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A Feasibility Study for Experimentally Determining Dynamic Force Distribution in a Lap Joint

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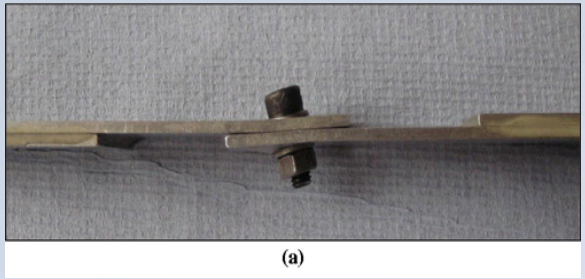
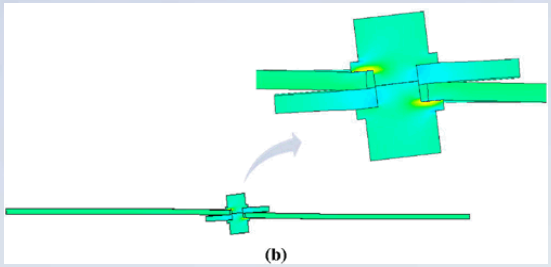
Feasibility Study Purpose Motivation, Goals and Approach

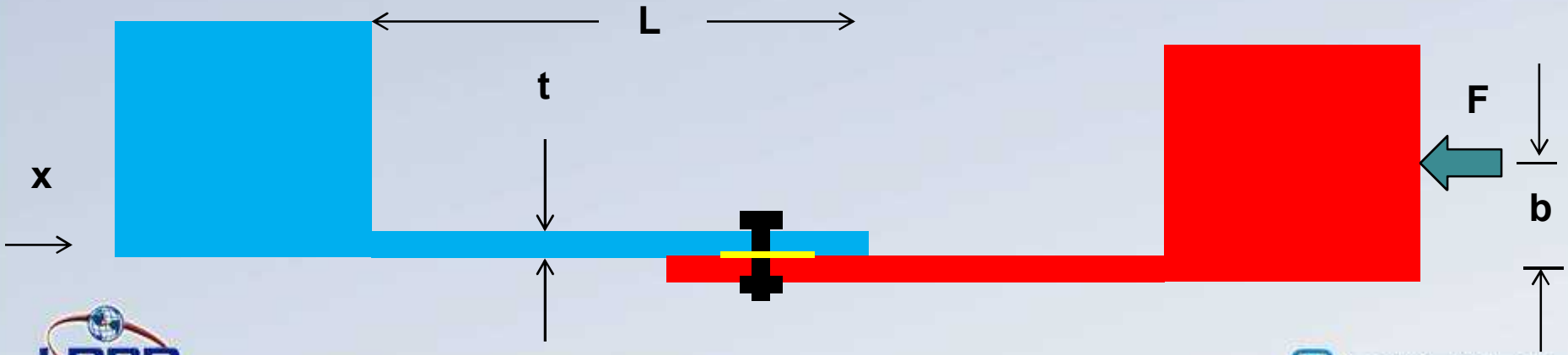
- *Constitutive models representing the dynamic physics of mechanical joints cannot be validated without experimental data*
- *The current state of the art is limited to measurements of the global joint stiffness and the loss of energy per cycle derived from force and response measurements across the joint*
- *A measurement of the forces and displacements at the interface is what is needed*
- *Installing sensors in the joint disrupts the physics we wish to measure*
- *This work investigates the feasibility of non-intrusive measurement of force distribution in the joint interface*
- *The approach is to attempt full field measurements using simple hardware and utilize proposed inverse methods with finite element modeling to determine forces and to assess feasibility with proposed sensors and newly modified theory*
- *Last year results were presented for a typical problem that showed that obtaining force distribution using the Sum of Weighted Accelerations Technique was infeasible on a 2D beam problem*
- *This paper shows that obtaining a reasonable estimate of force distribution in the joint is feasible using the same measurements as before with a new algorithm*


(a)


(b)

Envisioned Experimental Setup with Sinusoidal Force Applied Near First Elastic Resonant Frequency

