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DEMOCRATIZING A MULTIVARIATE STATISTICAL MODEL VALIDATION METHOD THROUGH AN INTELLIGENT FIT-FOR-PURPOSE APP

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2016 NAFEMS AMERICA CONFERENCE

JUNE 7TH, 2016

COMPANY OVERVIEW

FRONT END ANALYTICS: www.feasol.com

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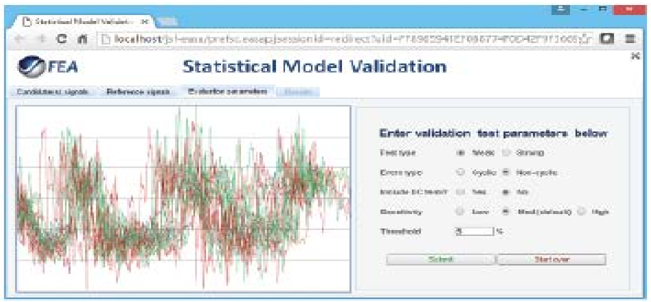
Powering Innovation through Simulation Services and Software

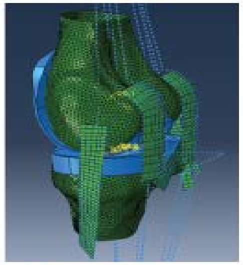
Driving Enterprise Impact by Democratizing Experts' Models

Delivering Business Advantage through Detailed Industry Experience

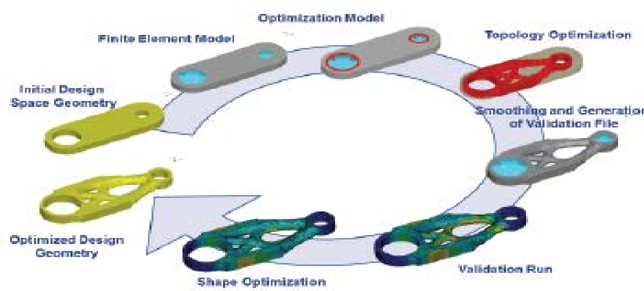


Advanced Analytical Capabilities

Intelligent Fit-for-Purpose Apps



Complex Numerical Modeling



Advanced Optimization Technologies

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COMPANY OVERVIEW

INTELLIGENT DEMOCRATIZATION

Intelligent fit-for-purpose applications embed expert knowledge enabling non-expert users the ability to perform complex engineering workflows that traditionally only experts could complete.

Intelligent Apps features include:

1) Leverage the company's existing intellectual property (knowhow, methods, toolset, previous designs, etc.)

2) Work across a wide range of design changes and product families

3) Speak the language of the intended user and prevent non-expert users from creating invalid designs

4) Automate an entire workflow (i.e. should work for both CAD creation as well as analysis automation)

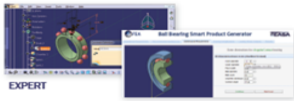
5) Can be employed for different levels of model abstraction (i.e. from 1D functional-centric to 3D CAD and FEA/CFD computational analysis).

DE Desktop Engineering®

Democratization Sponsored Report /// Front End Analytics

Engineering for Everyone

Intelligent web-enabled applications (Smart Apps) allow everyone in your organization to safely create product designs.



What would it mean to a manufacturer, if anyone who wanted to create a product design could do it per company standards, within minutes and with reduced reliance upon the company's experts? What if the product design and simulation knowledge of the engineering experts in your organization could be tapped on-demand through the use of intelligent web-enabled "virtual expert" applications?

Imagine how your company's product development processes and go-to-market strategy would change. Designers could configure products with the assurance that their designs would be engineering validated. Sales reps could engineer products, on the fly, and in front of customers based on their requirements. Junior engineers would be able to generate product designs and perform analyses without bogging down your company experts.

Intelligent Automation

Juan Betts, Managing Director of Front End Analytics says, "Back in the early 1900s, during the infancy of the automotive industry, one needed to have deep knowledge of how a car worked in order to drive a car. Today the automotive industry is a $1.5 trillion industry because, through intelligent automation and controls, someone who has no clue how a car works can drive a car. The engineering design and simulation industry is still in the 1900s requiring the developers of engineering models to be the same persons as the users of these models. In the same way you don't need to be a mechanic to drive a car nowadays, our Smart Apps enable folks who are not experts to use engineering expertise to create a product design through intelligent automation methods."

Front End Analytics helps companies transform how they create, sell and service product via the use of intelligent web-enabled Smart Apps. These applications imbed design rules, engineering practices and experts' knowhow, thereby allowing anyone enterprise-wide to safely create a product design.

Smart Apps have five major characteristics. They:

1 Leverage the company's existing intellectual property (rules, knowhow, previous designs, etc.)
2 Work across a wide range of design changes and product families
3 Speak the language of the intended user and prevent non-expert users from creating invalid designs
4 Automate an entire workflow (i.e. should work for both CAD creation as well as analysis automation)
5 Can be employed for different levels of model abstraction (i.e. from 1D functional-centric conceptual design to 3D parametric CAD and FEA/CFD analysis in detailed design).

To create these Smart Apps, Front End Analytics leverages the company's existing IP and tool set (Excel spreadsheets, MATLAB scripts, in-house codes, CAD/CAE tools, databases, enterprise systems, etc.) and intelligently links them in an automation platform. A platform that Front End Analytics often uses is called EASA, a cloud-computing platform for rapid application development, process automation and enterprise-wide software accessibility.

These Smart Apps can be safely tucked away behind a company's firewall or accessible through the web. Different Apps or functionalities within Apps can be made available via user permissions following each company's IT policies.

The Process

Front End Analytics works closely with companies to assess their workflows, engineering challenges, design practices, expert knowhow, etc. to diagnose the best course of action that would lead to desired outcomes. "We always diagnose before we prescribe," says Betts.

"We meet with companies as a neutral third party, staying focused on the facts as part of our education. Extracting the deterministic rule sets needed for the automation leads to their own discoveries about what they did and did not know," says Mark Walker from Front End Analytics. "In the end, it's their consensus that makes the solution successful."

Once a company's core design process and engineering rules are codified, various applications can be created to help streamline product development. "We make the application speak the language of the intended users across the enterprise and add intelligent controls to prevent non-expert users from creating an invalid product design," Walker says.

Many companies begin with a small pilot and then scale up.

For more info on how Front End Analytics can help automate your engineering workflow, visit www.feasol.com.

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AGENDA

METHODOLOGY

VALIDATION

DEMOCRATIZATION

CONCLUSIONS

AGENDA

METHODOLOGY

VALIDATION

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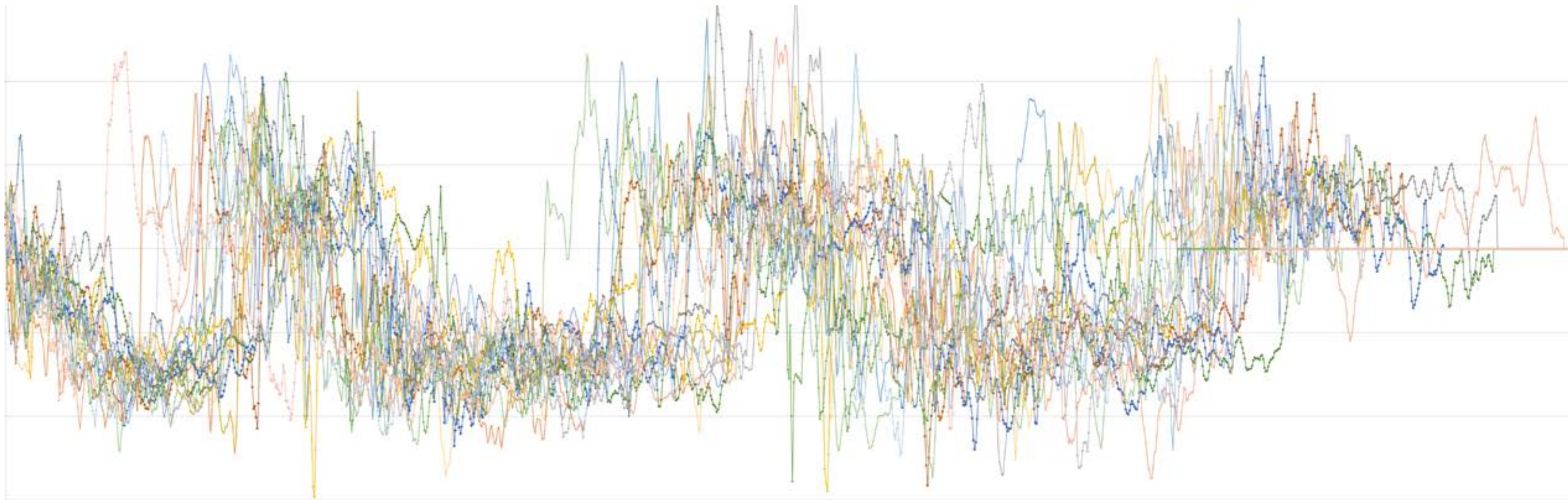
CONCLUSIONS

