The Deep Learning Data Dilemma
Solving It with Physics Based Modeling

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Deep Conversations on Deep Learning
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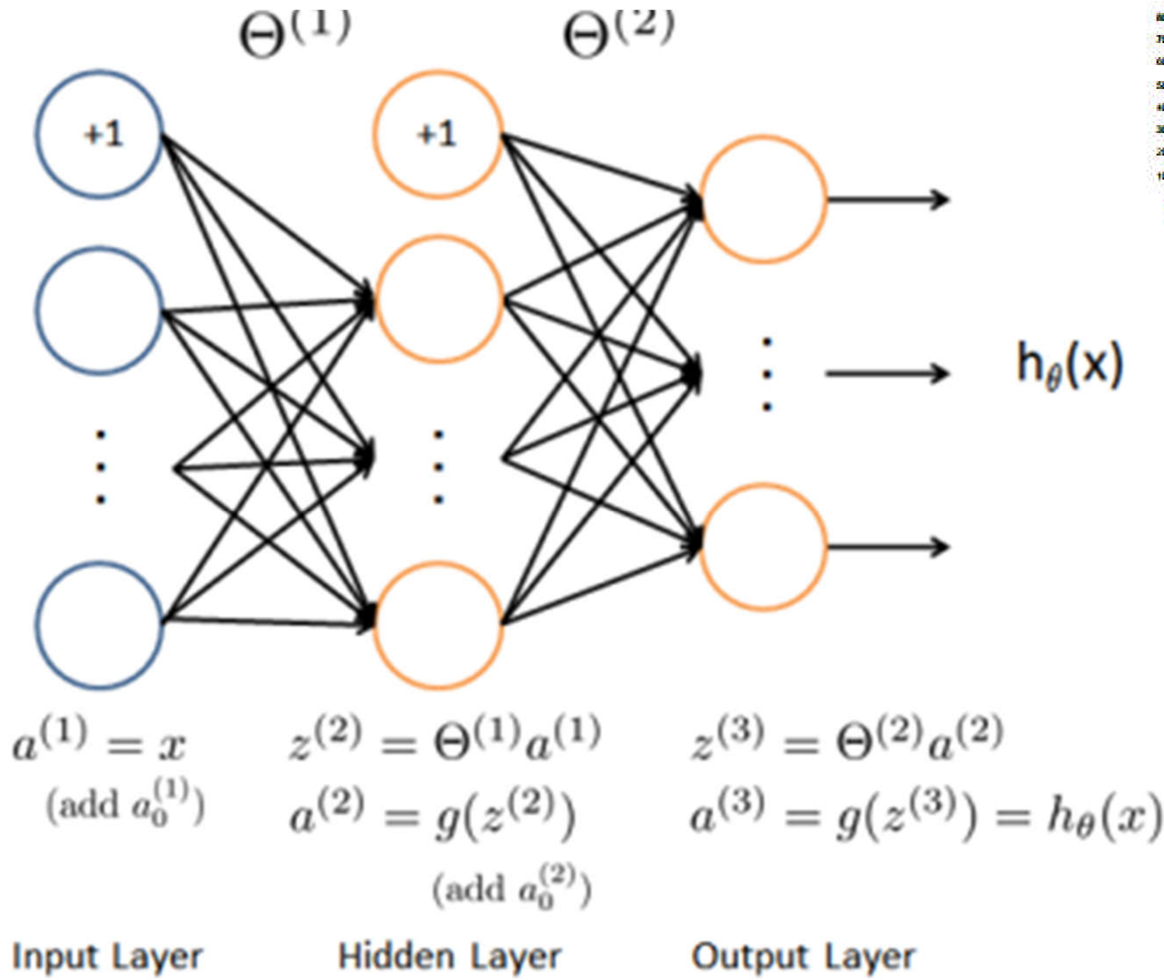
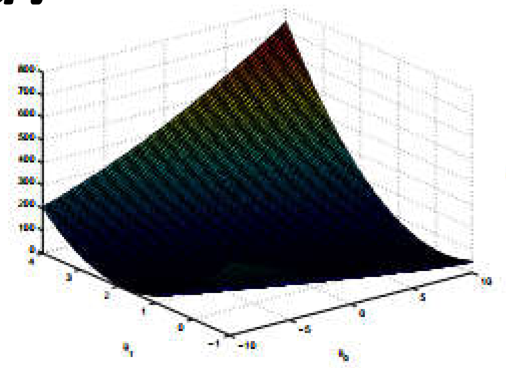
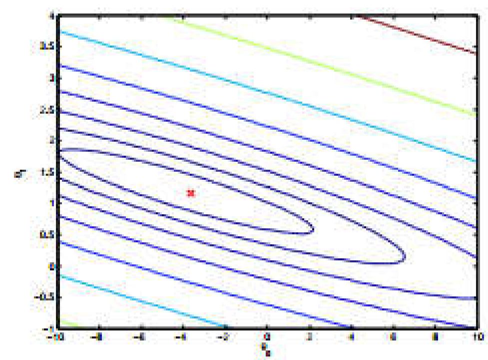
Why does Deep Learning Need Data?