- *System would be softly suspended and excited with a sinusoidal force*
- *Joint region shown nominally in yellow*
- *Imaging would only be required on visible surface of blue beam*
- *Sinusoidal force F would be applied on red beam*
- *A FE beam model was made for the blue beam to produce a "toy" model to test force reconstruction algorithms*
- *Last year, obtaining the force distribution in the contact patch appeared infeasible using the extended Sum of Weighted Accelerations (SWAT) algorithm with the toy model and standard noise obtained from typical DIC measurements*
- *Much better results were obtained with the toy model using the Method of Truncated Orthogonal Forces (Shown hereinafter)*



Method of Truncated Orthogonal Forces

$$M\ddot{\bar{u}} + K\bar{u} = \bar{f} \tag{1}$$

$$[-\omega^2 M + K]\bar{u} = \begin{Bmatrix} \bar{f}_{cp} \\ \bar{0} \end{Bmatrix} \tag{2}$$

Choose a truncated set of orthogonal force vectors for f_{cp}.

$$\mathrm{F}_o = \begin{bmatrix} \bar{f}_{o1} & \bar{f}_{o2} & \cdots & \bar{f}_{on} \\ \bar{0} & \bar{0} & \cdots & \bar{0} \end{bmatrix} \tag{3}$$

Calculate displacement u for each force vector from FE model of blue beam

Measured in the lab and averaged

$$\Gamma_o = \begin{bmatrix} \bar{u}_{m1} & \bar{u}_{m2} & \cdots & \bar{u}_{mn} \\ \bar{u}_{um1} & \bar{u}_{um2} & \cdots & \bar{u}_{umn} \end{bmatrix} \tag{4}$$

$$\bar{u}_{est} = \Gamma_o \Gamma_{om}^{+} \bar{u}_m \tag{5}$$

$$[-\omega^2 M + K]\bar{u}_{est} = \begin{Bmatrix} \bar{f}_{cp\_est} \\ \bar{0} \end{Bmatrix} \tag{6}$$

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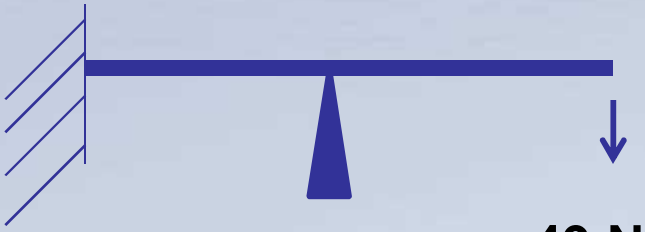
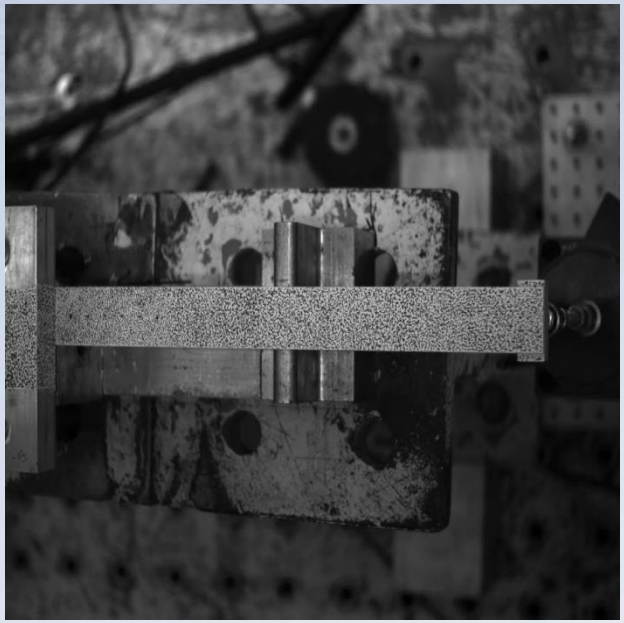
Deflection and Noise Studies on a Beam with Digital Image Correlation (DIC)

- *Two beam experiments were performed to determine static DIC sensitivity and noise floor*
- *They were also designed to see if moments/shear/surface load could be calculated directly from 2nd-4th derivatives of the displacement*