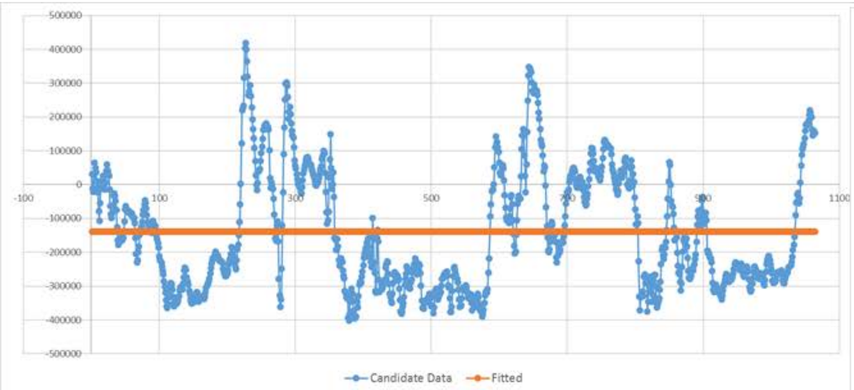
METHODOLOGY

ARE WE FROM THE SAME FAMILY?

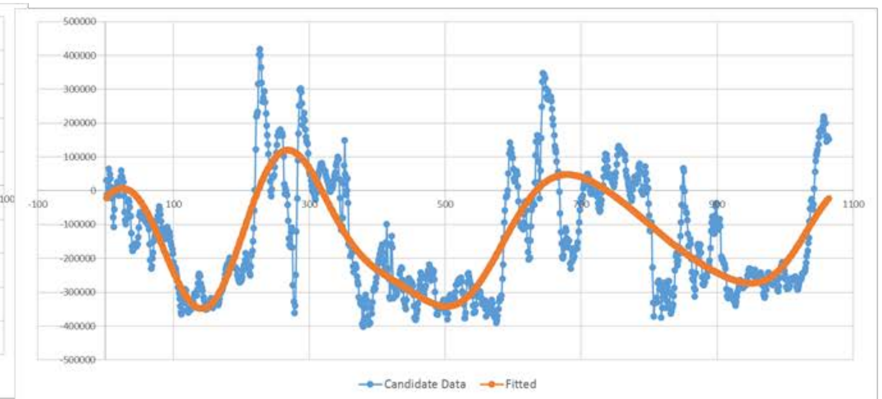


METHODOLOGY

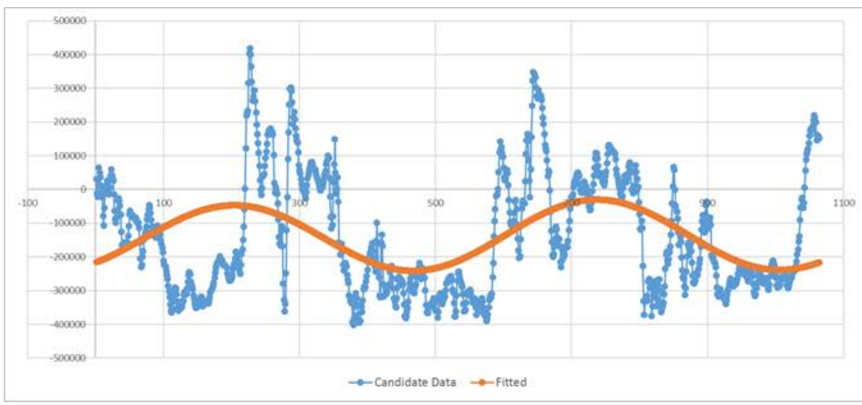
FOURIER SERIES UNCOVERS SHAPE



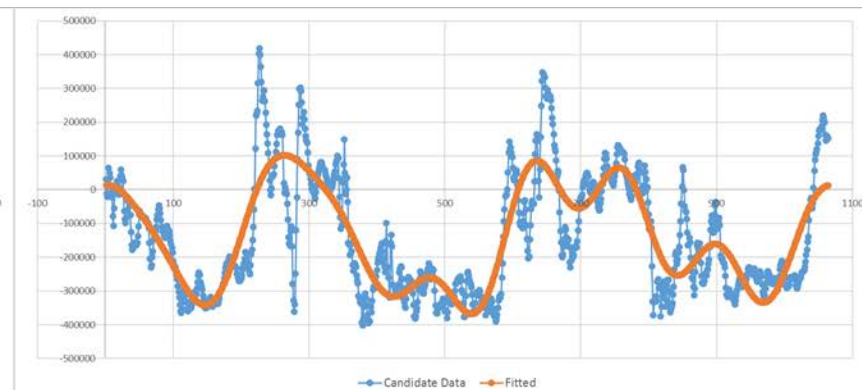
1 Fourier Term



7 Fourier Terms



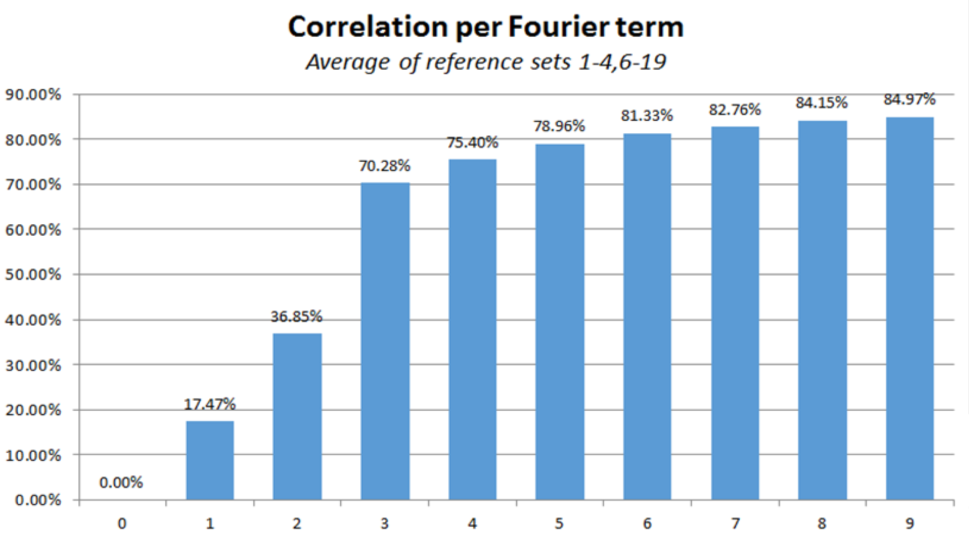
3 Fourier Terms

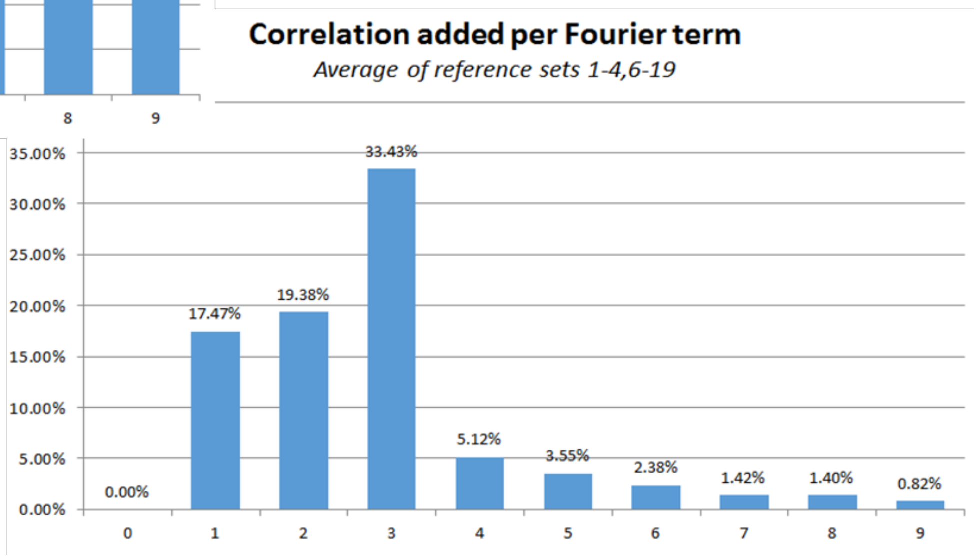


10 Fourier Terms

METHODOLOGY

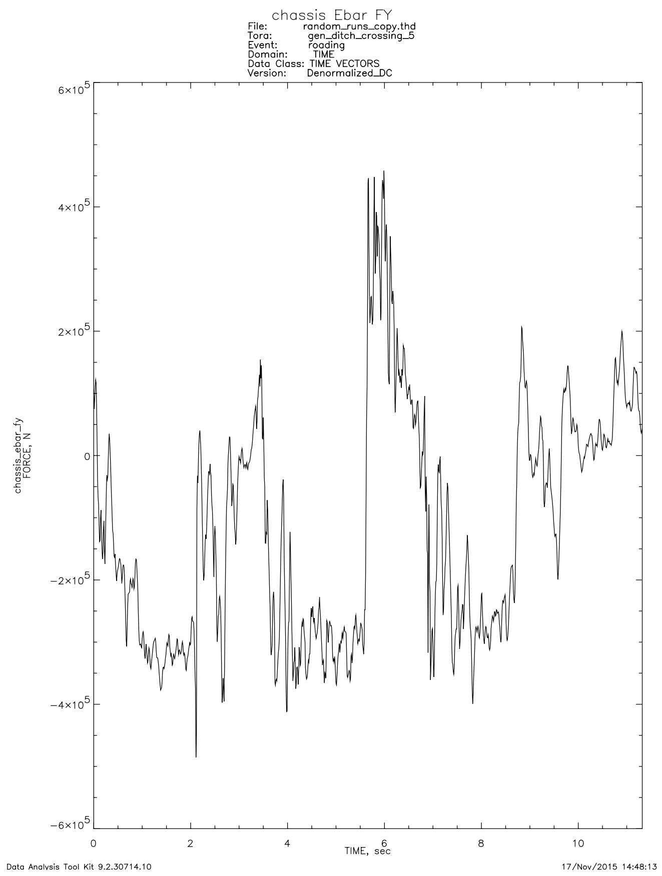
TIME SERIES CORRELATION OF FOURIER SERIES



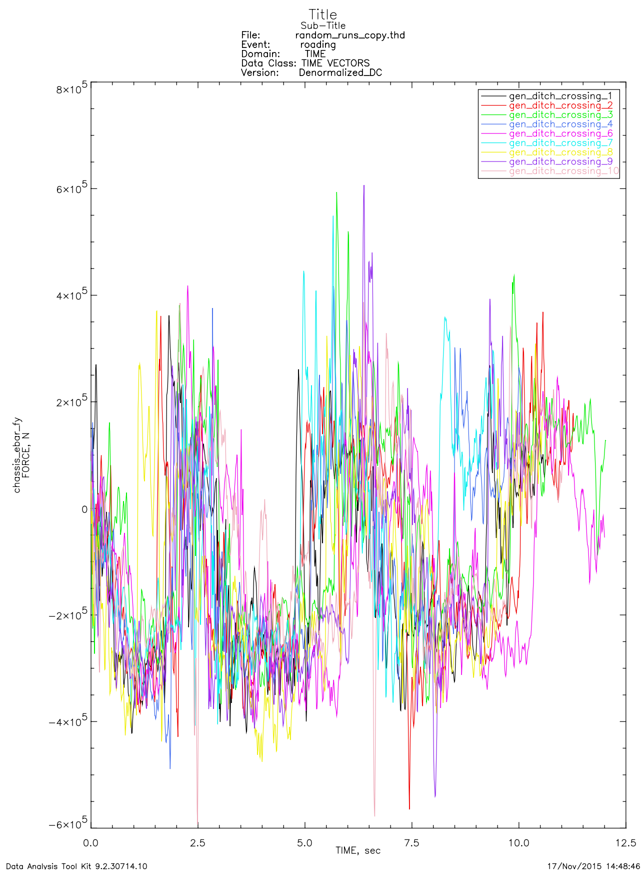


METHODOLOGY

WEAK TEST – ONE VS. MANY



Vs.



METHODOLOGY

