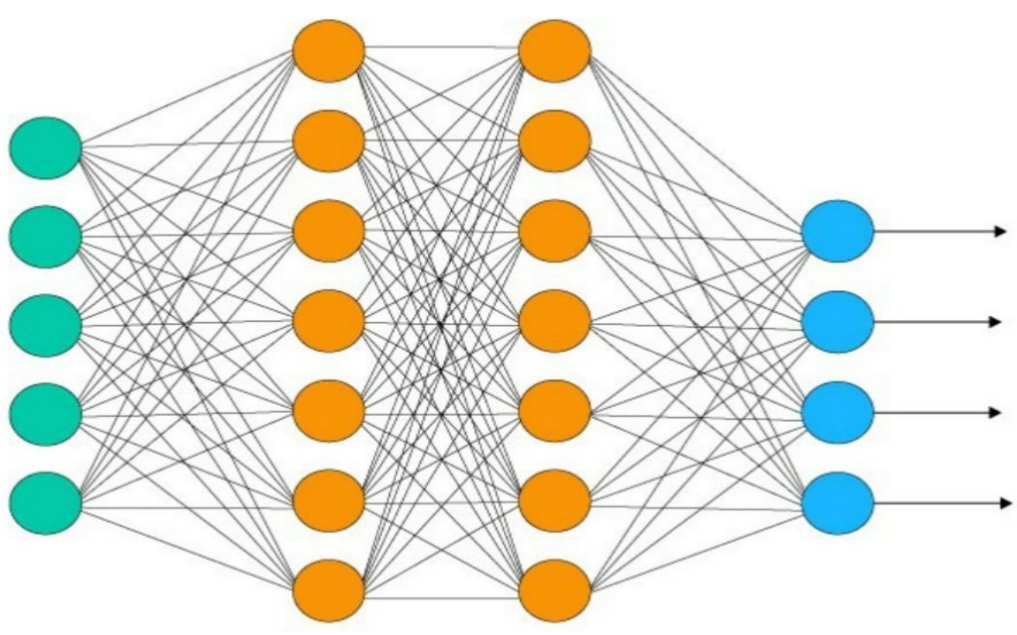
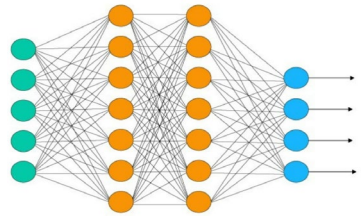


# AUTOMATED FEA-SURROGATE TRAINING CAD GENERATION WITH NXOPEN

**BRIAN SHULA, LEAD MECHANICAL DESIGN ENGR.**
**KEIANO STEPHENS, MECHANICAL DESIGN ENGR. II**

**Realize LIVE**
**June 2-5, 2025**
**Detroit, MI**

Honeywell



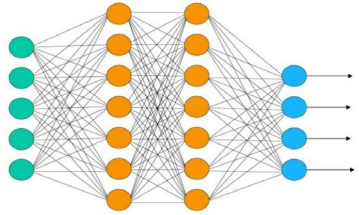
# AGENDA

- **Introductions**
  - Speakers, Honeywell, Aircraft Brakes, W&B Automation Ecosystem
- **Finite Element (FE) Surrogate Model Motivation and Approach**
  - Realtime design assessment with Machine Learning and Neural Networks
- **NXOpen Example Demonstration**
  - Data inputs and outputs
  - Robustness and coherent designs
  - Flowchart
  - Animations
- **FE-Surrogate Applications**
- **Tradeoffs and Considerations**
  - Setup investment and accuracy
  - Appropriate applications
- **Summary and Conclusions**

Abbreviations:
FE: Finite Element
ML: Machine Learning
TT: Torque Tube

**NXOpen Solves the First Hurdle of FE Surrogate Model Creation**

# SPEAKER INTRODUCTIONS



## Brian Shula, P.E.

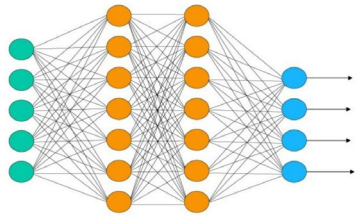
- Lead Mechanical Design Engineer
- BSME, MSME from Notre Dame
- 3 Patents granted, 5 published applications
- 20 years of non-linear themo-mechanical FEA experience
- Interests include Physics-based machine learning and process automation

## Keiano Stephens

- Mechanical Design Engr. II
- BSAE from Embry-Riddle Aeronautical Univ.
- 3 years Wheel & Brake design and automation experience
- Design interests include process automation and model-based definition (MBD)

**Strong Interests at the Intersection of Robust Product Design and Automation**

Honeywell | THE FUTURE IS WHAT WE MAKE IT



**Honeywell is delivering the future of automation, air travel, and energy** with our industry-leading, software-enabled solutions. We create shareholder value through profitable growth and strategic, high-return capital deployment.

**Charlotte, NC**
Headquarters

**HON**
NASDAQ

**$38B**
2024 Sales

**102,000**
2024 Employees

**~715**
Total Sites

**FORTUNE 500**

## HELPING SOLVE THE WORLD'S TOUGHEST CHALLENGES IN...

| AUTOMATION | AVIATION | ENERGY |
|---|---|---|

**UNDERPINNED BY DIGITALIZATION**

# HONEYWELL AEROSPACE (AT)

Honeywell Aerospace products and services are used on virtually every commercial, defense, and space aircraft. We build aircraft engines, cockpit and cabin electronics, wireless connectivity systems, mechanical components. Our hardware and software solutions help create more fuel-efficient aircraft, more direct and on-time flights and safer skies.

## BUSINESS PORTFOLIO

- Electronic Solutions
- Engines and Power Systems
- Advanced Electromechanical Solutions
- Services and Connectivity
- Unmanned Aerial Systems / Urban Air Mobility

## HEADQUARTERS

Phoenix, Arizona

## 2024 SALES

$15.5 Billion

## TECHNOLOGIES

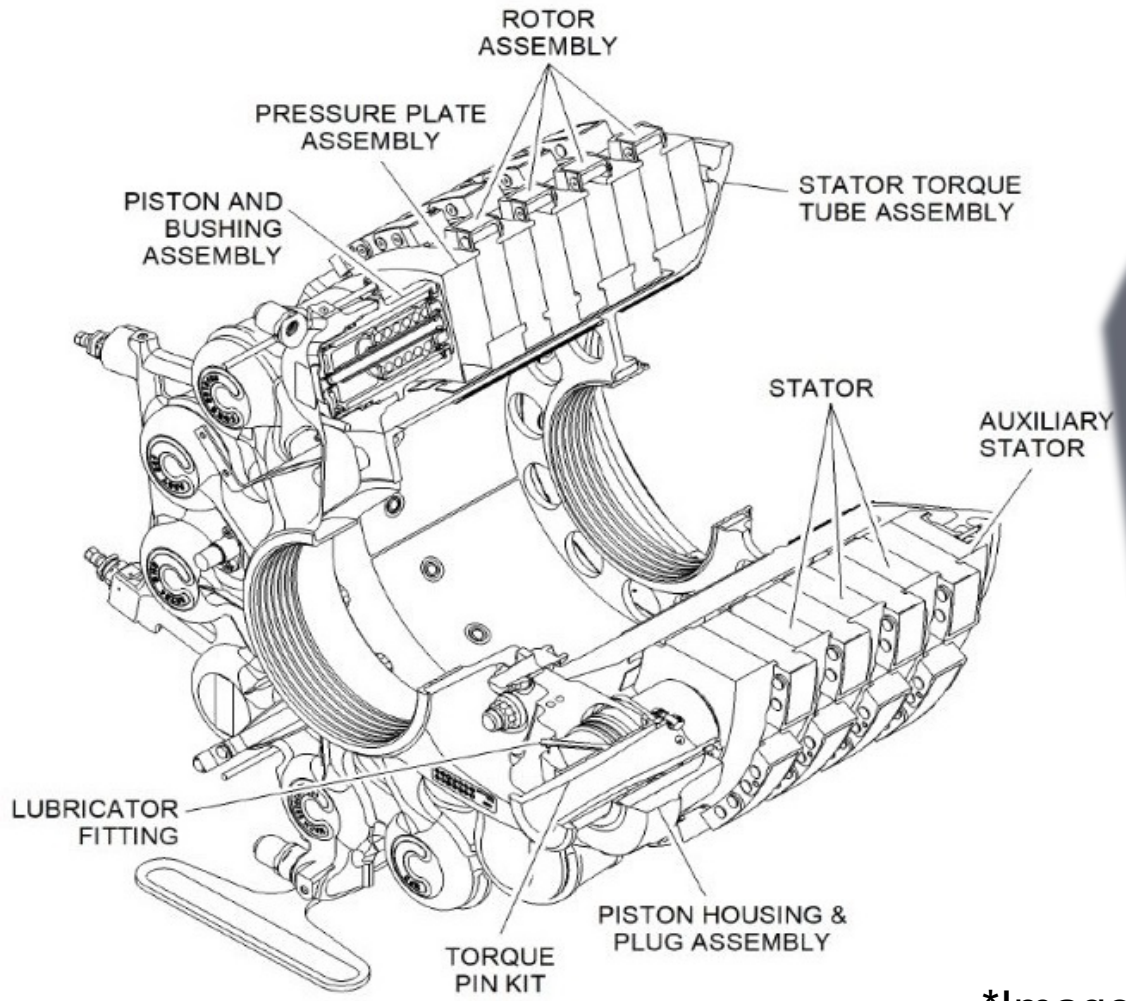
- Air and Thermal Management
- Aircraft Connectivity Systems and Integrated Services
- Autonomous Flight, Detect-and-Avoid Systems
- Federal Solutions Management and Operation
- Hybrid-Electric Systems
- Integrated Avionics and Flight Management Systems
- Life Support Systems and Air Travel Hygiene
- Flight Efficiency and Maintenance Optimization
- Manned/Unmanned and Satellite Applications/Space
- Electromechanical Solutions
- Navigation, Safety, and Surveillance Solutions
- Propulsion and Power Systems
- Runway and Flight Safety Technology
- Wheels and Braking Systems