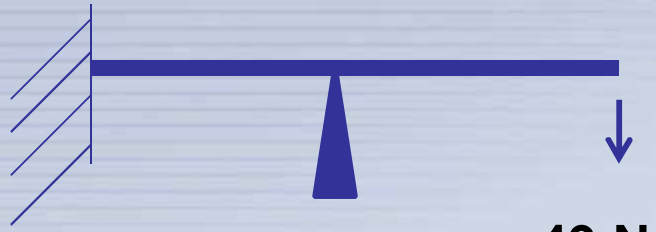


49 N Force

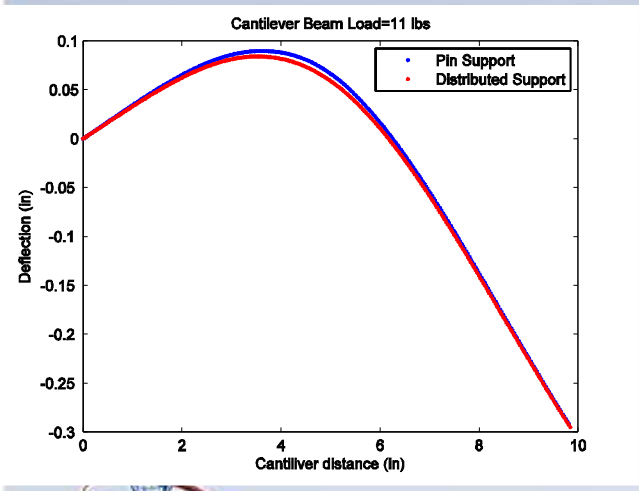


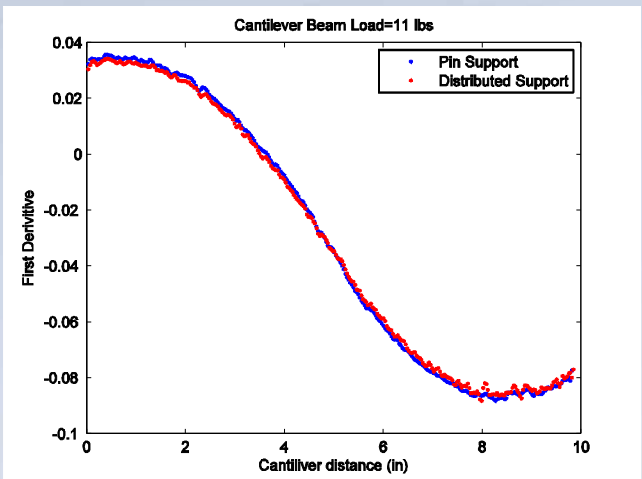
Deflection and Noise Studies on a Beam with Digital Image Correlation (DIC)

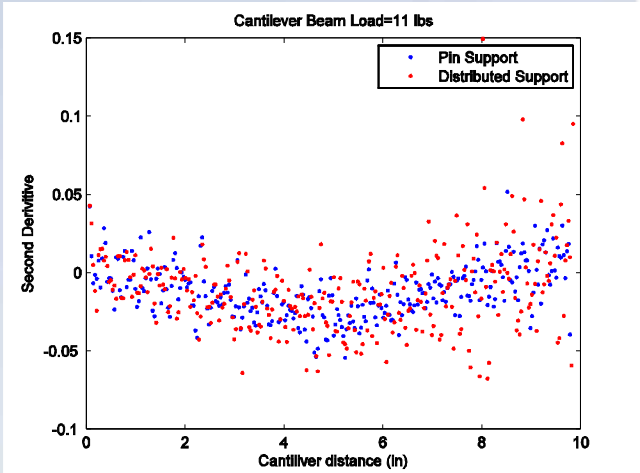
- *Deflection and derivatives shown for averaged 23 subsets across beam and 300 subsets along length*
- *Noise level is about 0.008 mm standard deviation on a subset*
- *Estimating polynomial coefficients for smoothly varying beam shape and derivatives is feasible for vertical motion*