WEAK TEST – EQUIVALENCE OF MEAN

A. Compute Fourier Coefficients (Candidate/Reference)

$$x_{ri}(t) = \frac{a_{r0i}}{2} + \sum_{n=1}^{N} [a_{rni} \cos\left(\frac{2\pi nt}{T_{ri}}\right) + b_{rni} \sin\left(\frac{2\pi nt}{T_{ri}}\right)]$$

B. Compute means and standard deviations

C. Compute reference covariance matrix

D. Invert reference covariance matrix

E. Assess Hotelling's T² distribution

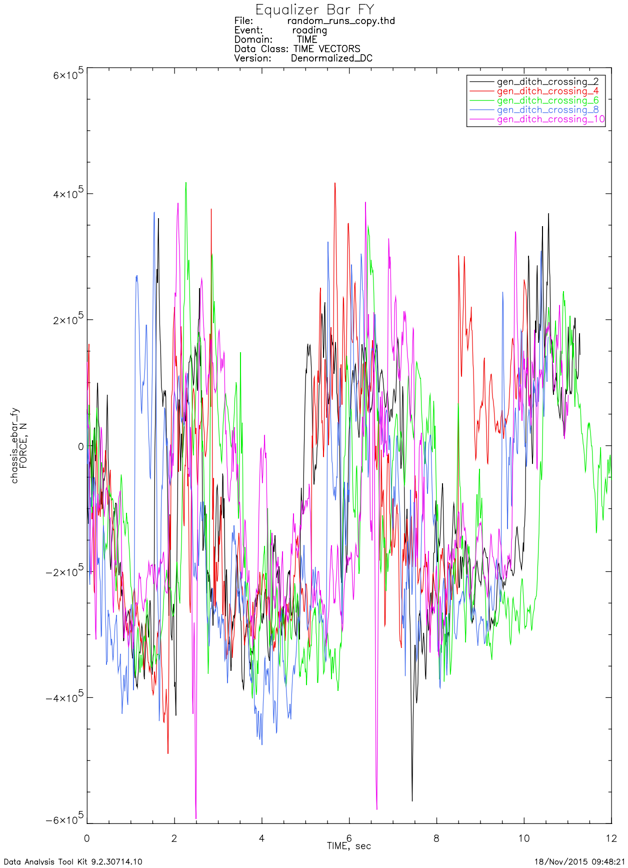
$$(\mathbf{y}_{\text{cand}} - \bar{\mathbf{y}}_{\text{ref}})^{\text{T}} \mathbf{S}_{\text{ref}}{}^{-1} (\mathbf{y}_{\text{cand}} - \bar{\mathbf{y}}_{\text{ref}}) \sim T^2_{p,n_{\text{ref}}-1}$$

