UNIVERSITY OF LIVERPOOL

Comparison of displacements fields from high speed impacts

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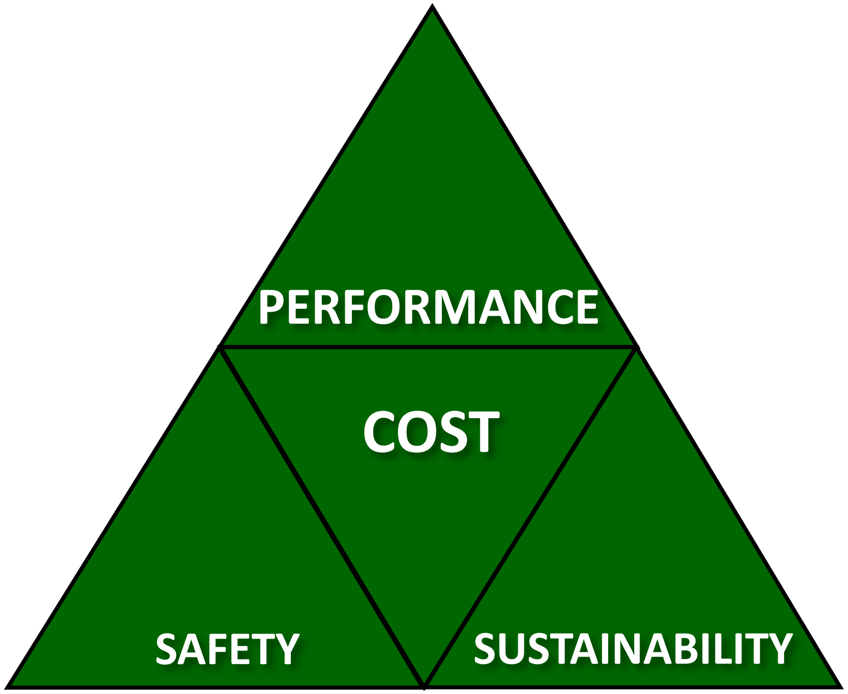
Outline

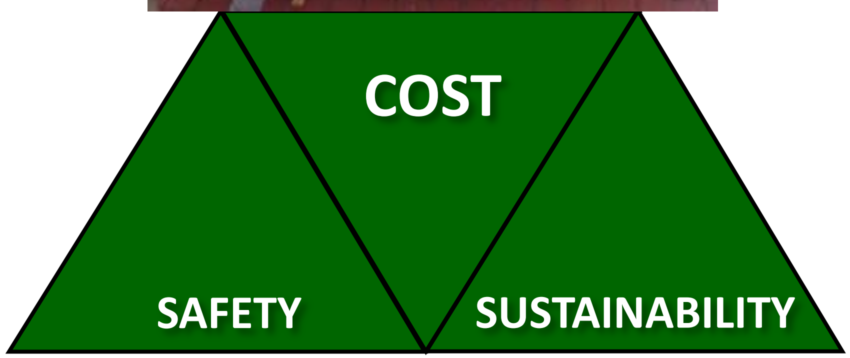
- **Opening remarks on need for comprehensive validation**
- **VANESSA validation protocol**
- **High-speed impact tests on a bonnet liner**
- **Conclusions**

Conflict resolution

Conflict resolution



Conflict resolution



Conflict resolution

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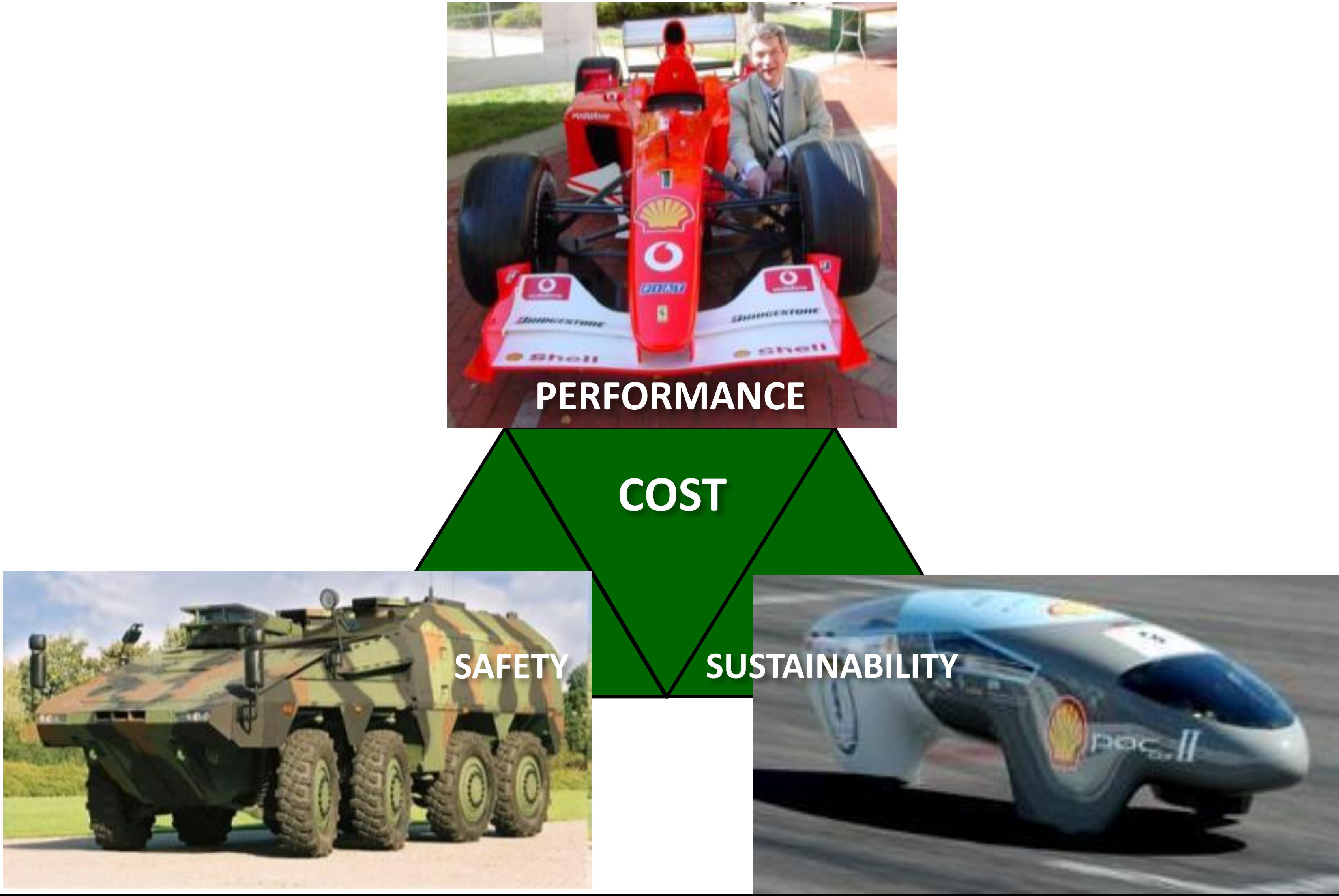


Conflict resolution

Green, low-risk design

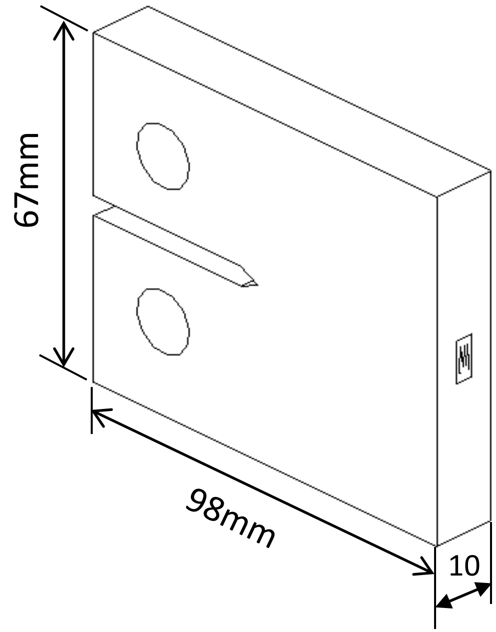
- **Engineering simulation used to resolve conflict between structural integrity, energy consumption and cost**
  - Design optimization using computation solid mechanics models

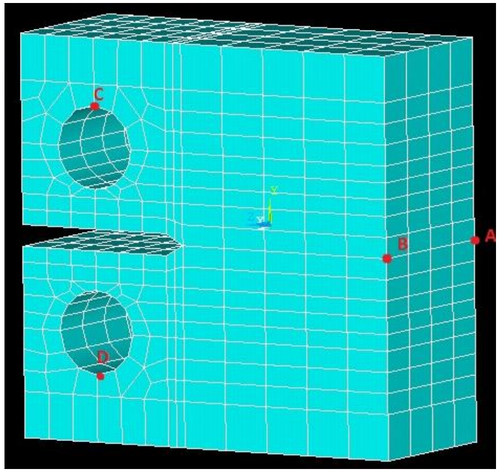
- **Elegant successful design implies**
  - Efficient use of materials
  - High credibility for simulation

- **'Model credibility is reflected by the willingness of persons to base decisions on information obtained from the model'[1]**

1. Schruben, L.W., Establishing the credibility of simulations, *Simulation*, 34:101-105, 1980.

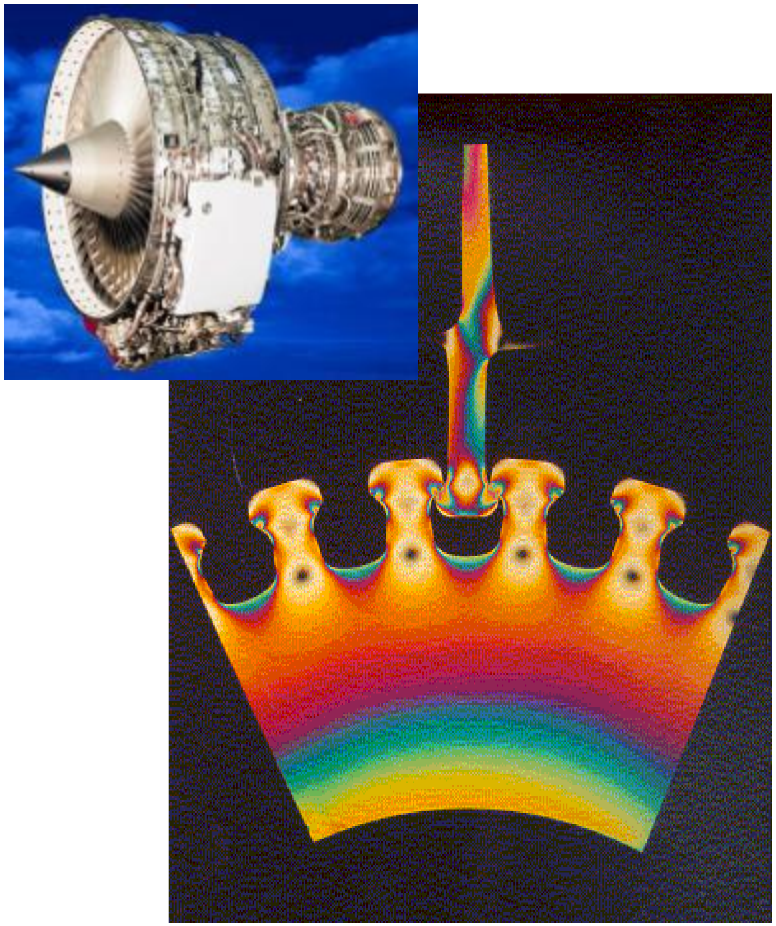
Is this model good enough?