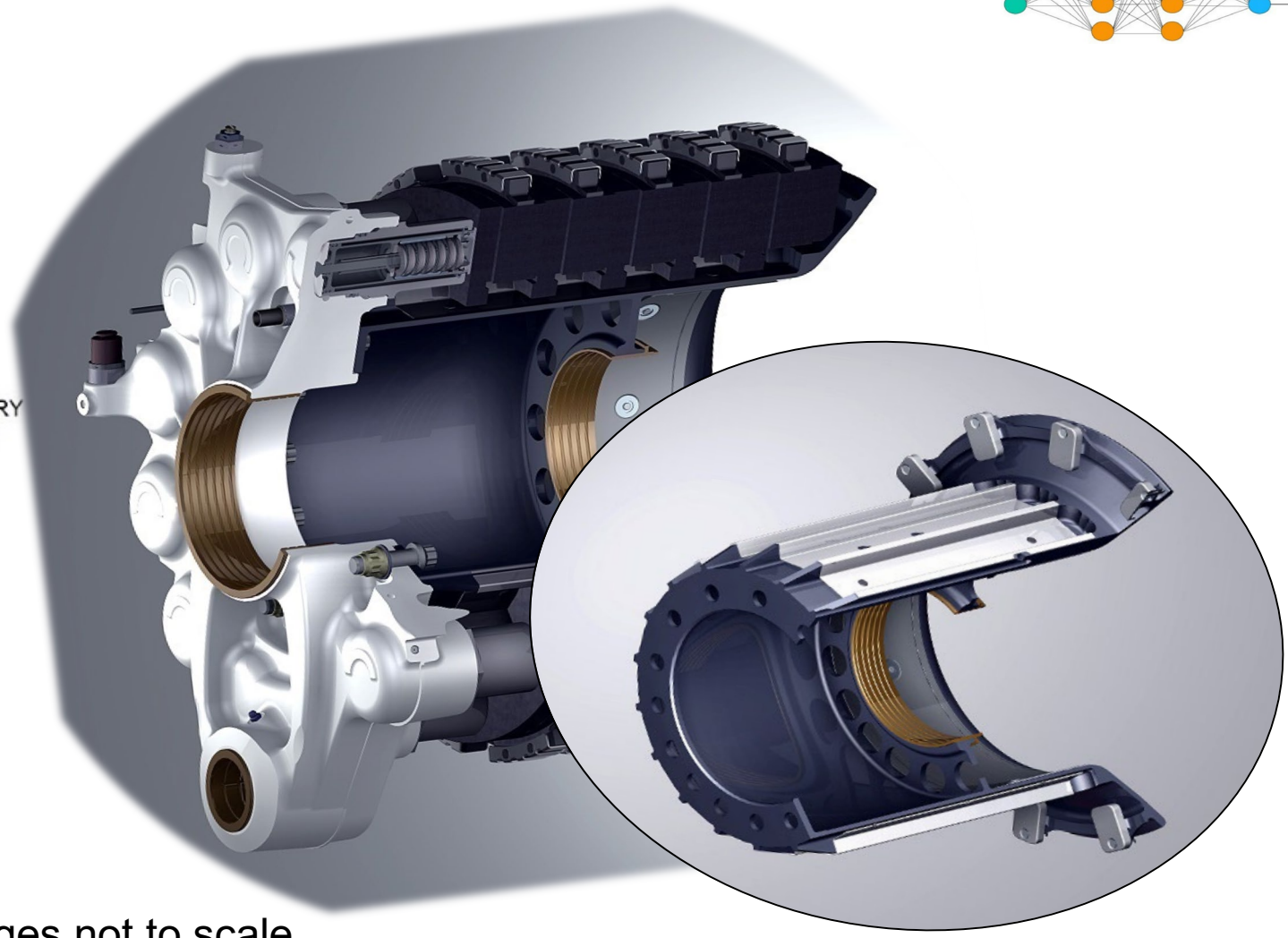
**Helping Make Safer, More Fuel-Efficient Flying and Innovations for the Future of Aviation**

# HONEYWELL WHEELS AND BRAKES


| | | |
|---|---|---|
| 1923 | BENDIX | Bendix Corporation. First South Bend plant was built. Automotive brakes. |
| 1926 | | Airplane Wheel & Brake Department Established - First Bendix Entry Into the Aircraft Market |
| 1929 | Bendix | Bendix Aviation Corporation was formed. |
| 1983 | ALLIED Bendix Aerospace | Bendix acquired by Allied Corporation |
| 1985 | AlliedSignal Aerospace | Allied and Signal Corporations Merge |
| 1999 | Honeywell Aerospace | AlliedSignal purchases Honeywell and retains the Honeywell name / brand. |

