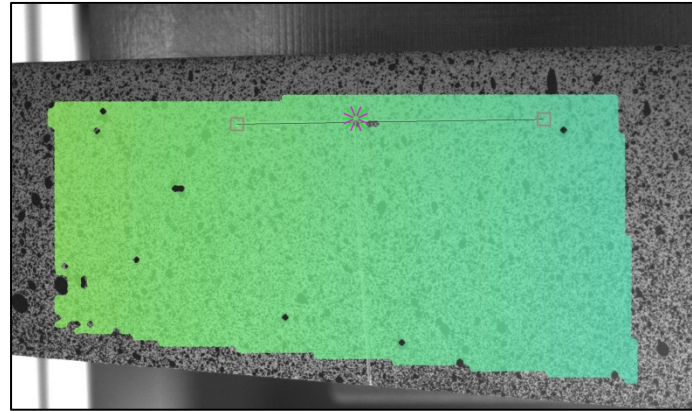
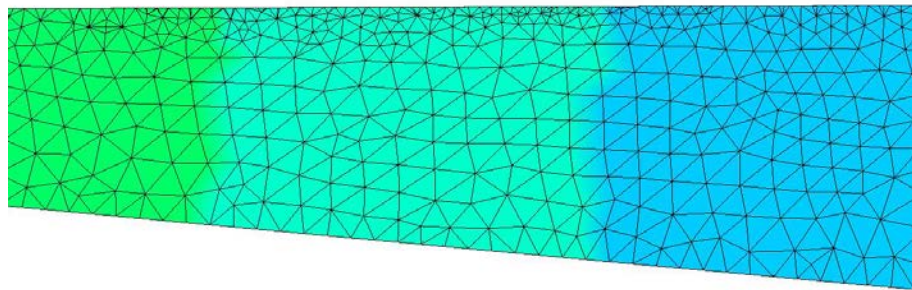
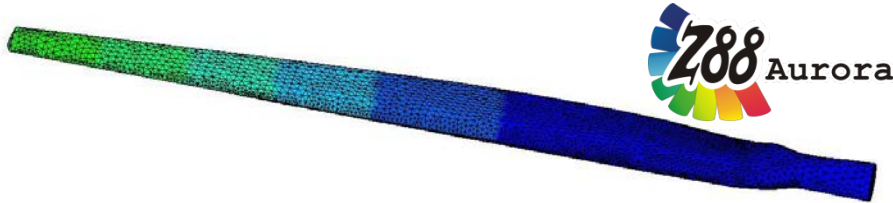
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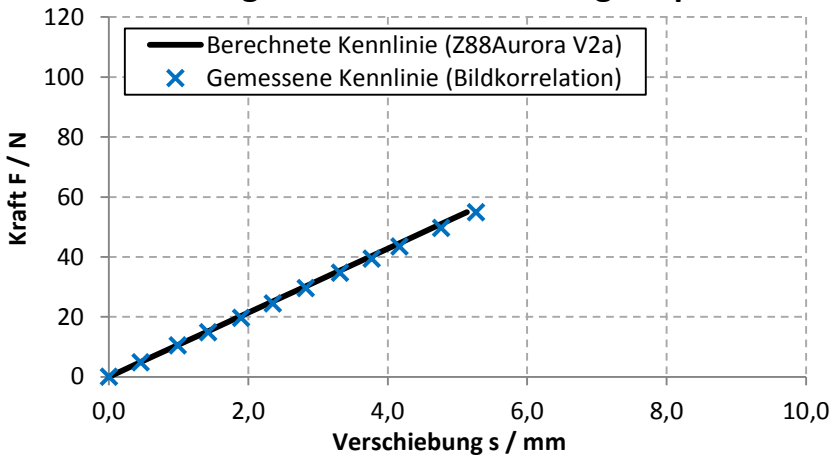




