Exceptional service in the national interest

Sandia National Laboratories

National Institute of Standards and Technology
U.S. Department of Commerce

iDICs INTERNATIONAL DIGITAL IMAGE CORRELATION SOCIETY

Digital Image Correlation and Standardization

Mark Iadicola and Phillip Reu

Philadelphia 2016

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Motivation for Standards

National Institute of Standards and Technology
U.S. Department of Commerce

- How to ensure that anyone within a framework/sphere can measure the same thing within a tolerance anywhere else within that framework?

- The framework is made up of more or less interdependent elements having a defined organizational structure.

Achieved through a shared/open "standards"

Motivation for Standards

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U.S. Department of Commerce

What do standards accomplish?

- Safety of people and property
- Economy of scale
- Comply with regulation
- Interoperability of products and services
- Encourages competition
- Diminish trade barriers
- Promote common understanding
- Innovation

Business & Research
are Global!

Standards

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Standards: Requires Interoperability

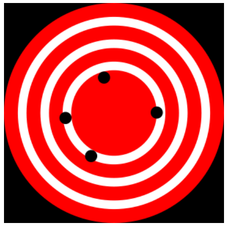
- Repeatability (I can get the same answer again)
- Reproducibility (someone else can get the same answer)
- Compatibility (comparative or traceable)

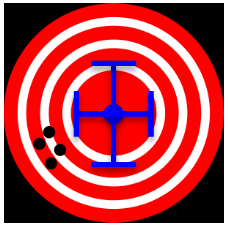
Comparative:

- one vs. another (e.g. A is heavier than B)
  - by consensus, but no anchor

Traceable:

- calibration to a known/true value
  - precision
  - accuracy





Standards Frameworks

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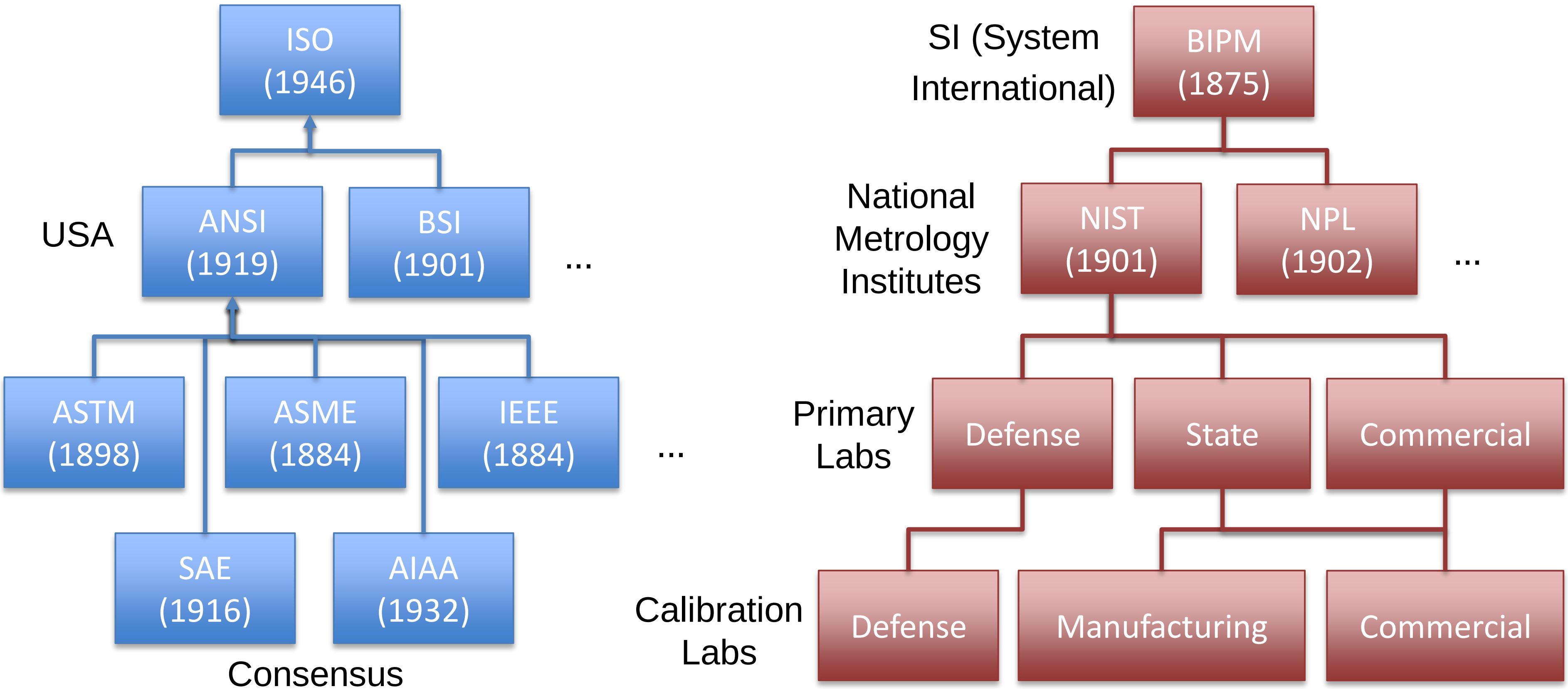
Documentary Standards

Physical Standards



Consensus
Repeatability
Reproducibility

Consensus
Traceability

Documentary, Reference Materials (Artifacts), Reference Data

Standards Frameworks

Documentary standards come from

ASTM, AFNOR, API, ASME, BSI, EN, CSA, DIN, GB, ISO, JIS, SAE, ...

Acronym Soup!

does not matter because they all fall under

the framework and "traceability" to shared standards

Ensures "Standard" of Units, Processes, and Procedures

to realize the necessary

- Repeatability
- Reproducibility
- Compatibility

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Some Legal Aspects of Standards

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Legal Contracts & Treaty Agreements
requires some method to enforce compliance

- Regulations
- Key comparisons
- Audits
- Certifications
- Inspections
- Documentation

Contract Law & Wording of Documentary Standards

- shall = requirement*
- should = recommendation*
- may = permission*
- can = possibility or capability*
- ~~must~~ = law of nature, but should be avoided*

*ISO/IEC Directives Part 2 ed.7 Tables 3-6

Standards: Controlling Error & Uncertainty

Controlling (& Assessing) Error & Uncertainty

1) Remove what error and uncertainty sources you can
2) Measure or assess the rest

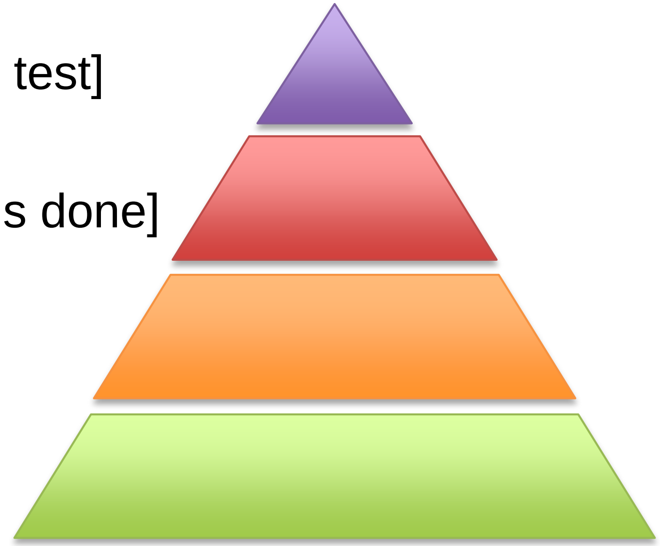
- error budget (propagation), variability studies, benchmarking/round-robin, ...

Preliminary: [development stage]

Pre-test: [start of a series of tests]

During testing: [while we run the test]

Post-test: [some time after the test is done]



Standards: Controlling Error & Uncertainty

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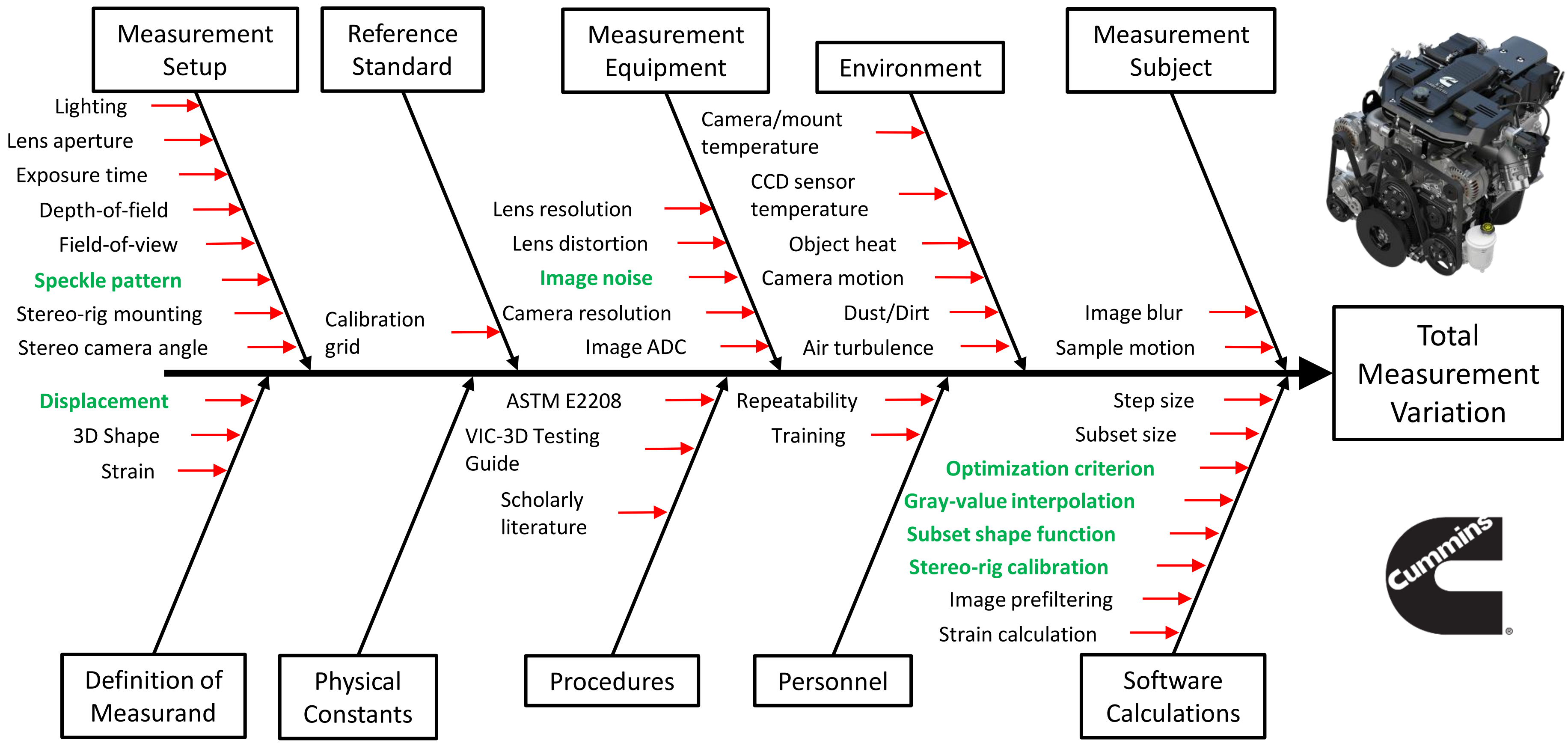
Preliminary: [development stage]

intralaboratory, interlaboratory, benchmarking

- repeatability, reproducibility, method, procedures, classifications, analysis
- defining your sources of error (fish-bone diagram), while some sources we neglect