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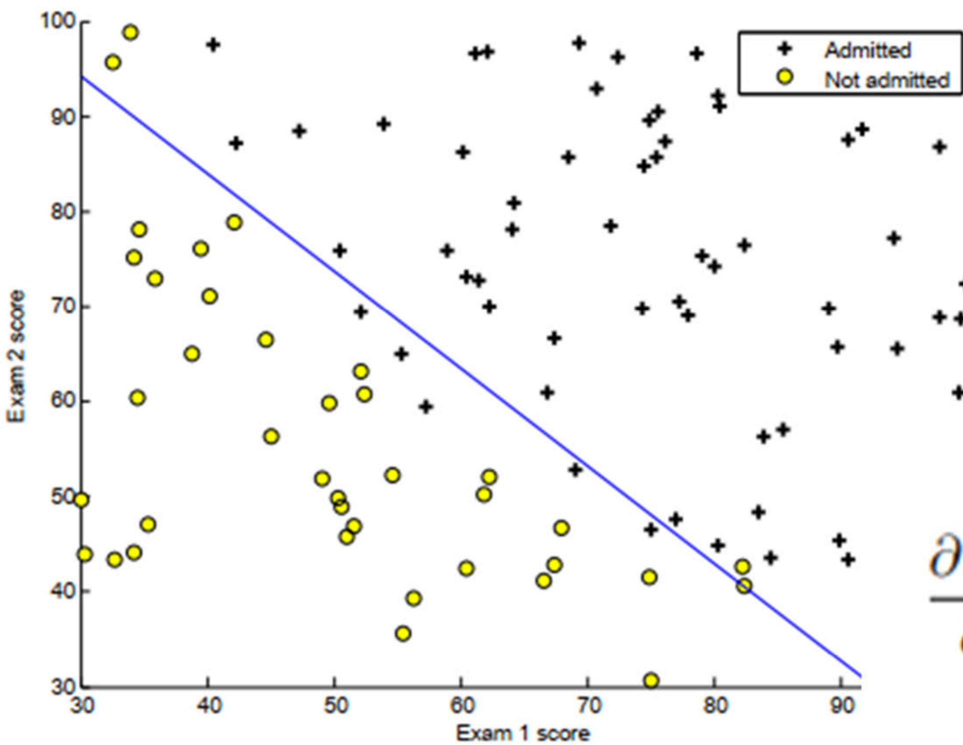

Logistic Regression

$$h_\theta(x) = g(\theta^T x),$$

Activated hypothesis

$$g(z) = \frac{1}{1+e^{-z}}.$$

Non linear activation

$$\frac{\partial J(\theta)}{\partial \theta_j} = \frac{1}{m}\sum_{i=1}^{m}(h_\theta(x^{(i)}) - y^{(i)})x_j^{(i)}$$

Parameter Gradient

$$J(\theta) = \frac{1}{m}\sum_{i=1}^{m}\left[-y^{(i)}\log(h_\theta(x^{(i)})) - (1-y^{(i)})\log(1-h_\theta(x^{(i)}))\right],$$

Cost function

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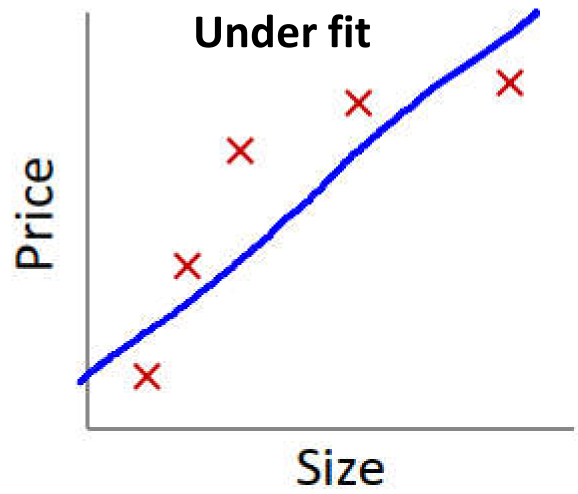
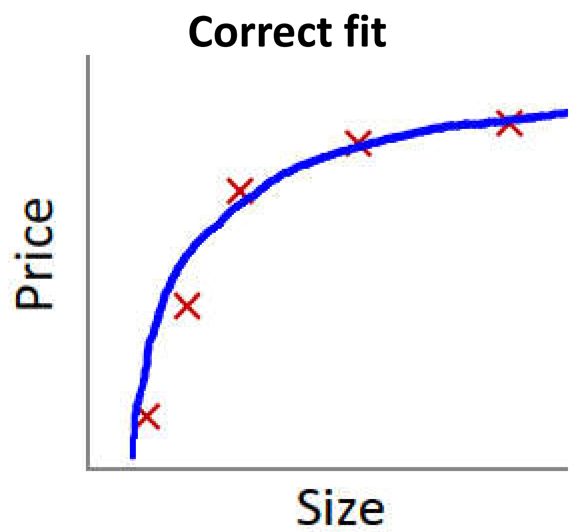
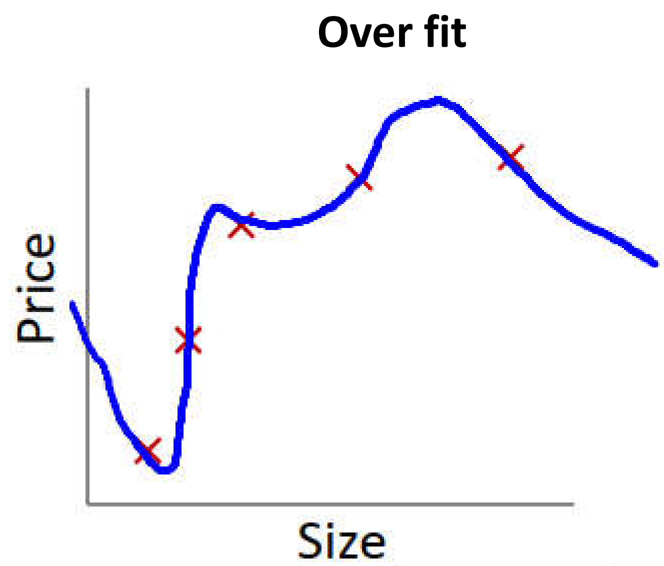


$$\theta_0 + \theta_1 x$$



$$\theta_0 + \theta_1 x + \theta_2 x^2$$



$$\theta_0 + \theta_1 x + \theta_2 x^2 + \theta_3 x^3 + \theta_4 x^4$$

In general, NNs require sufficient data to generate simply convex cost function, and certain applications require HUGE datasets