# AIRCRAFT BRAKE INTRODUCTION



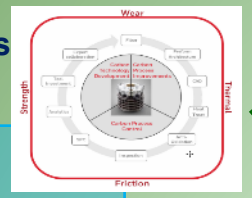



*Images not to scale

**Aircraft Brakes are Highly Engineered to Withstand Harsh Environments**

# W&B AUTOMATION ECOSYSTEM: REDUCE COST & CYCLE TIME

Carbon Pillars




Customer Input

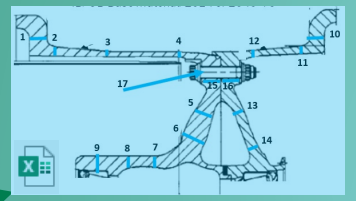
Internal SME Input

Manufacturing Input

## Initial Sizing Tool

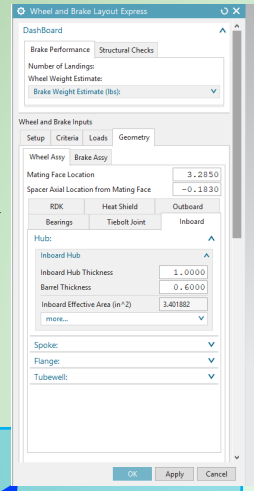
Tire

Bearings

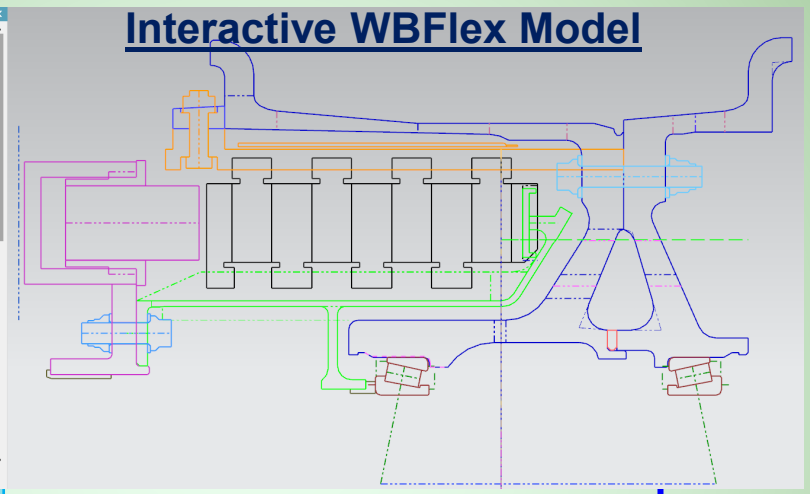


Max Static Load
Service Pressure

17 Thickness Parameters

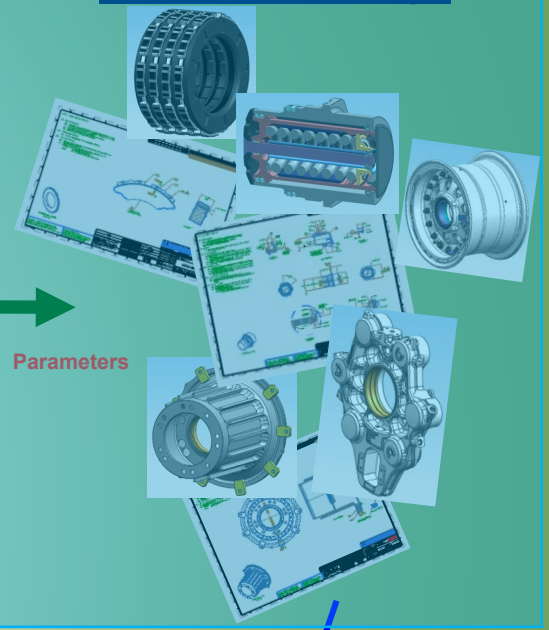



## Interactive WBFlex Model

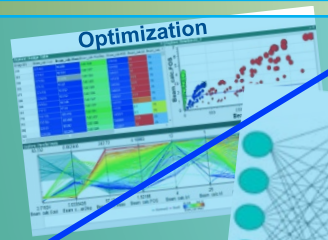


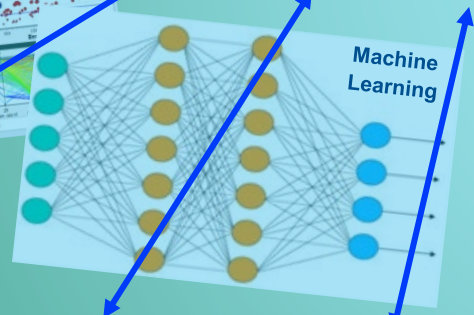
~500 Parameters

## 3D Parametric Models/Drawings



~1500 Parameters




Performance And Sizing Tools

Preliminary Analysis Models

Detailed Sizing Tools

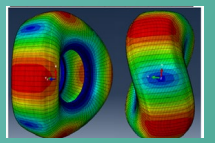
Tolerance Stacks

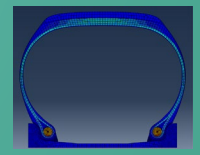
Rough Models for Customer

## Analysis Models

Structures

Thermal Dynamics

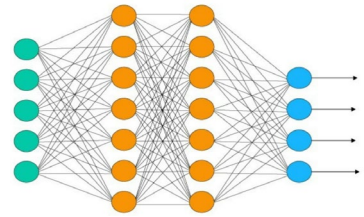




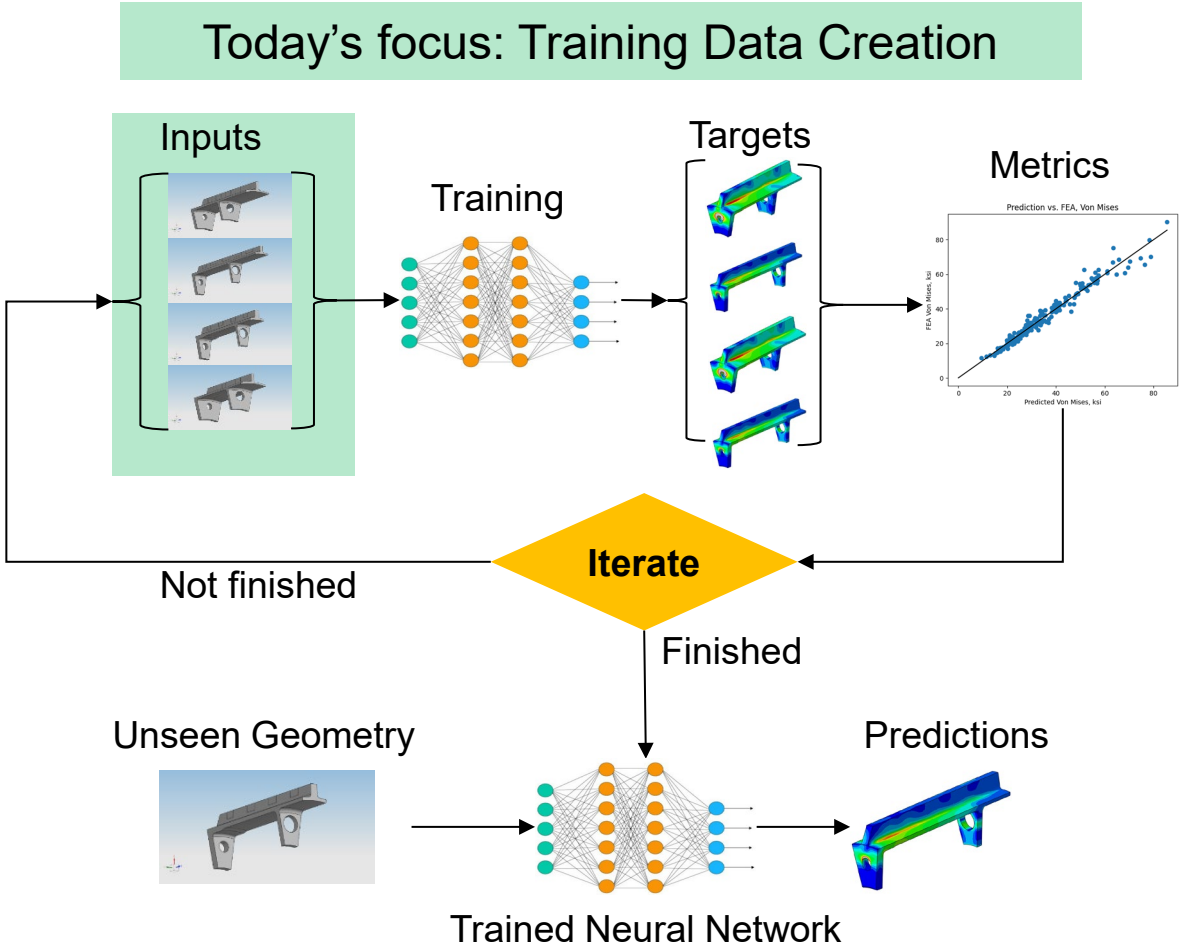
## GOAL: W&B in a Day!