Jordan E. Kelleher, Paul J. Gloeckner, An Applications-Oriented Measurement System Analysis of 3D Digital Image Correlation, 2016 SEM Annual Conference & Exposition on Experimental & Applied Mechanics

Standards: Controlling Error & Uncertainty

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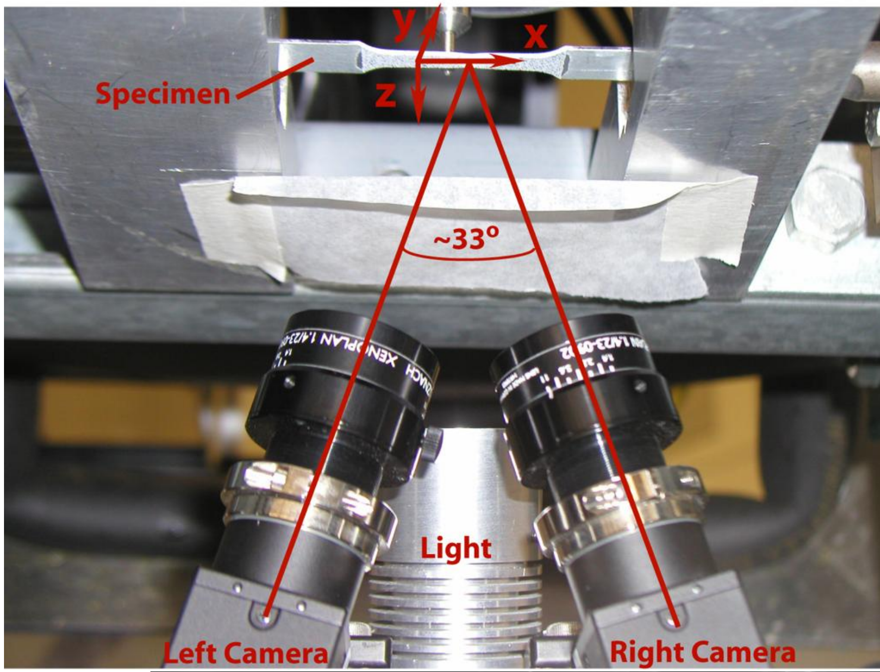
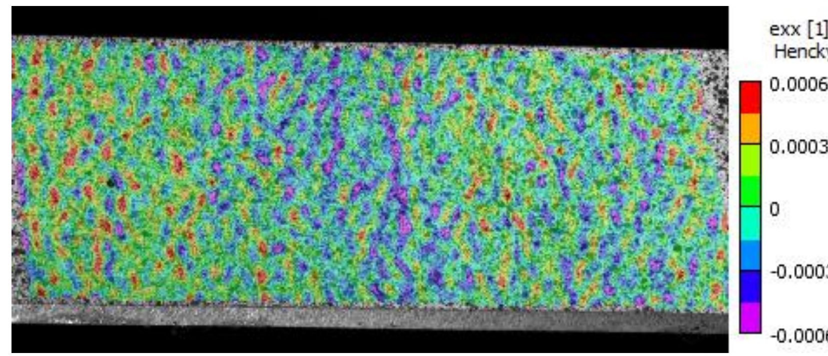
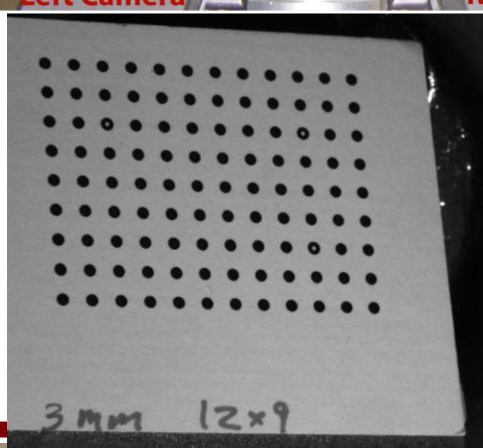
Pre-test: [start of a series of tests]

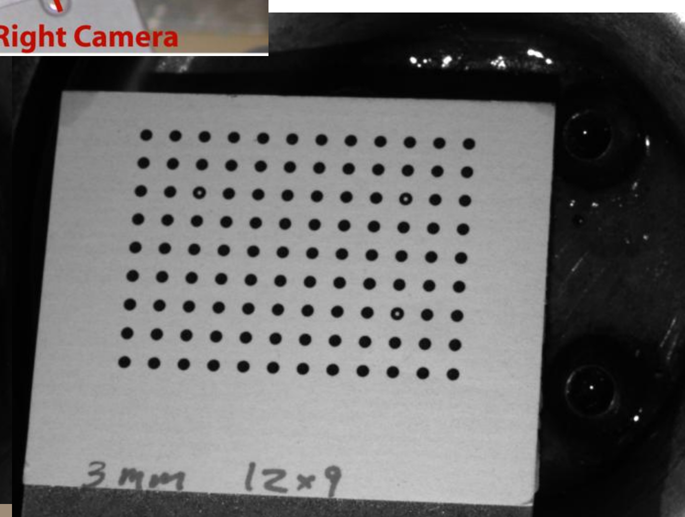
setup (method), calibration, and verification/classification





Noise Floor Check





Standards: Controlling Error & Uncertainty

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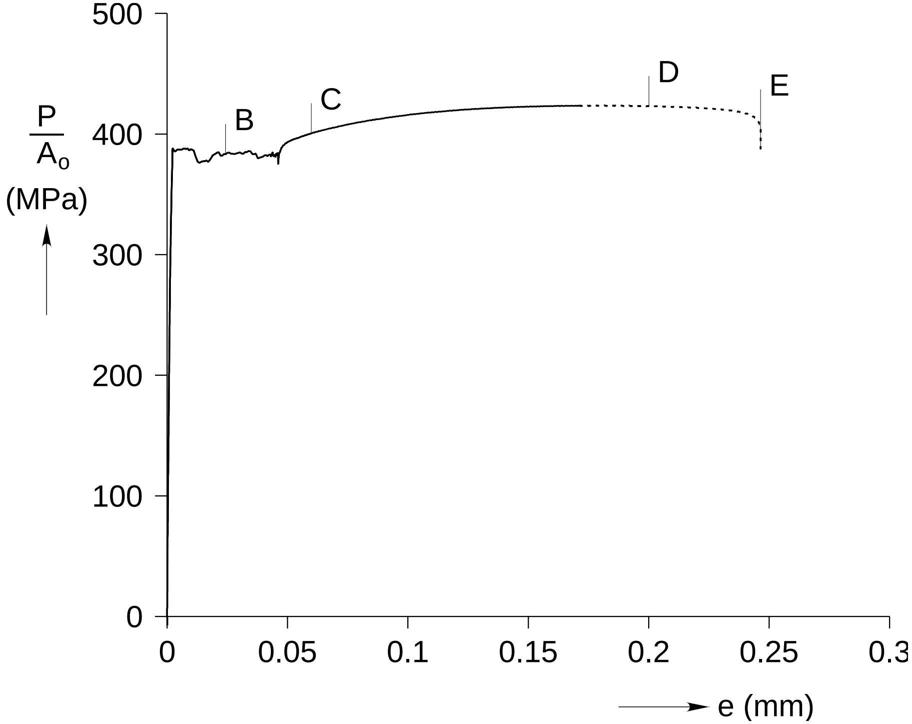
During testing: [while we run the test]
methods, procedures, and acquisition

Engineering
Stress vs. Strain



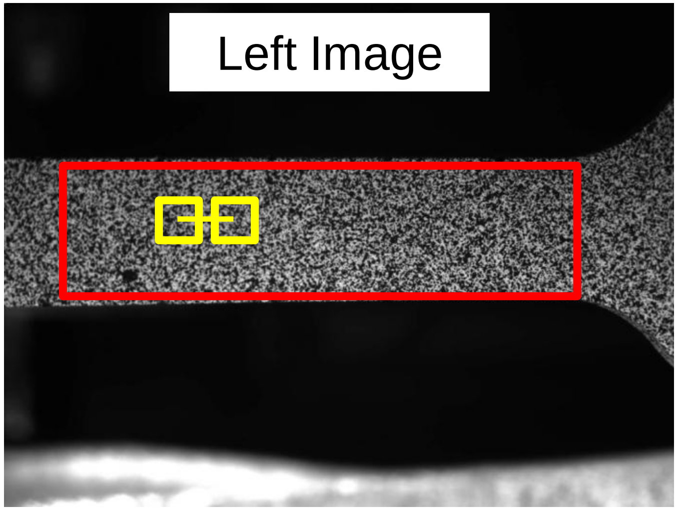
Required or Suggested

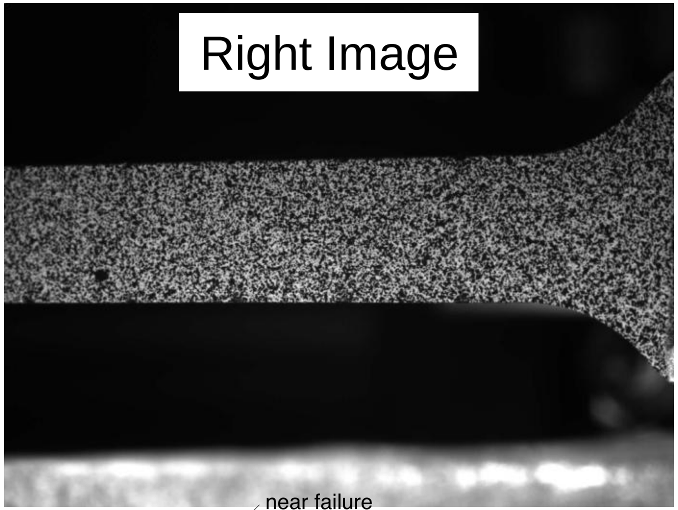
- Specimen insertion
- Strain rate
- Analog signals
- Frame rates or Triggering
- ... etc.

Standards: Controlling Error & Uncertainty

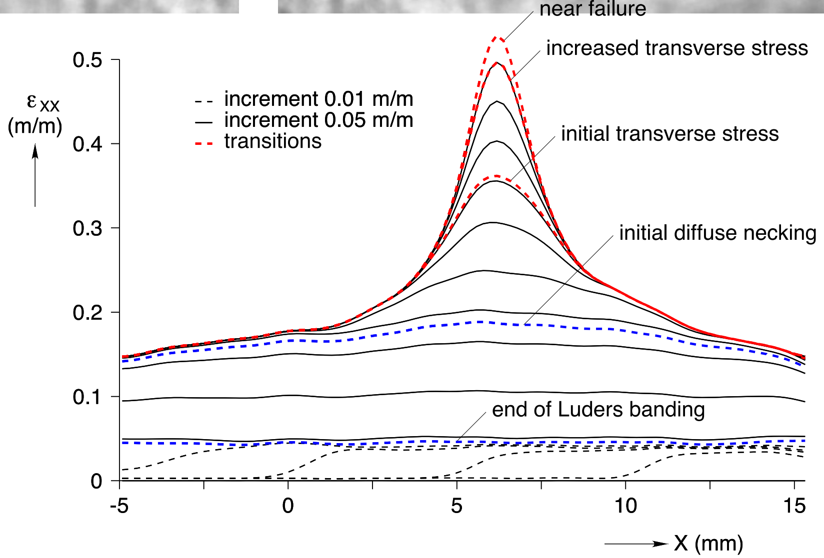
Post-test: [some time after the test is done]
analysis, rejection, and reporting

- Region of Interest
- Subset
- Step
- Correlation Thresholds
- ... etc.