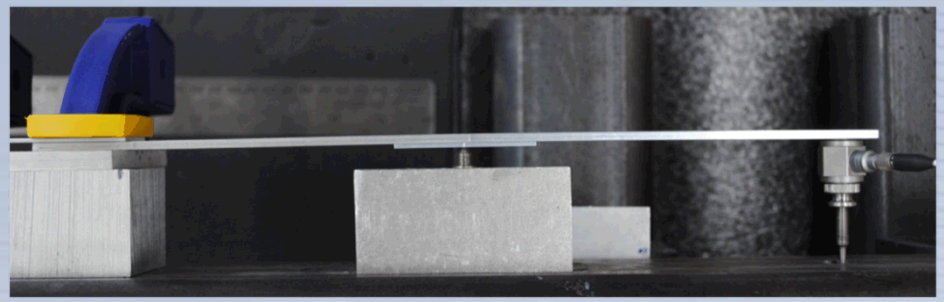
49 N Force

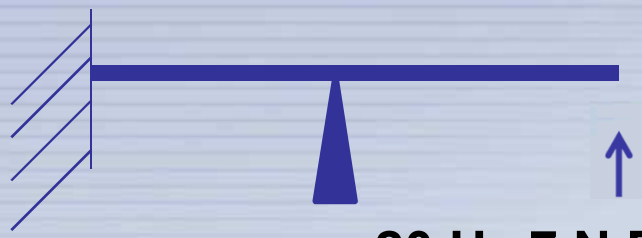




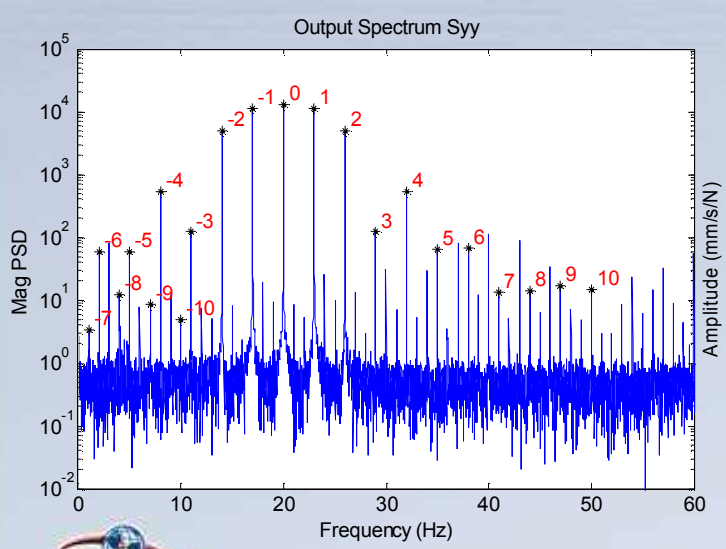


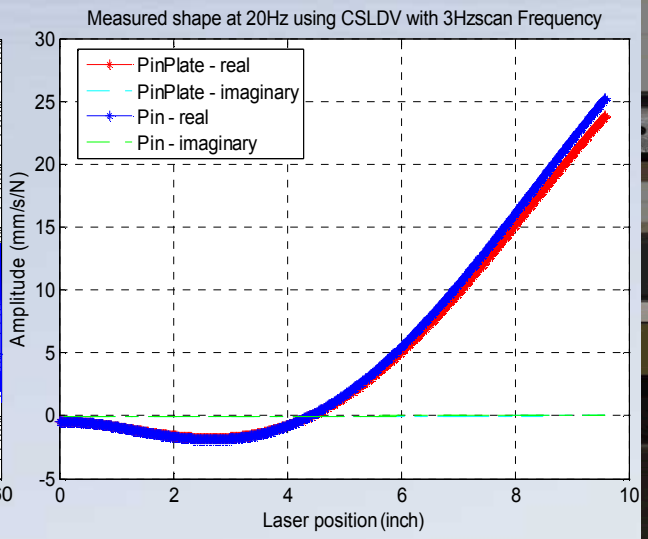
Dynamic Deflection and Noise Studies on a Beam with Scanning Laser Doppler Velocimetry with 3 scans per second for 102 seconds