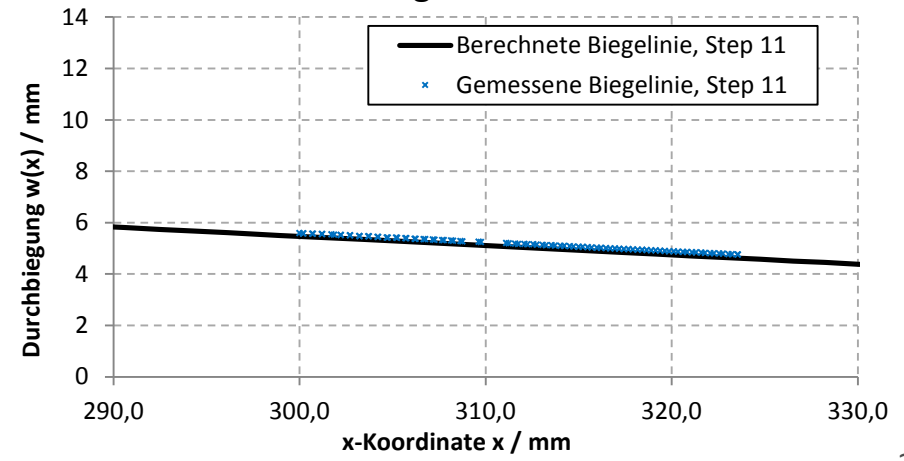


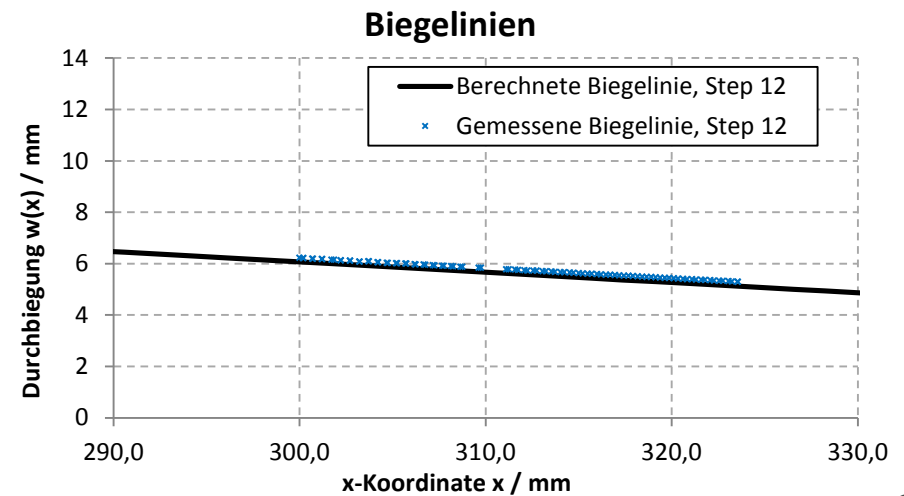
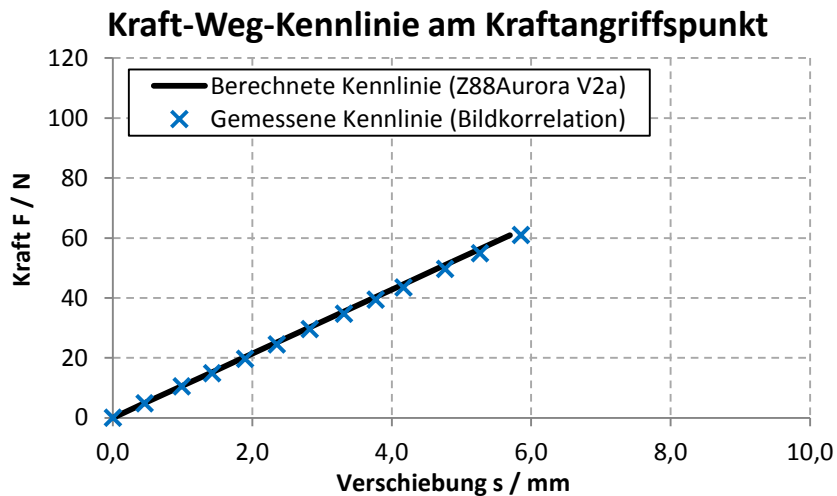
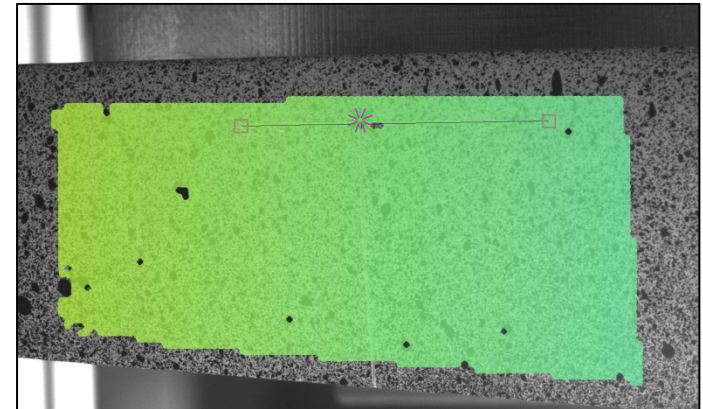
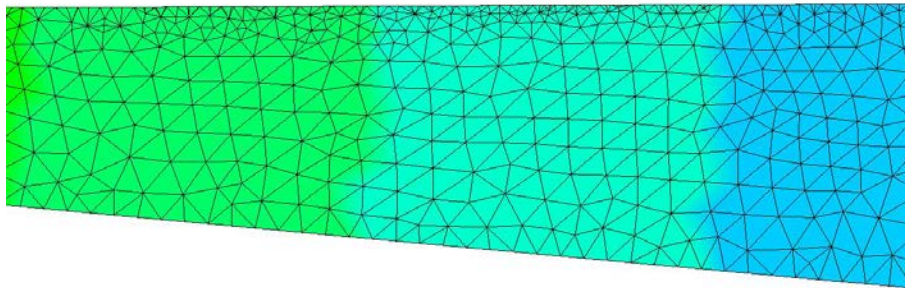
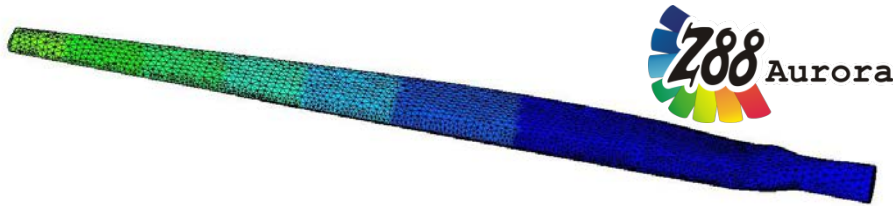


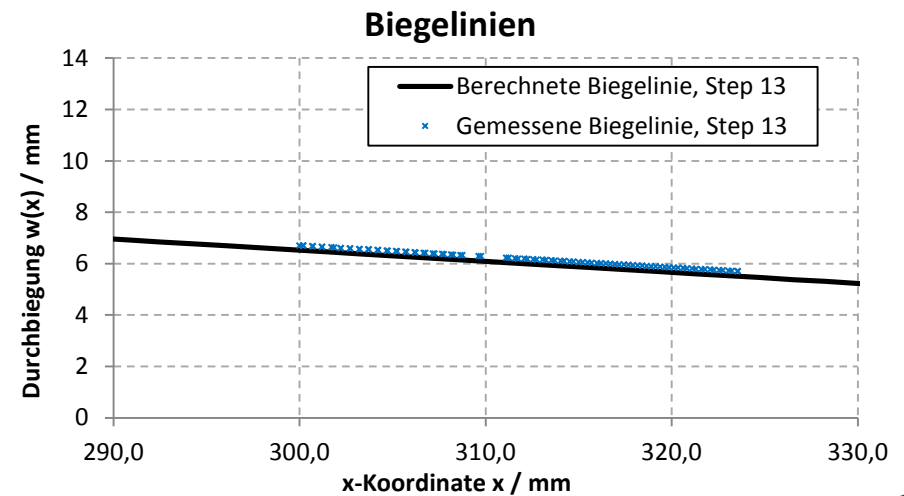
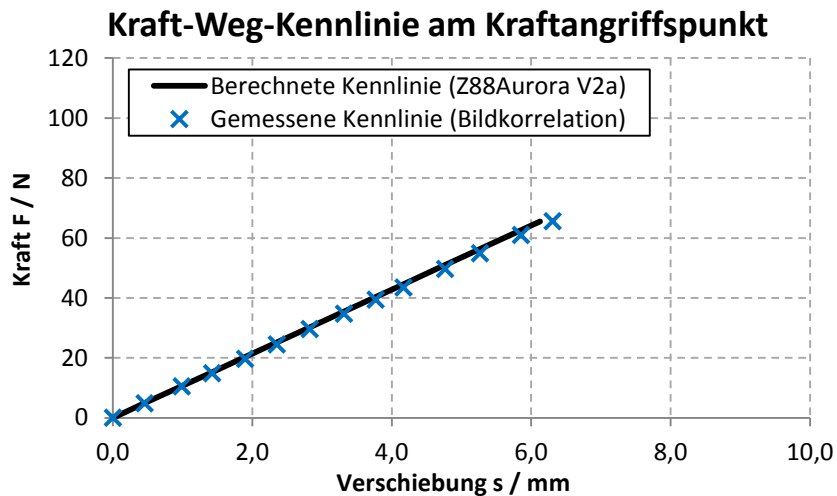
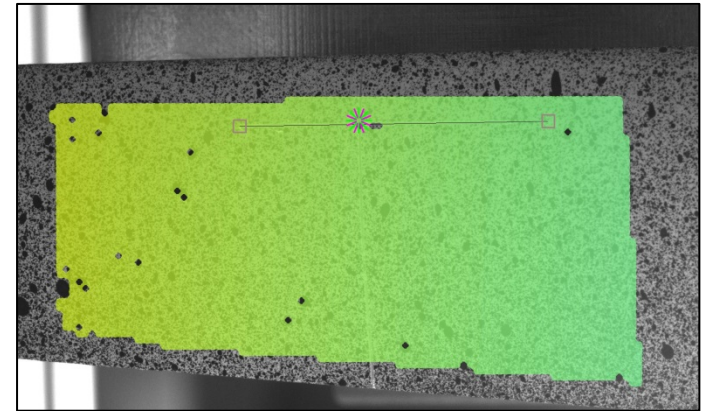
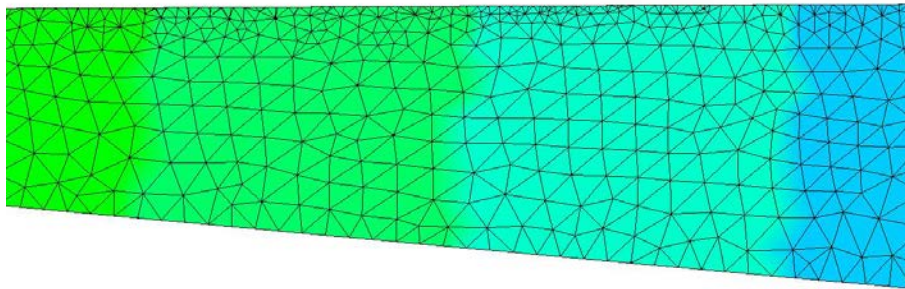
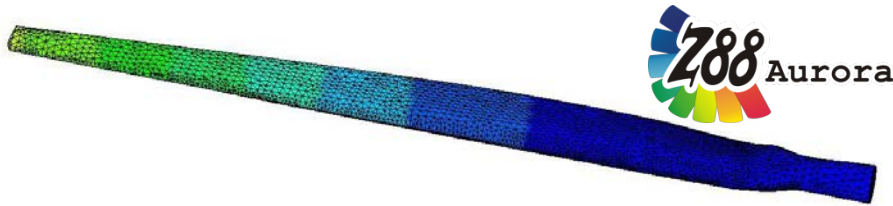
Kraft-Weg-Kennlinie am Kraftangriffspunkt