- Strain Calculation
- Sampling
- Reporting
- ... etc.



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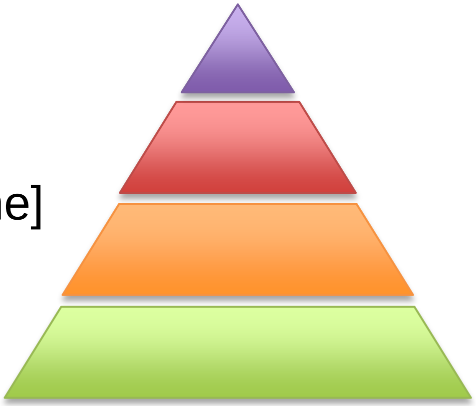

Is DIC "Fit-for-purpose"? Which DIC set-up is the best "Fit-for-purpose"?

Which DIC set-up best “Fit-for-purpose”?

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Standards or Experiments

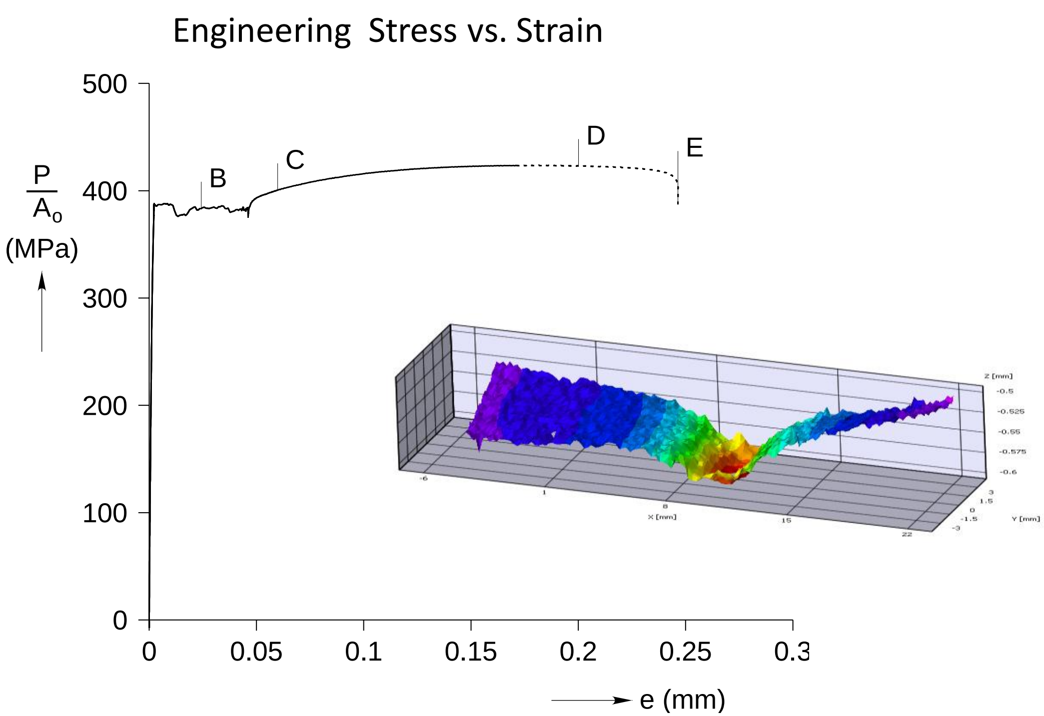
Strain measurement: 2-point / uniform field / variable field / localized

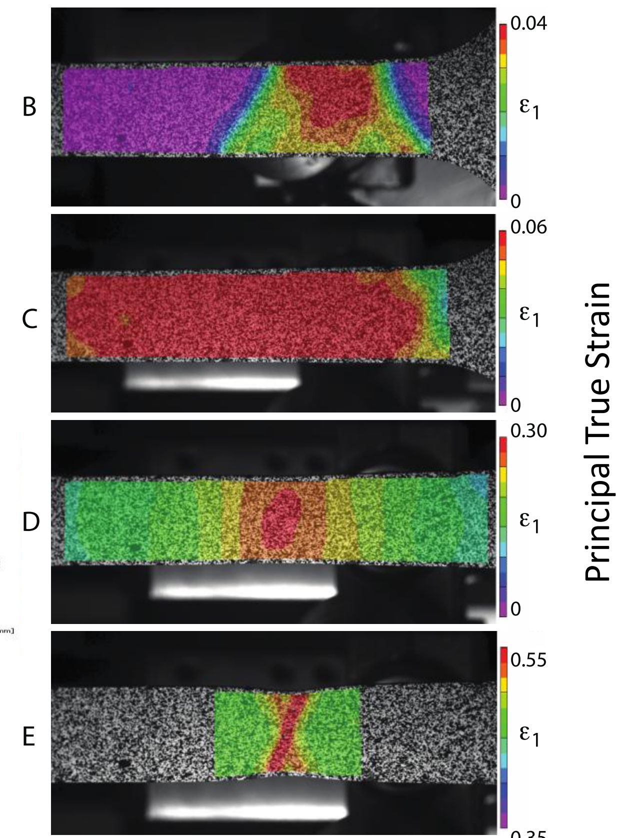
Displacement measurement: 2-point / displacements x, y, z / rotations

Specimen shape: flat / curved / initially flat then curved

Strain range: elastic / plastic / near-failure strains

Temporal range: static / quasi-static / dynamic





Which DIC set-up best “Fit-for-purpose”?

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Standards Requirements

Technique: general-optical / 2D-DIC / 3D(stereo)-DIC / 3D(volumetric)-DIC

Camera: resolution / frame rate / noise level / ...

Lens: field-of-view / distortions / telecentric / depth-of-field /...

Pattern: size / distribution / contrast / ...

Lighting: white / coherent / strobe or pulsed / filtering / ...

Verification: yes / no

Which DIC set-up best "Fit-for-purpose"?

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Standards or Experiments

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Lens: field-of-view / distortions / telecentric / depth-of-field /...

Pattern: size / distribution / contrast / ...

Lighting: white / coherent / strobe or pulsed / filtering / ...

Verification: yes / no

Existing Standards that Permit DIC

		Optical / DIC
General Use		
ISO 9513:2012	**Extensometer calibration**	Optical or DIC
ASTM E83-06	**Extensometer calibration**	Optical
ASTM E28.01 AC273	**Task group on DIC**	Optical or DIC
ASTM E2208-02	**Guide on-contact optical strain**	Optical or DIC
Fracture		
ISO 22889:2013	**Stable crack extension test**	Optical or DIC
ASTM E2472-12	**Stable crack extension test**	Optical or DIC
ASTM E2899–15	**Initiation toughness in surface cracks test**	DIC

		Optical / DIC
High strain rate		
ISO 26203-2:2011	**Tensile high strain rate servo-hydraulic test**	Optical
ISO 26203-1:2010	**Tensile high strain rate elastic bar test**	Optical
Sheet Metal Testing		
ASTM E517-00 (2017)	**Plastic R-ratio sheet metal test**	DIC
ASTM B831-14	**Shear test thin Aluminum**	DIC
ISO 16842	**Biaxial cruciform test**	Optical
EN ISO 16808:2014	**Biaxial bulge test**	Optical
ISO 12004-1	**Forming limit test**	Optical
ISO 12004-2	**Forming limit test**	Optical or DIC
ASTM E2218-15	**Forming limit test**	DIC

Existing Independent Projects/Methods

		Optical / DIC
Independent Projects/Methods		
SPOTS P1	**Elastic 4-point bend RM**	Optical or DIC
SPOTS P2	**Hertzian disk RM**	Optical or DIC
ADVISE	**Elastic vibrating rectangular plate & cantilever beam RMs**	Optical or DIC
CWA 16799:2014	**Elastic 4-point bend & cantilever beam RMs**	Optical or DIC
Boeing Laboratory	**Elastic bent beam RM**	DIC

General Use - DIC Standards

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		Optical / DIC	Strain measurement	Required technique	Strain range	Temporal range	Verification
General Use							
ISO 9513:2012	**Extensometer calibration**	Optical or DIC	2-point	2D	elastic & plastic	quasi-static	yes
ASTM E83-06	**Extensometer calibration**	Optical	2-point	2D	elastic & plastic	quasi-static	yes
ASTM E28.01 AC273	**Task group on DIC**	Optical or DIC	2-point	2D	elastic & plastic	quasi-static	yes
ASTM E2208-02	**Guide on-contact optical strain**	Optical or DIC	uniform or variable	2D or 3D	elastic or plastic	all	yes (only 2-point)

Fracture & High-rate Tests - DIC Standards

		Optical / DIC	Strain measurement	Required technique	Strain range	Temporal range	Verification
Fracture							
ISO 22889:2013	**Stable crack extension test**	Optical or DIC	2-point	2D	NA	quasi-static	no
ASTM E2472-12	**Stable crack extension test**	Optical or DIC	2-point	2D	NA	quasi-static	no
ASTM E2899–15	**Initiation toughness in surface cracks test**	DIC	2-point	2D	NA	quasi-static	no
High strain rate							
ISO 26203-2:2011	**Tensile high strain rate servo-hydraulic test**	Optical	2-point	2D	plastic	dynamic	no
ISO 26203-1:2010	**Tensile high strain rate elastic bar test**	Optical	2-point	2D	plastic	dynamic	no

Sheet Metal Tests - DIC Standards

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		Optical / DIC	Strain measurement	Required technique	Strain range	Temporal range	Verification
Sheet Metal Testing							
ASTM E517-00 (2017)	**Plastic R-ratio sheet metal test**	DIC	2-point & localized	NA	plastic	quasi-static	no
ASTM B831-14	**Shear test thin Aluminum**	DIC	uniform	NA	plastic	quasi-static	no
ISO 16842	**Biaxial cruciform test**	Optical	variable	NA	elastic & plastic	quasi-static	no
EN ISO 16808:2014	**Biaxial bulge test**	Optical	local	3D	plastic	quasi-static	yes disp.RM
ISO 12004-1	**Forming limit test**	Optical	local	3D	plastic	static	no
ISO 12004-2	**Forming limit test**	Optical or DIC	localized	3D	plastic or near-failure	quasi-static	no
ASTM E2218-15	**Forming limit test**	DIC	localized	3D	plastic	quasi-static	no