F. Map to F distribution

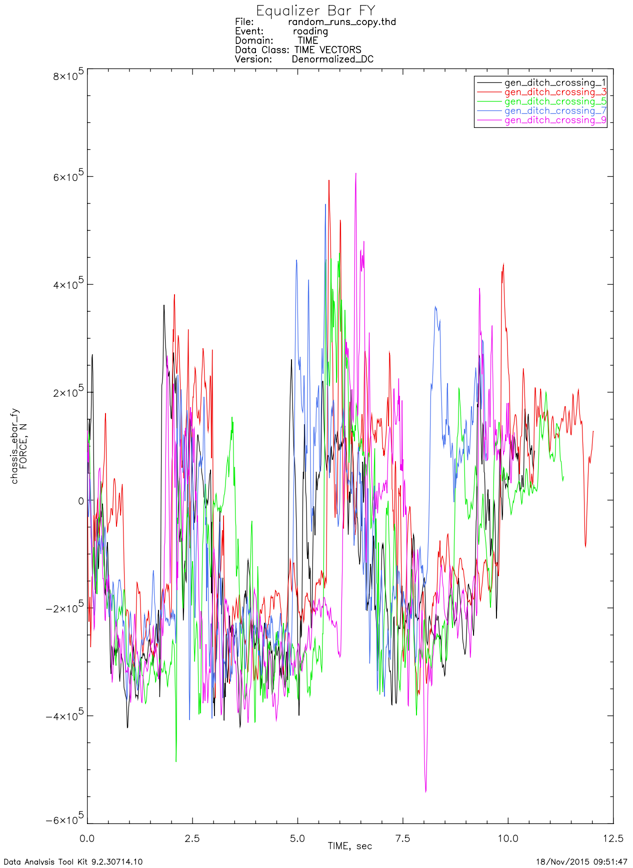
$$\frac{(n_{\text{ref}} - p)}{p(n_{\text{ref}} - 1)} T^2_{p,n_{\text{ref}}-1} \sim F_{p,n_{\text{ref}}-p}$$

G. Get P-value of F distribution

METHODOLOGY
STRONG TEST – MANY VS. MANY



VS



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METHODOLOGY

STRONG TEST- EQUIVALENCE OF MEAN

A. Same as A & B in Weak Test

B. Compute pooled covariance matrix

$$\mathbf{S}_{\mathrm{pl}} = \frac{1}{n_{\mathrm{ref}} + n_{\mathrm{cand}}}\left[(n_{\mathrm{ref}} - 1)\mathbf{S}_{\mathrm{ref}} + (n_{\mathrm{cand}} - 1)\mathbf{S}_{\mathrm{cand}}\right]$$

C. Invert pooled covariance matrix

D. Assess Hotelling's T^2 distribution

$$(\bar{\mathbf{y}}_{\mathrm{cand}} - \bar{\mathbf{y}}_{\mathrm{ref}})^{\mathrm{T}}\left[\left(\frac{1}{n_{\mathrm{ref}}} + \frac{1}{n_{\mathrm{cand}}}\right)\mathbf{S}_{\mathrm{pl}}\right]^{-1}(\bar{\mathbf{y}}_{\mathrm{cand}} - \bar{\mathbf{y}}_{\mathrm{ref}}) \sim T^2_{p, n_{\mathrm{ref}} + n_{\mathrm{cand}} - 2}$$

E. Map to F distribution

$$\frac{n_{\mathrm{ref}} + n_{\mathrm{cand}} - p - 1}{(n_{\mathrm{ref}} + n_{\mathrm{cand}} - 2)p} T^2 = F_{p, n_{\mathrm{ref}} + n_{\mathrm{cand}} - p - 1}$$

F. Get P-value of F distribution

METHODOLOGY

STRONG TEST- EQUIVALENCE OF VARIANCE

A. Calculate M-statistic for M-test

$$M = \frac{|\mathbf{S}_{\text{ref}}|^{(n_{\text{ref}}-1)/2}|\mathbf{S}_{\text{cand}}|^{(n_{\text{cand}}-1)/2}}{|\mathbf{S}_{\text{pl}}|^{(n_{\text{ref}}+n_{\text{cand}}-2)/2}}$$

B. Calculate c1 coefficient

$$c_1 = \left[\frac{1}{n_{\text{ref}}-1} + \frac{1}{n_{\text{cand}}-1} - \frac{1}{n_{\text{cand}}+n_{\text{ref}}-2}\right]\frac{2p^2+3p-1}{6(p+1)}$$

C. Calculate u for p-value lookup

$$u = -2(1-c_1)\ln(M) \sim \chi^2\,[p(p+1)/2]$$

D. Get P-value from Chi-squared distribution

AGENDA

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VALIDATION

DEMOCRATIZATION

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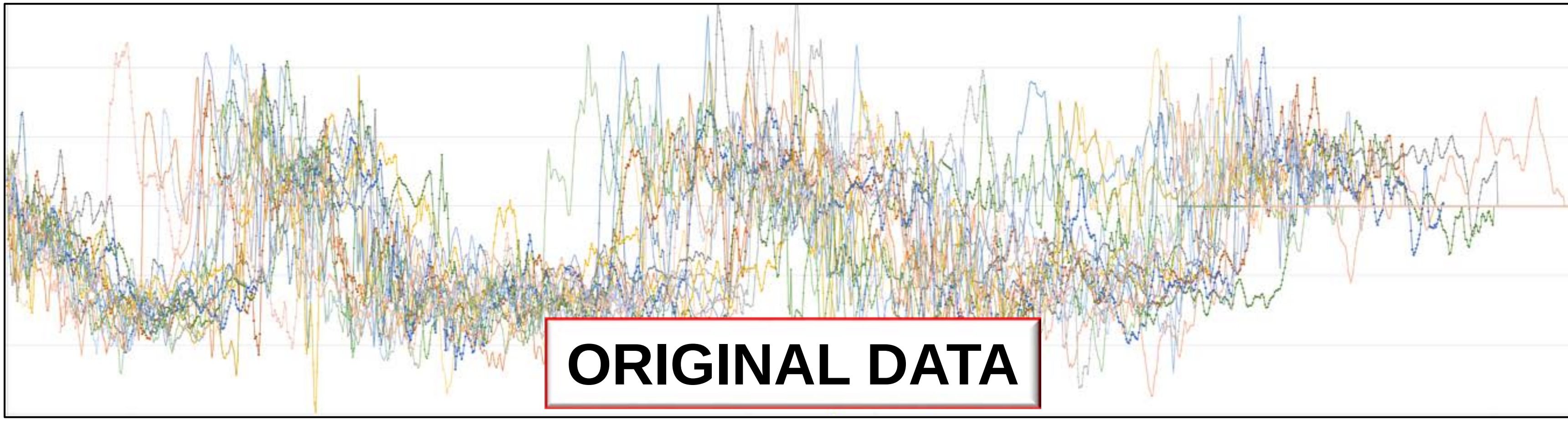
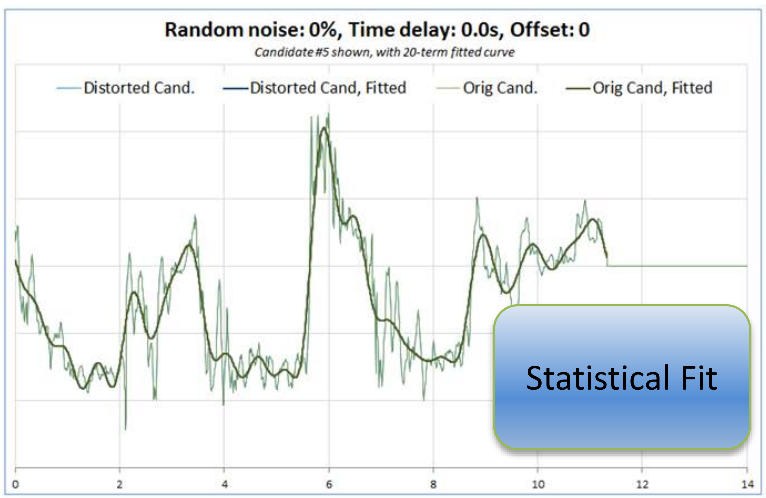
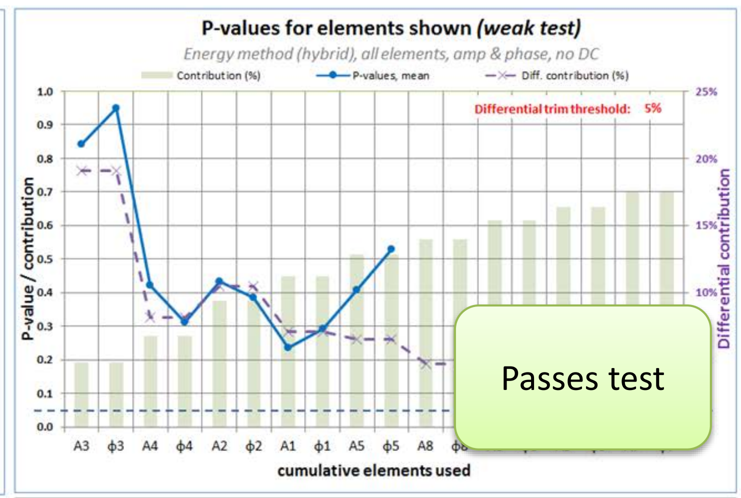
STATISTICAL MODEL VALIDATION