**Customer Requirements to 1st iteration 3D W&B Assembly Models**

# BRIEF INTRODUCTION TO MACHINE LEARNING

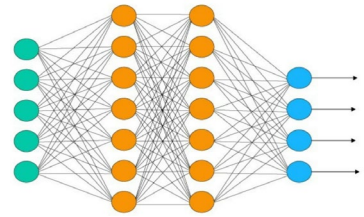


- **ML models learn input-target relationships**
  - FE-Surrogate models trained using FEA inputs and results (targets)
    - Input geometric parameters
    - Predict stresses, displacements
    - Predict for entire model or subset
  - →Neural Networks predict multiple outputs simultaneously

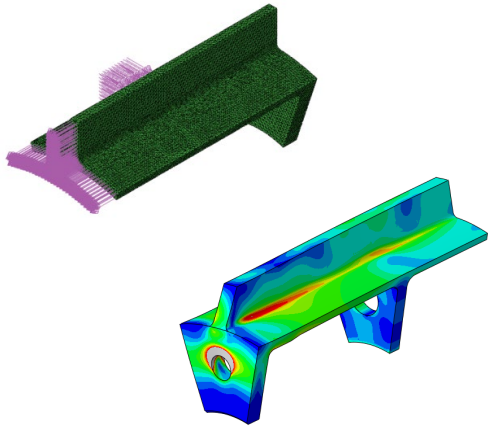


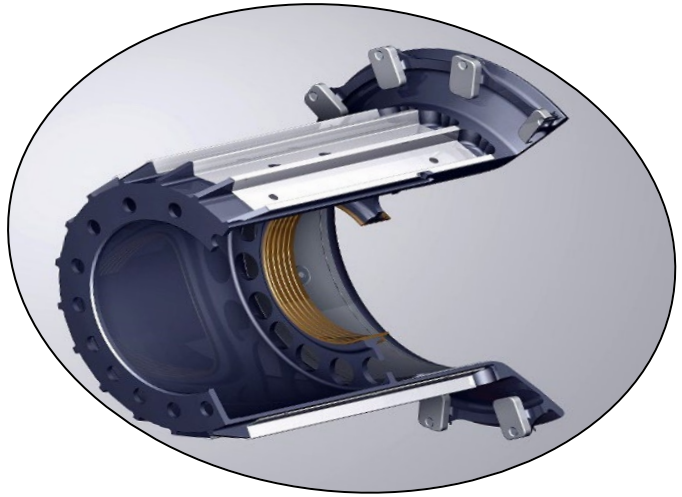

**Data Driven Models Require Large Training Data Sets**

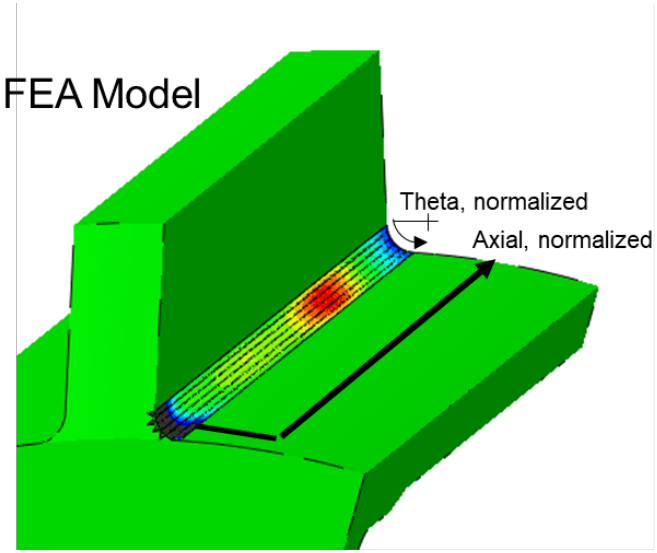
# FEA-SURROGATE MODEL INTRODUCTION



- **Today's content from project in 2022**
- **FEA iterations are time consuming**
- **FE-Surrogates provide near-real-time design assessment**
  - Provide approximations of FEA
  - Reduce cycle time, cost
  - Allow better design definition upstream

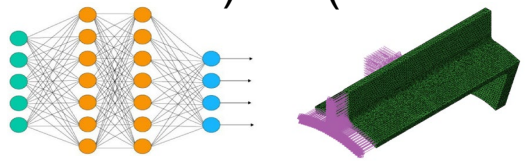




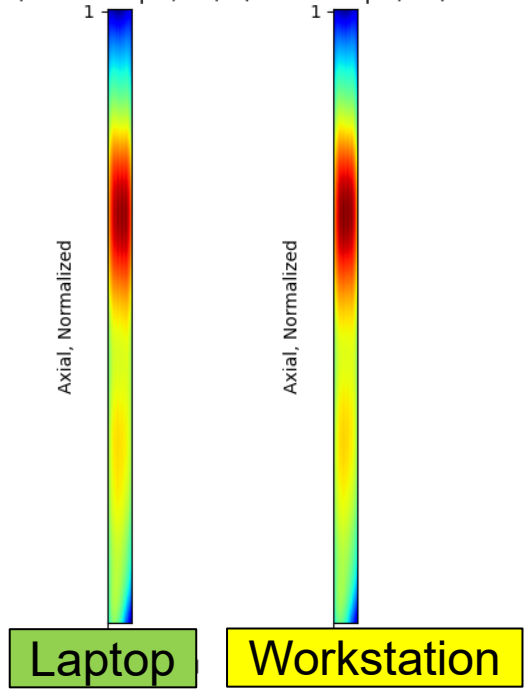



FE-Surrogate (< 1 second)

FEA (1-2 hours)