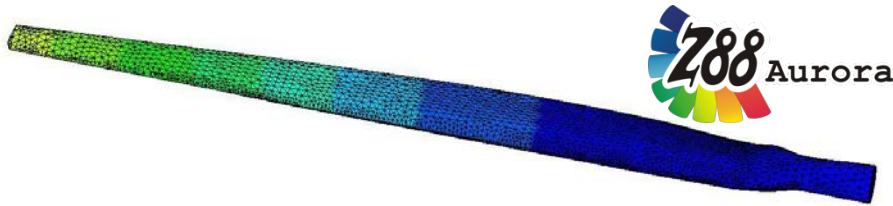


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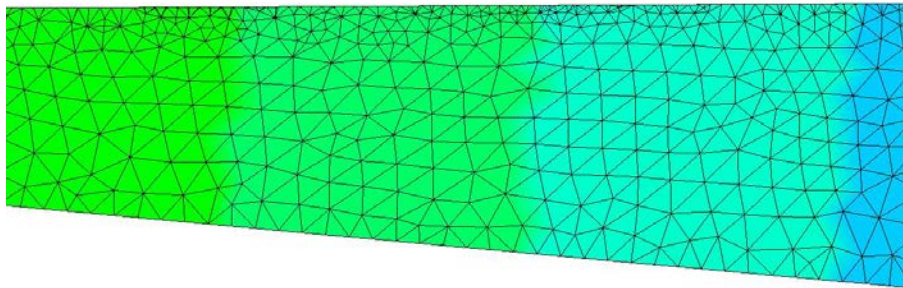
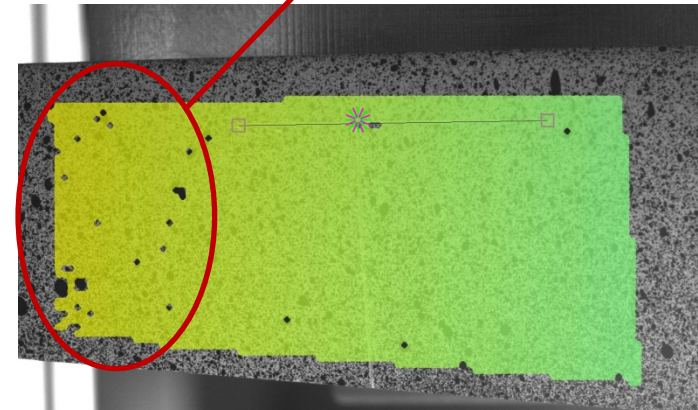




