

**2017 Haulage and Loading**

**Phoenix, AZ**

Shovel Control Advancements

John Burant

VP of Global Business Development



**FLANDERS**

**Listen. Innovate. Serve.**

# Great to be Back!

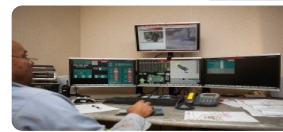


# Agenda

- FLANDERS Background
- Classic Control Method
- Challenges in Shovel Control Systems
- Adaptive Control Technology
- Model of the “Plant”
- Deployment of the Technology
- Advanced Health Monitoring including Fatigue
- Current Market Dynamics
- Q&A



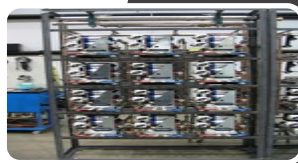
# Expanding Capabilities



Advanced Technology  
Products



New Motors



Drives and Controls



Service and Repair

1950

1970

1990

2010

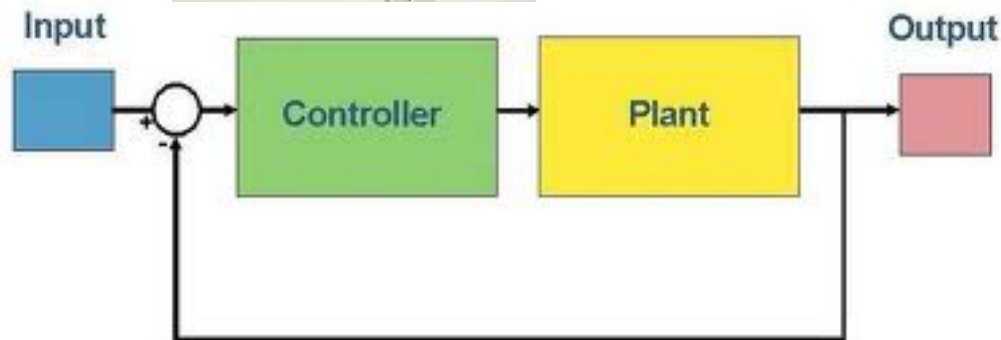
2015

Future

**FLANDERS**

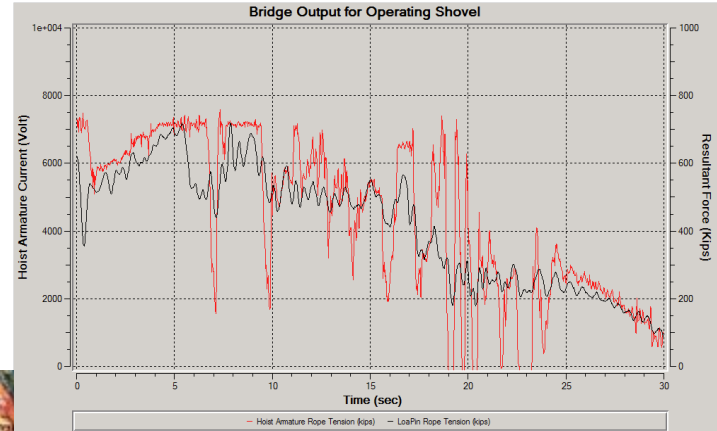
# How it use to be done?

- Classical control systems technology defined:

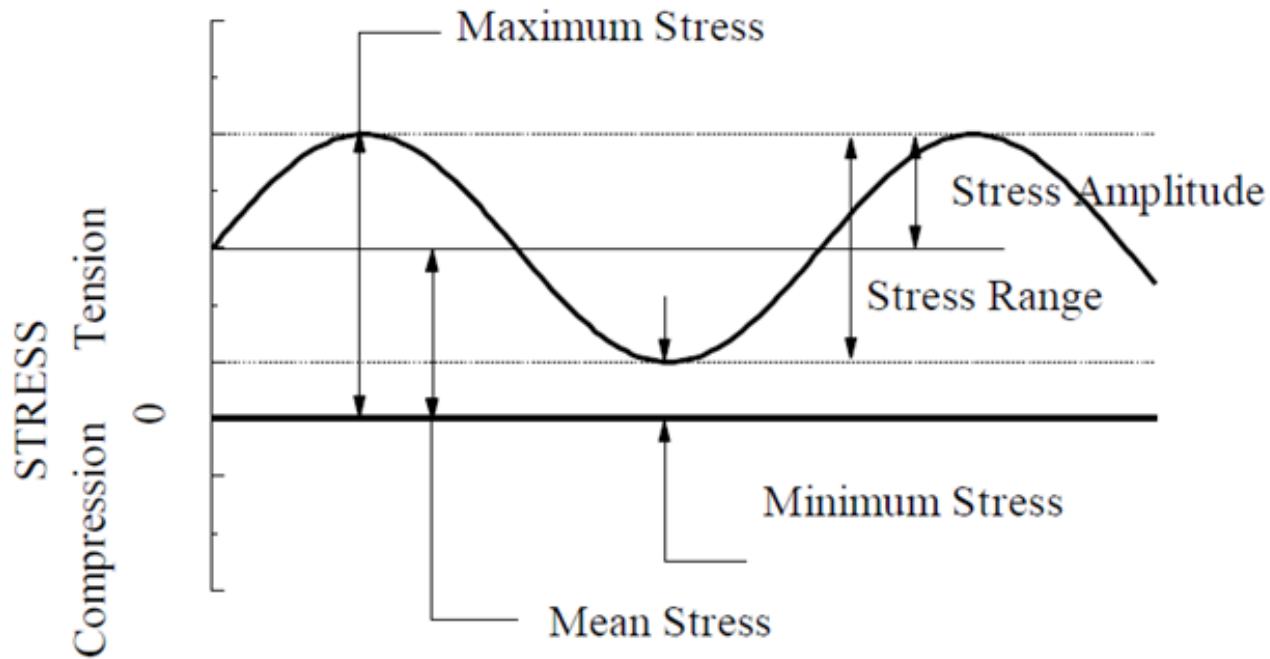


# Overcoming the Challenges:

- Dynamic loading
- Harsh environmental considerations
- Extensive variability
- High reliability requirement (MTBF)
- Self diagnosing (MTTR)