SEE IF TEST PASSES ON KNOWN DATA

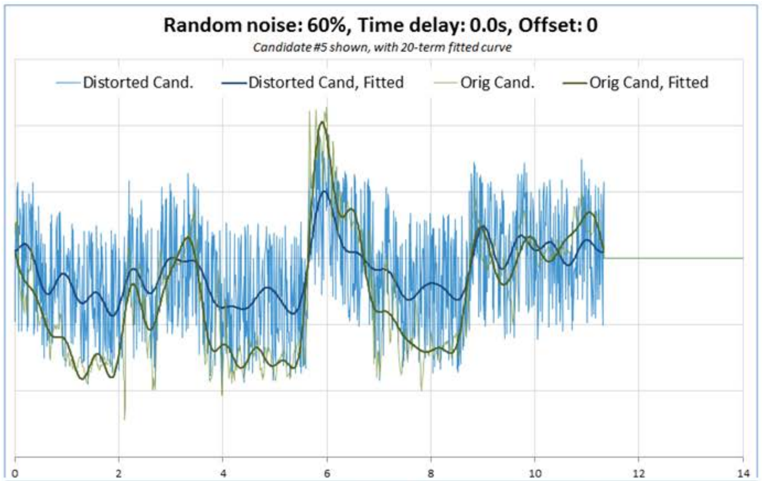


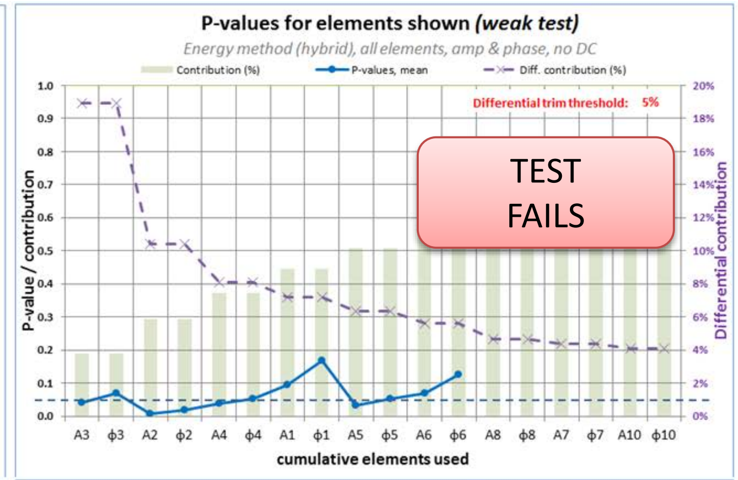


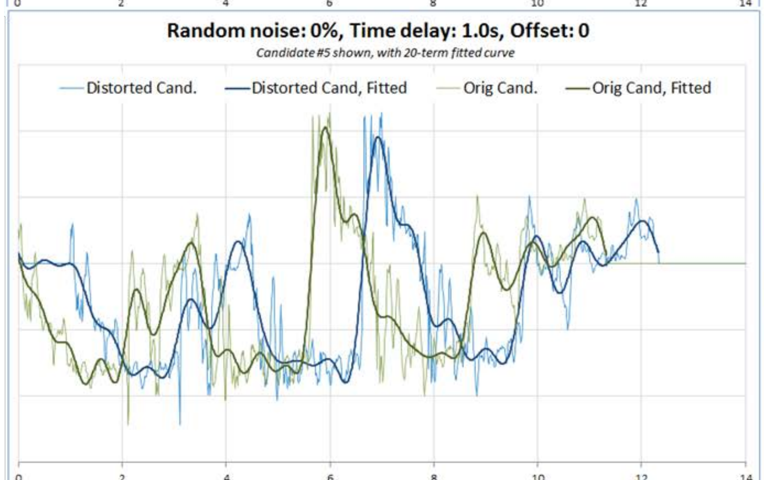


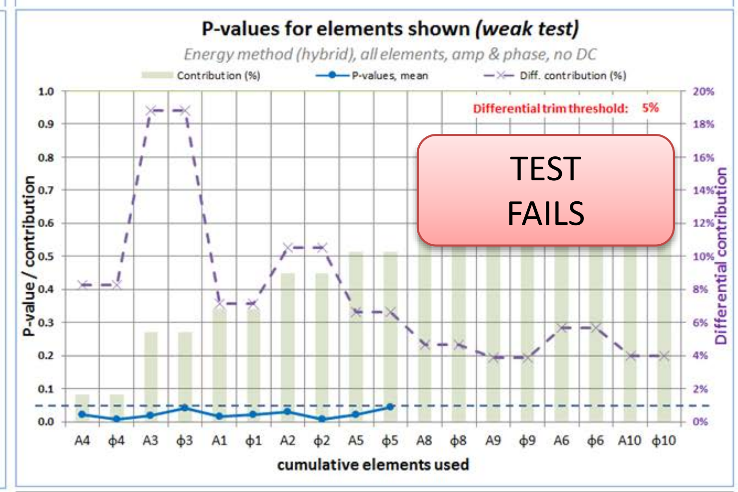
STATISTICAL MODEL VALIDATION

ADDING 60% NOISE AND SHIFTING CANDIDATE SIGNAL BY 1S









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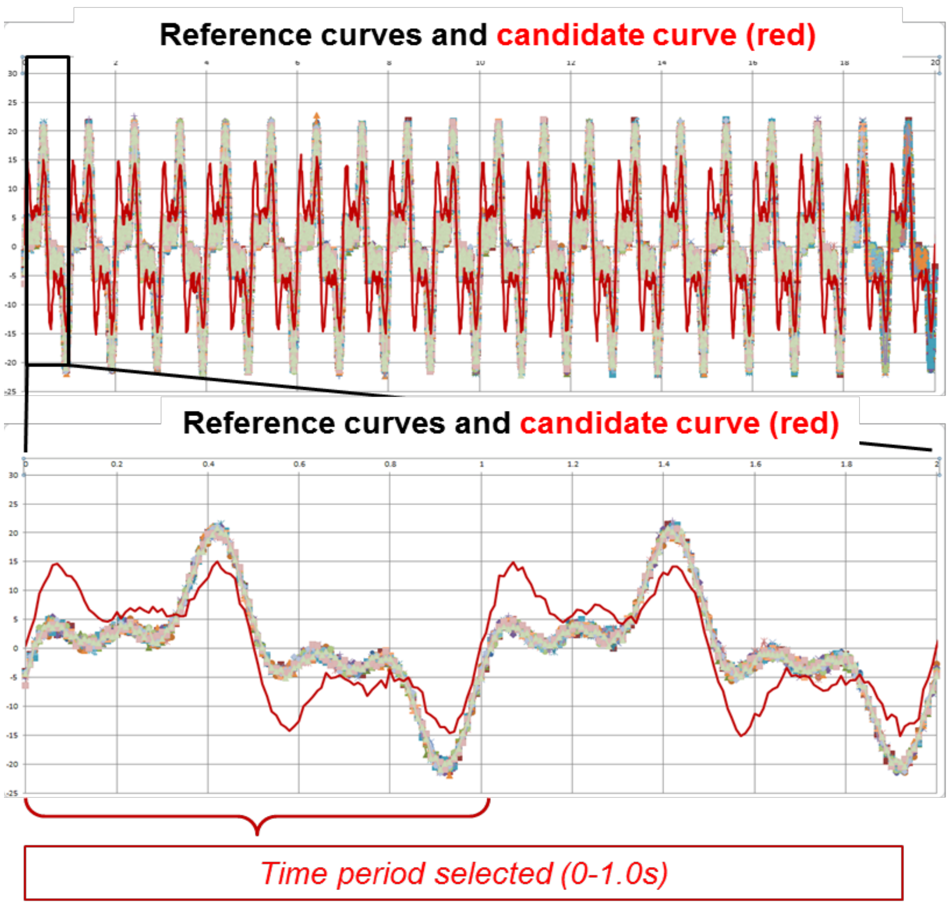
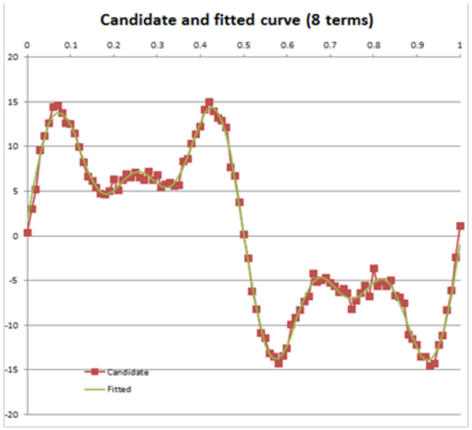
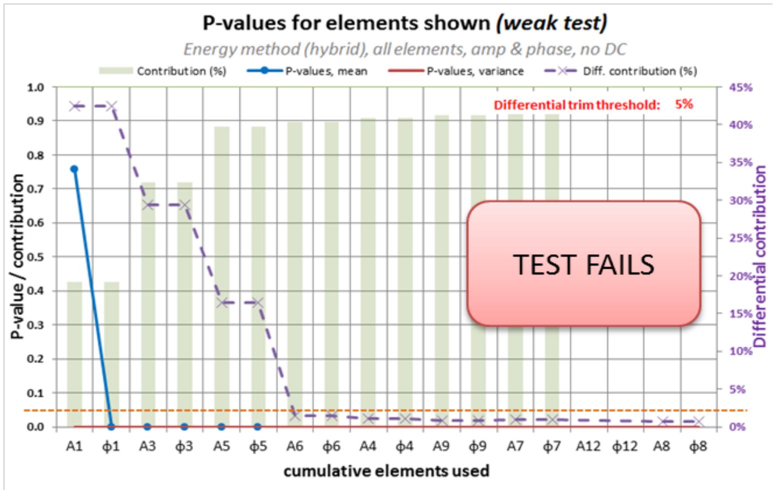