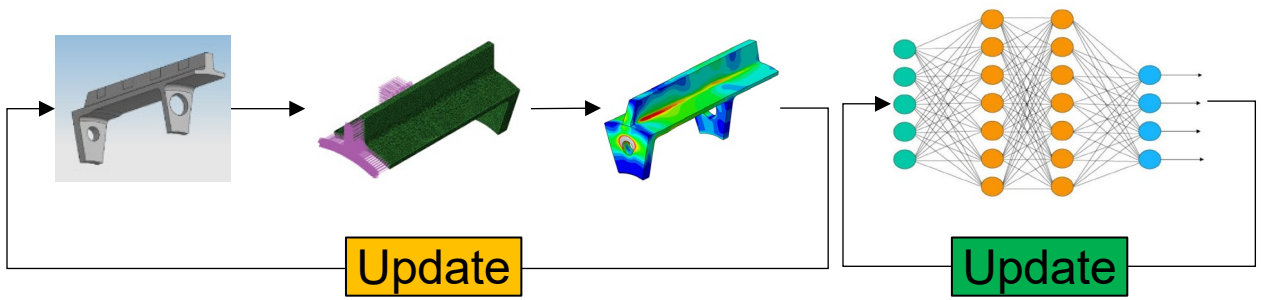


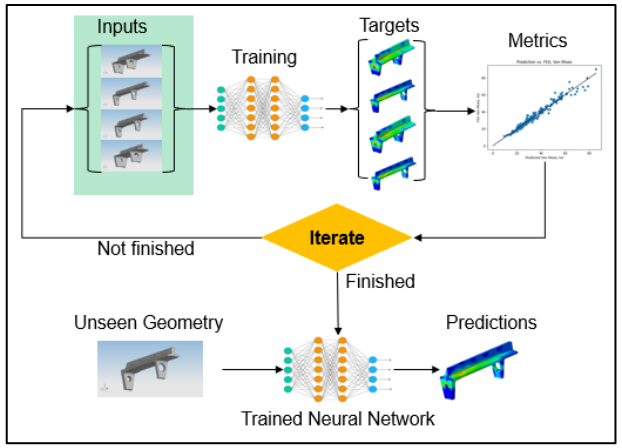


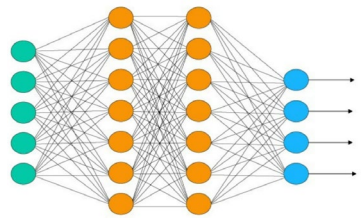


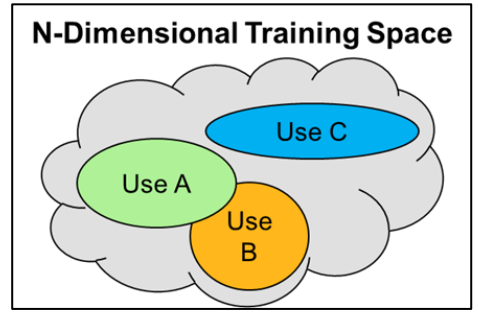

**Domain Expertise Facilitates FE-Surrogate Setup**

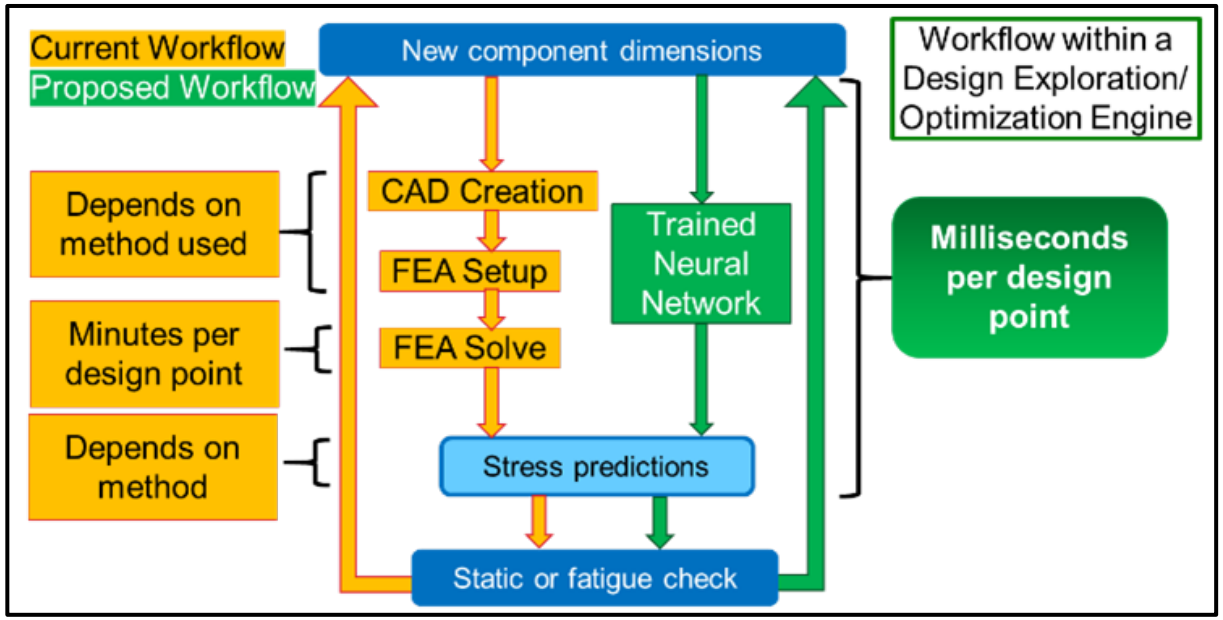
# APPROACH – FEA VS. SURROGATES

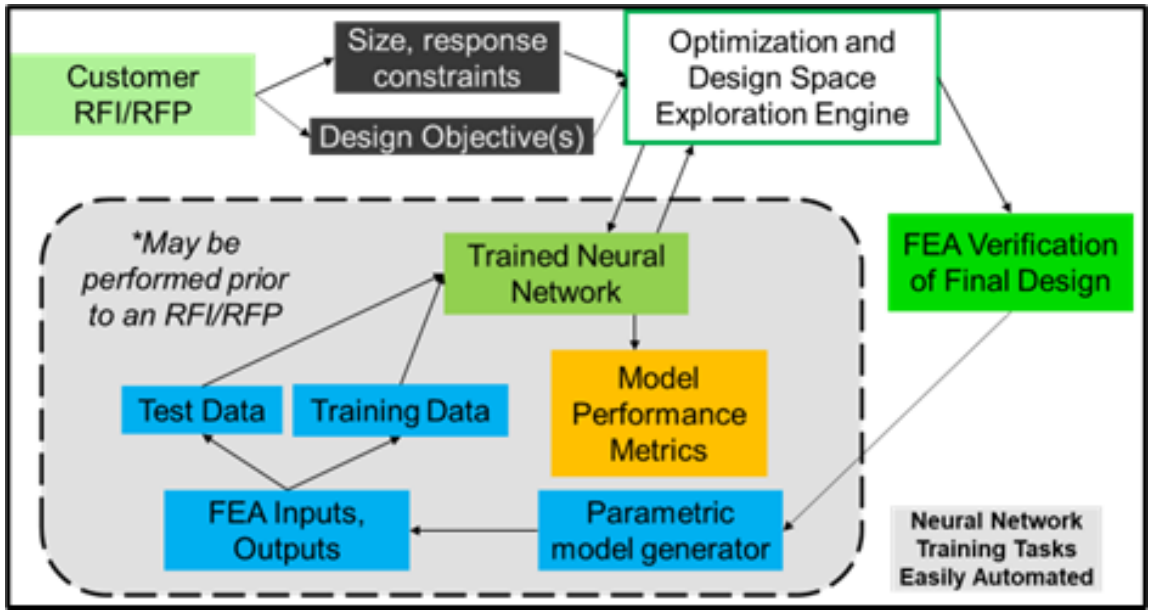


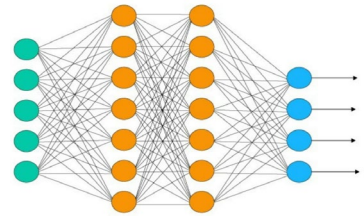


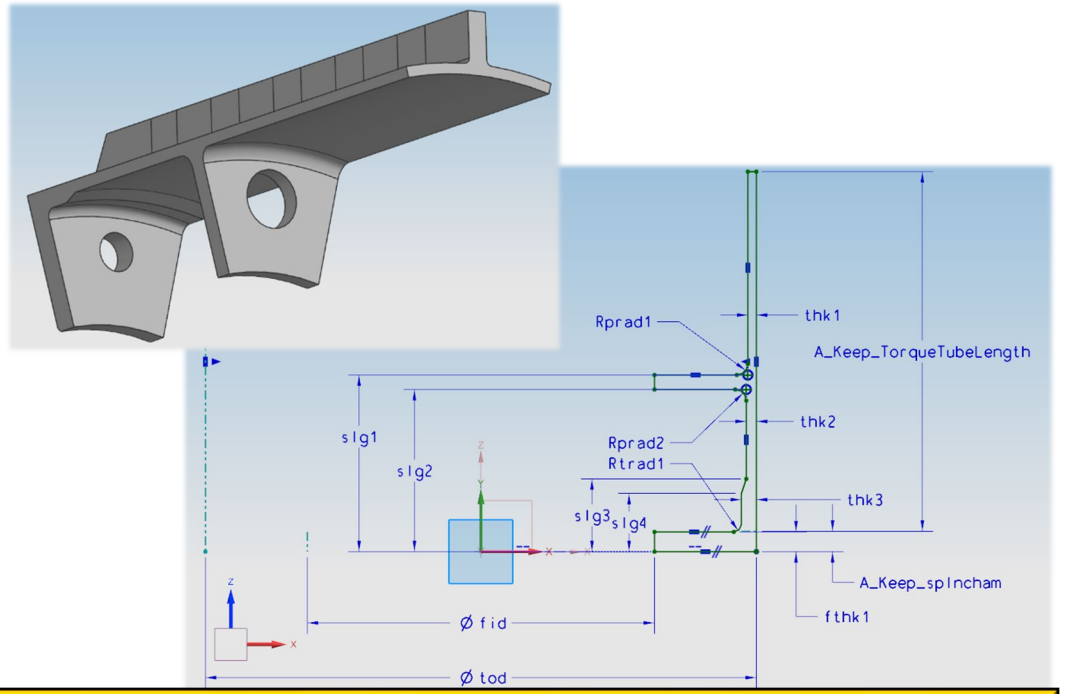




**Data Driven Models Enable Rapid Design Space Exploration**

# NXOPEN FOR TRAINING CAD



- **NXOPEN CAD Generation Script Setup**
  - Parameter bounds to define design space
  - Parameter dependencies
  - Random value generation and distribution type
  - Parameter set coherency checks
- **CAD Script Outputs**
  - Validation images
  - Parameter sets in CSV file
  - CAD file (NX Part, STEP, IGES, etc.)