Existing Independent Projects/Methods

		Optical / DIC	Strain measurement	Required technique	Strain range	Temporal range	Verification
Independent Projects/Methods							
SPOTS P1	**Elastic 4-point bend RM**	Optical or DIC	variable	2D	elastic	static	yes RM
SPOTS P2	**Hertzian disk RM**	Optical or DIC	variable & localized	2D	elastic	static	yes RM
ADVISE	**Elastic vibrating rectangular plate & cantilever beam RMs**	Optical or DIC	variable	3D	elastic	dynamic	somewhat RM (see CWA)
CWA 16799:2014	**Elastic 4-point bend & cantilever beam RMs**	Optical or DIC	variable	2D or 3D	elastic	quasi-static and dynamic	yes RM
Boeing Laboratory	**Elastic bent beam RM**	DIC	uniform & variable	3D	elastic	static	yes RM

Some Overall Trends

	General Use				Fracture			High strain rate		Sheet Metal Testing							Independent Projects/Methods				
	ISO 9513:2012	ASTM E83-06	ASTM E28.01 AC273	ASTM E2208-02	ISO 22889:2013	ASTM E2472-12	ASTM E2899–15	ISO 26203-2:2011	ISO 26203-1:2010	ASTM E517-00	ASTM B831-14	ISO 16842	EN ISO 16808:2014	ISO 12004-1	ISO 12004-2	ASTM E2218-15	SPOTS P1	SPOTS P2	ADVISE	CWA 16799:2014	Boeing Laboratory
Strain measurement	2-point				2-point			2-point					localized				variable				
Required technique	2D				2D			2D					3D								
Strain range	elastic and plastic							plastic		plastic (limited elastic)							elastic				
Temporal range	quasi-static				quasi-static			dynamic		quasi-static											
Verification	yes				no			no		no (limited)							yes (RM)				

Overview of ASTM E2208-02 "Guide for Evaluating Non-Contacting Optical Strain Measurement Systems"

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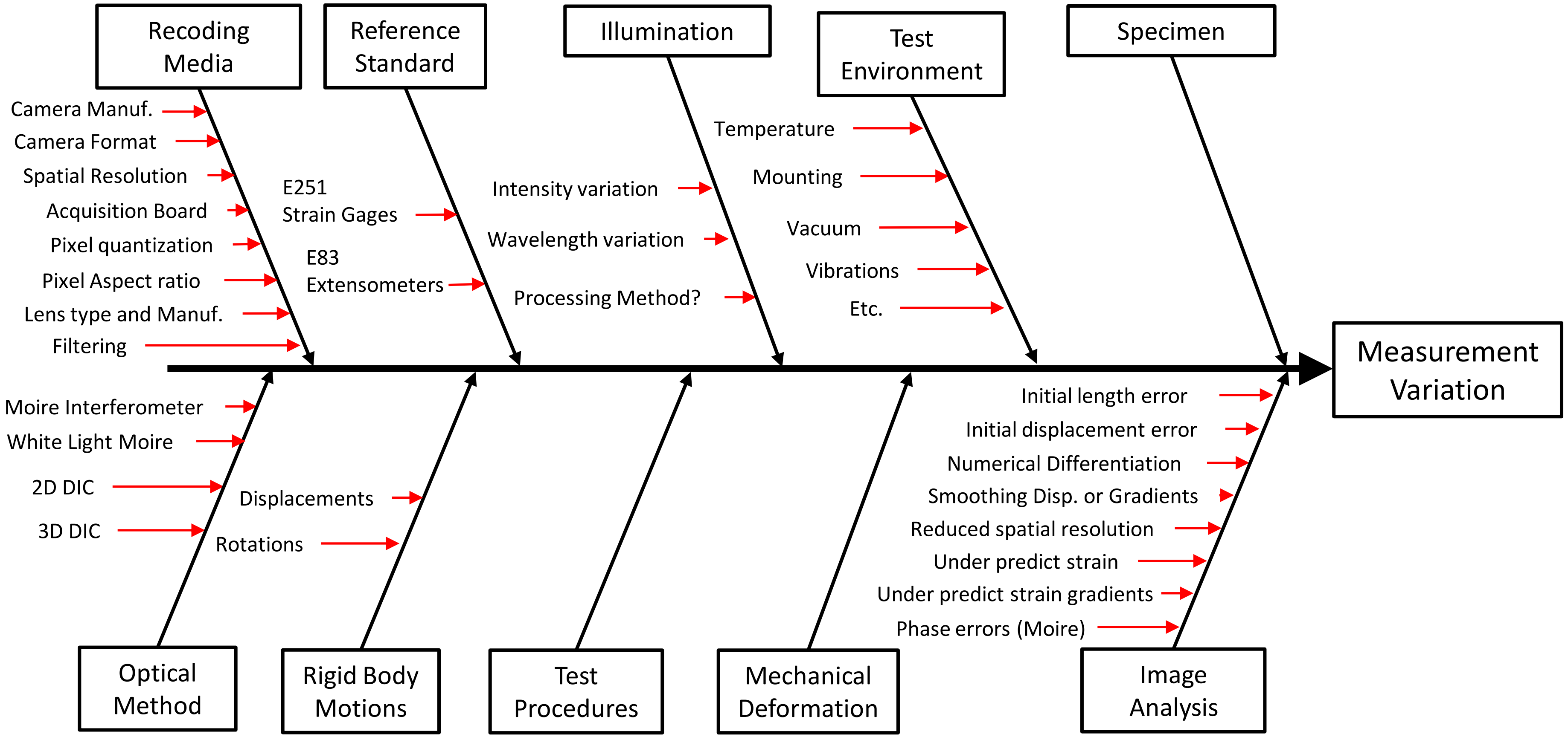
- Framework for quantitative comparison of optical systems
- Focus on optical data and image analysis data

Error Sources

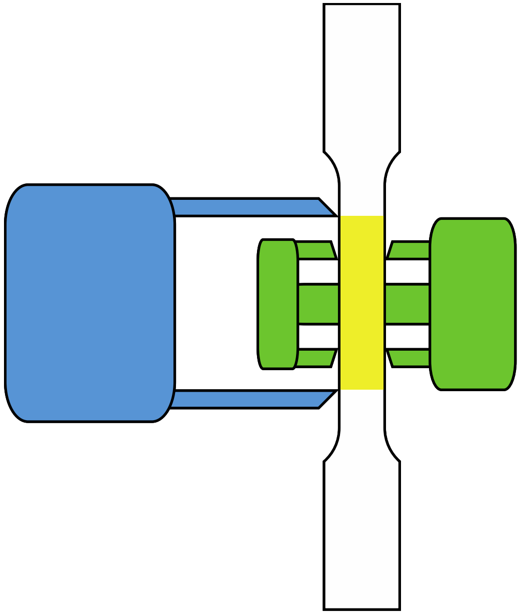


Overview of ASTM E2208-02 "Guide for Evaluating Non-Contacting Optical Strain Measurement Systems"

- Framework for quantitative comparison of optical systems
- Focus on optical data and image analysis data

System Accuracy Evaluation

- Direct comparison with established measurement method
  - valid only to extent of the established method
  - does not validate local measurement
- Perform comparison under same/similar test conditions
  - calibrate system in same environmental conditions
  - process the data in same manner as test results
- Perform comparison under approximated test conditions
  - calibrate system in approximated conditions
  - process the data in same manner as test results
- Simulated measurement system
  - can not quantitatively assess the accuracy
  - can assess theoretical limit of accuracy
  - can test experimental sensitivities



Overview of ISO 22889:2013 "Method of test for the determination of resistance to stable crack extension using specimens of low constraint"

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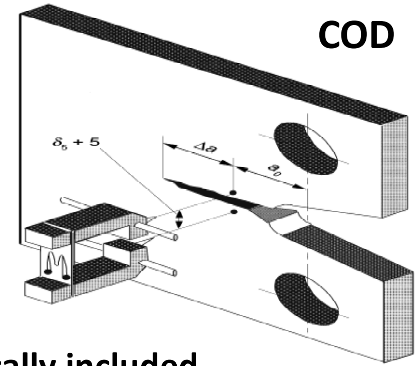
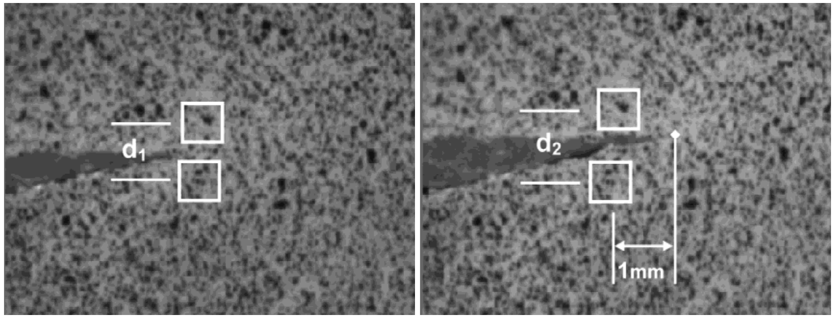
COD



DIC use specifically included

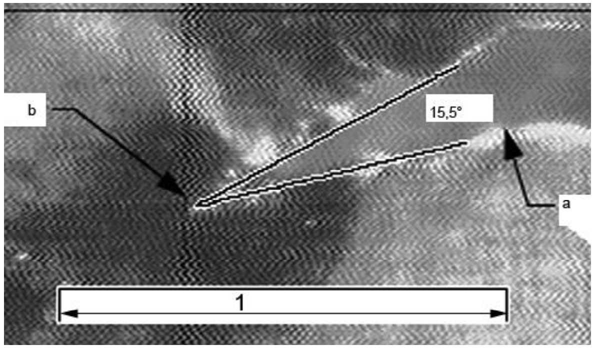
- Measurement of Crack Opening Displacement (COD) (Annex B may use digital imaging techniques)
  - Requires calibrated range of no more than 2x max.
  - Displacement with accuracy within 1% full range
  - Verified like Class 1 [C] extensometer
    - Extensometer calibrator or similar
    - Max. deviation 0.003 mm up to 0.3mm
    - Accuracy 1% of reading
- Measure displacements Crack Tip Opening Angle (CTOA) (Annex C informative has a section on DIC)
  - Describes resolution in pixels/mm,
  - Pattern size 3-5 pixels/mm for smallest possible subset
  - Overlap of images for translating DIC systems
  - Moving reference (want displacement not plasticity)
  - Subset sizes typical 12-20 pixels
  - Location of crack tip is the primary source of error

DIC for CTOA



Reference Image | Image after Crack Advance

Optical Microscopy for CTOA



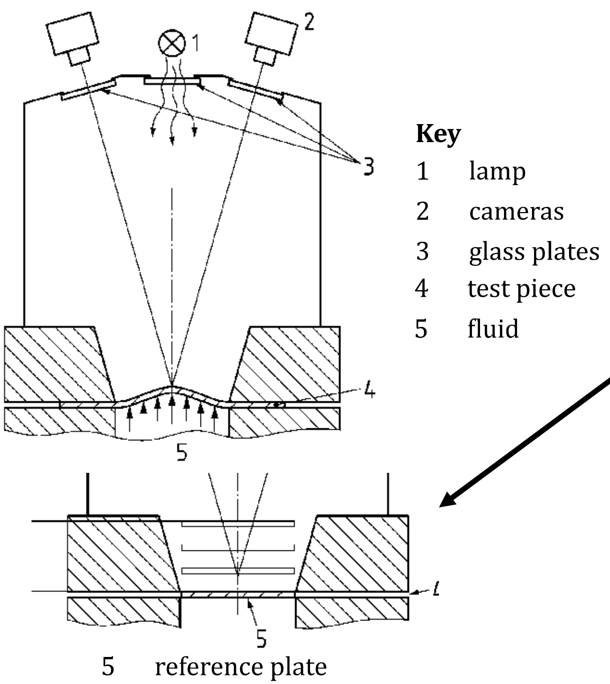
Report

- No measurement method or parameters
- Example report has footnote of method used