STATISTICAL MODEL VALIDATION

MORE COMPLEX CASES







Note how 5% contribution threshold limits p-chart

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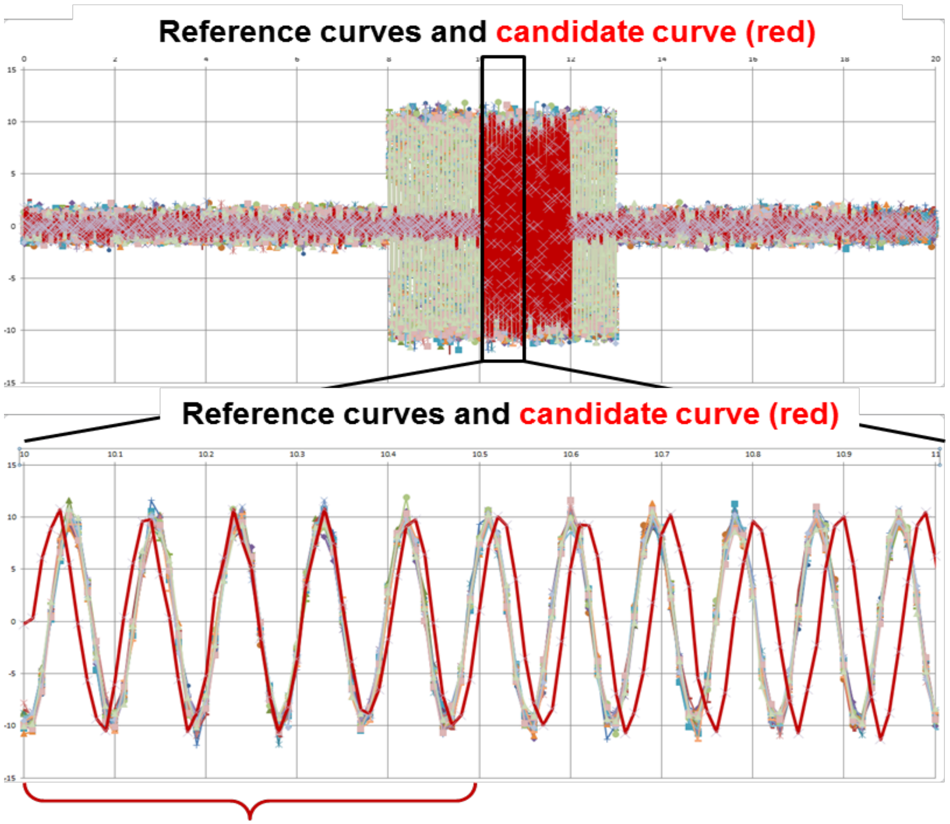
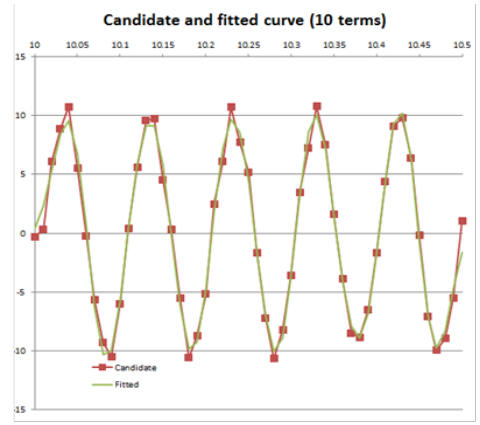
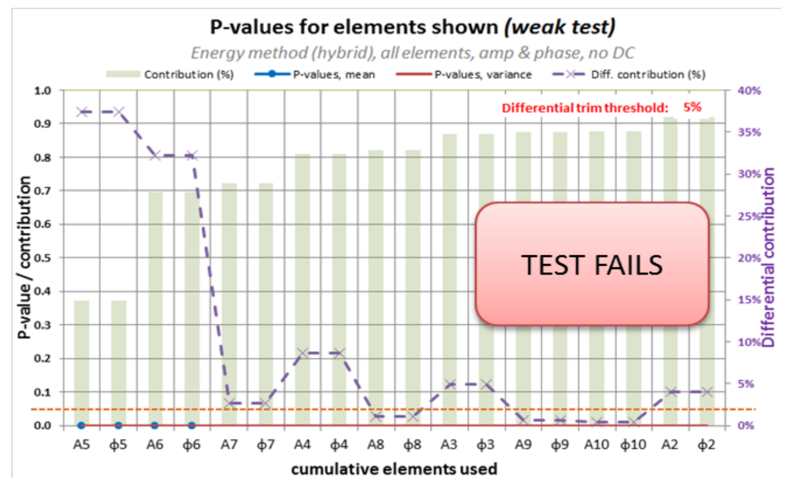
MORE COMPLEX CASES



Time period selected (10-10.5s)





Note how 5% contribution threshold limits p-chart

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STATISTICAL MODEL VALIDATION