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Deep Learning Needs Lots of Data

MNIST: developed by NIST – a database of handwritten digits, containing 60,000 training images and 10,000 testing images. Used for classifying digits from 0 to 9

IMAGENET: 14,197,122 images- one of the world's largest image databases used extensively for CNN training

MIMIC-III: Openly available dataset developed by the MIT Lab for Computational Physiology, comprising de-identified health data associated with ~40,000 critical care patients - demographics, vital signs, laboratory tests, medications, and more.

Deep Learning Needs Lots of Data

WAYMO OPEN DATA:

- **1,950 segments of 20s each, collected at 10Hz (200,000 frames) in diverse geographies and conditions**
- **Sensor data: 1 mid-range lidar, 4 short-range lidars ,5 cameras**
  Synchronized lidar and camera data, Lidar to camera projections
  Sensor calibrations and vehicle poses
- **Labeled data**
  Labels for 4 object classes - Vehicles, Pedestrians, Cyclists, Signs
  High-quality labels for lidar data in 1,200 segments
  12.6M 3D bounding box labels with tracking IDs on lidar data
  High-quality labels for camera data in 1,000 segments
  11.8M 2D bounding box labels with tracking IDs on camera data

But What Happens When There is Insufficient Data?

Equations that changed the world – a partial list – Ian Stewart

Wave Equation	$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$
Fourier Transform	$f(\omega) = \int_{\infty}^{\infty} f(x) e^{-2\pi i x \omega} \mathrm{d}\, x$
Navier-Stokes Equation	$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \nabla \cdot \mathbf{T} + \mathbf{f}$
Maxwell's Equations	$\nabla \cdot \mathbf{E} = 0 \quad \nabla \cdot \mathbf{H} = 0$ $\nabla \times \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{H}}{\partial t} \quad \nabla \times \mathbf{H} = \frac{1}{c}\frac{\partial E}{\partial t}$

Physics Based Models – Methods of Solution

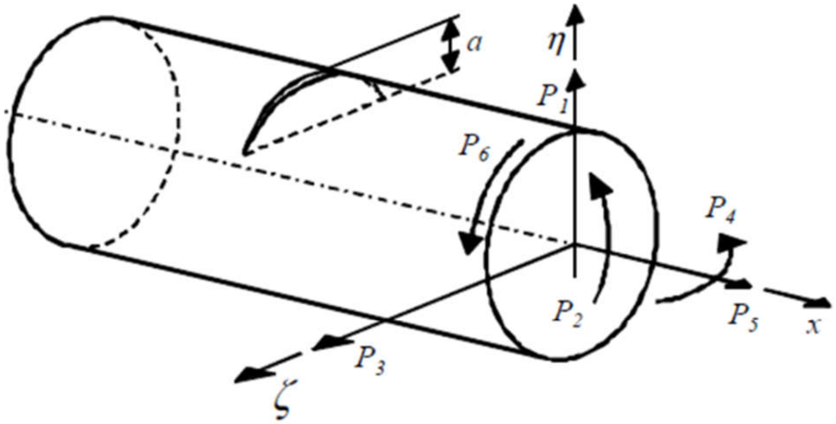
Analytical

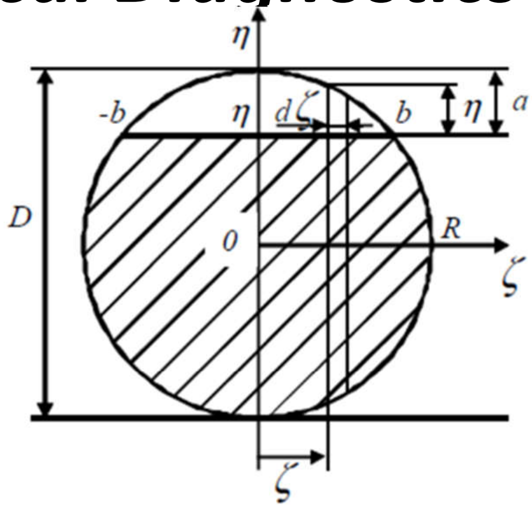
- **Separation of Variables- Sturm Louisville Problems**
- **Integral Transform infinite domains**
- **Green's Functions – excitation/response**
- **Method of Characteristics- domain mapping**