Overview of EN/ ISO 16808:2014 "Determination of biaxial stress-strain curve by means of bulge test with optical measuring systems"

Standard calls for a full-field optical method,
but clearly DIC is included
(either deterministic grid or stochastic pattern)

SETUP



DIC Requirements:
- Local curvature (shape) measurement
- True surface strain measurement
- Glass must be cleaned between tests
- Glass can not disturb the optical measurement quality
- Verification in required Annex B accuracy check
  rms(dz) ≤ 0.015 mm over RBM at ≥ 5 position
- Paint pattern must adhere and withstand deformation
- Do not use curvatures measurements at start of test

DIC Recommendations:
- Use glass plates to protect cameras
- Calibrate system with glass plates in place
- Use ≥ 2 cameras
- Suggested FOV and ROI for analysis and measurement
- Measurement spatial resolution
- Restrict drop out in ROI to ≤ 5% of data points
- rms(e1) ≤ 0.003 & rms(e2) ≤ 0.003
- Pattern size and contrast sufficient for measurement
- Suggest ≥ 100 images through loading history

DIC Report:
- grid, camera, & software used
- position of glass plates

Overview of ISO 12004-2 "Determination of forming-limit curves in the laboratory"

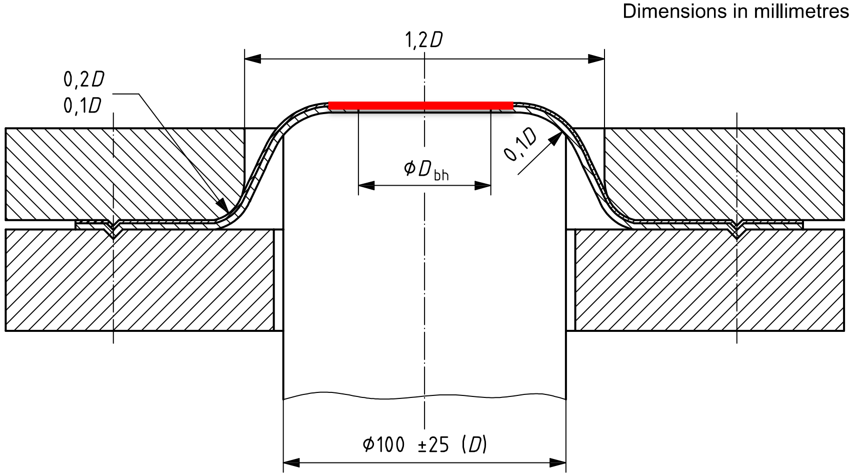
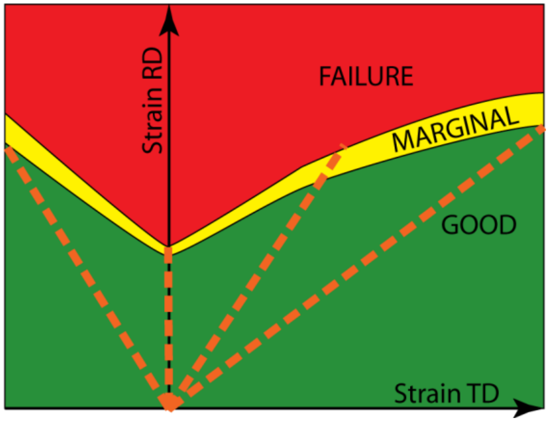
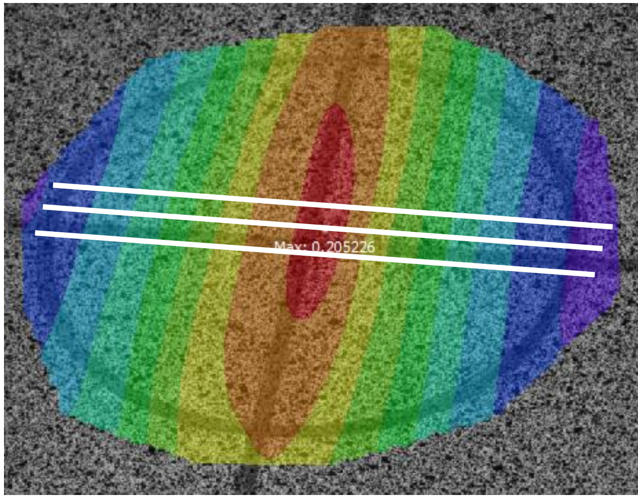


Figure 6 — Illustration of the cross section of the tool used for Marciniak testing



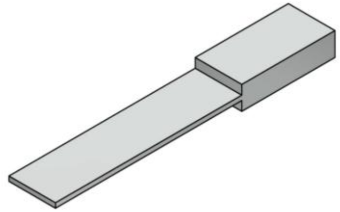


Notable Aspects of Strain Measurement:

- Well defined method and procedure
- Required image capture rate associated with punch tool displacement rate
- Optical method that is "position dependent" (local strain), NOT DIC specific
- Pattern can be Grid or Stochastic
- Suggested grid or virtual-grid spacing of data points
- Strain accuracy better than 2% strain
- Initial grid accuracy better than 1%
- Length measurement with uncertainty <1% of the length, for a total accuracy better than 2%
- Extract various strain profiles across the localization and post process to get forming-limit strains
- "(accuracy depends on grid accuracy/resolution, camera resolution, measuring field, calculation algorithm ...)"

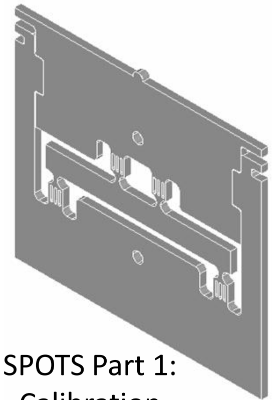
History of the SPOTS & ADVISE Projects

1990-2008 VAMAS - TWA 26 [1]
"Full field optical stress and strain measurement"
- Photoelasticity
- Moiré methods
- Laser speckle and interferometry methods
- Image correlation techniques
- Thermoelastic methods



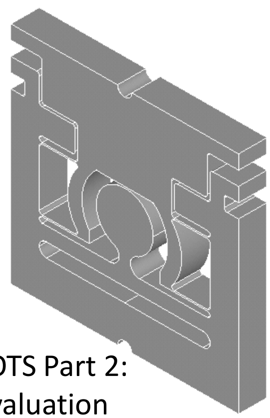
20011-2012 ADVISE project [3]
"Advanced Dynamic Validations using Integrated Simulation and Experimentation"
- Laser speckle and interferometry methods
- Image correlation techniques
- Thermoelastic methods
- Dynamic
- 3D

1990 2002 2008 2011 2014



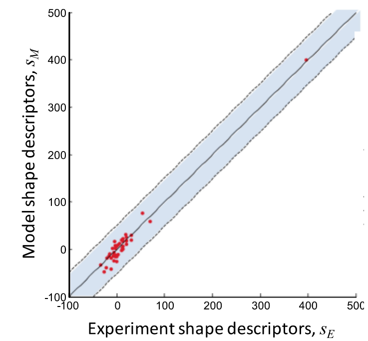
SPOTS Part 1:
Calibration
(Reference Material)

2007-2008 SPOTS Guidelines [2]
"Standardization Project for Optical Techniques of Strain measurements"
- various optical measurement techniques
- Static
- 2D



SPOTS Part 2:
Evaluation
(Challenge Material)

2014 CEN Workshop Agreement 16799 [4]
"Validation of computational solid mechanics models"
- compare model and measurement
- static and dynamic
- 2D and 3D



References:
[1] http://www.vamas.org/twa26/index.html
[2] Guide. for the Cal. & Eval. of Optical Sys. for Strain Measure., ISBN 978-0-9842142-2-8, 2010
[3] http://www.dynamicvalidation.org/
[4] CWA 16799:2014 en

SPOTS "Guidelines for the Calibration and Evaluation of Optical Systems for Strain Measurement Part 1: Calibration"

National Institute of Standards and Technology
U.S. Department of Commerce

Goal: Traceability for a strain field through a reference material (artifact) to a primary international standard (i.e. SI) for various optical strain measurement systems

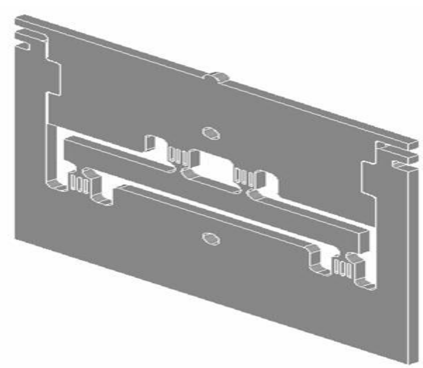
Optical Systems Considered
- Photoelasticity
- Moiré methods
- Laser speckle and interferometry methods
- Image correlation techniques ← **DIC**
- Thermoelastic methods

→

Restrict to:
- In-plane strain field (ideally plane-strain)
- Static or quasi-static loading
- Elastic strain
- Material requirements

Essential Attributes:
- Easy optical access
- Lack of hysteresis
- In-plane strain field
- Traceability to the SI
- Use the length standard for traceability