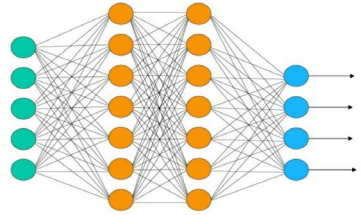


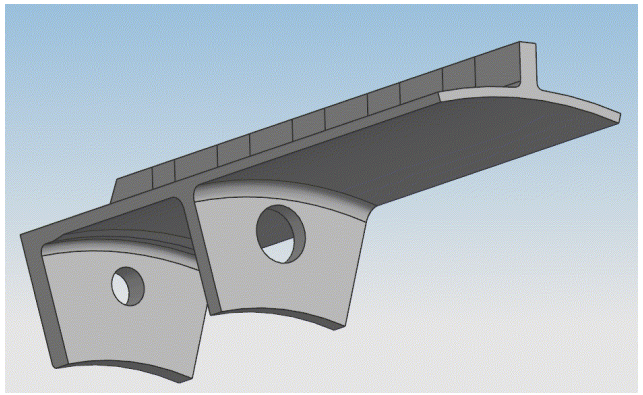

***Conceptual parameterization with randomly generated values***

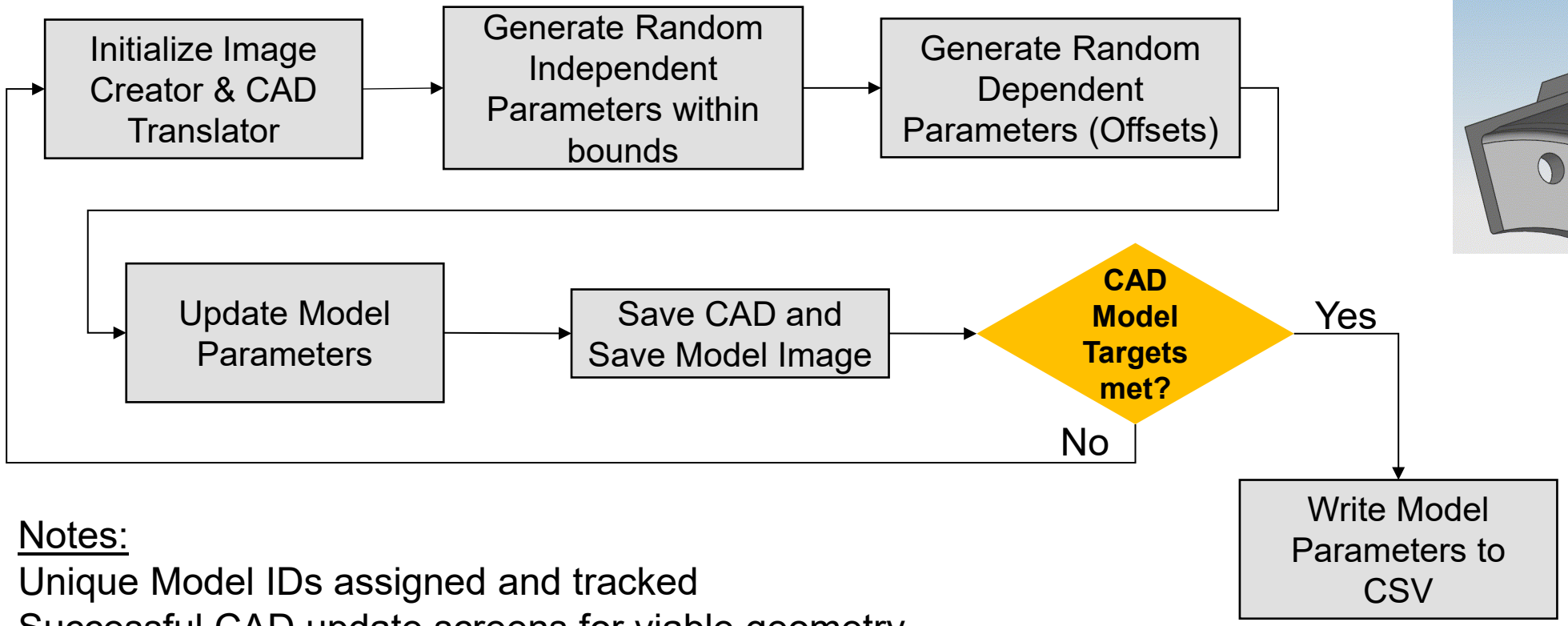
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Name | nspln | nsta | bolthead | fholedia | fid | fthk1 | pdhole | prsfiloffs | prsoffset | prsthk | rotthk | slg1 | slg2 | slg3 | slg4 |
| 2 | tube_0000 | 9 | 3 | 0.75 | 0.5 | 5.609996 | 0.34 | 0.75 | 0.17642 | 0.72959 | 0.52375 | 0.561315 | 3.328597 | 3.078597 | 1.253433 | 1.003433 |
| 3 | tube_0001 | 17 | 4 | 0.75 | 0.5 | 5.577839 | 0.34 | 0.75 | 0.156778 | 0.524725 | 0.517967 | 0.644491 | 3.337639 | 3.087639 | 1.445661 | 1.195661 |
| 4 | tube_0002 | 10 | 4 | 0.75 | 0.5 | 6.318345 | 0.34 | 0.75 | 0.169725 | 0.646102 | 0.580273 | 0.588703 | 3.61747 | 3.36747 | 1.213375 | 0.963375 |
| 5 | tube_0003 | 10 | 3 | 0.75 | 0.5 | 5.63128 | 0.34 | 0.75 | 0.139522 | 0.721817 | 0.520232 | 0.794158 | 3.493805 | 3.243805 | 1.177491 | 0.927491 |
| 6 | tube_0004 | 15 | 4 | 0.75 | 0.5 | 6.133199 | 0.34 | 0.75 | 0.185633 | 0.586488 | 0.586842 | 0.631066 | 3.537258 | 3.287258 | 1.463669 | 1.213669 |

**NXOpen Accessed with Python Commands through Journaling**

# HIGH-LEVEL FLOWCHART



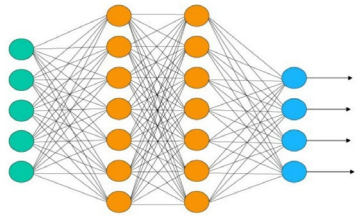





Notes:
Unique Model IDs assigned and tracked
Successful CAD update screens for viable geometry