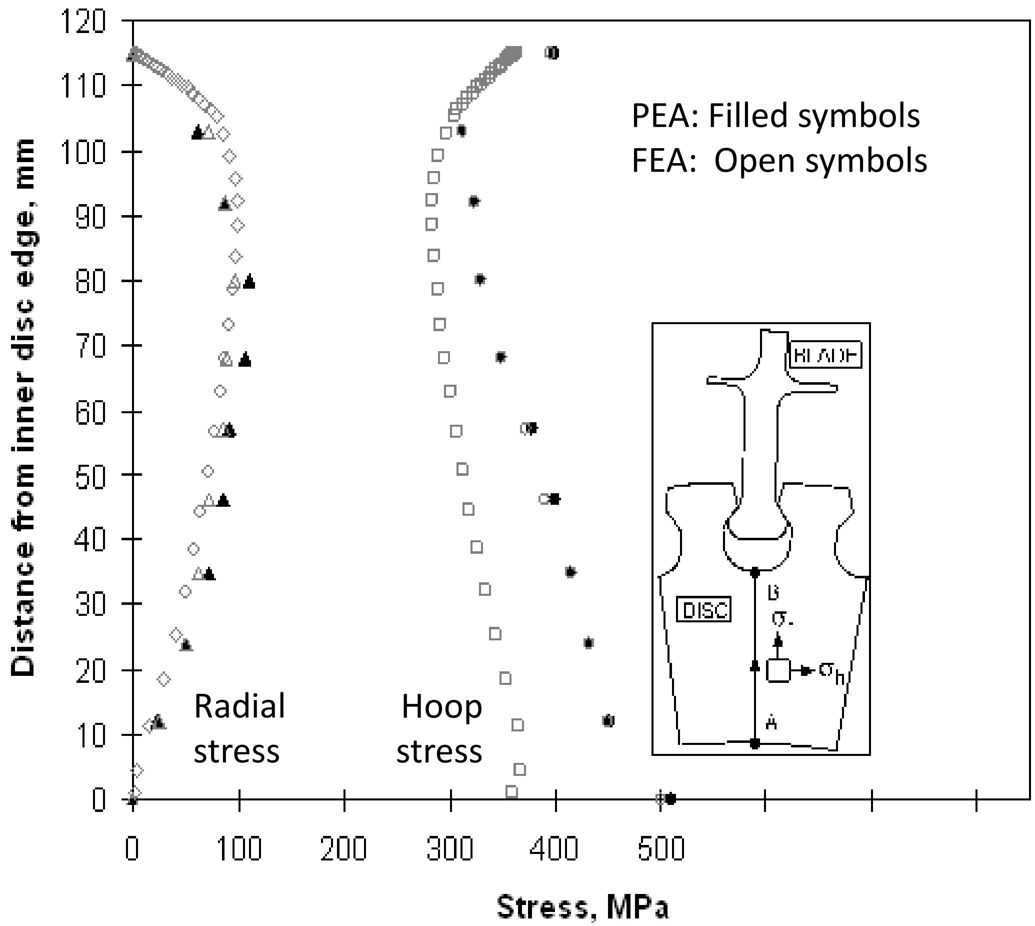




- **Strain gauge result**
  - 252 ± 9 $\mu\varepsilon$
- **Finite element analysis**
  - 245 $\mu\varepsilon$

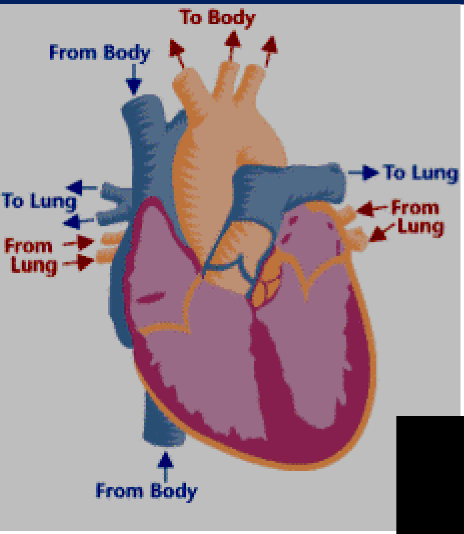
Would you fly with this engine?

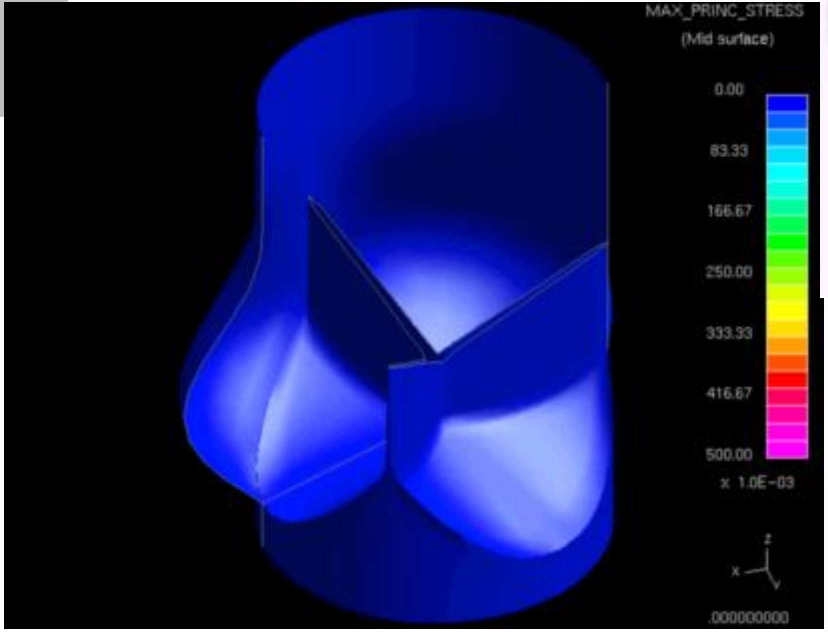


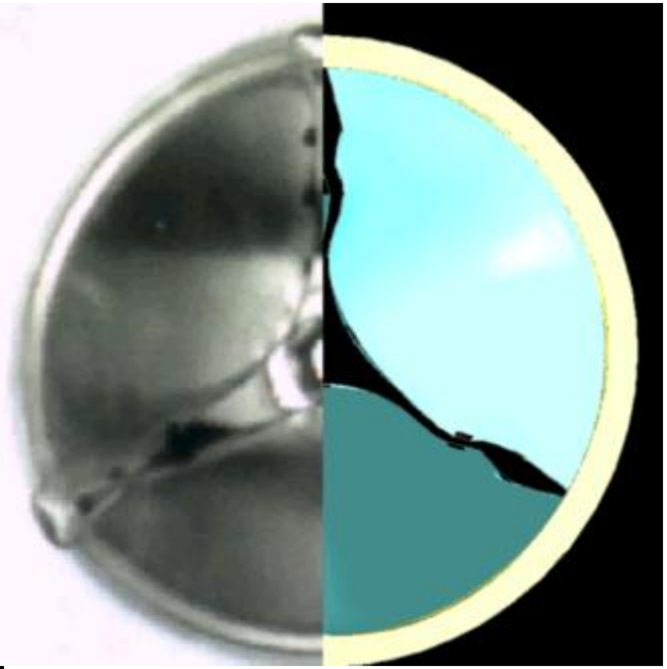


Patterson, E.A., Brailly, P., Taroni, M., 2006, ‘High frequency quantitative photoelasticity applied to jet engine components’, *Exptl. Mech.*, 46(6):661-668

Would you have this heart valve implanted?







Howard, I. C., Patterson, E.A., Yoxall, A., 2003, 'On the opening mechanism of the aortic valve: some observations from simulations', *J. Medical Engineering & Technology*, 27(6):259-267.

What is acceptable?

- **Hume [1748] suggested that observational evidence will never support any hypothesis about the unobserved.**

Hume, D., 1748 [1999], *An enquiry concerning human understanding*. Oxford Philosophical Texts, Oxford University Press, Oxford, edited by T.L. Beauchamp
Popper, K., 1959, *The logic of scientific discovery*, Hutchinson, London.

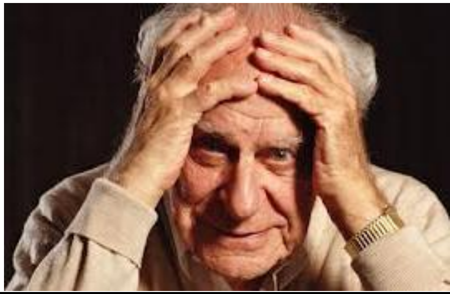
What is acceptable?

- **Hume [1748] suggested that observational evidence will never support any hypothesis about the unobserved.**

More pragmatic approach required...

- **Popper [1959] proposed that observational evidence cannot prove a hypothesis correct, but it can demonstrate its inappropriateness or falsity**

- **Implies that there is always a possibility of making a mistake when accepting [or rejecting] a hypothesis**



Hume, D., 1748 [1999], *An enquiry concerning human understanding*. Oxford Philosophical Texts, Oxford University Press, Oxford, edited by T.L. Beauchamp
Popper, K., 1959, *The logic of scientific discovery*, Hutchinson, London.