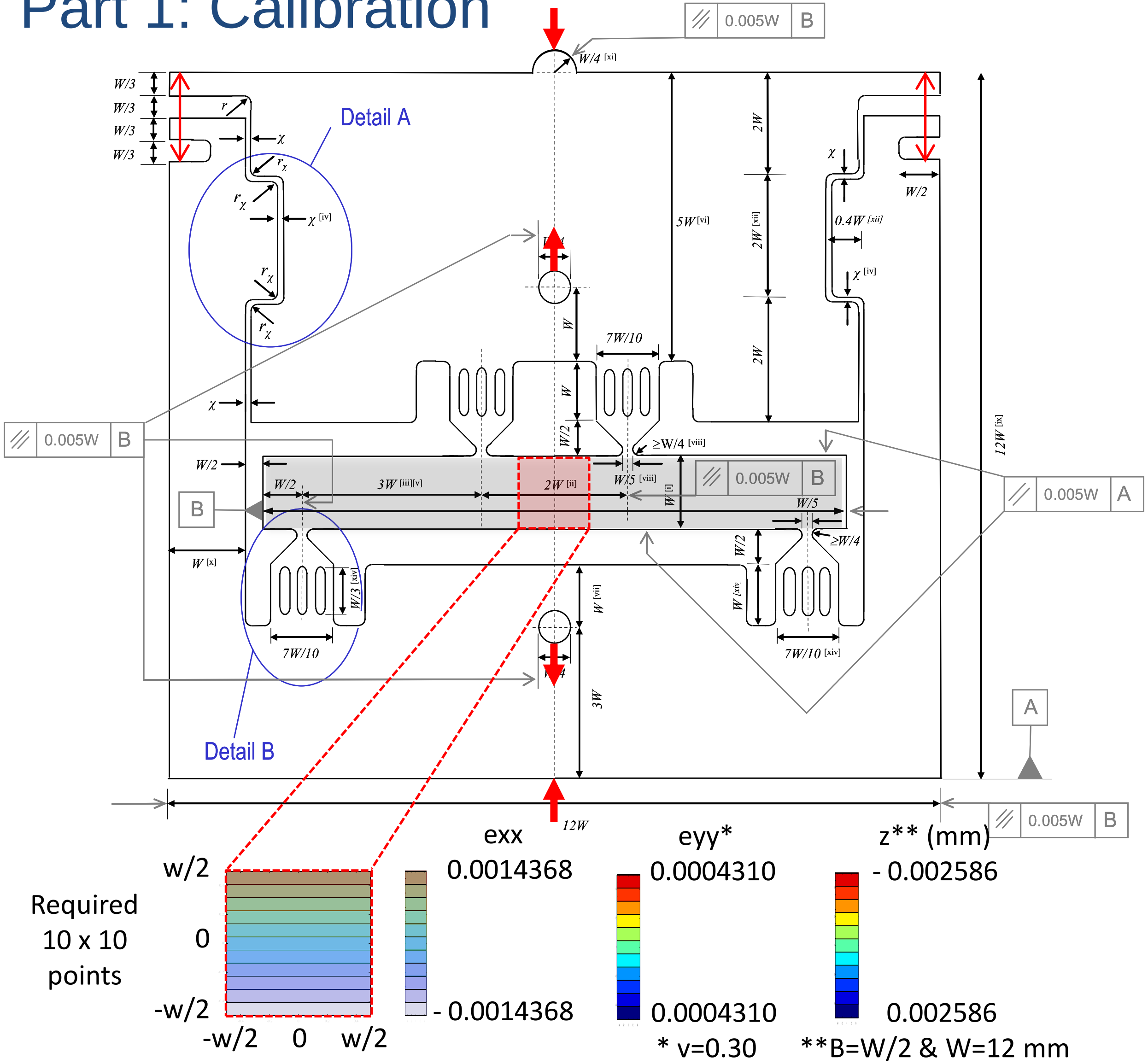
Preliminary designs (beam in 4-point bend or Hertzian disk on half space) tested in round-robin, that showed reproducibility problems due to load frame.



- Monolithic design (improve reproducibility)
- Traceable to length standard (and displacement)
- Scalable parametric design
- Material requirements: homogenous, isotropic, no hysteresis, linear elastic, known Poison's ratio
- Any one can manufacture
- Uncertainty can be characterized

SPOTS "Guidelines for the Calibration and Evaluation of Optical Systems for Strain Measurement Part 1: Calibration"

NIST National Institute of Standards and Technology U.S. Department of Commerce



Positives:

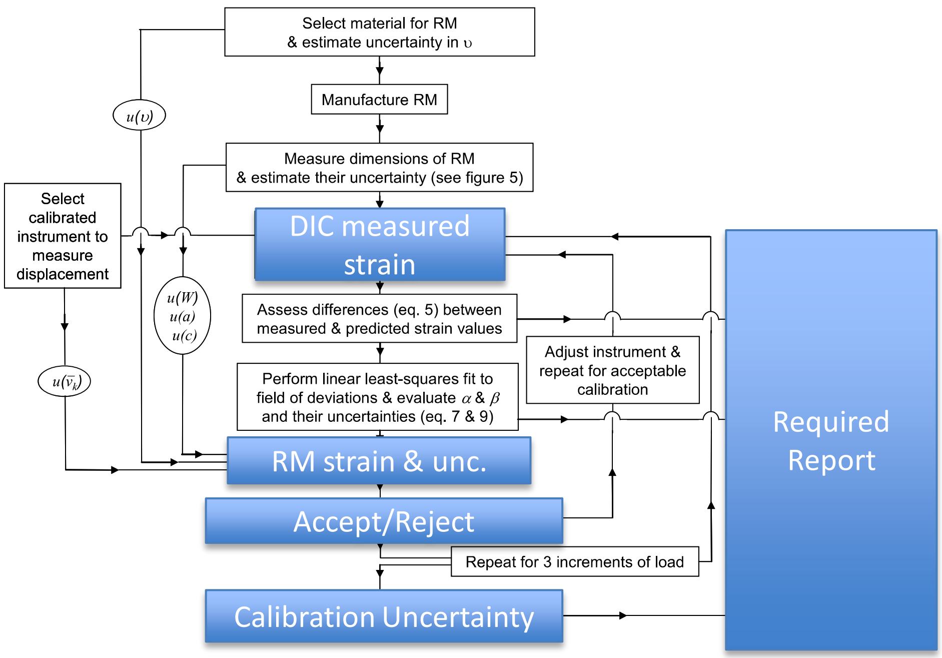
- Prevent overload
- Compression & tension
- Variable strain field in x and y
- Traceable to displacement
- Quantifiable uncertainty due to manufacture
- Well defined analysis procedure (including rejection criteria)

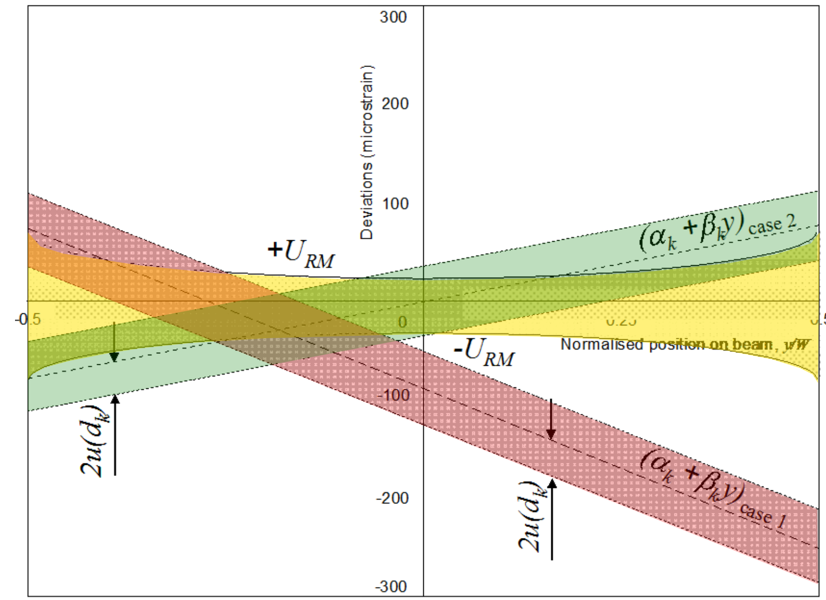
Negatives:

- Need a material that will work
- No hysteresis (procedure?)
- Flat after machining (residual stress?)
- Limited strain range
- Supports are not as idealized
- Some corrections required
- May require strain gauging (added traceability issues)
- Out-of-plane motion neglected

SPOTS "Guidelines for the Calibration and Evaluation of Optical Systems for Strain Measurement Part 1: Calibration"

National Institute of Standards and Technology
U.S. Department of Commerce





Examples

Defined Methodology for use:

- Estimate RM Strain & Uncertainty (Traceable)
- Quantifiable uncertainty due to manufacture
- Measure strain field in defined area
- Correction for non-ideal behavior
- Well defined analysis procedure (with acceptance/rejection criteria)

Case 1:

- Poor overlap
- Coincides in part of negative loading
- Very limited verification over a small load level window

Case 2:

- Good overlap
- Coincides with reference at all load levels

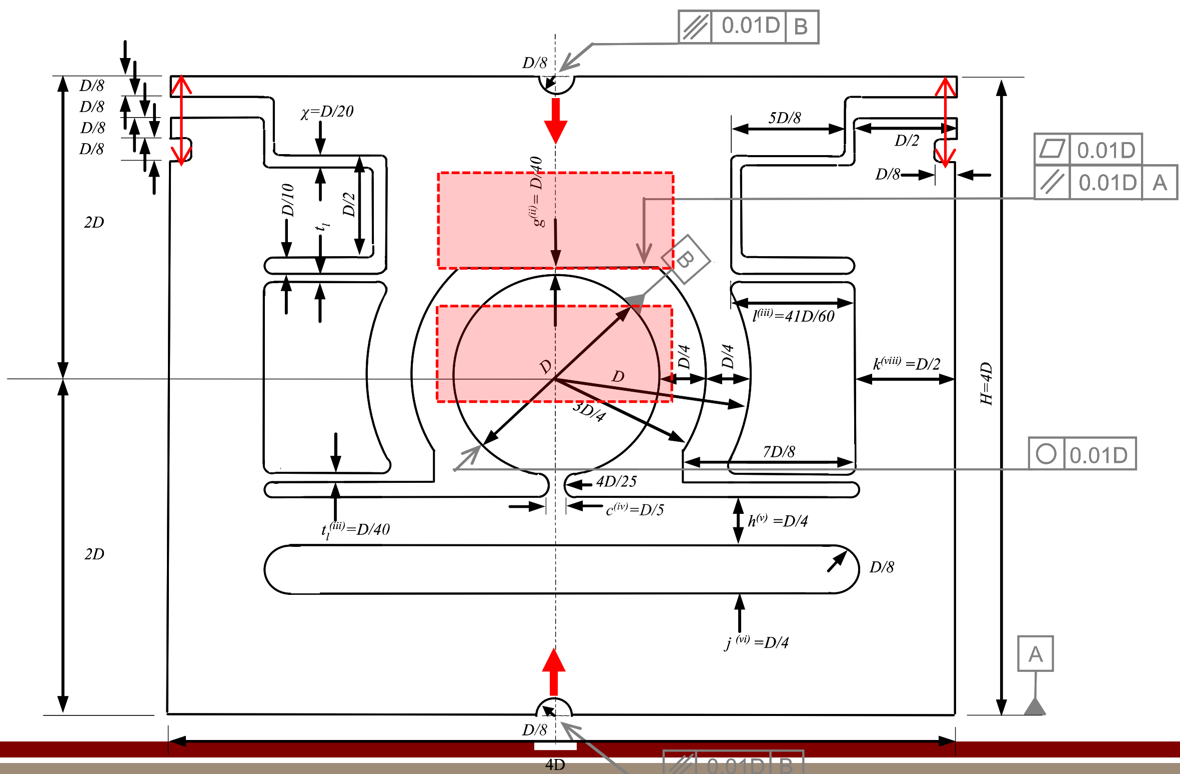
SPOTS "Guidelines for the Calibration and Evaluation of Optical Systems for Strain Measurement Part 2: Evaluation"

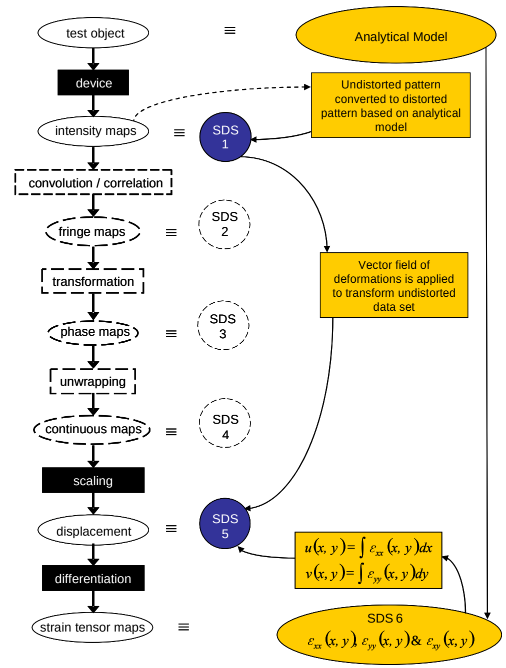
National Institute of Standards and Technology
U.S. Department of Commerce

<u>Goal</u>: This preliminary design was seen to be more difficult to characterize and results in a more challenging strain field compared to Part 1.