**NXOpen Capabilities Leveraged Through Journaling with Python Scripts**

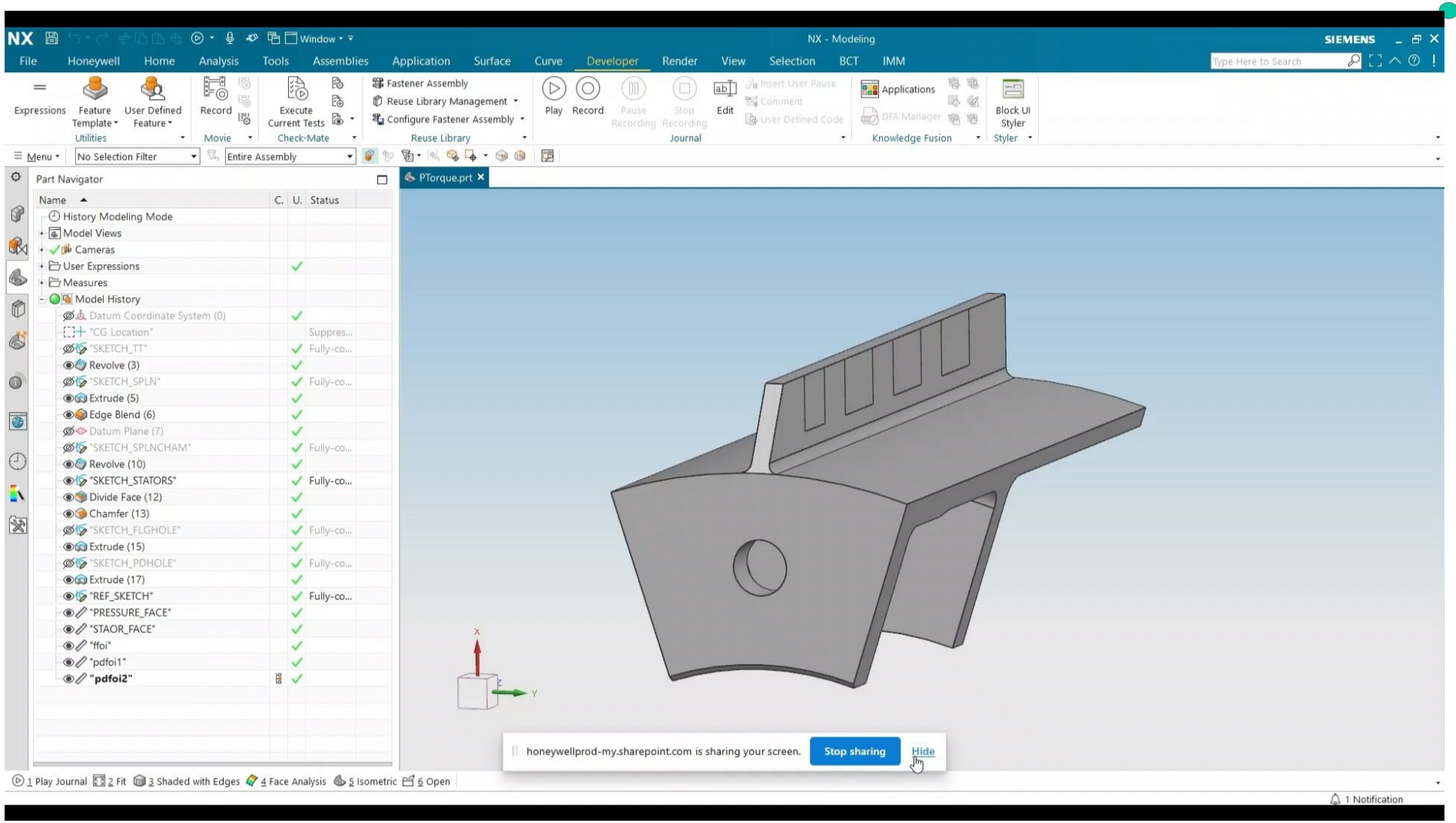
# MODELING STRATEGY



- **Fully Parameterized Model**
  - Independent expressions: To drive initial geometry updates
  - Measurement expressions: Rapid collection of relationships between geometry
    - Reduce noise in training data for difficult dimensions to calculate
  - Dependent expressions: To drive 2nd round of updates based on measurements
- **Parametric Sizing: In-model vs. In-code Logic**
  - In-model logic preferred to establish boundaries of the 3D model (ex. angled surfaces dependent on spline count)
  - In-code logic preferred to drive geometry changes, especially between related features.
- **Problem Statement Focus**
  - Simplified definition compared to real parts (general features included)
    - Ex. Holes to spline location
  - Tubewell only style, section to aid in solving time during analysis step
  - Measured expressions reported to output files to support analysis automation.

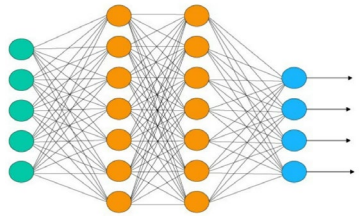
**Modeling Strategy Designed to Support Stress Solutions**

# NXOPEN DEMONSTRATION VIDEO




**NXOpen Runs Unattended for Large Dataset Creation**

# NXOPEN CONSIDERATIONS



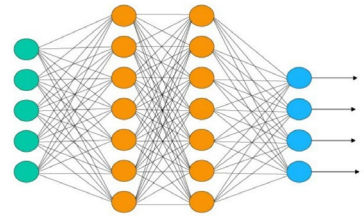
**Improvements with each iteration since inception in 2022**

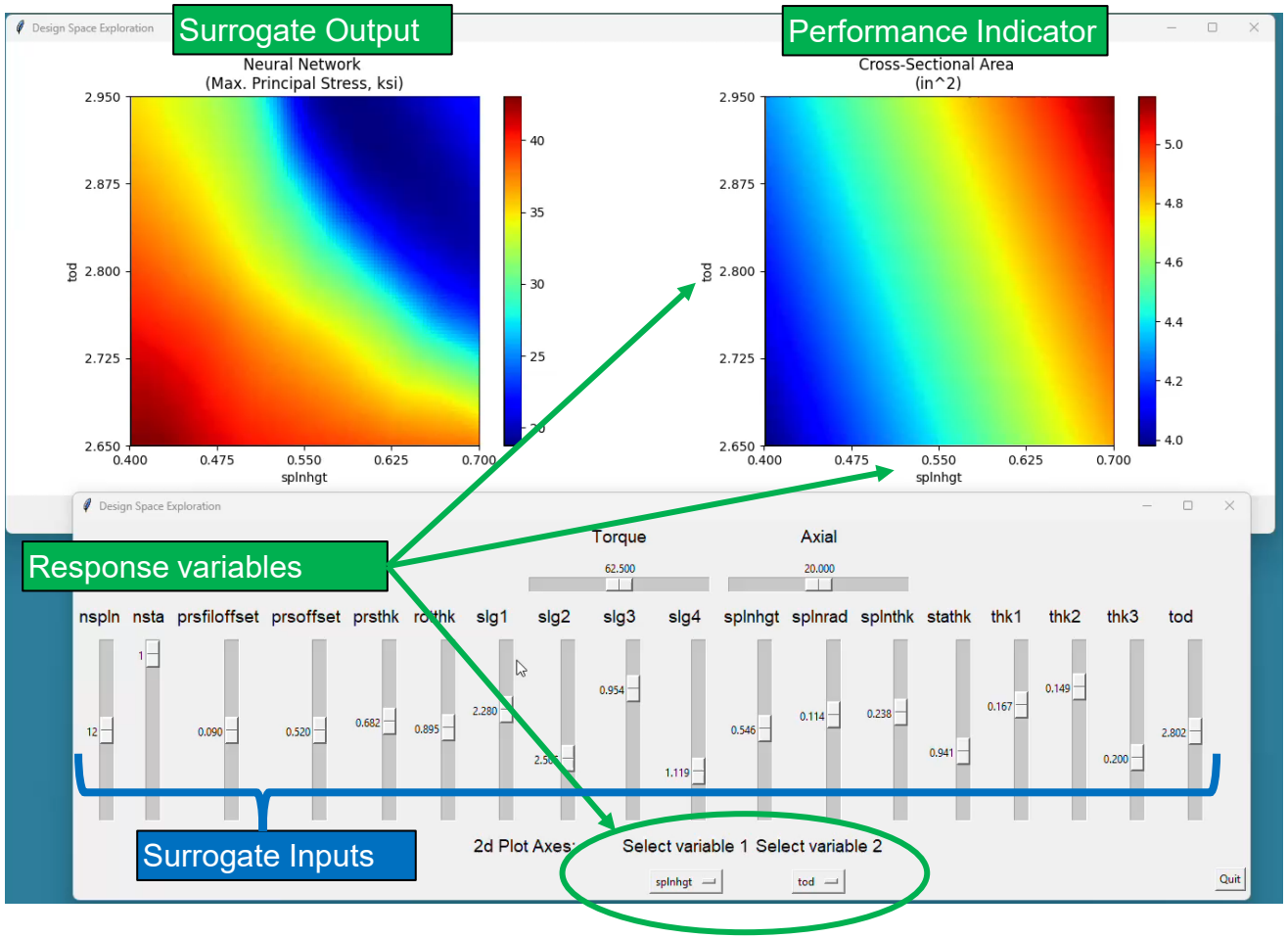
- **Parameters directly written to NX model, eliminating Expression file Input/Output that was done initially**
- **Custom NXOpen Python functions to execute expression replacements before update, reducing the complexity of the main code.**
- **Improved risk mitigation in the case of model/sketch-based exception.**
- **Improved resource conservation through headless Python journaling initialized with simple batch files.**