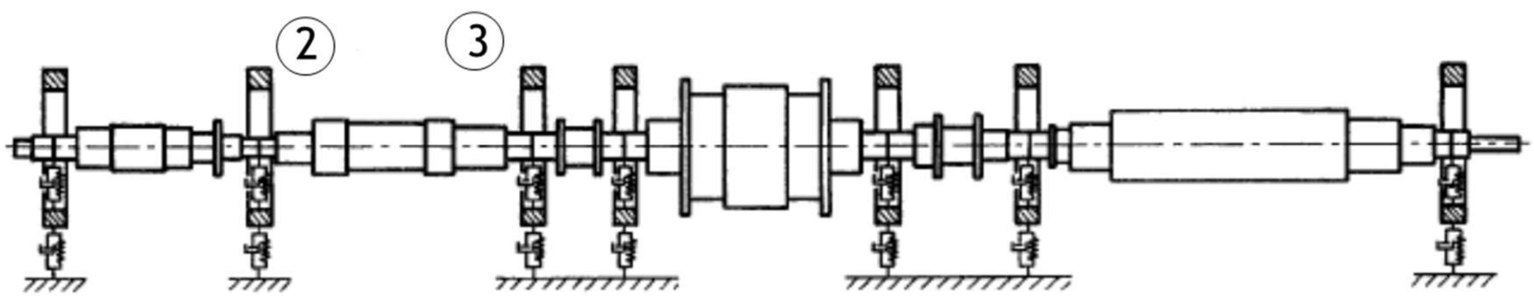
Numerical

- **Finite Element**
- **Finite Difference**
- **Moment Method – reduction of integro differential system to vector space (basis and testing functions)**

The World of Mechanical Diagnostics

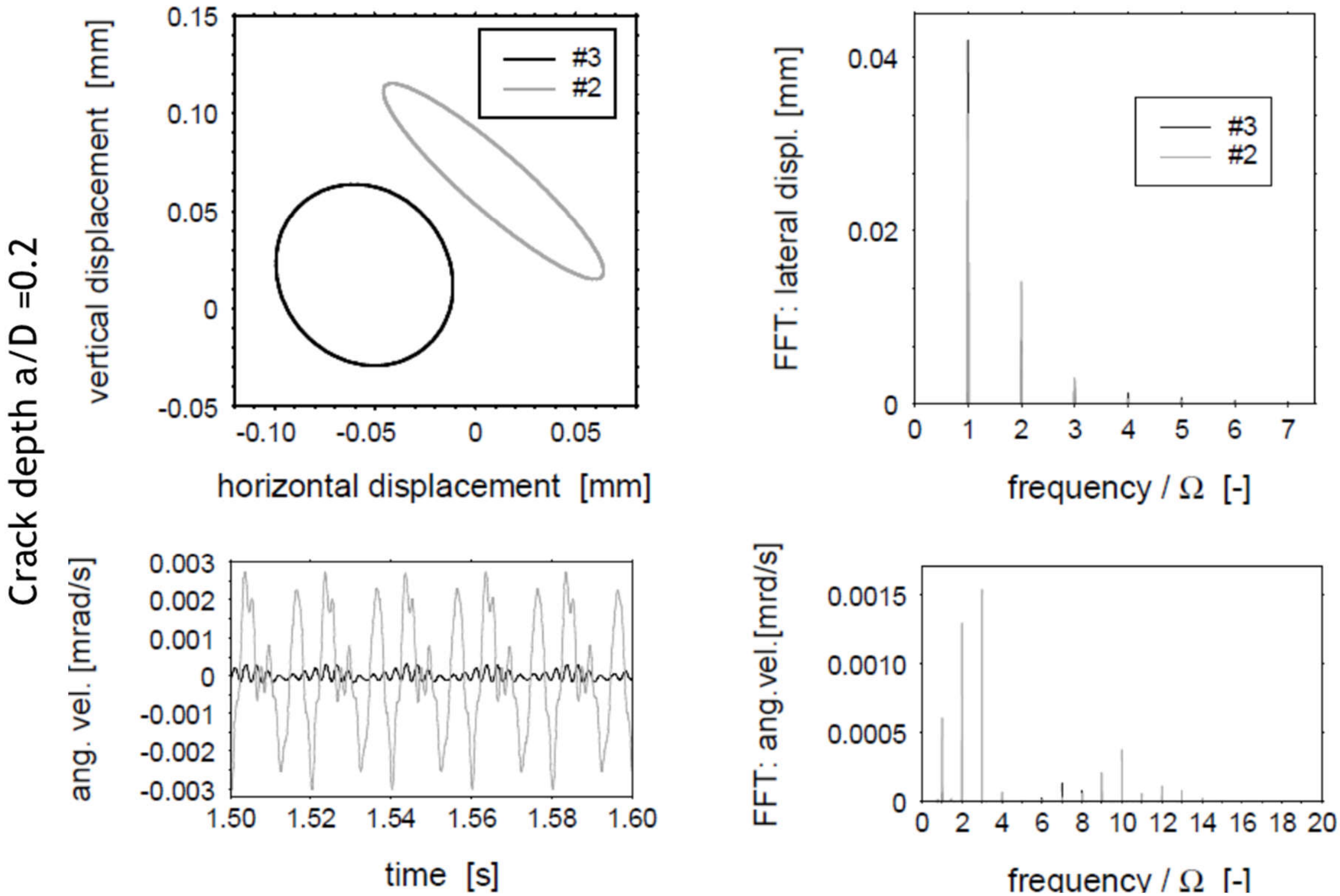






"Nonlinear and parametric coupled vibrations of the rotor shaft system as fault identification system using stochastic methods", T. Szolc, P. Tauzowski, J. Knabel, R. Stocki, Institute of Fundamental Technological Research, Polish Academy of Science