Similar to Part 1:

- Various optical systems considered
- Similar restrictions to in-plane and static
- Similar (maybe softened) essential attributes
- Monolithic and scalable design





Defined Methodology for use:

- Optical system (e.g. DIC) specific
- Compression only
- Two field comparison regions
- Some regions invalid to solution
- Some corrections still needed

ADVISE - Advanced Dynamic Validations using Integrated Simulation and Experimentation

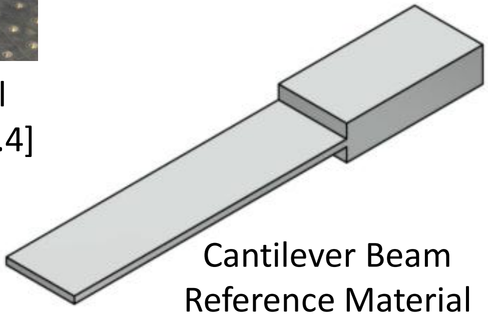
NIST National Institute of Standards and Technology U.S. Department of Commerce

Goal: Building on the success of the SPOTS project, expand the reference material method for non-planer deformations of cyclic, transient, non-linear dynamic events. Develop method for quantitative comparison with numerical modeling for validation.

Optical Systems Considered
- Digital Image Correlations
- Thermoelastic Stress Analysis
- Digital Speckle Pattern Interferometry

Essential Attributes: [*D5.5]
- Access for full-field optical measurement
- Repeatable dynamic behavior
- Measureable deformations for calibration
- Traceability to the SI
- Optimization method for quantitative comparison

Plate Reference Material for Cyclic Calibration [*D3.4]

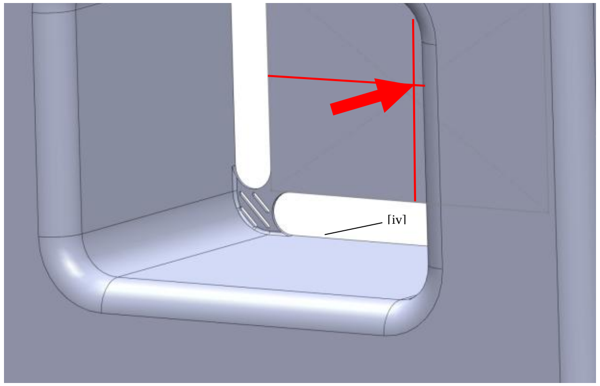


Cantilever Beam Reference Material for Transient [*D3.5] and Non-linear [*D3.7] Calibration

Outcomes:
- A list of essential attributes of a reference material
- ➡ Two potential reference material designs
- ➡ Guide for deformation and strain measurement techniques [*D2.8]
- Guide to damage quantification [*D2.6]
- ➡ Guide for validation of simulations by experiments based on comparison of shape descriptors [*D4.7]

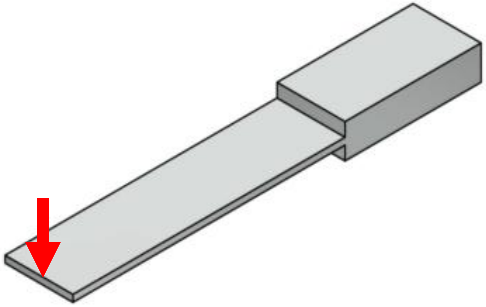
ADVISE - Advanced Dynamic Validations using Integrated Simulation and Experimentation

Plate Reference Material for Cyclic Calibration



- Cyclic dynamic deformation
- u, v, w displacements in x, y, z directions
- In-plane strain field
- Range of displacements in FOV
- b.c. reproducible (but complicated "pinned"), portable, & robust
- Machining considerations (e.g. residual stress)

Cantilever Beam Reference Material for Transient and Non-linear Calibration



- Transient & non-linear dynamic deformation
- u, v, w displacements in x, y, z directions
- In-plane strain field
- Range of displacements in FOV
- b.c. reproducible, portable, & robust
- Machining considerations (e.g. fillet radius & residual stress)
- Tip deflection measurement & elastic solution
- Low elastic modulus and high yield strength

ADVISE - D2.8 "Draft standard guide for optical deformation measurements in dynamic events"

NIST National Institute of Standards and Technology U.S. Department of Commerce

Overview

- Systems (references for each):
  - DIC
  - Thermoelastic Stress Analysis
  - Digital Speckle Pattern Interferometry
- General concepts/principles with definitions of terms
- General parts of apparatus (e.g. cameras, optics, lighting)
- Special requirements for dynamic measurements
- Sample preparation recommendations
- Calibration description and recommends verification by reference material (static or dynamic)
- Potential areas of application
  - Determination of material properties
  - Mode shape analysis
  - Impact event measurement
  - Numerical simulation evaluation

Specific procedural recommendations

- DIC measurement setup and recording procedures
  - Mechanical system setup
  - Optical setup of system
  - Determination of projection parameters
  - Recording of Images
- DIC data processing procedures
  - Select images to process
  - Define correlation parameters
  - Select a starting point
  - Perform full-field evaluation
  - Reconstruct the object surface
  - Calculate deformations
  - Visualization and extraction of data

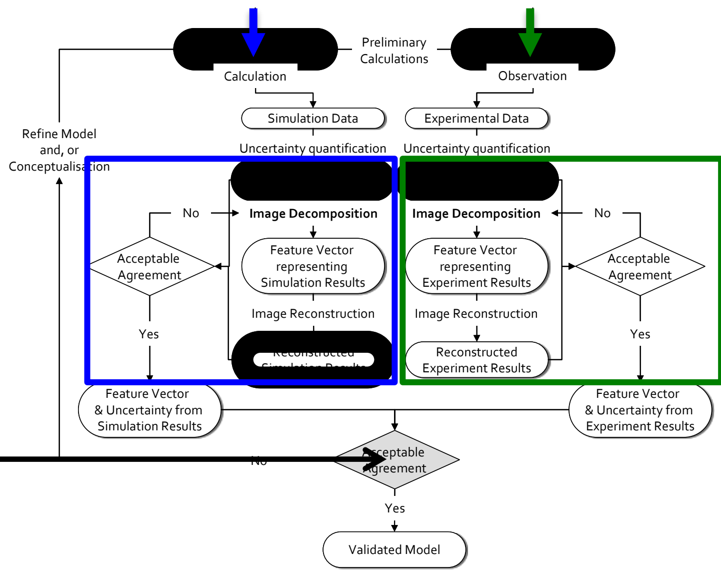
May be a good starting point for standard procedure.
May be a good start of fish-bone diagram of potential errors.

CWA 16799 "Validation of computational solid mechanics models"

(Similar to ADVISE – D4.7 "Guide for the validation of computational solid mechanics models using full-field optical data")

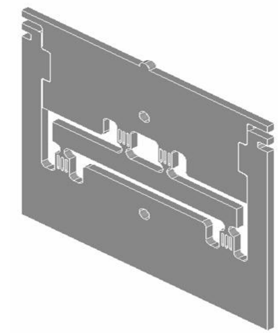
Plan/Strategy for Validation

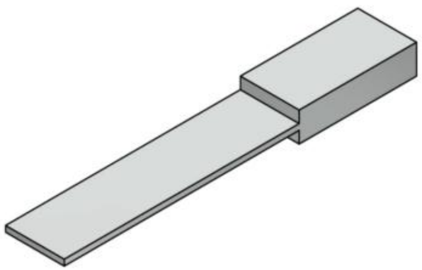
Simulation Experiment



- Decompose into a form that is invariant to rotation, scale, or translation
- Match to with in measurement uncertainty (rejection & refinement)
- Compare reduced set of data

Calibration/Verification





SPOTS Part 1: Beam ADVISE Cantilever Beam

- in-plane
- static or quasi-static static

- out-of-plane
- dynamic

Recommendations

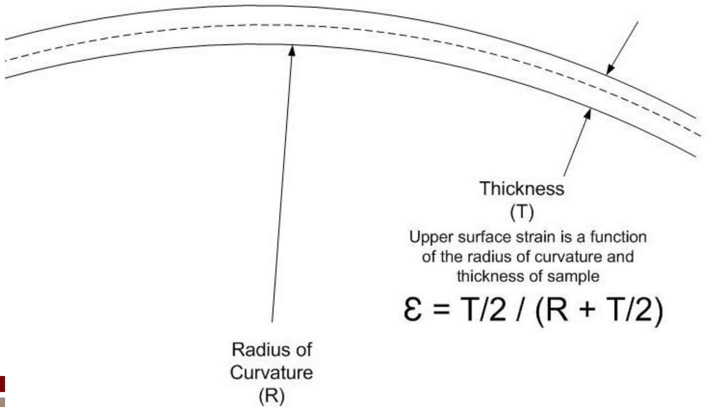
- Verify the measurements in full-field & rate
- Validate with full-field data
- Need good setup including FOV and resolution
- Use displacements or strains as appropriate to the mechanics problems (e.g. buckling or material failure)
- Similar to design of experiment concept

"Optical Mechanical Strain Validation Standards at The Boeing Company"

By Thomas Valenti at ASTM E28.01 AC273 Nov. 2015

Goal: A traceable, representative, and in-situ simulator of an optical strain field for use as a reference for mechanical strain.

- A set of reference tooling blocks, and a set of shims of various thicknesses to create strain fields for placement in the FOV of the DIC system.
- Pattern shims same a test specimens
- Assume uncertainty sources considered sheet thickness, curvature of block paint thickness offset
- Assume simple beam theory
- Reference flat on back face
- Reference curved to create compressive strains



Standards and the International Digital Image Correlation Society

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IDICS Mission includes "Standardizing for Industry" & "Improving Practice"

Standardization, Best Practices, & Uncertainty Quantification Committee

- Accuracy and traceability
- Promote Standardization
- Point of contact for standards bodies (technical advisory group)
- Underpinnings of uncertainty quantification
- Develop best practices
- Terminology unification
- DIC Challenge
- Quantification of comparisons to DIC
- Round-robin organization or referee work

JOIN US WEDNESDAY AFTERNOON OVER LUNCH!

Training & Certification Committee

- Workshops or short courses
- Certification levels and training
- Develop best practices
- Terminology unification

JOIN US WEDNESDAY MORNING OVER BREAKFAST !

iDICs INTERNATIONAL DIGITAL IMAGE CORRELATION SOCIETY

My hope is that this society can build the consensus that can then be propagated out the the standards community.

Digital Image Correlation and Standardization
Take Away Points

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Conclusion Summary Other

How do consensus standards come about?

De facto Standards (consumer expectations, general use)
Industrial Standards (grow from multiple companies in a sector)
International Standards (consensus between countries or multiple sectors)
Regulatory Standards (governmental bodies) (and borrow from above)

examples
radio in car
usb3
???
CAFE

Introduce interested parties?