MORE COMPLEX CASES

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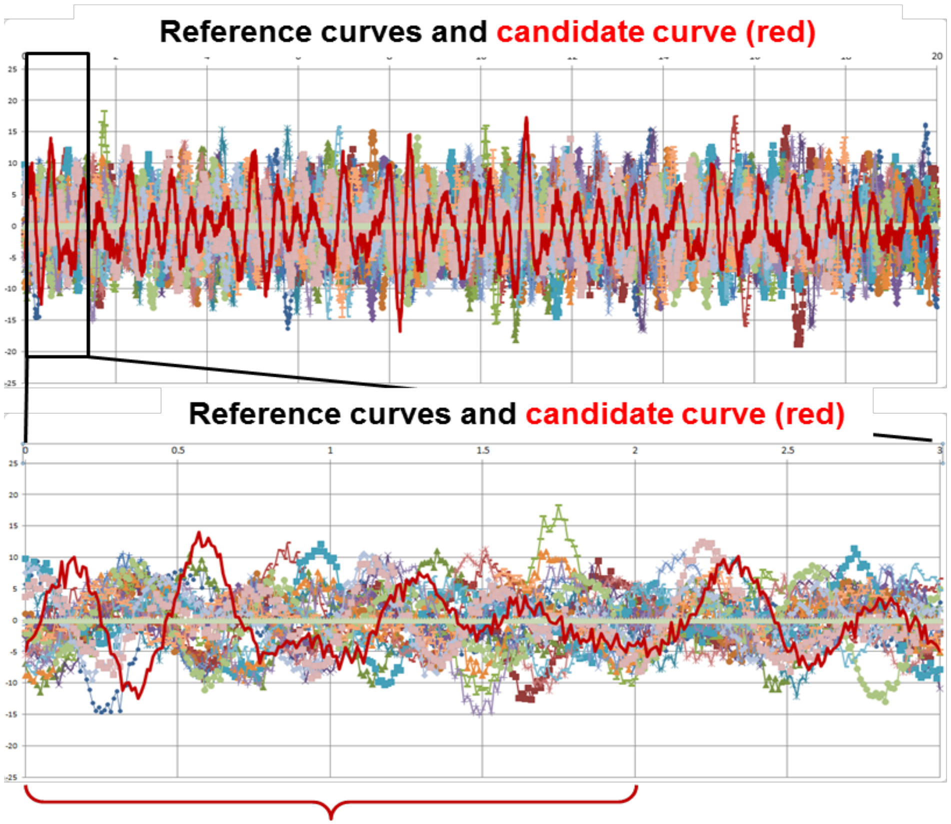

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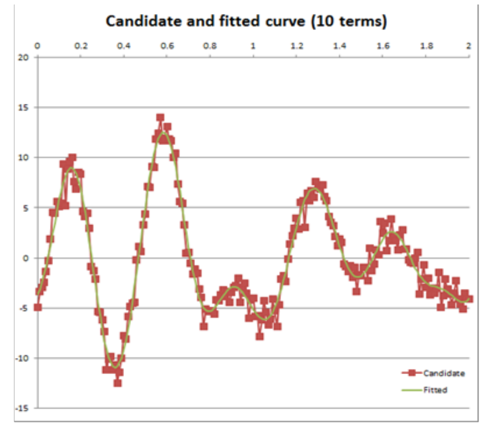

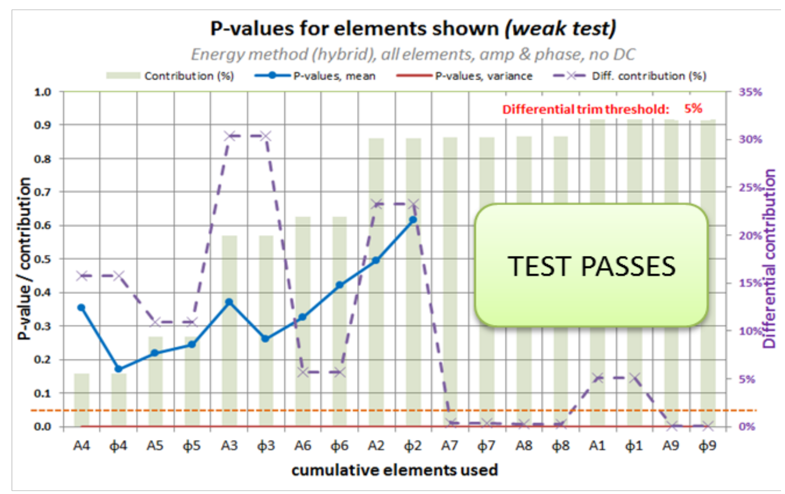

Note how 5% contribution threshold limits p-chart

AGENDA

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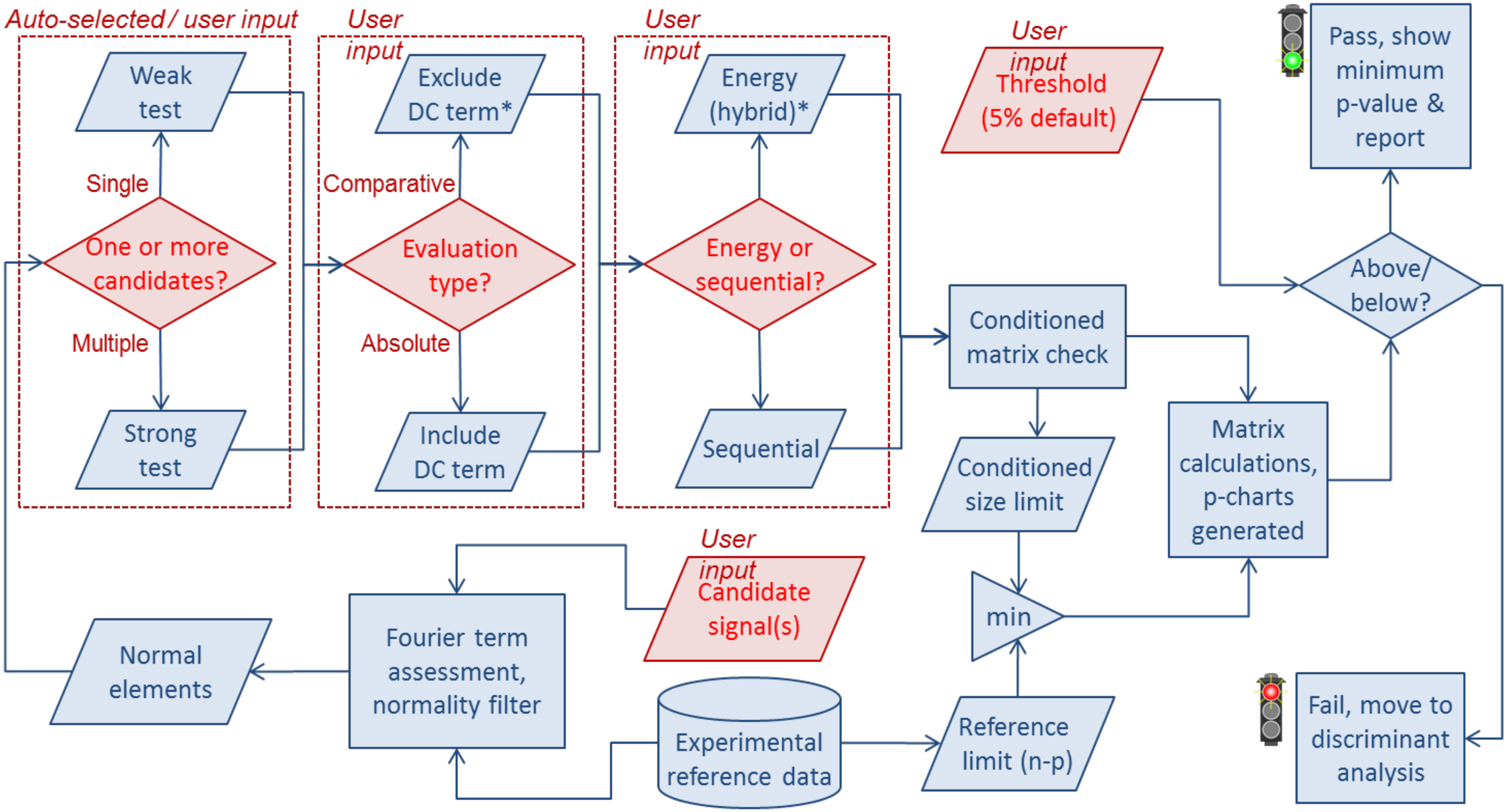
DEMOCRATIZATION