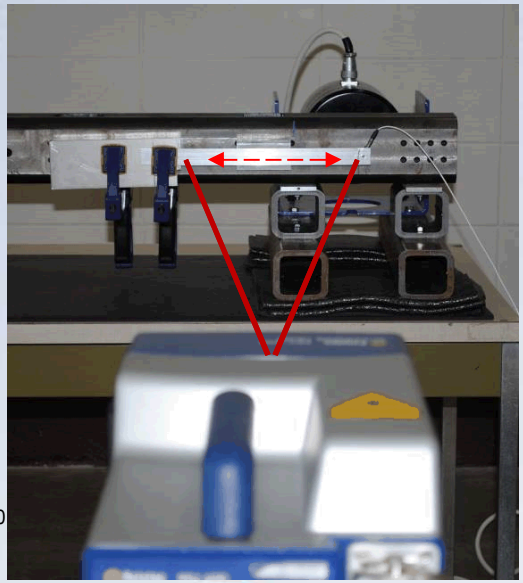




20 Hz 7 N Force







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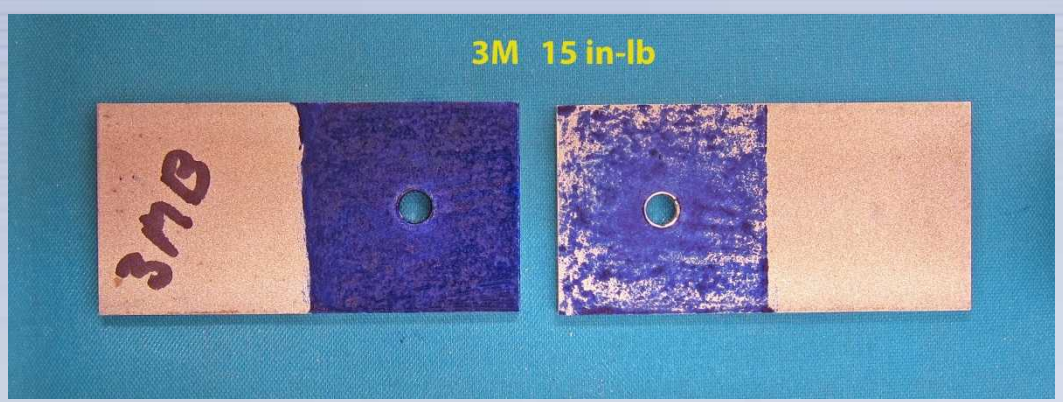
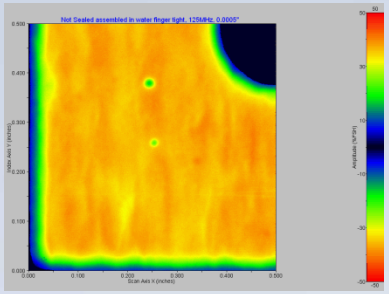
Methods to determine contact area of two plates with bolt through center