Experimental mechanics

- **Validity of computational solid mechanics models should be treated in manner analogous to scientific hypotheses**
  - Recognise that observational [experimental] data cannot prove its validity
  - Increasing body of evidence can increase degree of belief in the model[1]

- **obvious that current practices, based on the strain value at a small number of locations, are inadequate**

1. Audi, R., 2011, *Epistemology: a contemporary introduction to the theory of knowledge*, 3rd edition, Routledge, New York.

Experimental mechanics

- **Validity of computational models is analogous to scientific hypotheses**
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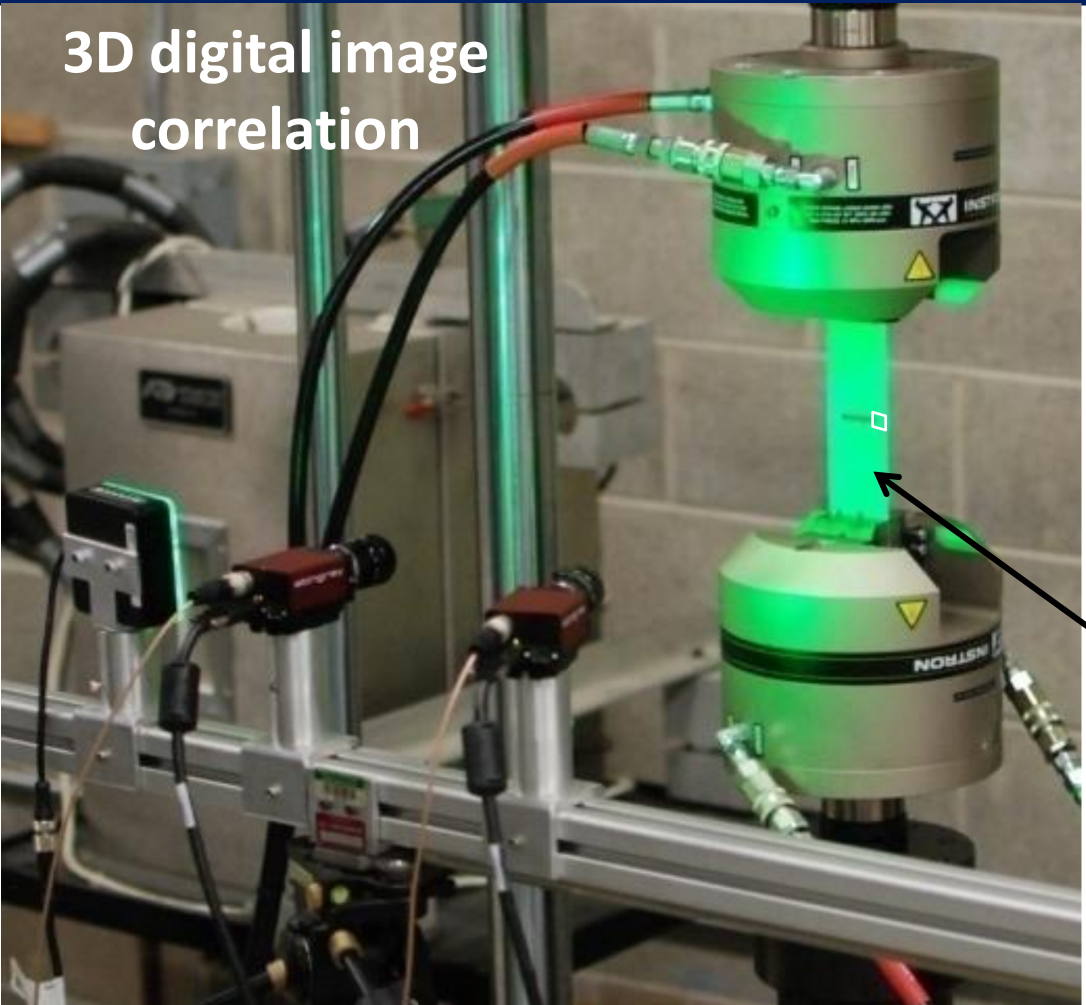
- **obvious that current practices, based on the strain value at a small number of locations, are inadequate**

- **until now, obviousness over-powered by cost of experimental data**
  - alleviated by new technologies e.g DIC, DVC, ESPI & TSA

  and, lack of methods for quantitative comparisons of full-field data
  - Different orientation, coordinate system, scale, pitch of data
  - Resolved by use of image decomposition[2]
    - Reduces dimensionality of data & is invariant to rotation, scale & translation

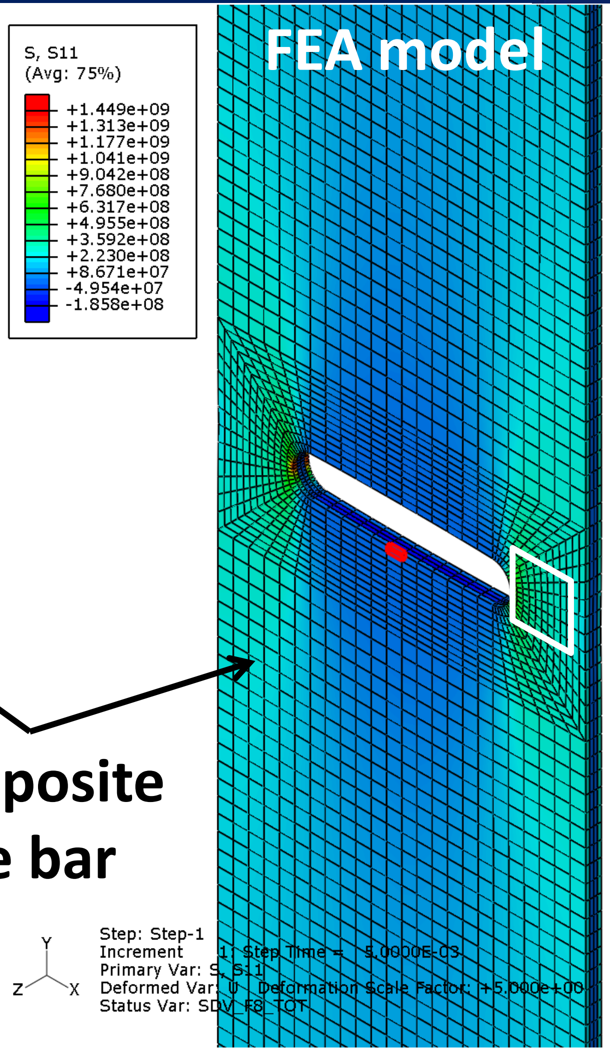
1. Audi, R., 2011, *Epistemology: a contemporary introduction to theory of knowledge*, 3rd ed., Routledge, New York.
2. Wang, W., Mottershead, J.E., Sebastian, C.M., Patterson, E.A., 2011, Shape features and finite element model updating from full-field strain data, *Int. J. Solids Struct*. 48(11-12), 2011, 1644-1657.

Massive datasets: $>10^5$ values

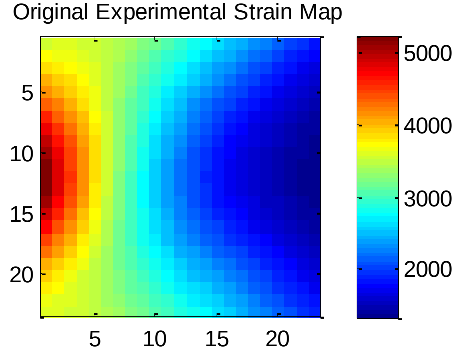


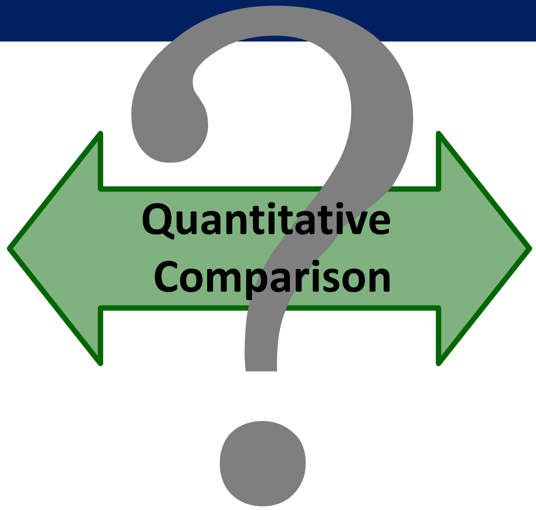
Conway, A.R., Xiao, X., 2010, Implementing a Finite Element Module for Fatigue Damage Modelling in Fiber Reinforced Composite Materials, *Proc. 25th Tech. Conf. Am. Soc. Composites*, Dayton, Ohio, (2):1173-1783.