The World of Mechanical Diagnostics



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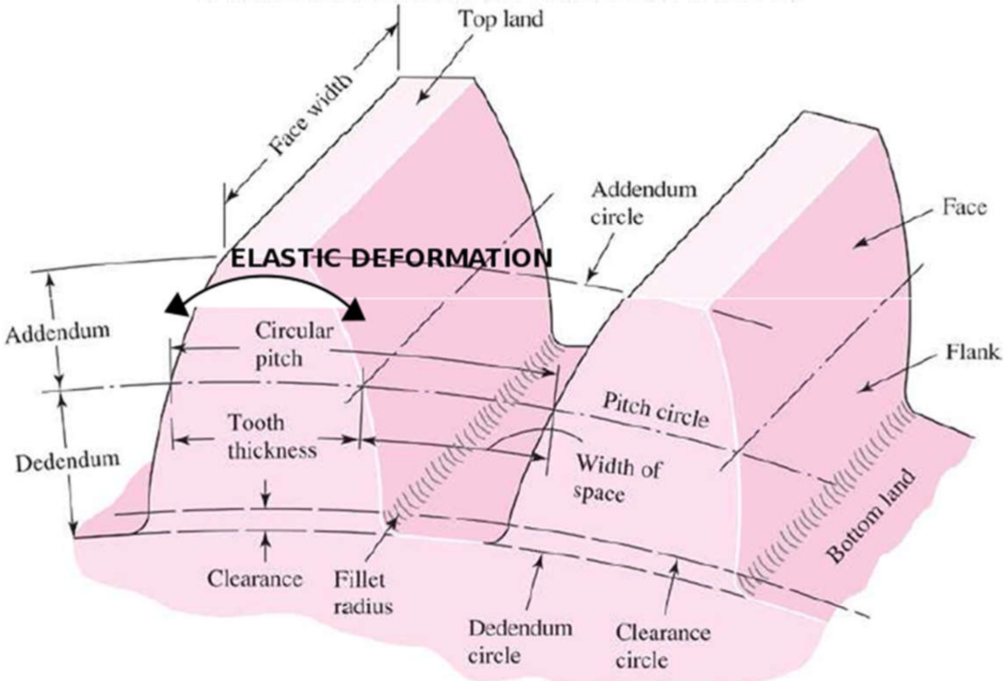
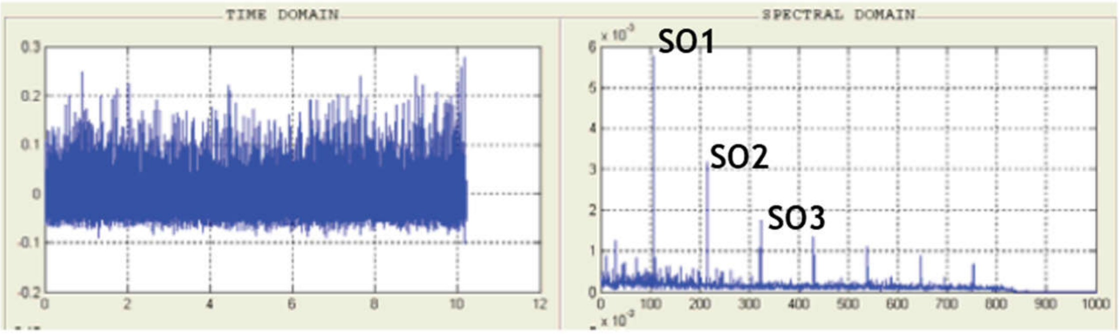


"Amplitude of Probability Density Function (APDF) of vibration response as a robust tool for gearbox diagnosis", P.T. Rzeszucinski, J.K. Sinha, R. Edwards, A. Starr, B . Allen, *Strain*, Vol 48 No 6 pp 510-516, Dec 2012

The World of Mechanical Diagnostics

TSA spectrum with gear mesh overlay



Time synchronous average (time domain)

Time synchronous average (frequency domain)

Shaft order 1 magnitude: *magnitude of shaft first harmonic in frequency domain, indicator of mass imbalance or bent shaft*

Shaft order 2 magnitude: *magnitude of shaft second harmonic in frequency domain, indicator of coupling failures (misalignment) or bent shaft*

Shaft order 3 magnitude: *magnitude of shaft third harmonic in frequency domain, indicator of coupling failures.*