Prussian Blue

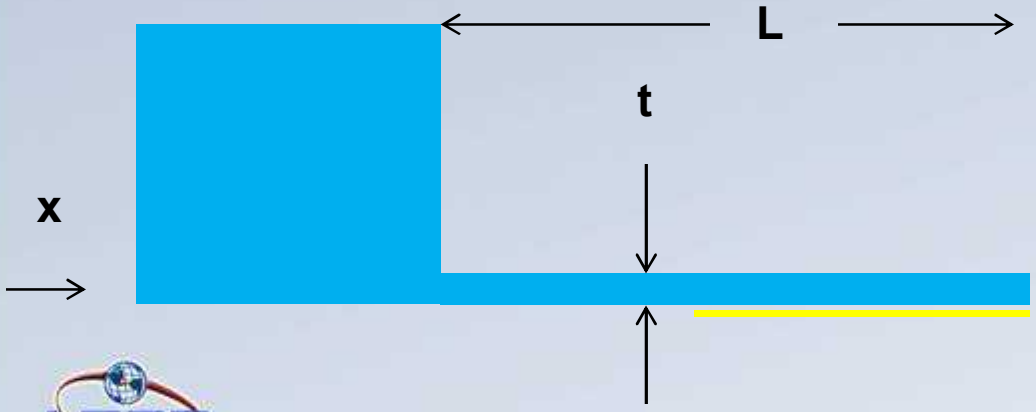


Ultrasonic



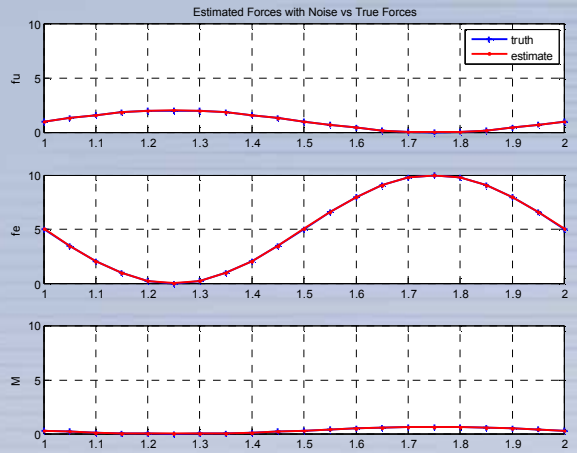
Method of Truncated Orthogonal Forces – Calculating 2D Force Distribution in contact patch

- *Full field measurements are required in the vertical and axial directions on the top of the blue beam*
- *Sinusoidal force is applied on red beam near the resonance of the combined systems*
- *System would be softly suspended approximating free system*
- *Length of aluminum beams is 50.8 mm and overlap in contact is 25.4 mm*
- *Width of beams is 25.4 mm*
- *Masses are 14.2 kg*
- *Assume some force distributions and typical measurement noise and use the FE model to produce a virtual experiment to see how well the method replicates the assumed applied force*



Sinusoidal force results with typical DIC noise added to data

Case 1 – Sine wave + offset (n=3 ea direction)

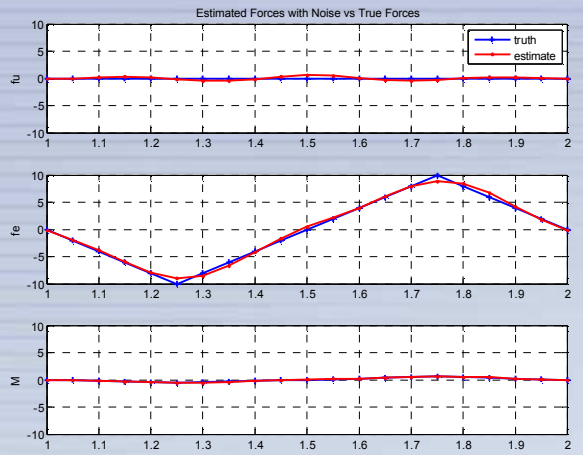


F vertical

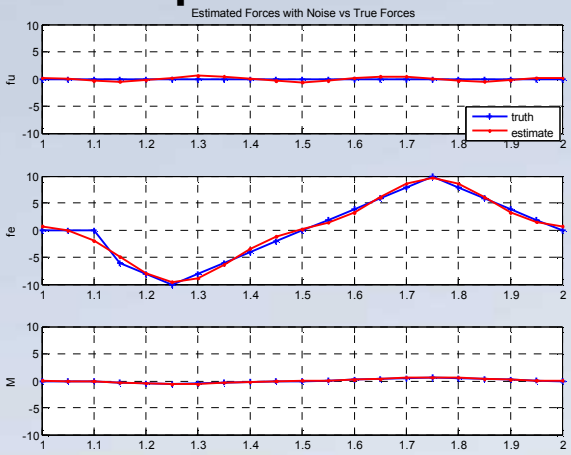
F horizontal

Moment

Case 2 – Sawtooth Wave (n=7)



Case 3 – Sawtooth plus no contact region (n=7)



F vertical

F horizontal

Moment

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Feasibility Effects / Statements

No. terms for each direction	No. images required for averaging
3	100
5	1000
7	10,000

- *With DIC noise we measured in lab, it seems feasible to extract 2D distribution of a sinusoidal force by averaging a number of images*
- *DIC analysts indicate that 10,000 images could be processed in an overnight computer run*
- *Lower frequency sinusoids seem feasible with DIC*
- *Higher frequency sinusoids may require laser velocimetry. (Full field in plane displacements may be more difficult to obtain with laser velocimetry)*