	Sheet Metal Testing							Fracture			High strain rate		General Use				Independent Projects/Methods				
	ASTM E517-00	ASTM B831-14	ISO 16842	EN ISO 16808:2014	ISO 12004-1	ISO 12004-2	ASTM E2218-15	ISO 22889:2013	ASTM E2472-12	ASTM E2899–15	ISO 26203-2:2011	ISO 26203-1:2010	ISO 9513:2012	ASTM E83-06	ASTM E28.01 AC273	ASTM E2208	SPOTS P1	SPOTS P2	ADVISE	CWA 16799:2014	Boeing Laboratory
2-point/ uniform/ variable/ localized strain field				localized				2-point			2-point		2-point				variable				
Required 2D/3D				3D				2D			2D		2D								
elastic/ plastic/ near-failure strains	plastic										plastic		elastic and plastic				elastic				
static/ quasi-static/ dynamic	quasi-static							quasi-static			dynamic		quasi-static								
Verification included yes/no	no							no			no		yes				yes RM				

		ASTM E517-00	ASTM B831-14	ISO 16842	EN ISO 16808:2014	ISO 12004-1	ISO 12004-2	ASTM E2218-15
2-point/ uniform/ variable/ localized strain field	Sheet Metal Testing				localized			
Required 2D/3D					3D			
elastic/ plastic/ near-failure strains		plastic						
static/ quasi-static/ dynamic		quasi-static						
Verification included yes/no		no						

2-point/ uniform/ variable/ localized strain field

Required 2D/3D

elastic/ plastic/ near-failure strains

static/ quasi-static/ dynamic

Verification included yes/no

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		DIC/Optical	2-point/ uniform/ variable/ localized strain field	Required 2D/3D	elastic/ plastic/ near-failure strains	static/ quasi-static/ dynamic	Verification included yes/no
<u>Sheet Metal Testing</u>							
ASTM E517-00	**Plastic R-ratio sheet metal test (Draft 2016)**	x	2-point and localized	NA	P	quasi-static	no
ASTM B831-14	**Shear test thin Aluminum**	x	uniform	NA	P	quasi-static	no
ISO 16842	**Biaxial cruciform test**		variable	NA	E & P	quasi-static	no
EN ISO 16808:2014	**Biaxial bulge test**		local	3D	P	quasi-static	yes disp.RM
ISO 12004-1	**Forming limit test**		local	3D	P	static	no
ISO 12004-2	**Forming limit test**	x	localized	3D	P & Fail	quasi-static	no
ASTM E2218-15	**Forming limit test**	x	localized	3D	P	quasi-static	no
<u>Fracture</u>							
ISO 22889:2013	**Stable crack extension test**	x	2-point	2D	NA	quasi-static	no
ASTM E2472-12	**Stable crack extension test**	x	2-point	2D	NA	quasi-static	no
ASTM E2899–15	**Initiation toughness in surface cracks test**	x	2-point	2D	NA	quasi-static	no
<u>High strain rate</u>							
ISO 26203-2:2011	**Tensile high strain rate servo-hydraulic test**		2-point	2D	P	dynamic	no
ISO 26203-1:2010	**Tensile high strain rate elastic bar test**		2-point	2D	P	dynamic	no

Standard	Test	DIC/Optical	2-point/ uniform/ variable/ localized strain field	Required 2D/3D	elastic/ plastic/ near-failure strains	static/ quasi-static/ dynamic	Verification included yes/no
Sheet Metal Testing							
ASTM E517-00	**Plastic R-ratio sheet metal test (Draft 2016)**	x	2-point and localized	NA	P	quasi-static	no
ASTM B831-14	**Shear test thin Aluminum**	x	uniform	NA	P	quasi-static	no
ISO 16842	**Biaxial cruciform test**		variable	NA	E & P	quasi-static	no
EN ISO 16808:2014	**Biaxial bulge test**		local	3D	P	quasi-static	yes disp.RM
ISO 12004-1	**Forming limit test**		local	3D	P	static	no
ISO 12004-2	**Forming limit test**	x	localized	3D	P & Fail	quasi-static	no
ASTM E2218-15	**Forming limit test**	x	localized	3D	P	quasi-static	no
Fracture							
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High strain rate							
ISO 26203-2:2011	**Tensile high strain rate servo-hydraulic test**		2-point	2D	P	dynamic	no
ISO 26203-1:2010	**Tensile high strain rate elastic bar test**		2-point	2D	P	dynamic	no

Interested Parties (With whom is the "consensus" built?)

ASTM: (representatives of)

user

producer

consumer

other general

ISO: (representatives of)

each country's standard body (ANSI, BSI,...)

Voting can be limited too. One rep. of each company or country.
P and O membership etc.

For each there is requirements on

Required Quorum

Defined/Open Voting/Commenting Process

Required Affirmative (>1/2 or >2/3 depending on what)

Addressing Negatives or Comments

Defined/Open Appeals process

How (consensus) standards are created, revised, and reviewed

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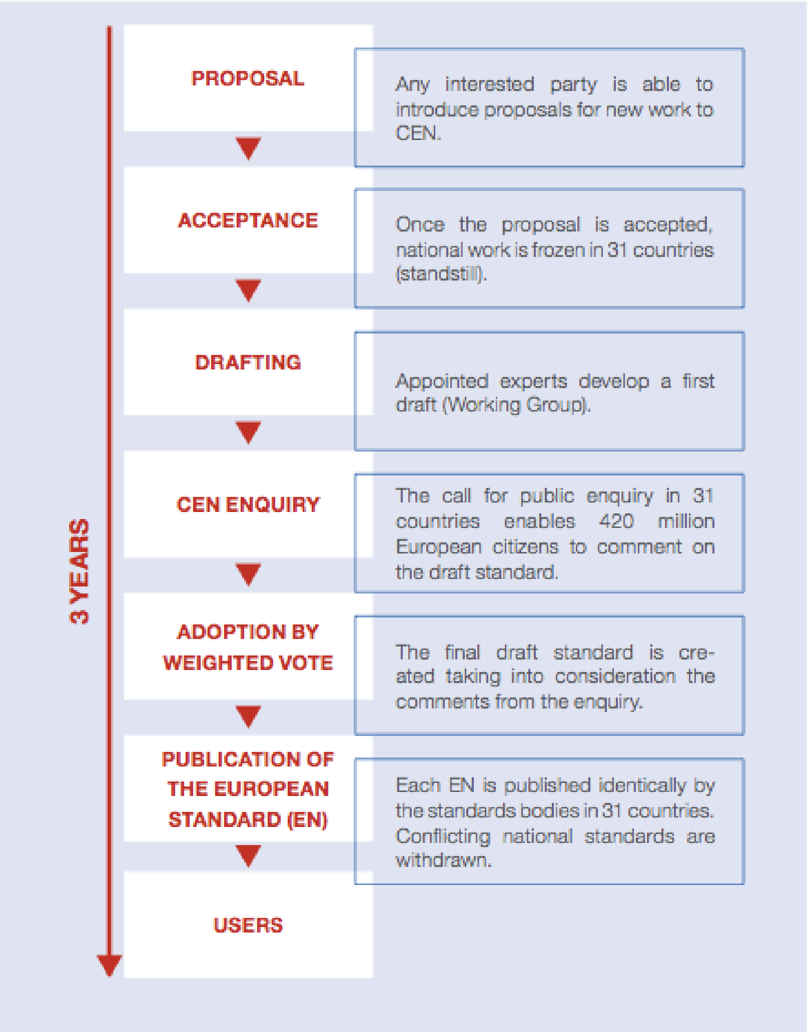
CEN



ISO

ASTM

- Sources of error – fishbone, error budget

Verification/classification vs. calibration

Repeatability vs. reproducibility
inter- versus. intra-lab testing

Best practices/Guides

round robin

benchmarking

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- Uncertainty propagation vs. Monte Carlo

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U.S. Department of Commerce

- Ways to represent: point size, error-bars, box shape, box-whisker, violin,...

DIC Standards

Detailed ISO and ASTM universal vs. ad hoc SPOTS

ISO

ISO 16808:2014 Metallic materials — Sheet and strip — Determination of biaxial stress-strain curve by means of bulge test with optical measuring systems

ISO 22889:2013 Metallic materials — Method of test for the determination of resistance to stable crack extension using specimens of low constraint

ISO 9513:2012 Metallic materials — Calibration of extensometer systems used in uniaxial testing

ISO 12004-1 First edition 2008-10-15 Metallic materials — Sheet and strip — Determination of forming-limit curves — Part 1: Measurement and application of forming- limit diagrams in the press shop

ISO 12004-2 First edition 2008-10-15 Metallic materials — Sheet and strip — Determination of forming-limit curves — Part 2: Determination of forming-limit curves in the laboratory

Optical Method...

ISO 16842 Metallic materials — Sheet and strip — Biaxial tensile testing method using cruciform specimen

ISO 26203-2:2011 Metallic materials — Tensile testing at high strain rates — Part 2: Servo-hydraulic and other test systems

Optical displ. or extensometer, or laser extensometer

ISO 26203-1:2010 Metallic materials — Tensile testing at high strain rates — Part 1: Elastic-bar-type systems

checked and N/A:

ISO/TTA 2:1997 Tensile tests for discontinuously reinforced metal matrix composites at ambient temperatures

ISO 11003-2:2001 Adhesives — Determination of shear behaviour of structural adhesives — Part 2: Tensile test method using thick adherends [mentions optical microscopy]

ASTM

E2208 Standard Guide for Evaluating Non-contacting Optical Strain Measurement Systems

E83-06 Standard Practice for Verification and Classification of Extensometer Systems

E2218-15 Standard Test Method for Determining Forming Limit Curves

E517-00 Standard Test Method for Plastic Strain Ratio r for Sheet Metal

B831-14 Standard Test Method for Shear Testing of Thin Aluminum Alloy Products

E2472-12 Standard Test Method for Determination of Resistance to Stable Crack Extension under Low-Constraint Conditions

E2899−15 Standard Test Method for Measurement of Initiation Toughness in Surface Cracks Under Tension and Bending

•Contract Law & Treaty Agreements
shall
should
may

•Verification vs. calibration

•Best practices
round robin
benchmarking

•Interested Parties
user
producer
consumer
other general
countries

•Controlling error
pre, during, and post test

•Reference materials
artifacts
types of documentary standards
roles

•Need for standards

•Compare vs. traceable

•Error vs. uncertainty
Bias vs. Precision

•BIPM vs. SI vs. ISO

•Repeatability vs. reproducibility
inter- versus. intra-lab testing

•How standards are created and revised and reviewed

•ISO and ASTM universal vs. ad hoc SPOTS

•Motivation umbrella under which we could compare and contrast effectively

• Ways to represent: point size, errorbars, box shape, box-wisker, violin,...

• Uncertainty propagation vs. Monte Carlo

• Sources of error – fishbone, error budget

• Standards: de facto, industrial(sector based), consensus, regulatory

Documentary standards from ASTM, AFNOR, API, ASME, BSI, EN, CSA, DIN, GB, ISO, JIS, SAE, ...

Acronym Soup! but does not matter they all fall under the umbrella and "trace" to a shared standard

BIPM vs. SI vs. NMI vs. ISO

BIPM   International Bureau of Weights and Measures

SI   International System of Units

NMI   National Metrology Institute

ISO   International Organization for Standards

Ensures "Standard" of Units, Processes, and Procedures to realize the necessary Metrological Traceability

Consensus signing onto agreements/treaties