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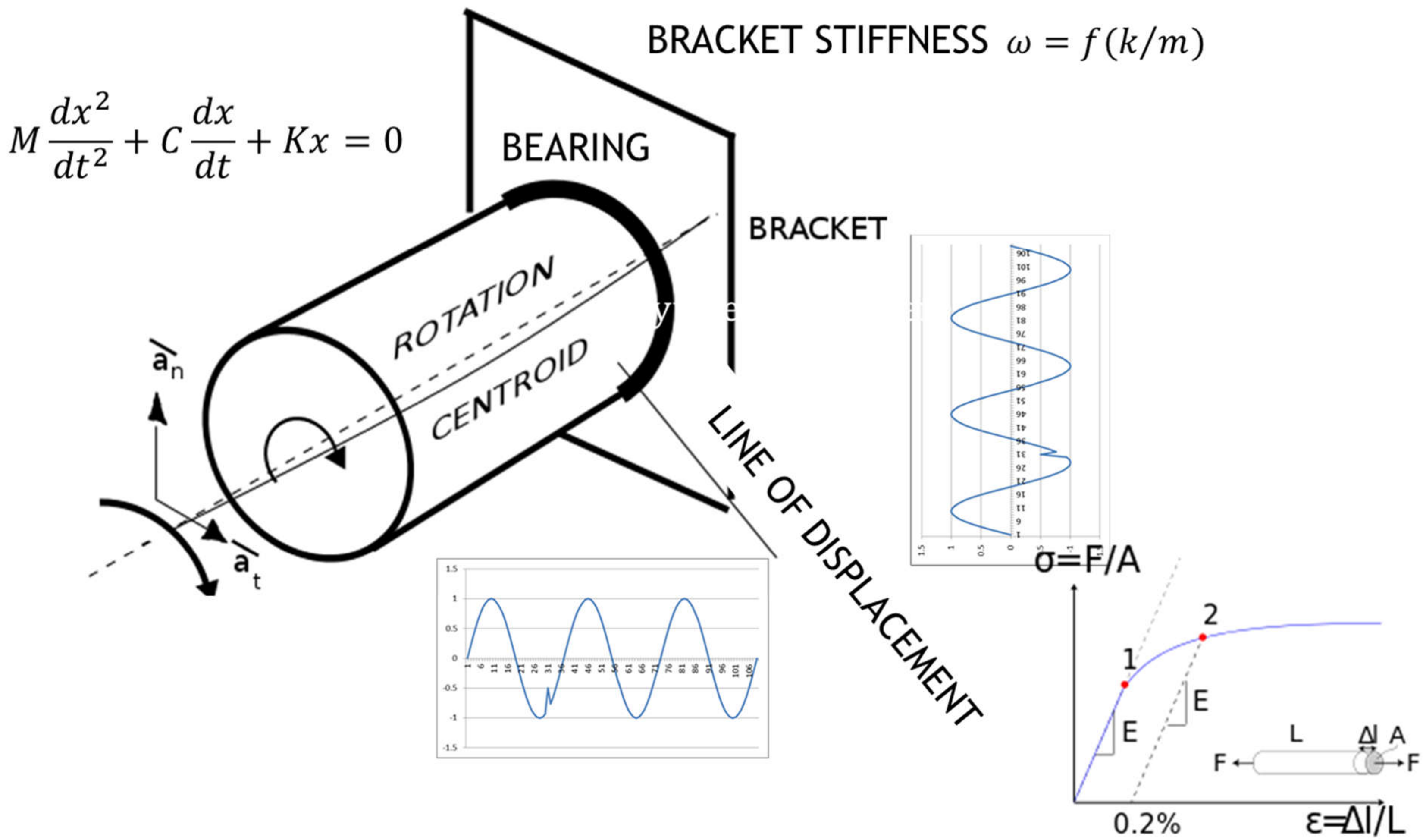
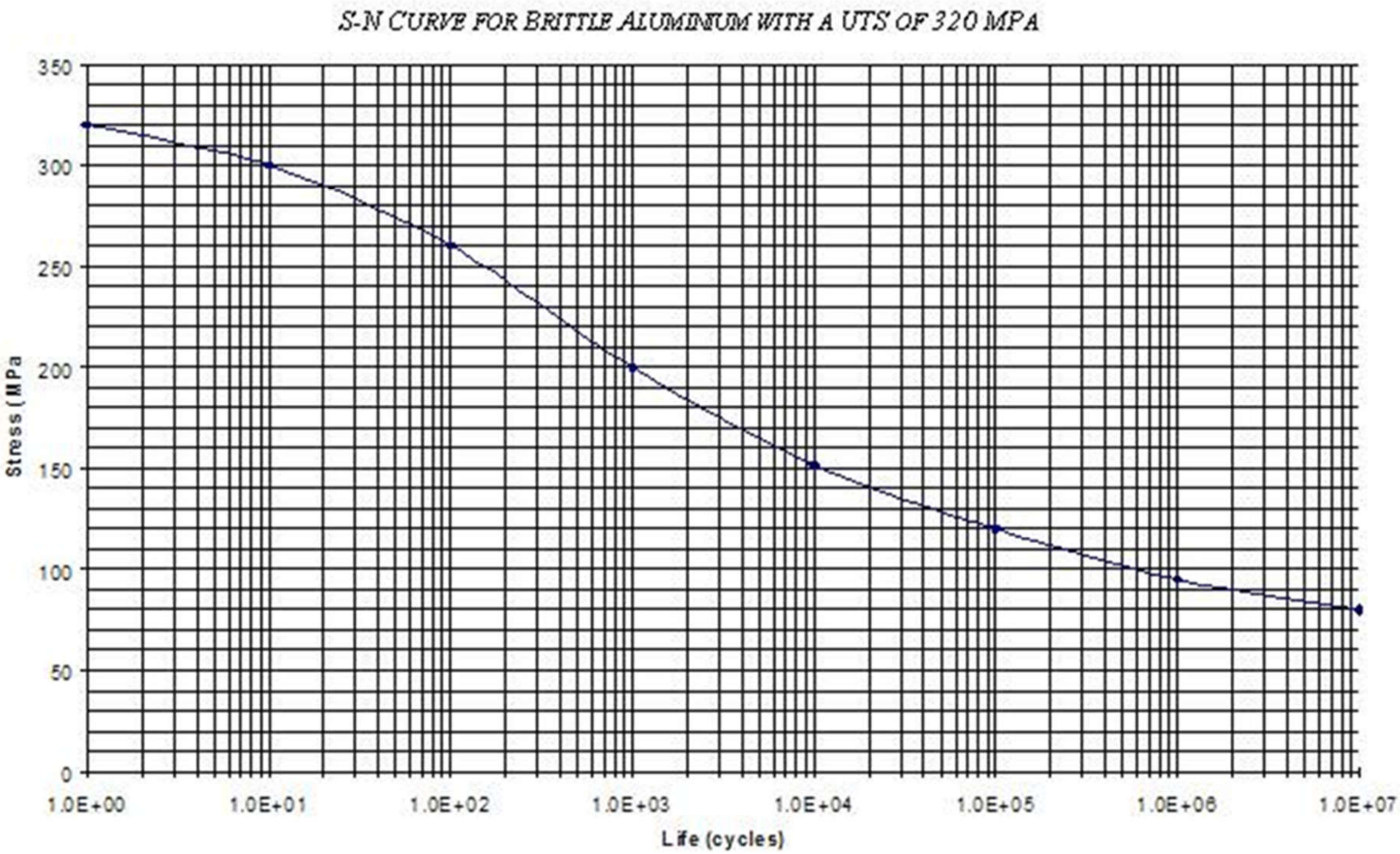
The World of Mechanical Diagnostics: PBM