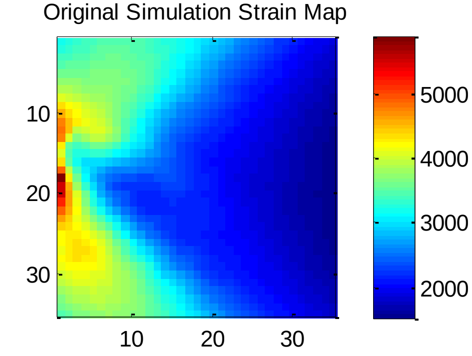
Composite tie bar



Validation procedure







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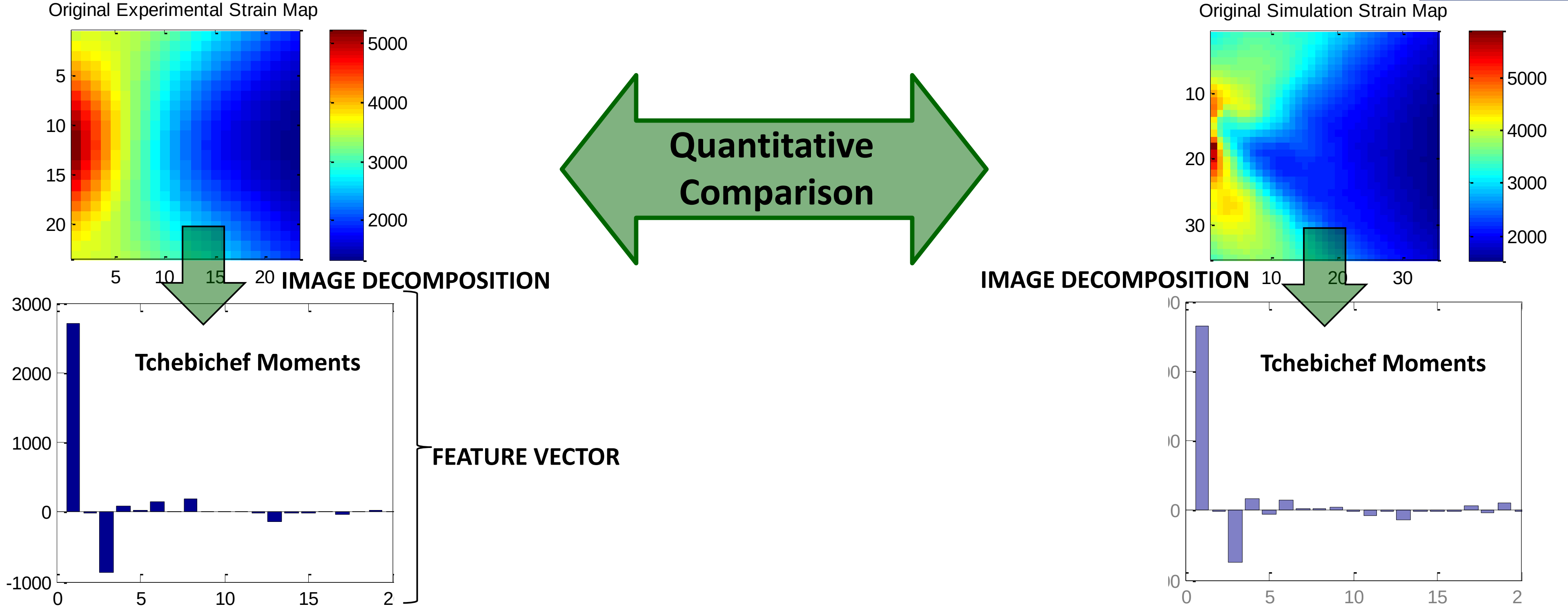
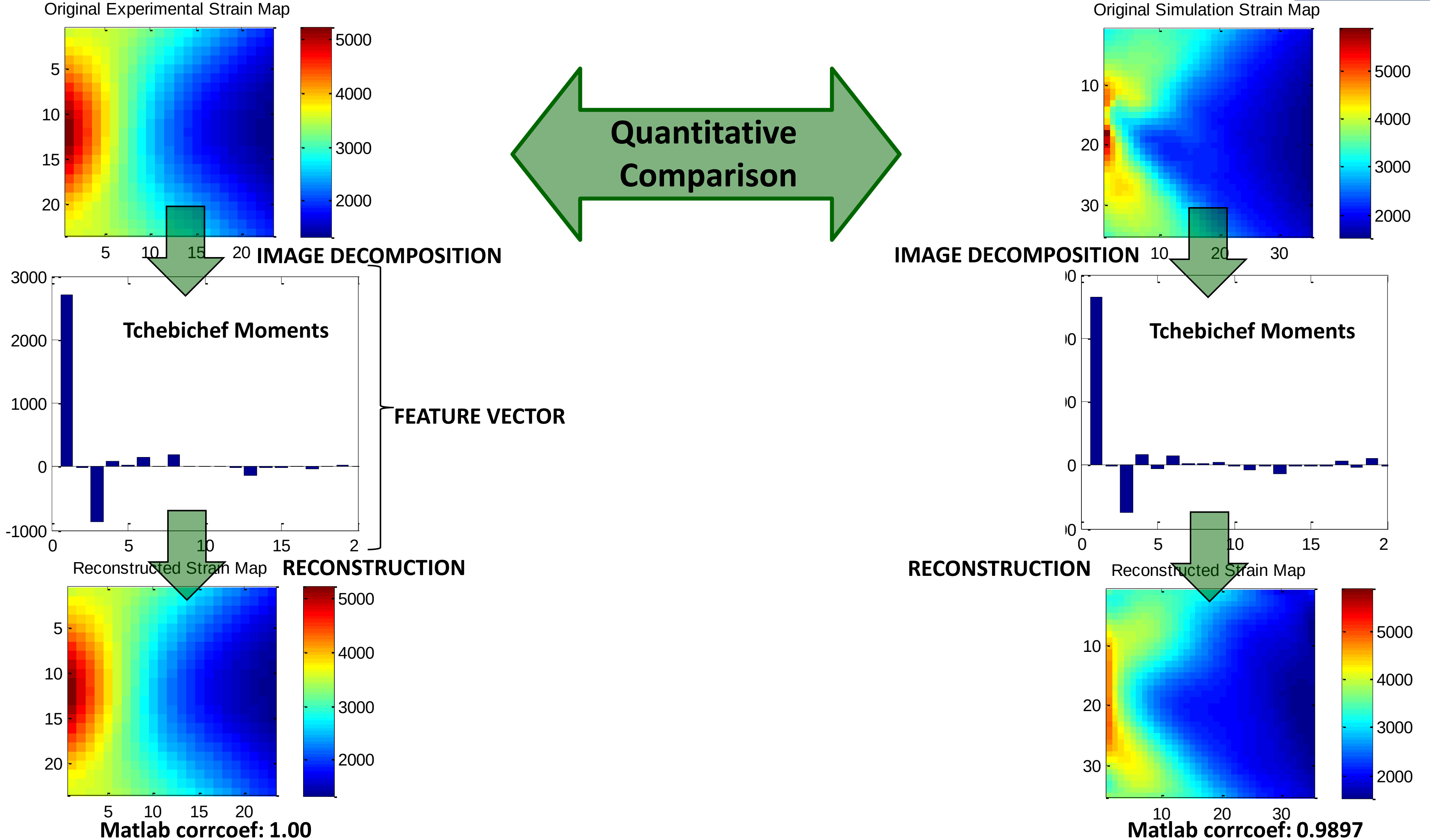


Validation procedure



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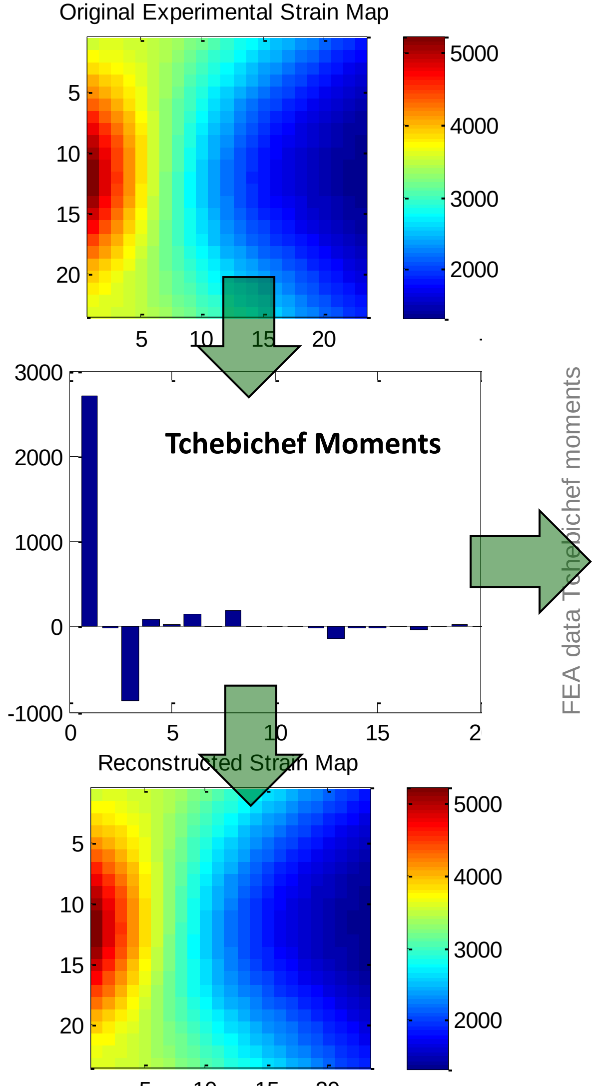
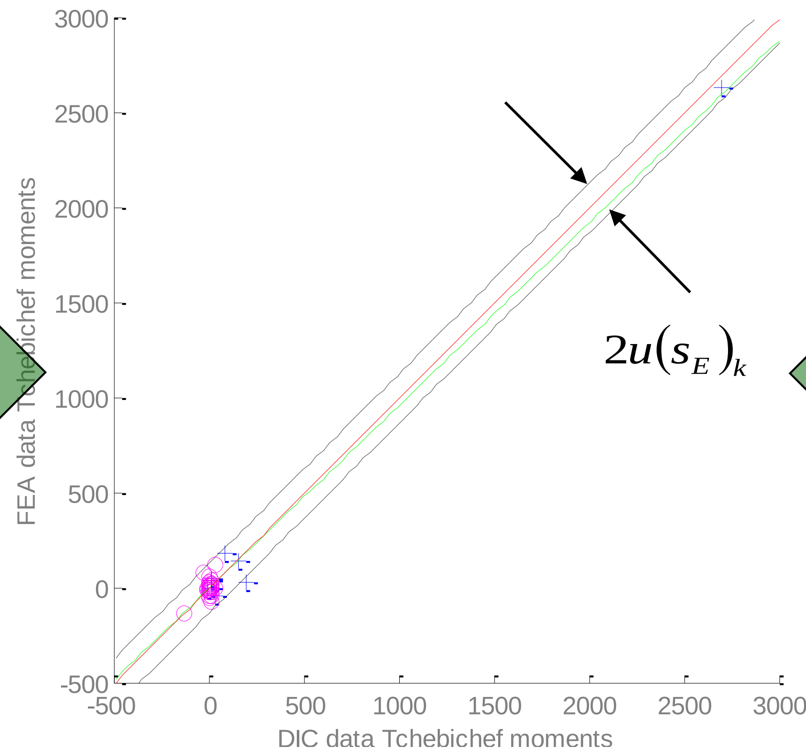
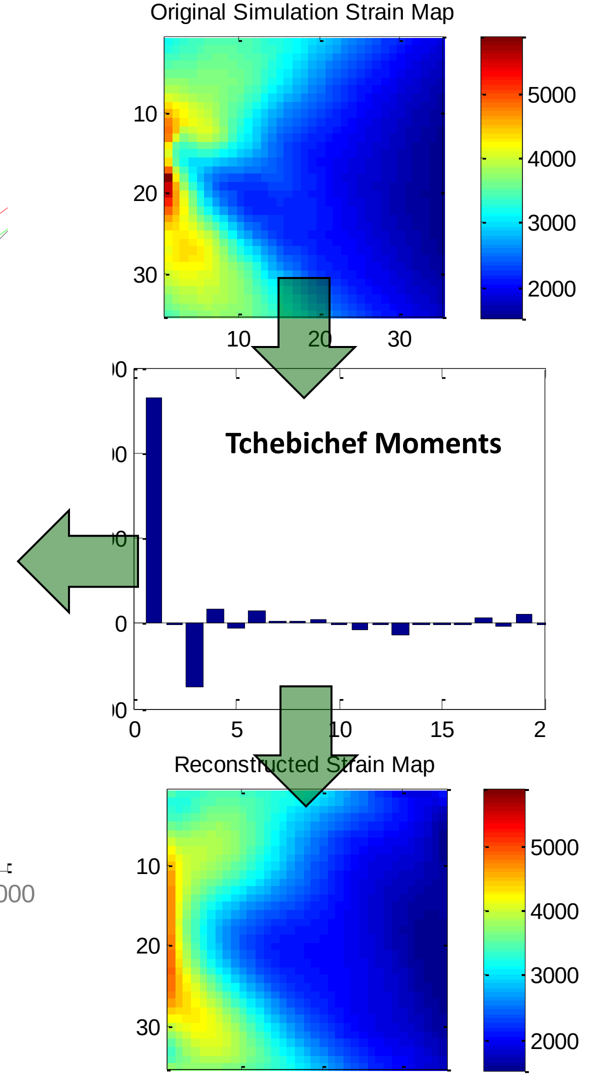