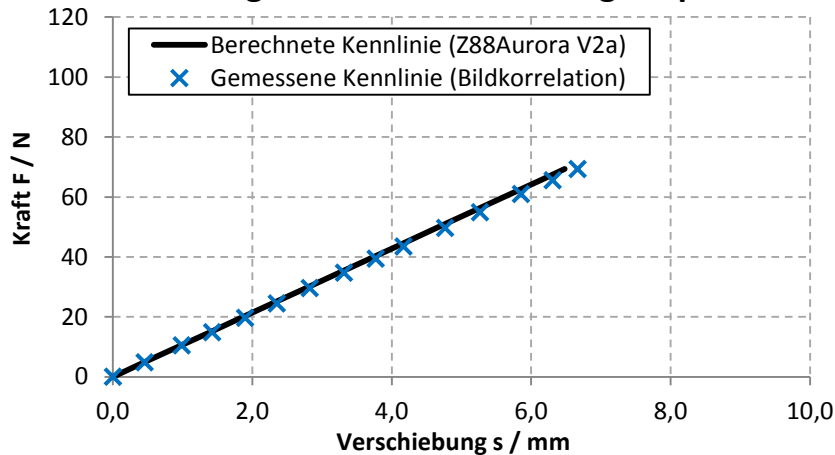




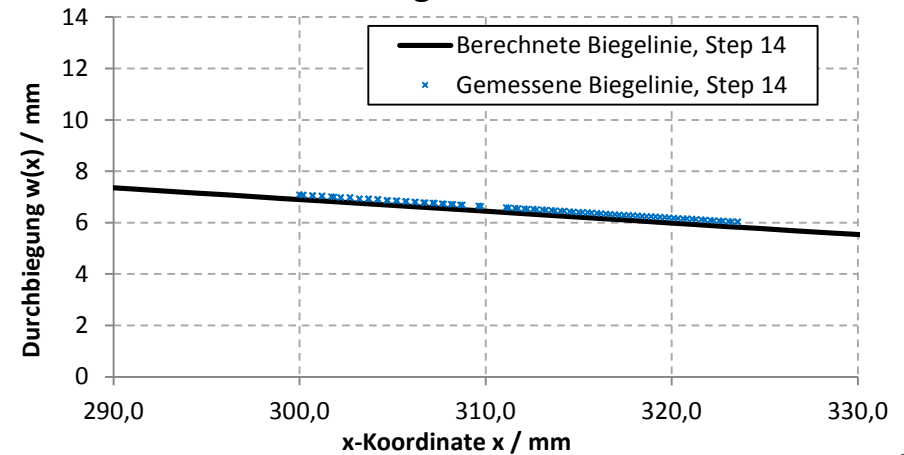
Zunehmende Anzahl von Erkennungsfehlern



Kraft-Weg-Kennlinie am Kraftangriffspunkt

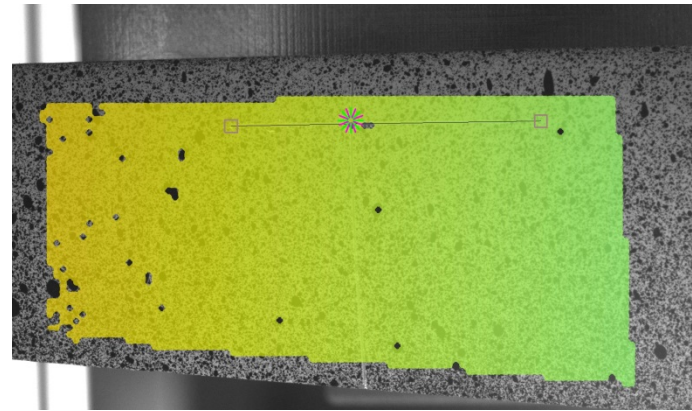
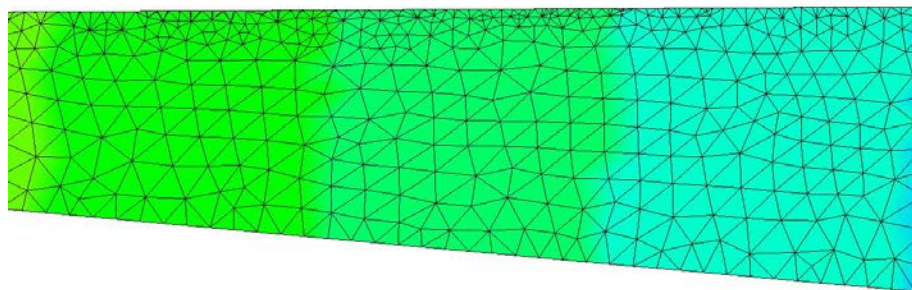
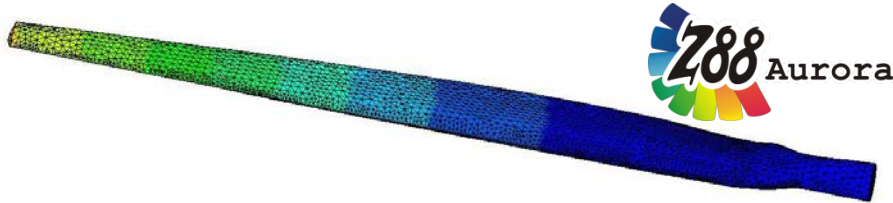


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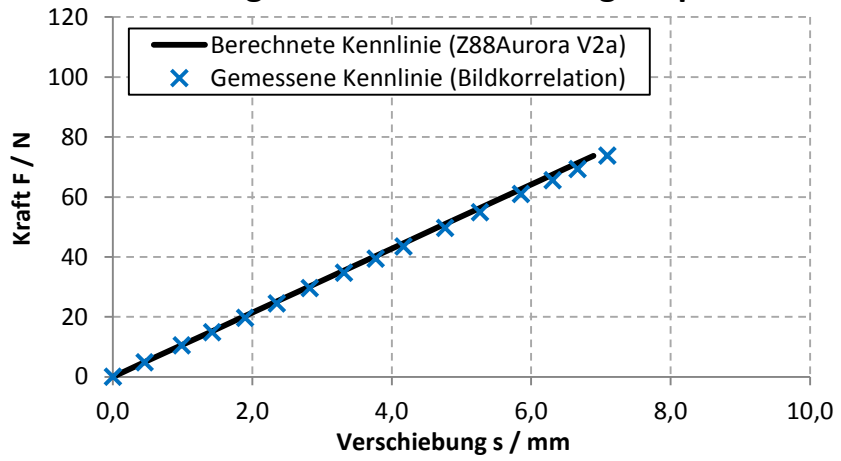


Auswertung

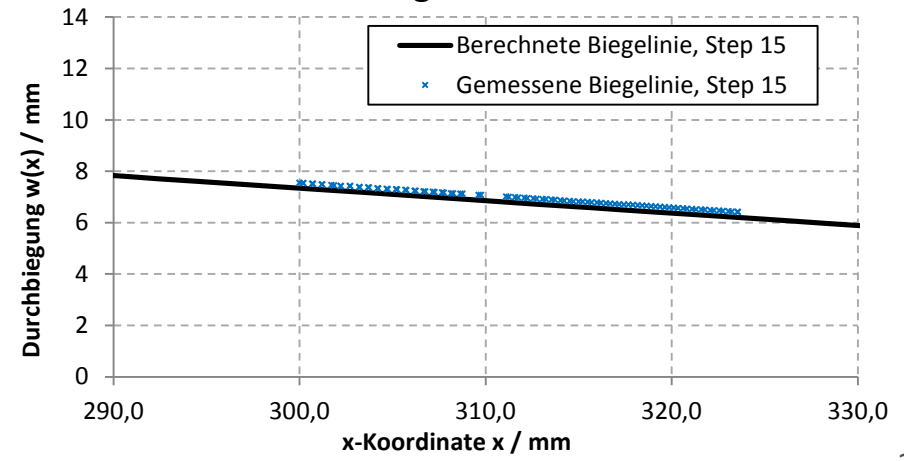
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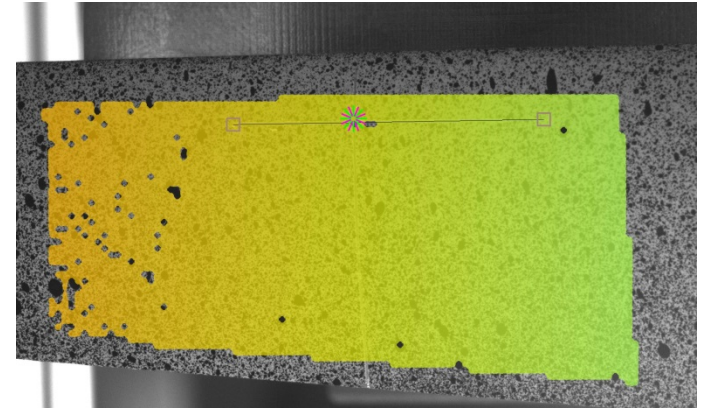
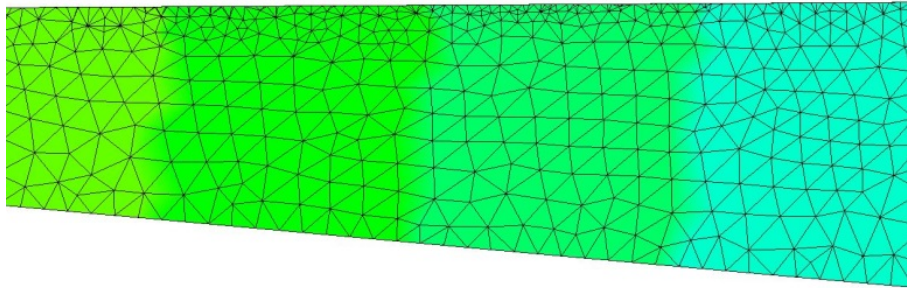
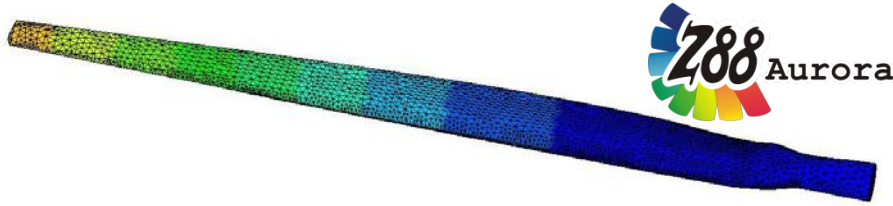