The World of Mechanical Diagnostics: PBM



The World of Mechanical Diagnostics: PBM

PHYSICS BASED MODEL PROCESS

GEN GEOMETRY/ MECH PROPERTIES	SELECT/DISCRETIZE VOLUME	APPLY EXCITATION EVAL ELEMENT σ/ε
EVAL FAILURE/ CRACK GROWTH	UPDATE GEOMETRY	APPLY EOM TO EVAL VIBRATION
ASSESS VIB IMPACT ON CRACK GROWTH	EVAL FAILURE LIMITS	CORRELATE FAILURE EVENTS TO INPUTS

Electromagnetic Path Evaluation: LIDAR

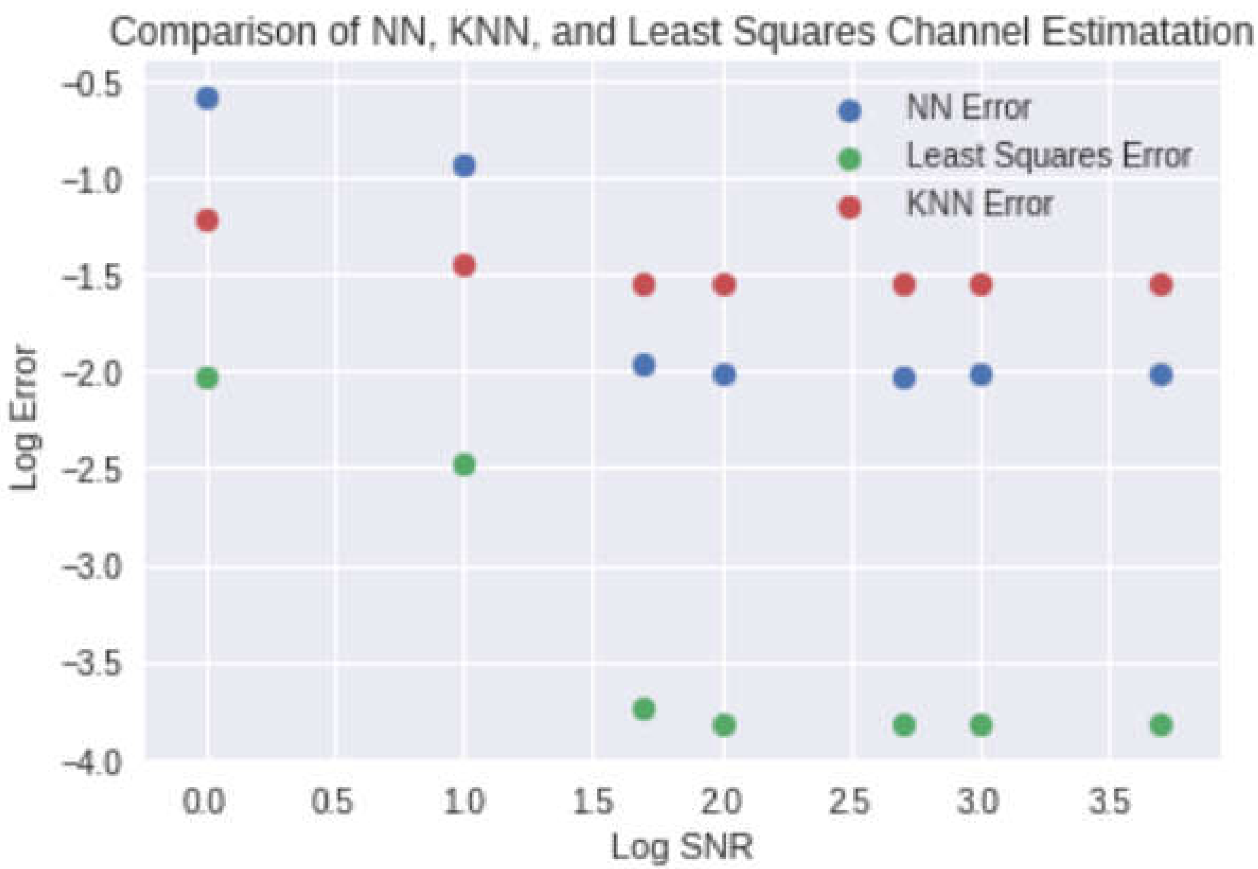
Electromagnetic Path Evaluation: LIDAR

Elastic Backscatter LIDAR Extinction Ambiguity

$$P_{\lambda_0}(R) = \frac{K_{\lambda_0}}{R^2}\left[\beta^{aer}_{\lambda_0}(R) + \beta^{mol}_{\lambda_0}(R)\right] T^2_{\lambda_0}(R) O_{\lambda_0}(R)$$