Uncertainty in feature vectors

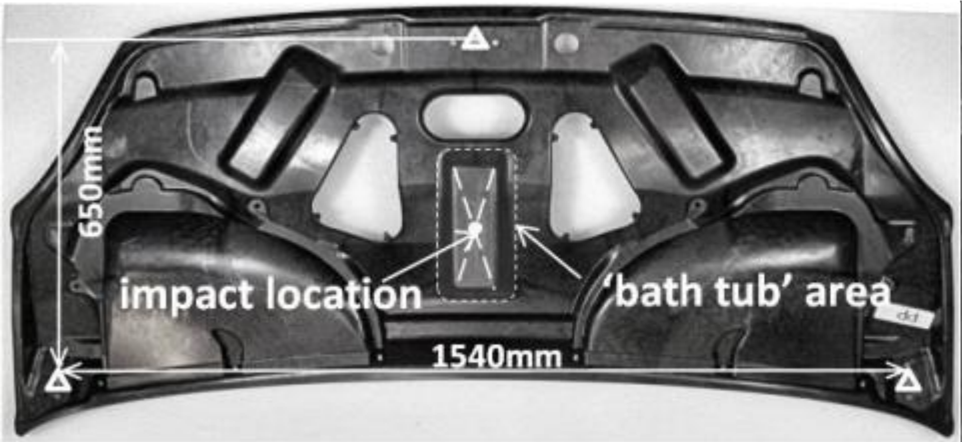
$$u(s_E)_k = \sqrt{u_{cal}^2(\varepsilon) + u_{ID}^2}$$

Matlab corrcoef: 1.00

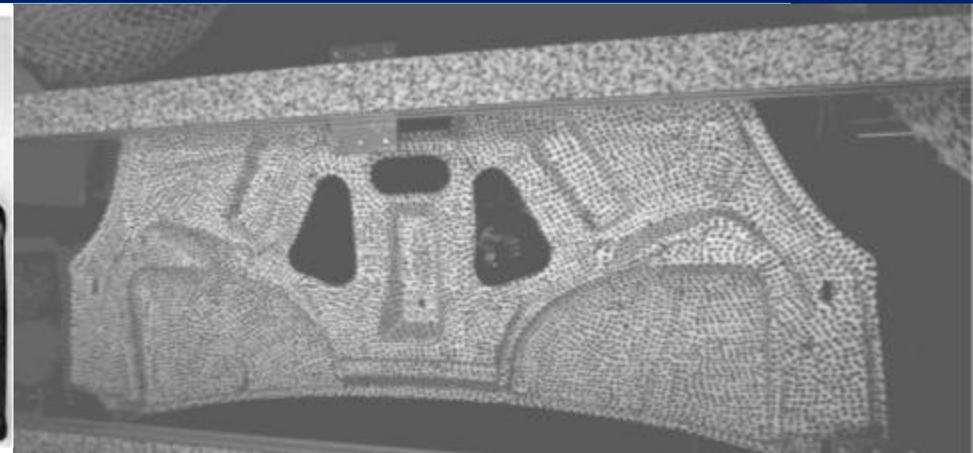
Matlab corrcoef: 0.9897

Crash test ?

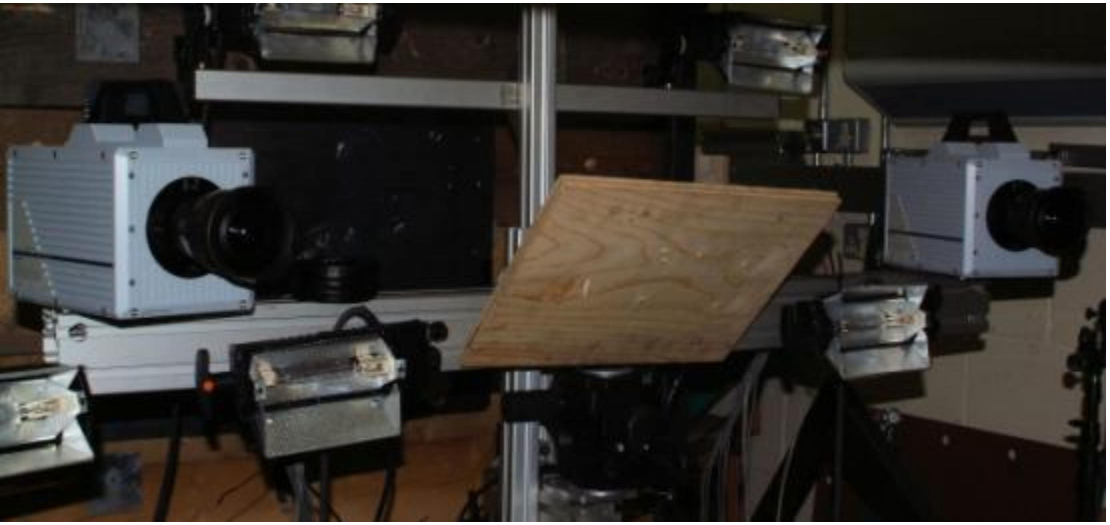
Experimental set-up

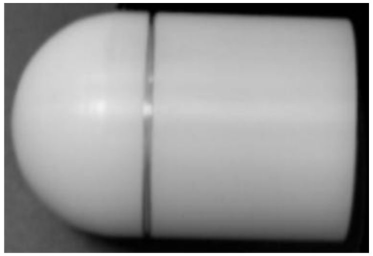


Bonnet liner: short fibres in polyamide matrix



Bonnet liner painted with speckle pattern

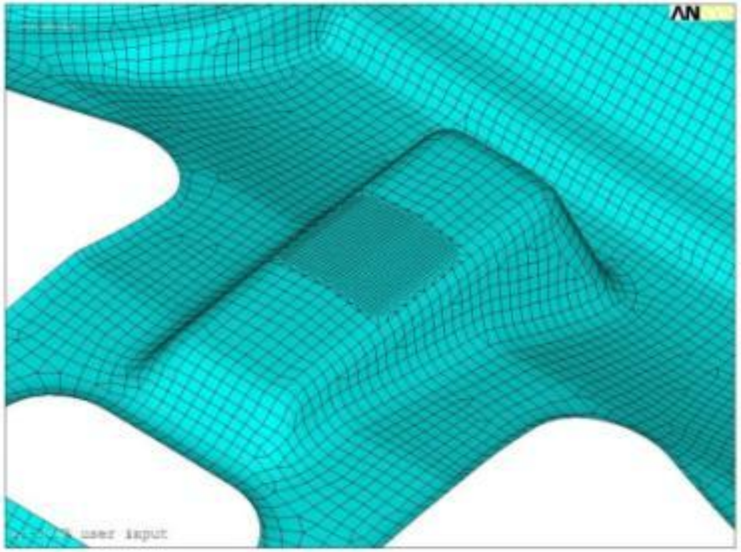




Projectile: 50mm diameter
125g polyethylene
Speed: 70m/s (250km/hr)
Energy: 300J

Burguete RL, Lampeas G, Mottershead JE, Patterson EA, Pipino A, Siebert T, Wang W, 2013, Analysis of Displacement Fields from a High Speed Impact using Shape Descriptors, *J. Strain Analysis*, 49(4): 212-223.