Kraft-Weg-Kennlinie am Kraftangriffspunkt

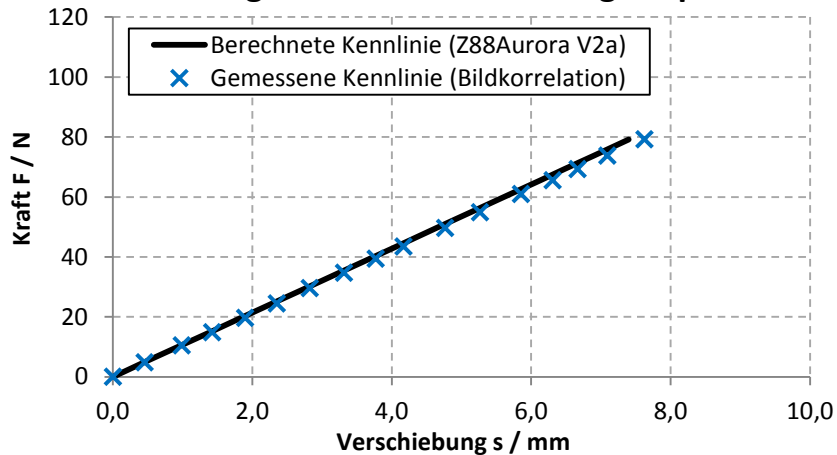


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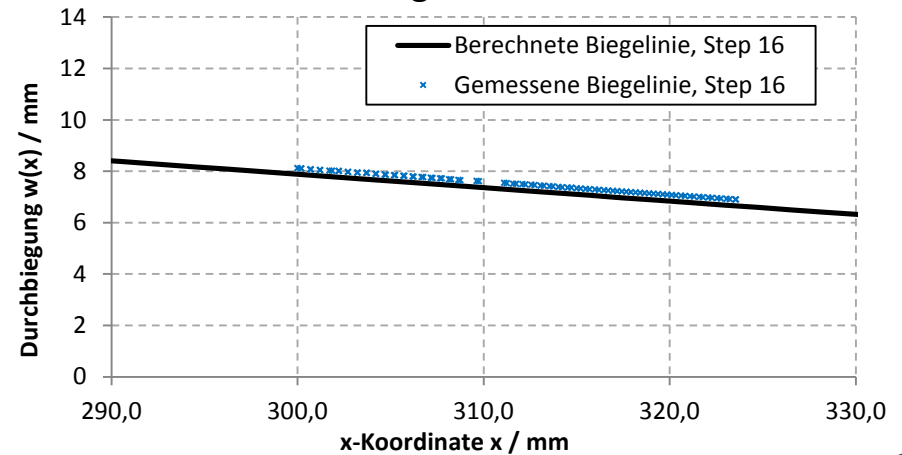




Kraft-Weg-Kennlinie am Kraftangriffspunkt

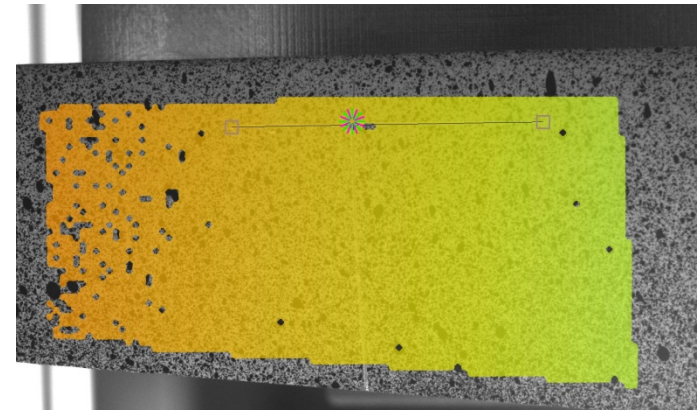
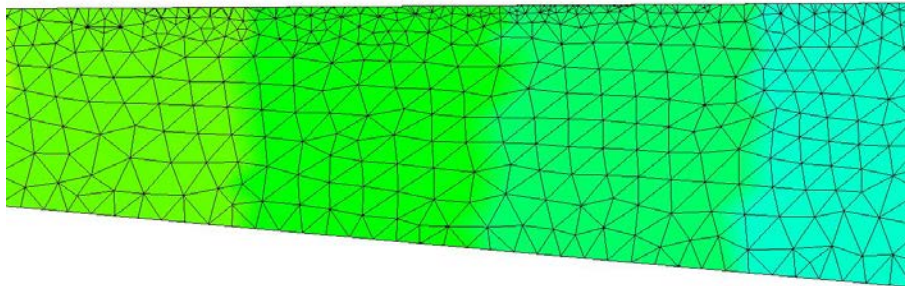
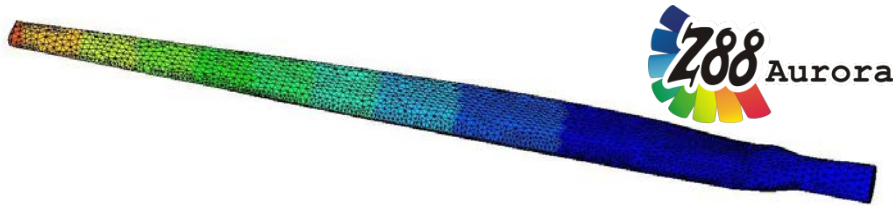