**NXOpen Journaling supports several languages**

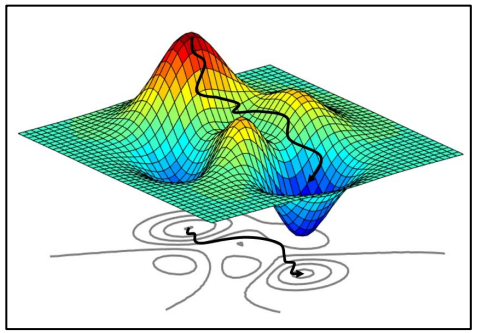
- **C++, C#, Java, VB, Python**
- **Python chosen for familiarity and for compatibility with other Honeywell tools**
- **Exploring ways for external libraries (NumPy, PANDAS) to function in the NX Python environment.**

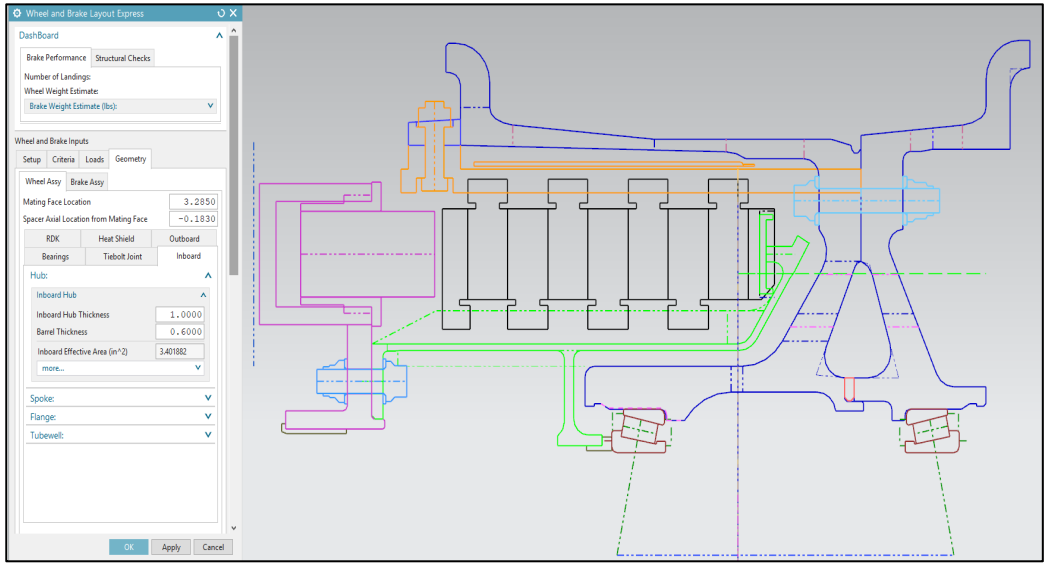
# FE-SURROGATE APPLICATIONS





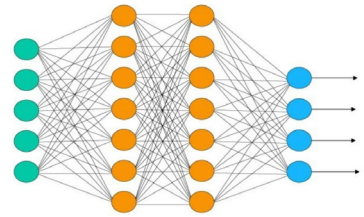

- Design space exploration
- Optimization and robustness studies
- High-fidelity analysis selection
- W&B Automation Tool



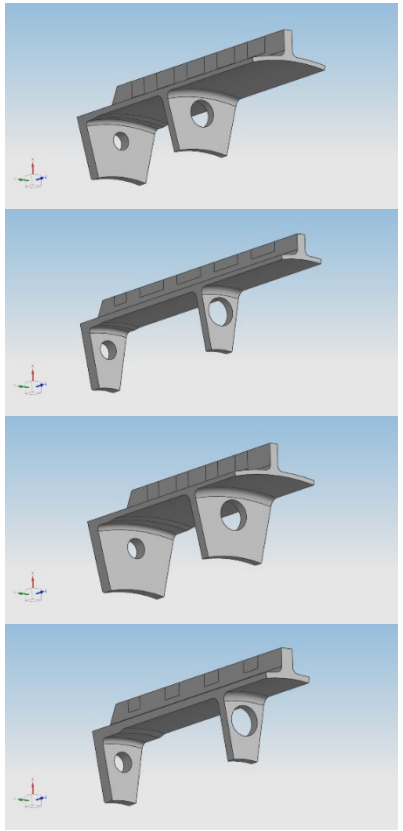


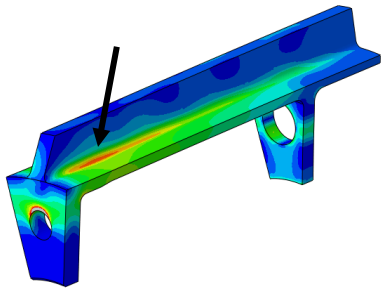

**FE Surrogate Models Enable Design Space Comprehension**

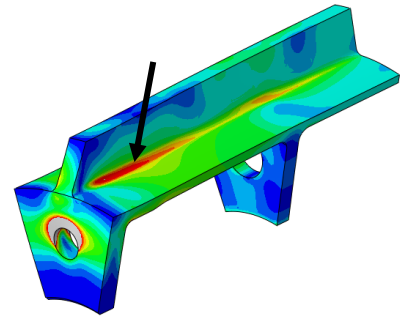
# TRADEOFFS AND CONSIDERATIONS

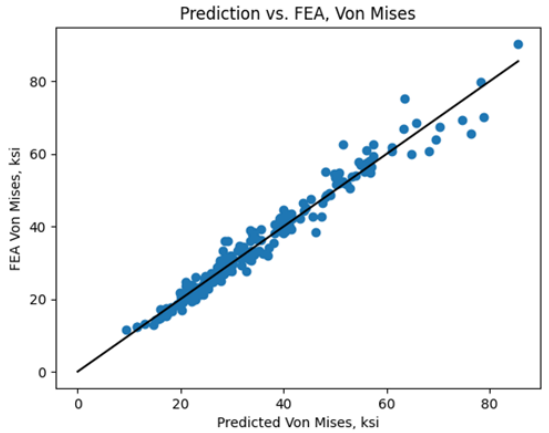


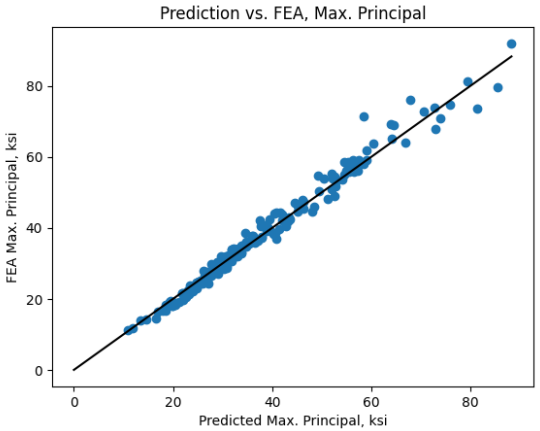
- **ML Model accuracy**
  - Managed with high-fidelity FE analysis downstream
  - Closed-form solutions will be faster and more accurate
- **Setup effort**
  - Scripted parametric FE models
  - ML Model training
  - Training CAD generation
    - ***→ Solved with NXOPEN scripting***





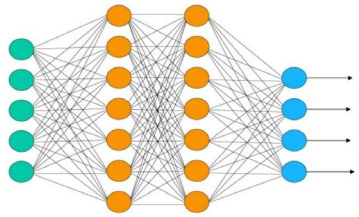





**Training Model Population Depends on Response Complexity**

# SUMMARY AND CONCLUSIONS



- **NX CAD can be parameterized with Expressions**
- **Python scripts can leverage NXOpen to update parameters and generate CAD designs**
- **FE-Surrogates require training data from numerous FE models**
- **Automated CAD generation facilitates training data generation**
- **FE-Surrogate models can reduce design cycles times**
  - Real-time design feedback
  - Complement Wheel and Brake Design Tool ecosystem
  - Facilitate system-level optimization
- **FE-Surrogates enable design space comprehension**

**NXOpen Scripting Solves One of the First Hurdles for Data Driven FE-Surrogates**

# THANK YOU

Honeywell