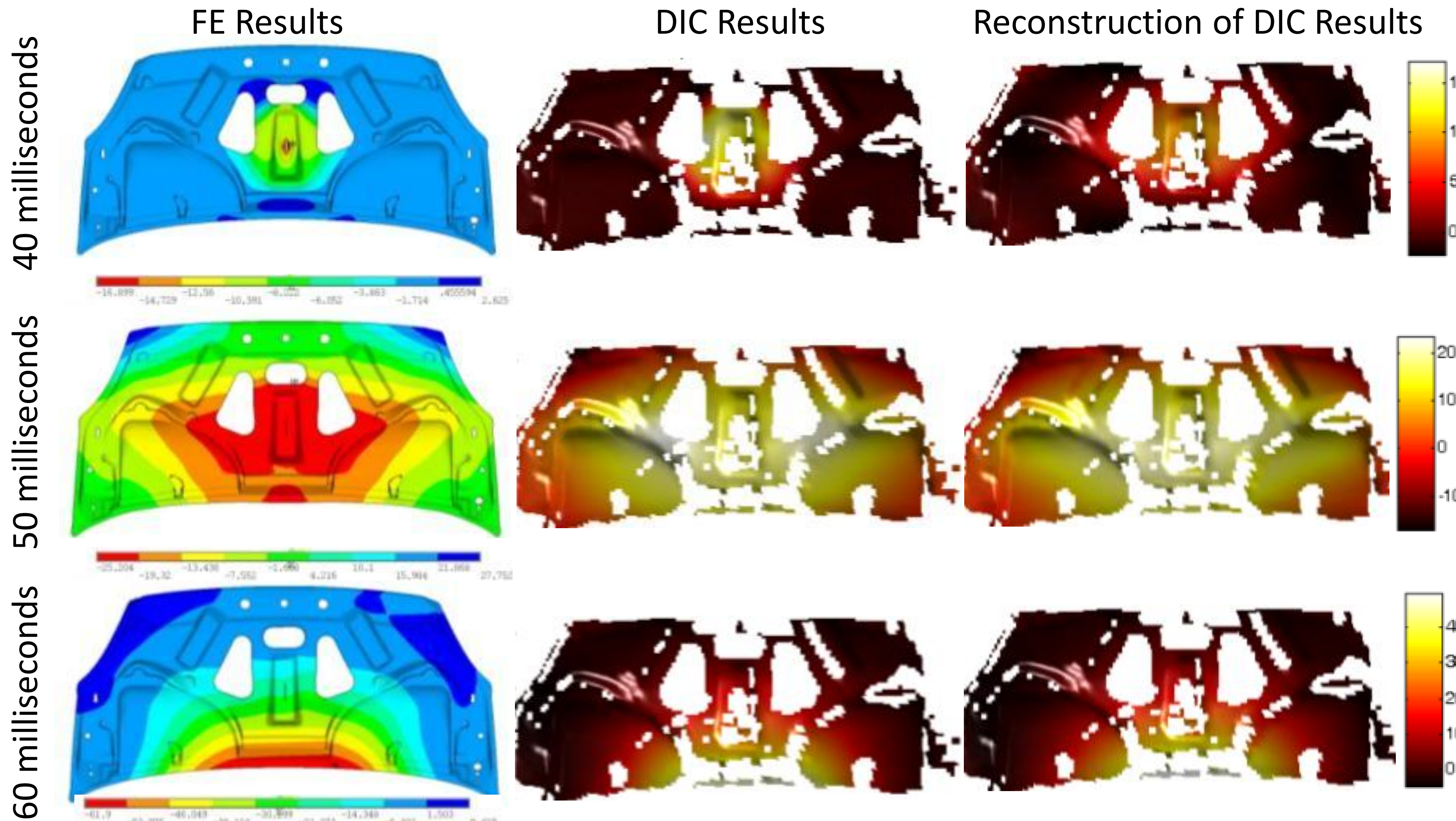
Impact on composite bonnet liner



Burguete RL, Lampeas G, Mottershead JE, Patterson EA, Pipino A, Siebert T, Wang W, 2013, Analysis of Displacement Fields from a High Speed Impact using Shape Descriptors, *J. Strain Analysis*, 49(4): 212-223.

About 0.05 milliseconds before impact

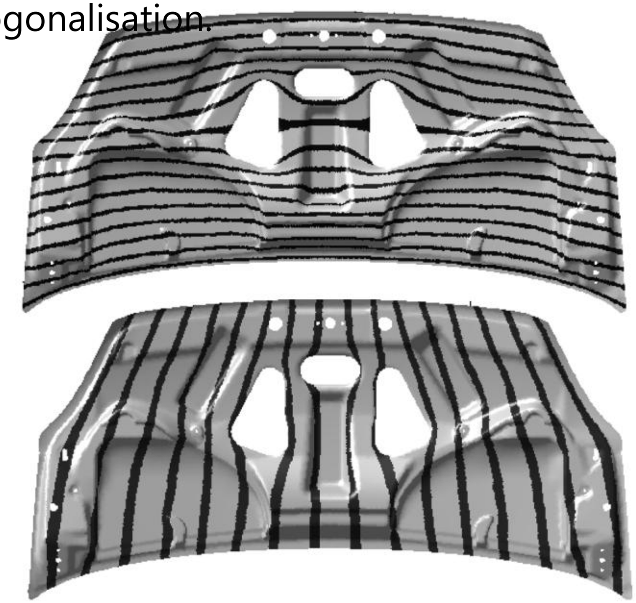
Data Processing



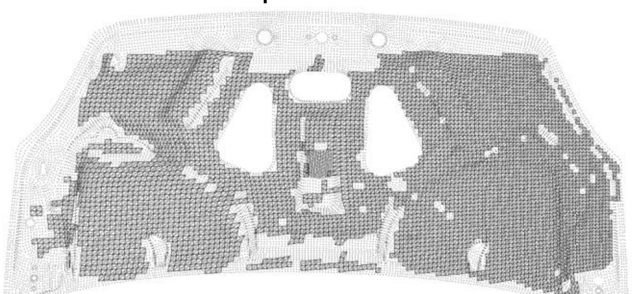
Burguete RL, Lampeas G, Mottershead JE, Patterson EA, Pipino A, Siebert T, Wang W, 2013, Analysis of Displacement Fields from a High Speed Impact using Shape Descriptors*, J. Strain Analysis*, 49(4): 212-223**.**

Adaptive Geometric Moment Descriptors

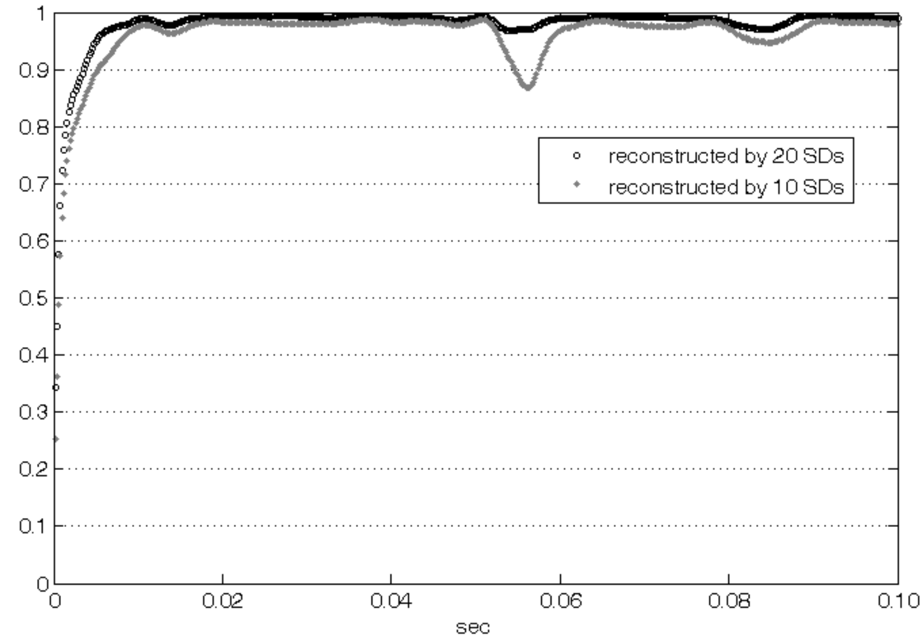
Mapping bonnet surface from 3D space to a 2D planar parametric domain isomorphically enables the utilisation of image decomposition techniques defined on planar domains via Gram–Schmidt orthogonalisation.



Iso-u & iso-v parametric coordinates

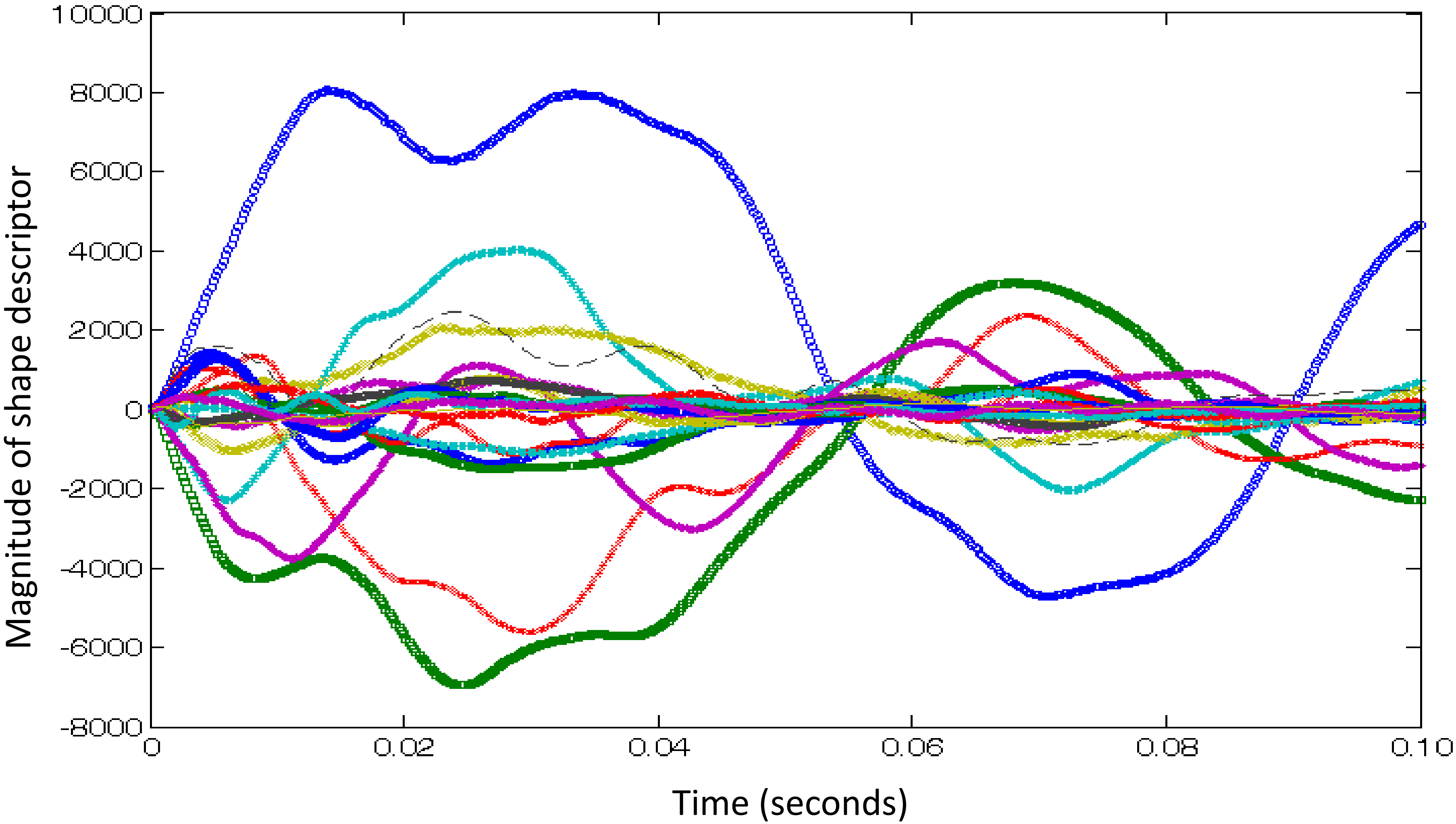


Matching FE nodes (grey dots) & DIC grids (black lines)