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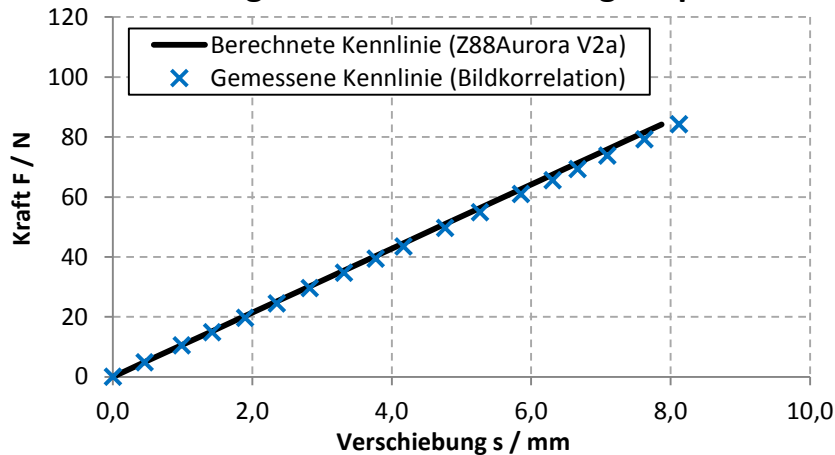


Auswertung

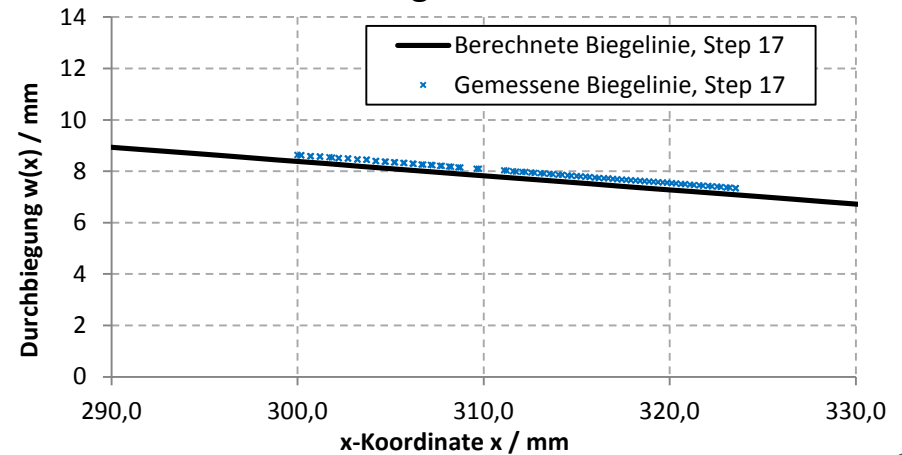
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Kraft-Weg-Kennlinie am Kraftangriffspunkt

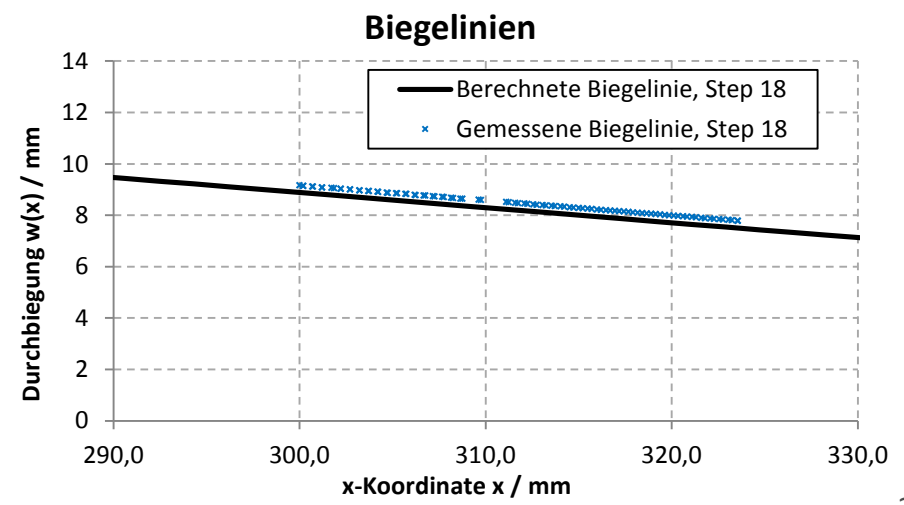
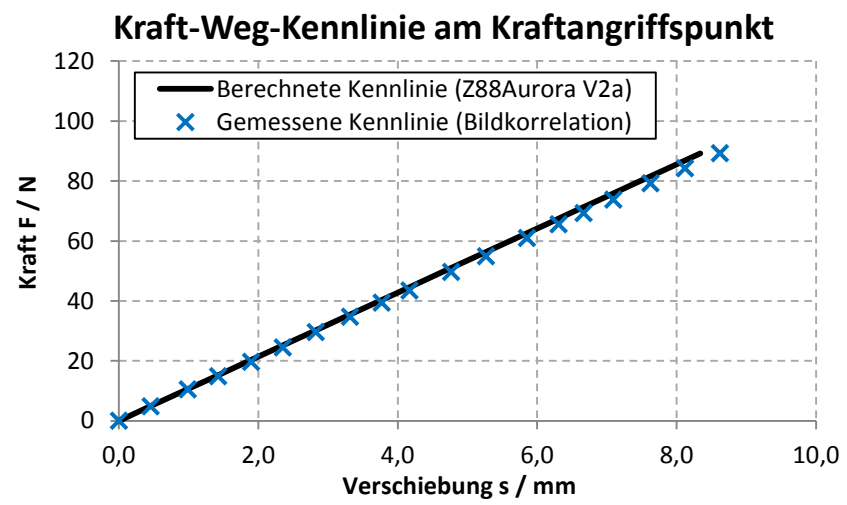
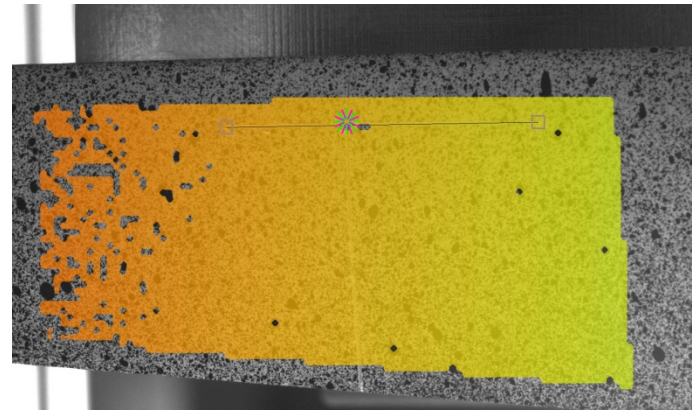
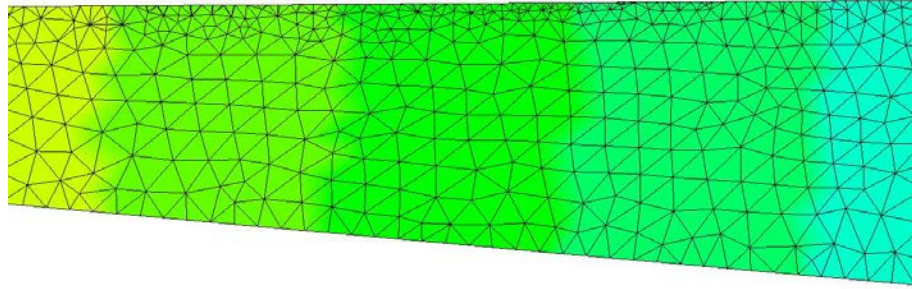
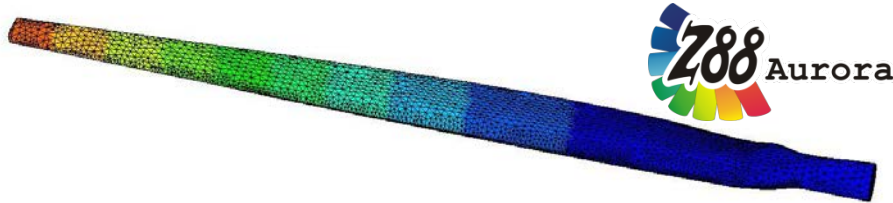