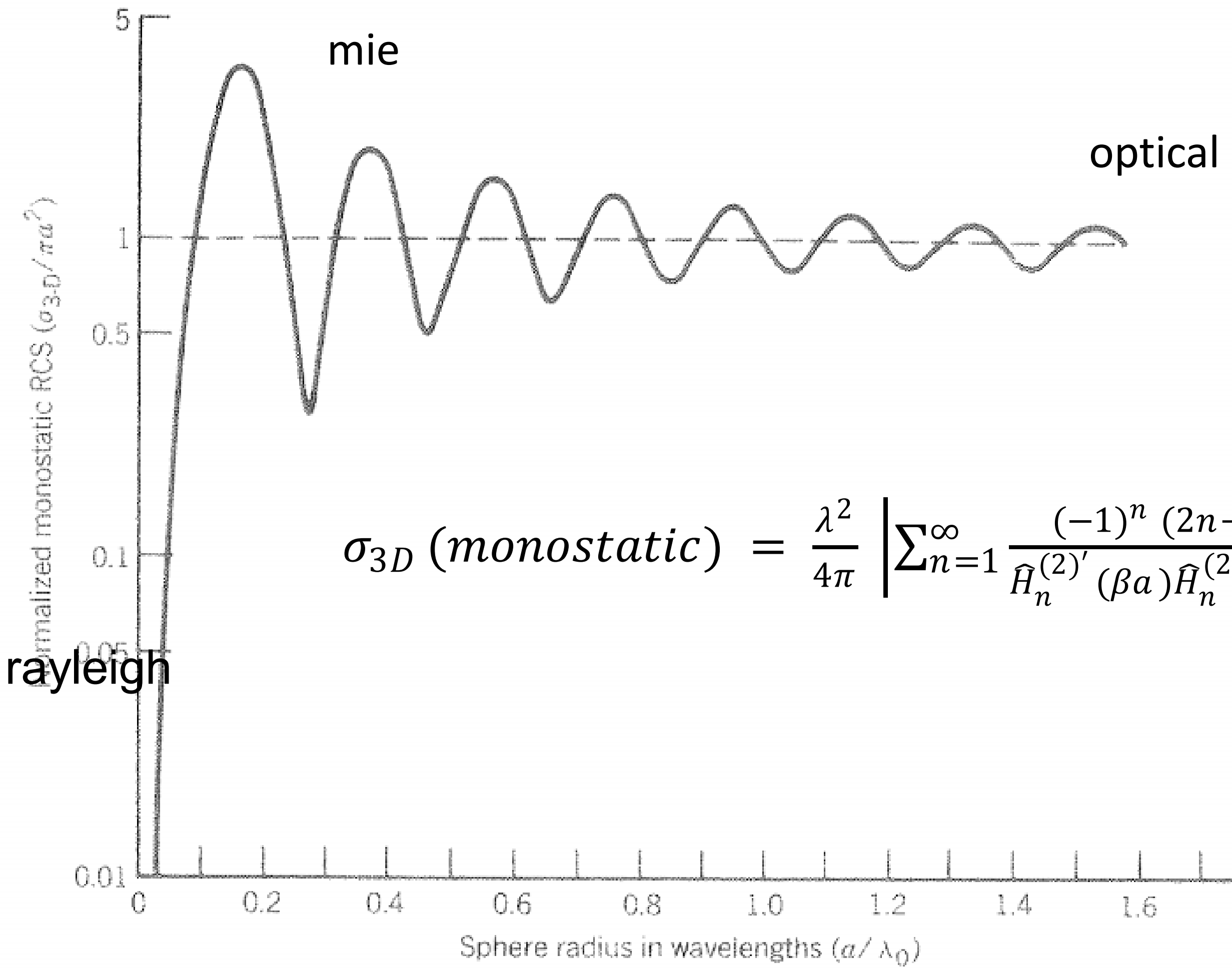
where $P_{\lambda o}(R)$ is the LIDAR elastic backscattered power *(W)* from range *(R)*, $K_{\lambda o}$ is the LIDAR system constant incorporating the transmitted optical pulse energy, the effective telescope receiving area, and the optical path losses in the system. $\beta^{aer}_{\lambda o}$ and $\beta^{mol}_{\lambda o}$ comprise the two elements of the extinction coefficient: aerosol backscatter and molecular absorption. $T^2_{\lambda o}$*(R)* represents the two-way admittance from the instrument to the backscatter target. $O_{\lambda o}$ *(R)* represents to so called overlap function, incorporating the unit normalized cross over function between the laser illuminated atmosphere at range *R* and the telescope's field of view.

Electromagnetic Path Evaluation: 5G



Deep Networks for Equalization in Communications
Technical Report No. UCB/EECS-2018-177
December 14, 2018

Electromagnetic Path Evaluation: PBM



$$\sigma_{3D}\,(monostatic) \;=\; \frac{\lambda^2}{4\pi}\left|\sum_{n=1}^{\infty}\frac{(-1)^n\,(2n+1)}{\hat{H}_n^{(2)'}(\beta a)\hat{H}_n^{(2)}(\beta a)}\right|^2$$

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Electromagnetic Path Evaluation: PBM

PHYSICS BASED MODEL PROCESS

GEN GEOMETRY/ EM PROPERTIES	SELECT/DISCRETIZE VOLUME	APPLY EXCITATION EG: UPW
DISTRIBUTE SCATTERERS (MONTE CARLO)	EVAL SCATTERING/ DIFFRACTION	EVAL PATH CHARACTERISTICS
EVAL PATH ON CHANNEL	EVAL BER/LIDAR PERFORMANCE	CORRELATE PERFORMANCE WITH ENVIRONMENT

Physics Based Modeling: Additional Considerations

- **Algorithms**
- **Software Design**
- **Computer Resources**
- **Data Conventions and File Structure**
- **Open Access/Collaboration**

Thank you

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