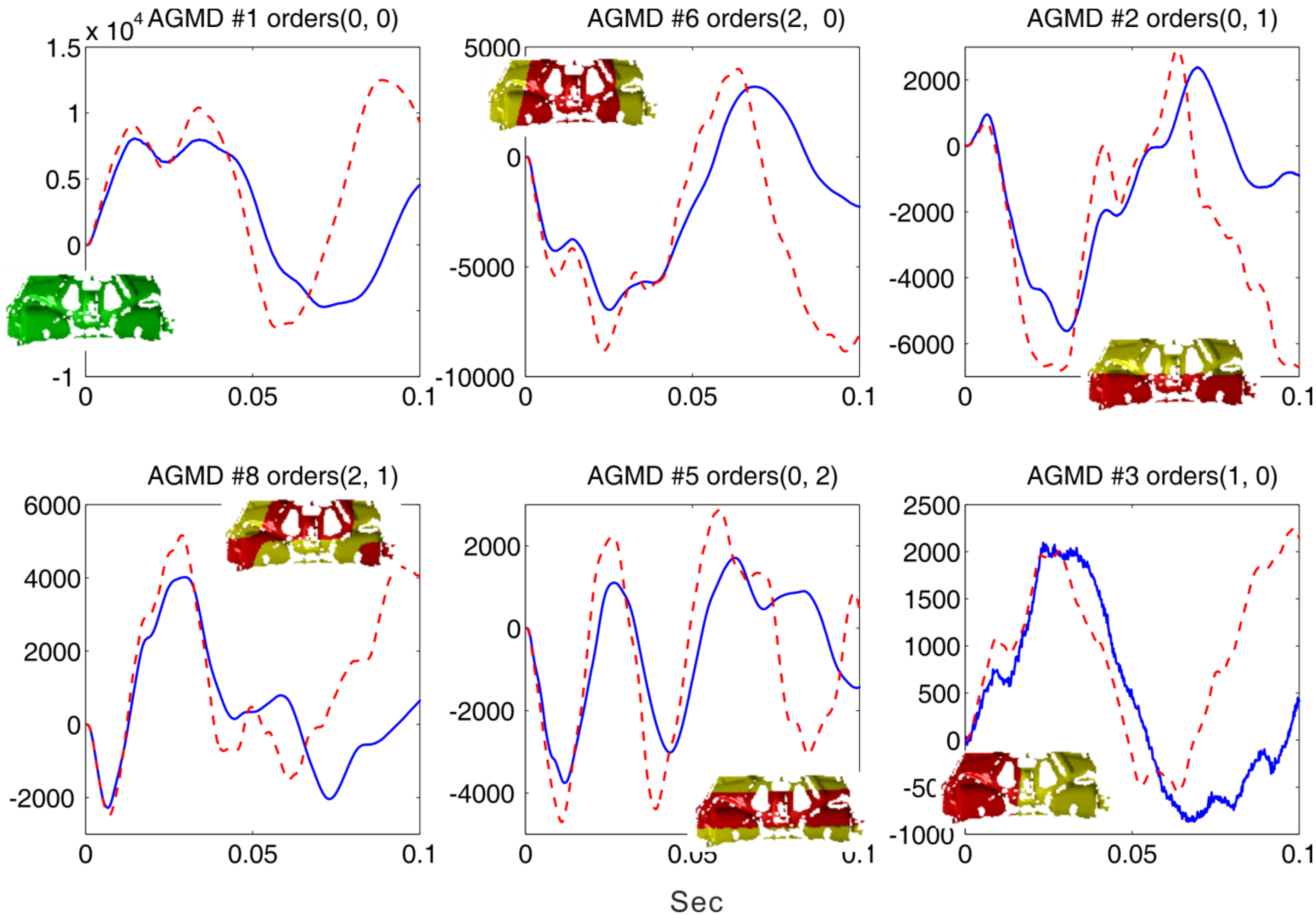


Correlation coefficient between out-of-plane displacements from DIC and their reconstructions from shape descriptors

DIC Shape descriptors

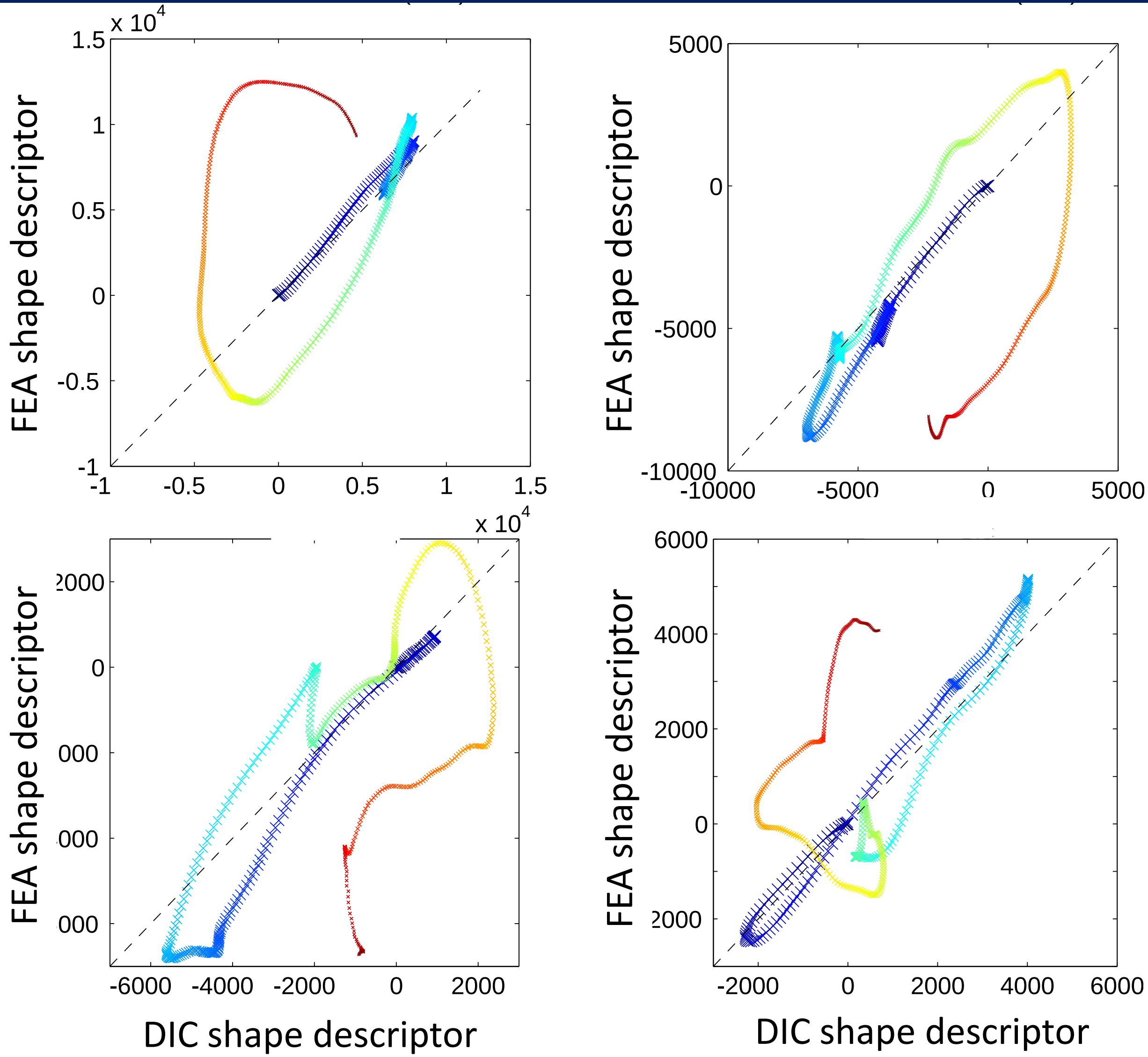


Six largest shape descriptors

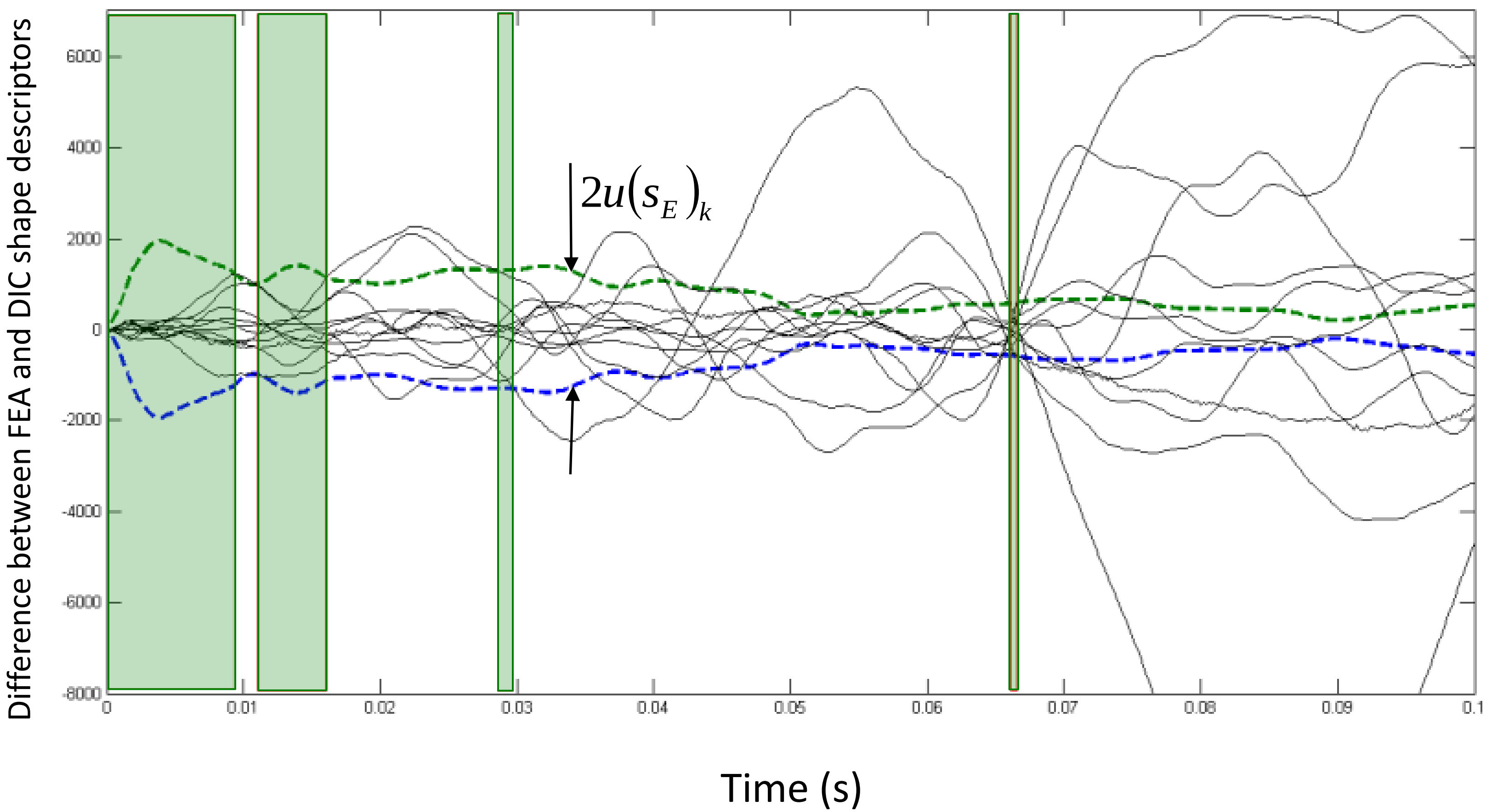


AGMDs numbers 1, 6, 2, 3, 5, and 8 (*clockwise from top left*) representing measured (solid lines) and simulation (broken lines) data with the corresponding kernel functions shown as insets.