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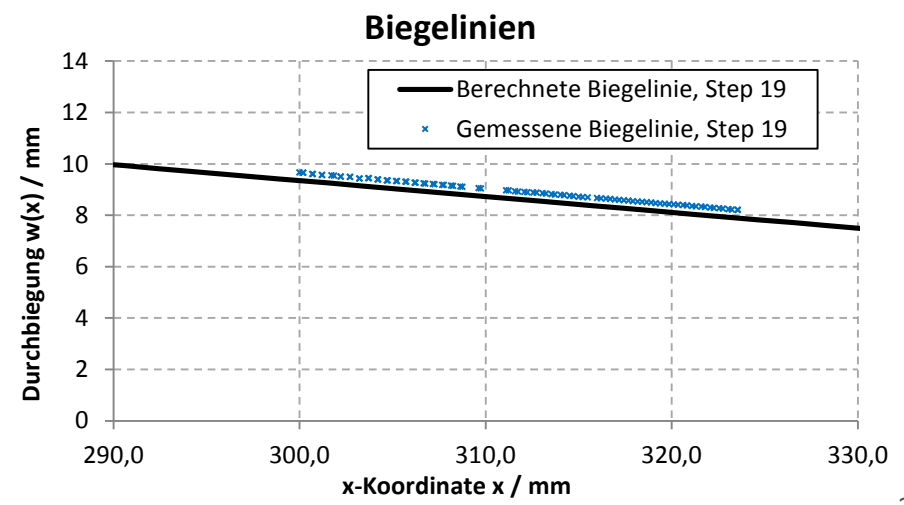
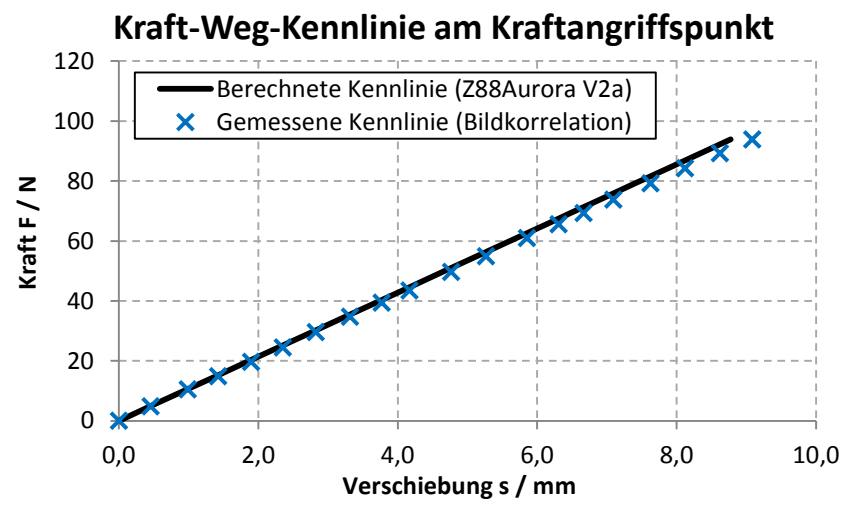
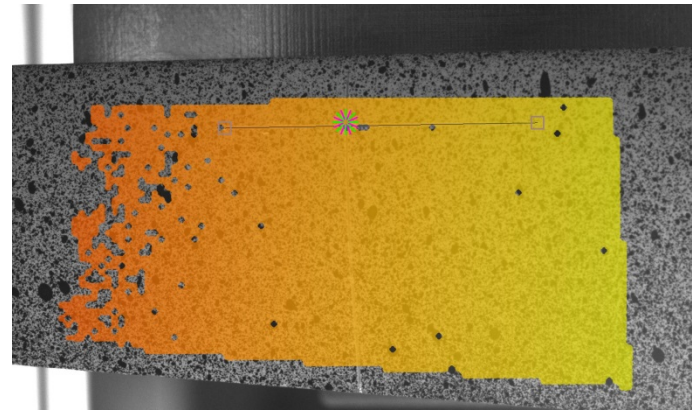
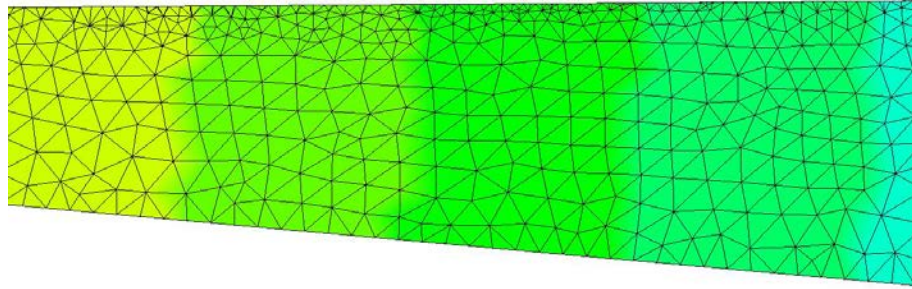
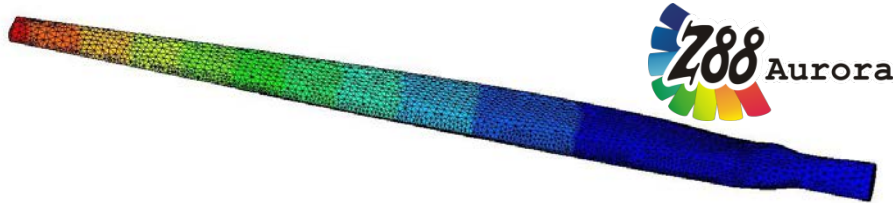
Auswertung