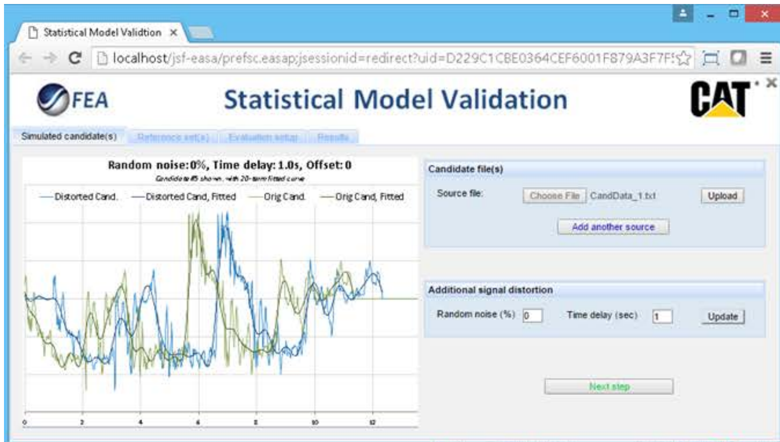
WORKFLOW



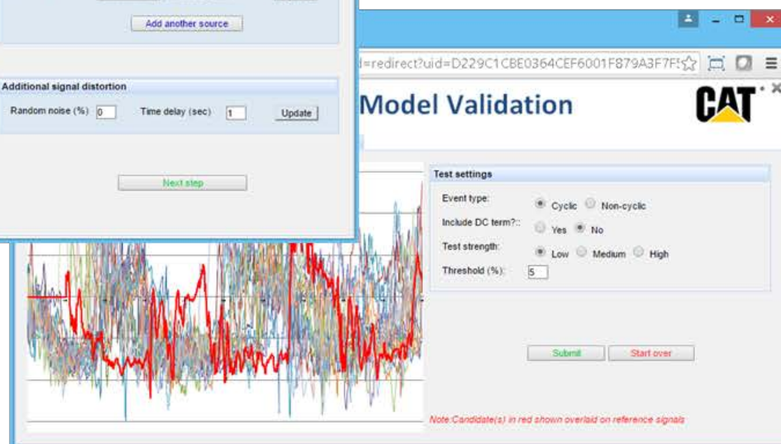
** Default values*

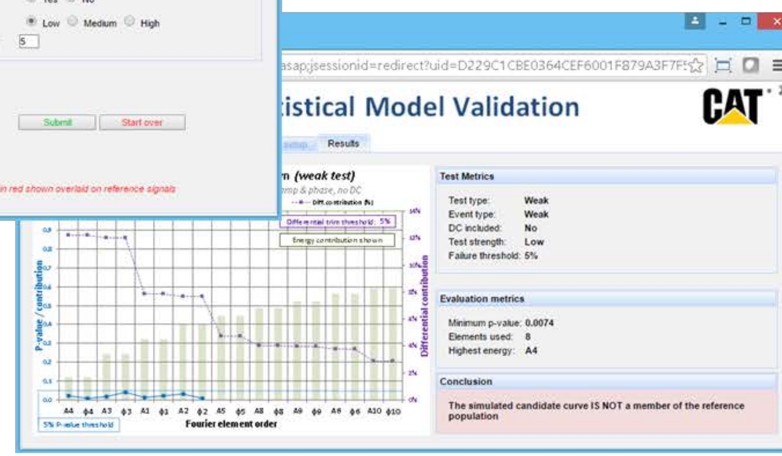
DEMOCRATIZATION

SAMPLE GUI (1/2)



Candidate signals are identified, distortion is added here for testing, reference sets are identified, and the evaluation parameters are set

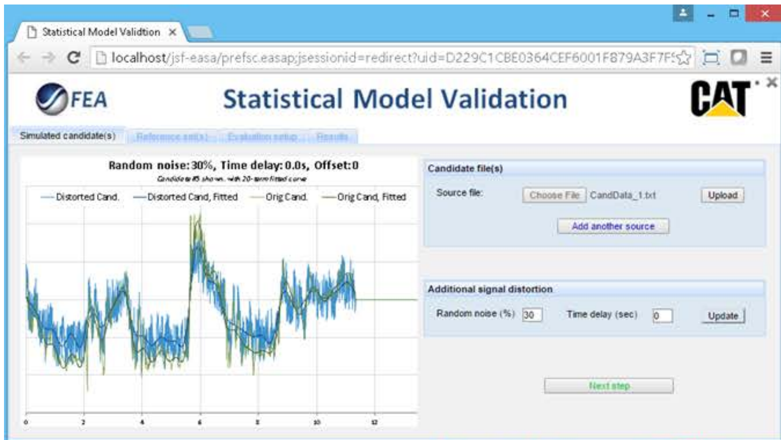




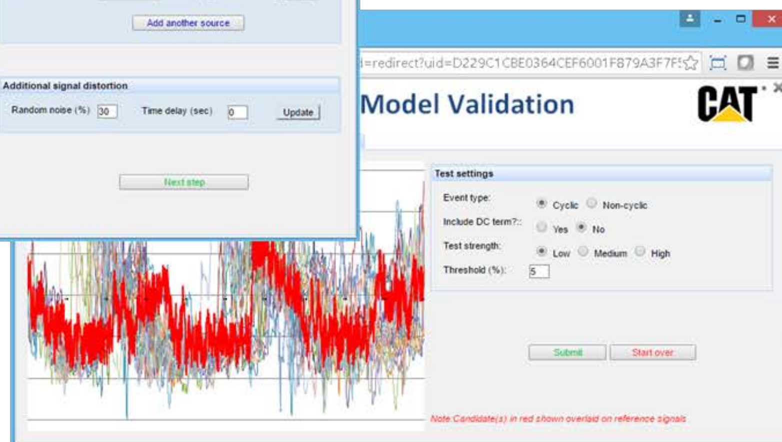
An additional **1sec delay** signal distortion on top of the candidate **IS NOT** a believable member of this reference set

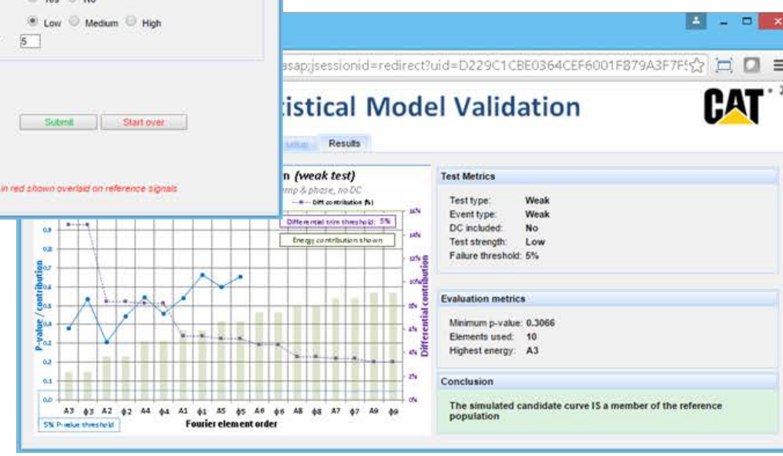
DEMOCRATIZATION

SAMPLE GUI (2/2)



Candidate signals are identified, distortion is added here for testing, reference sets are identified, and the evaluation parameters are set





An additional **30% noise** signal distortion on top of the candidate **IS** a believable member of this reference set

AGENDA

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CONCLUSIONS

SUMMARY

- Manual time histories alignment no longer necessary
- Consistent and user-independent results are obtained
- Greater method adoption due to streamlined workflow and embedded expert knowledge in the tool.
- Use of multivariate statistical approach reduces exposure to Type I and II error
- Power of the hypothesis test can be "tuned" to the specific problem being validated

FUTURE WORK

- Automated routine that automatically improves numerical models to pass hypothesis testing validation
- Other multivariate problems: e.g. inverse problem, load uncertainty, predictive maintenance, IoT, etc.

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QUESTIONS?

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