Largest four of 20 shape descriptors



Comparison for validation of model



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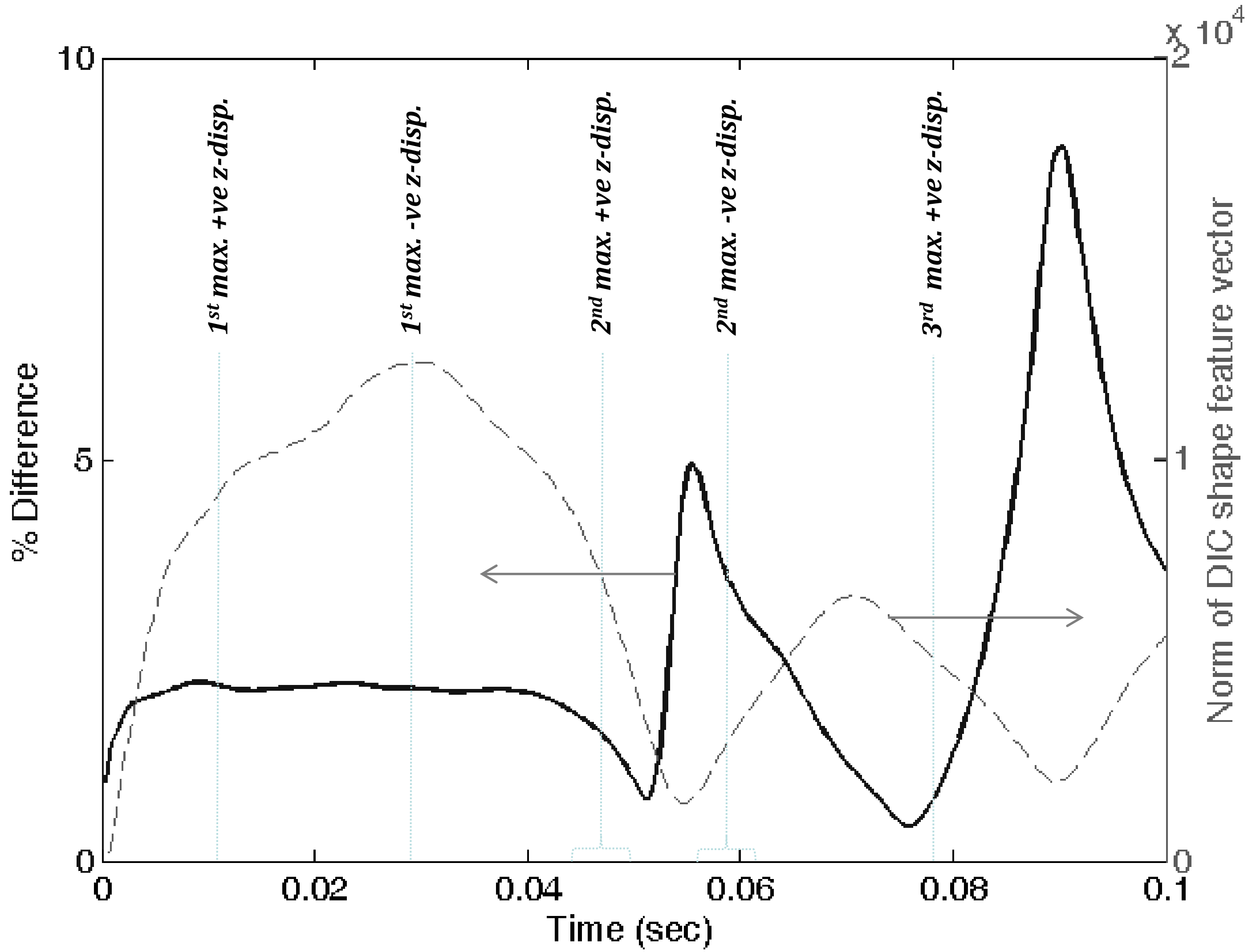
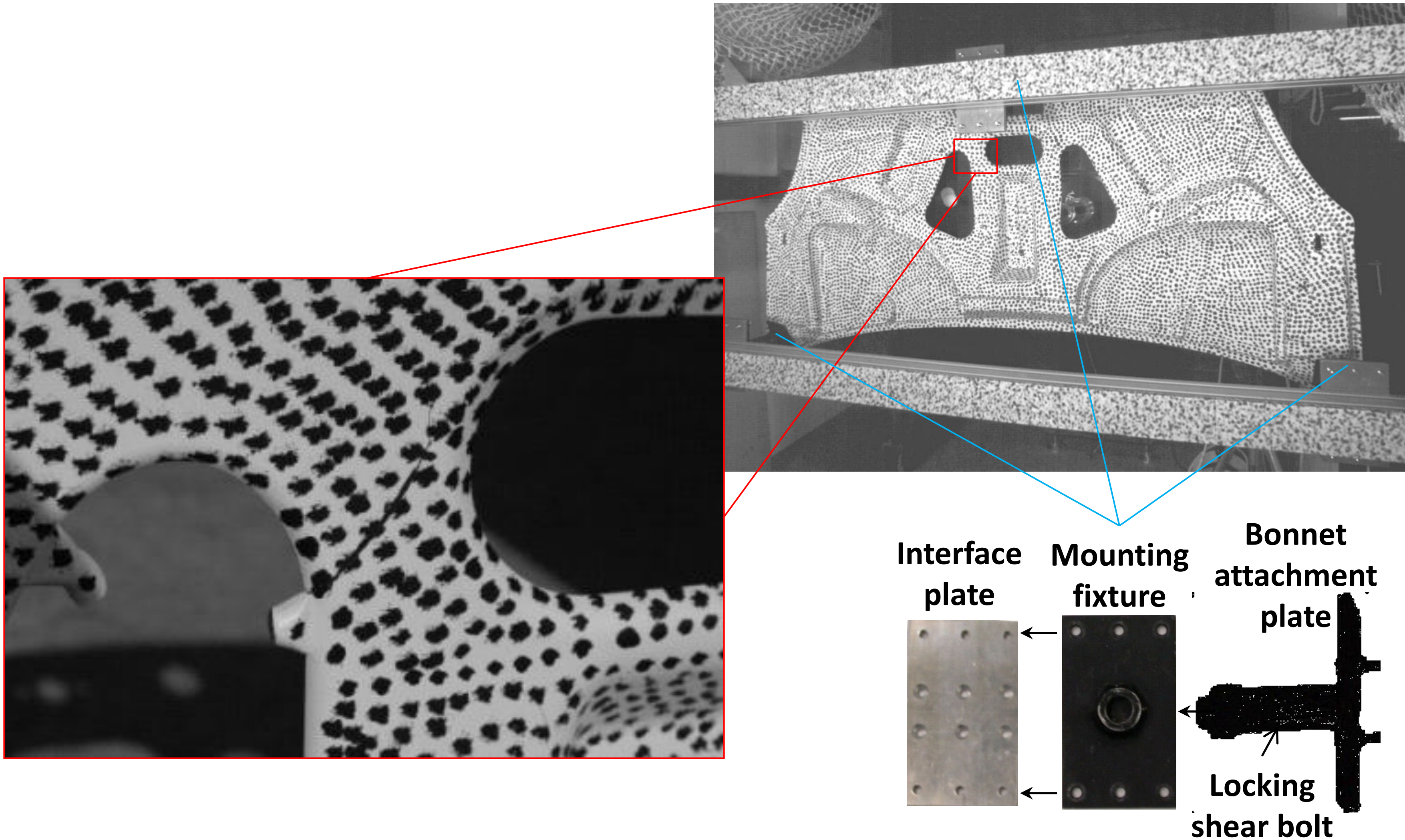
Euclidean distance between feature vectors



Model limitations



Conclusions

- **DIC and FE data generated for high velocity (70m/s) relatively low energy (50-300J) impact**
  - Displacement field for majority of $1m^2$ area at 0.2ms intervals for 0.1s
- **Adaptive Geometric Moment Descriptors (AGMDs) uses to describe data fields with reduced dimensionality & fidelity**
  - 95% correlation on reconstruction
- **Explored comparison methodologies**
  - Simulation vs. Experiment feature vector elements as function of time
  - Difference of feature vector elements as function of time
  - Eulerian distance between feature vectors as a function of time
- **Model limitations**
  - Damage propagation
  - Boundary conditions

Acknowledgements

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- **ADVISE was a Seventh Framework Programme Collaborative Project within Theme 7: Transportation including Aeronautics**
  - ADVISE is funded by EU FP7 (grant no. 218595) & by the partners:

- **The author gratefully acknowledges contributions by:**
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  - George Lambeas, University of Patras
  - John Mottershead, Chris Sebastian, Sarah Tan & Victor Wang, University of Liverpool
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  - Andrea Davighi & Maurice Whelan, JRC-ICHP
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  - Alexander Ihle, HPS
  - Andrea Pipino, CRF

ADVISE

ADVANCED DYNAMIC VALIDATION BY INTEGRATING SIMULATION & EXPERIMENTATION

SEVENTH FRAMEWORK PROGRAMME