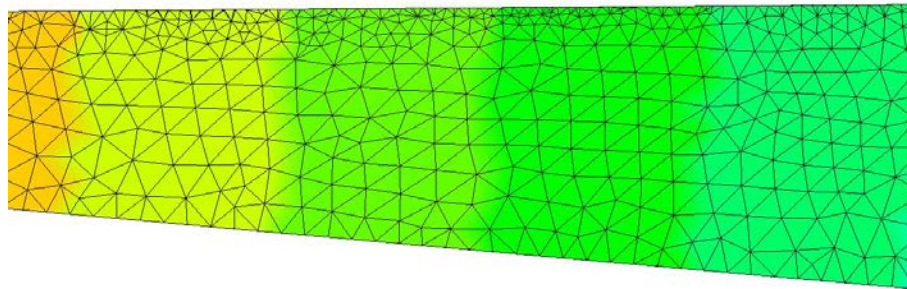
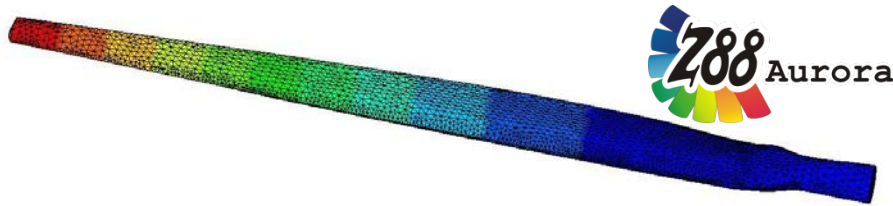
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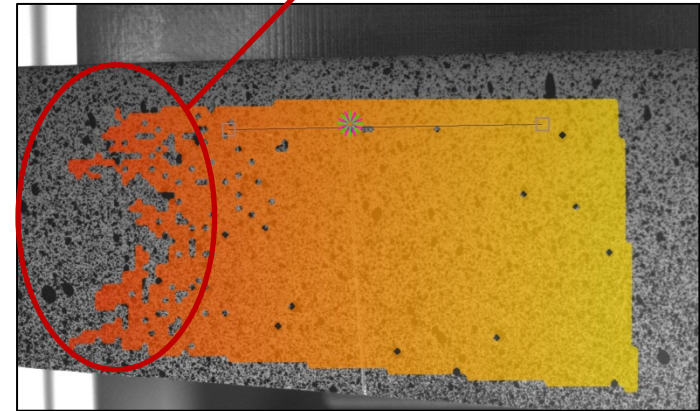
Auswertung

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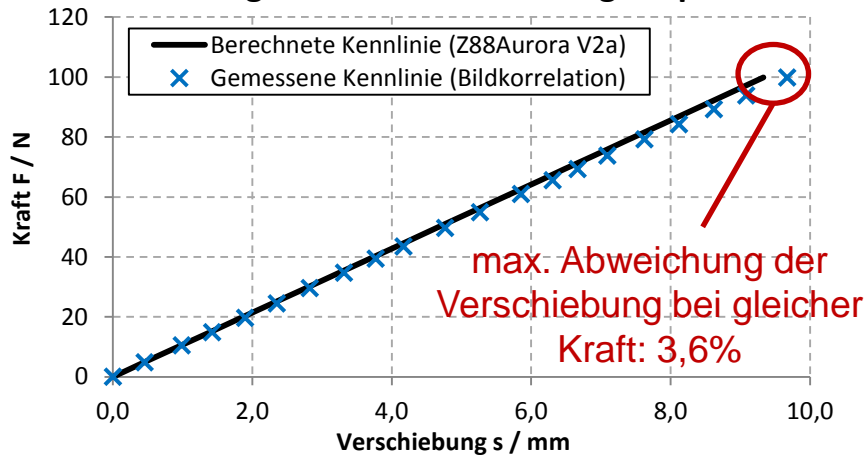




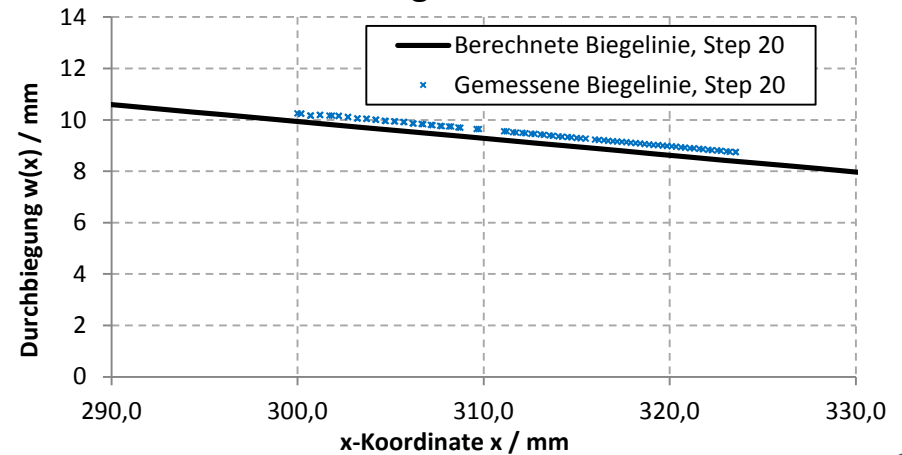
Große Anzahl von Erkennungsfehlern



Kraft-Weg-Kennlinie am Kraftangriffspunkt



Biegelinien





Zusammenfassung

- Die Bildkorrelation eignet sich sehr gut für die flächige Auswertung von Verformungen.
- Die Ergebnisse der Finite-Elemente-Analyse mit Z88Aurora konnten mittels der Bildkorrelation mit einer Abweichung von 3,6% abgebildet werden.

Ausblick

- nichtlineare Berechnung unter sonst gleichen Bedingungen
- weitere Validierungsversuche mit anderen Materialien/Randbedingungen



- [Dan13] Dantec Dynamics, Homepage des Herstellers:
<http://www.dantecdynamics.com>
- [LIM13] LIMESS GmbH, Homepage des Herstellers: www.limess.com, 2013
- [RHA12] F. Rieg, R. Hackenschmidt, B. Alber-Laukant: *Finite Elemente Analyse für Ingenieure*, 4. Ausgabe, Carl Hanser Verlag, München, Wien, 2012