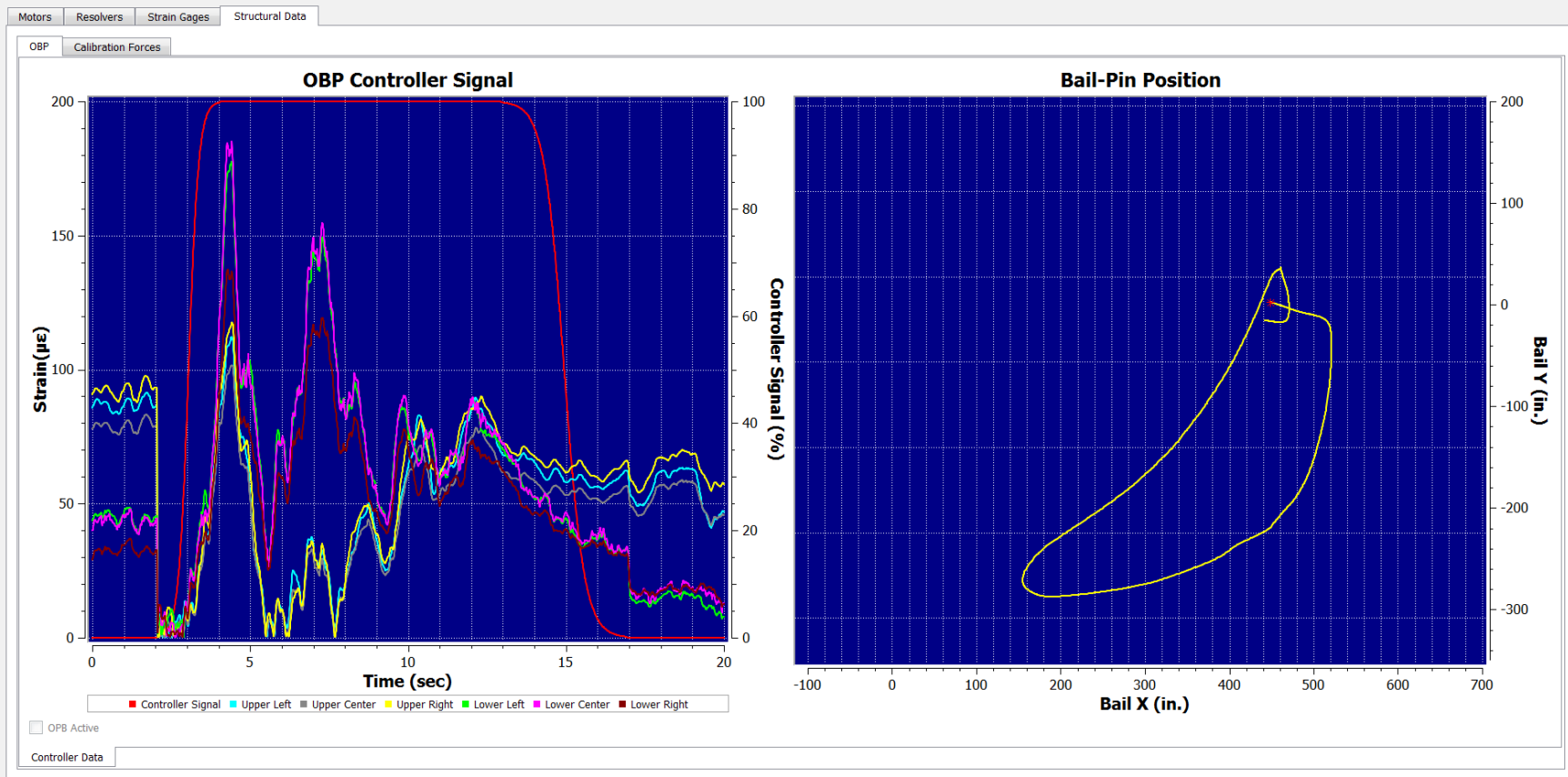


# The Fatigue Cycle



Cumulative damage is the sum of all load-unload cycles. May or may not include mean stress.

# Hoist Unload then Reload Cycle

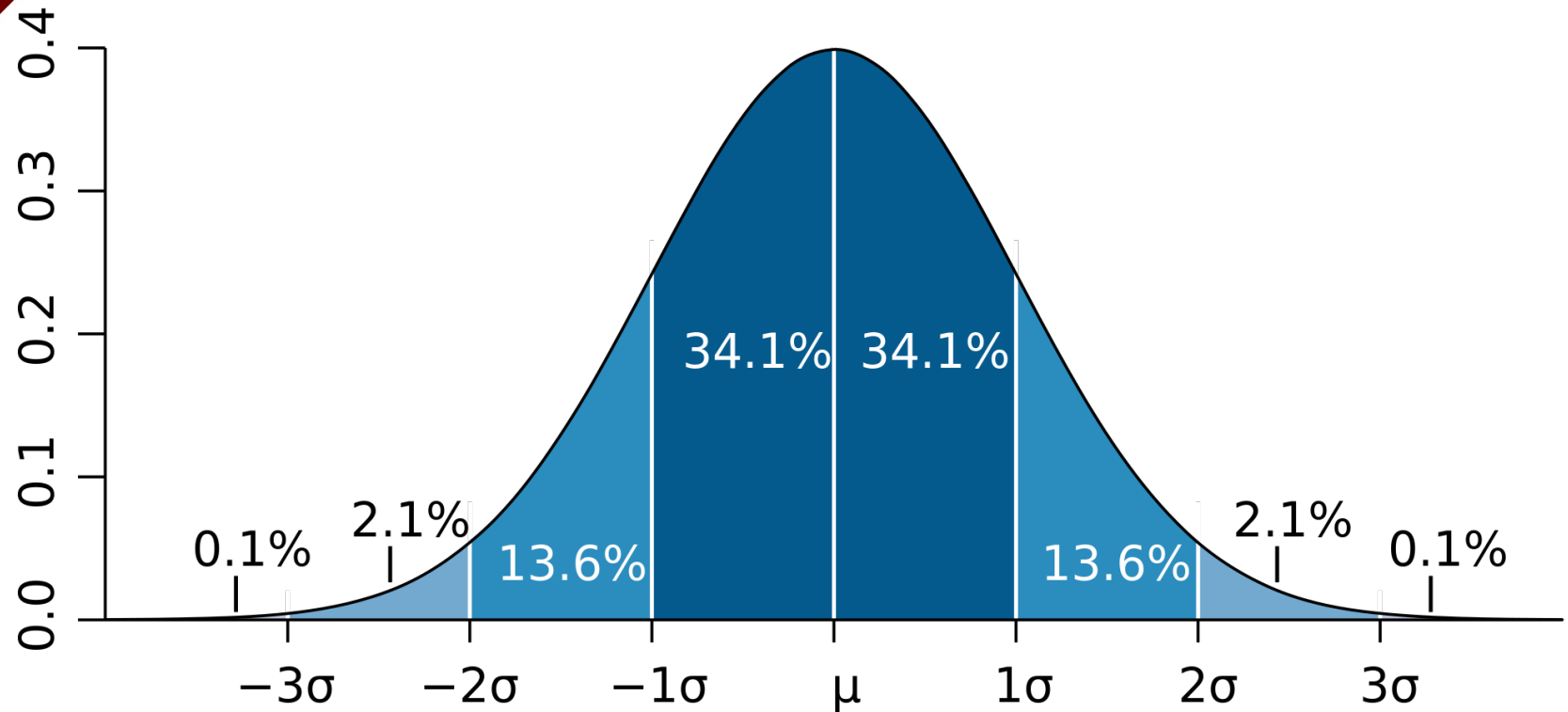




# 4100XPC Fracture in Parent Metal

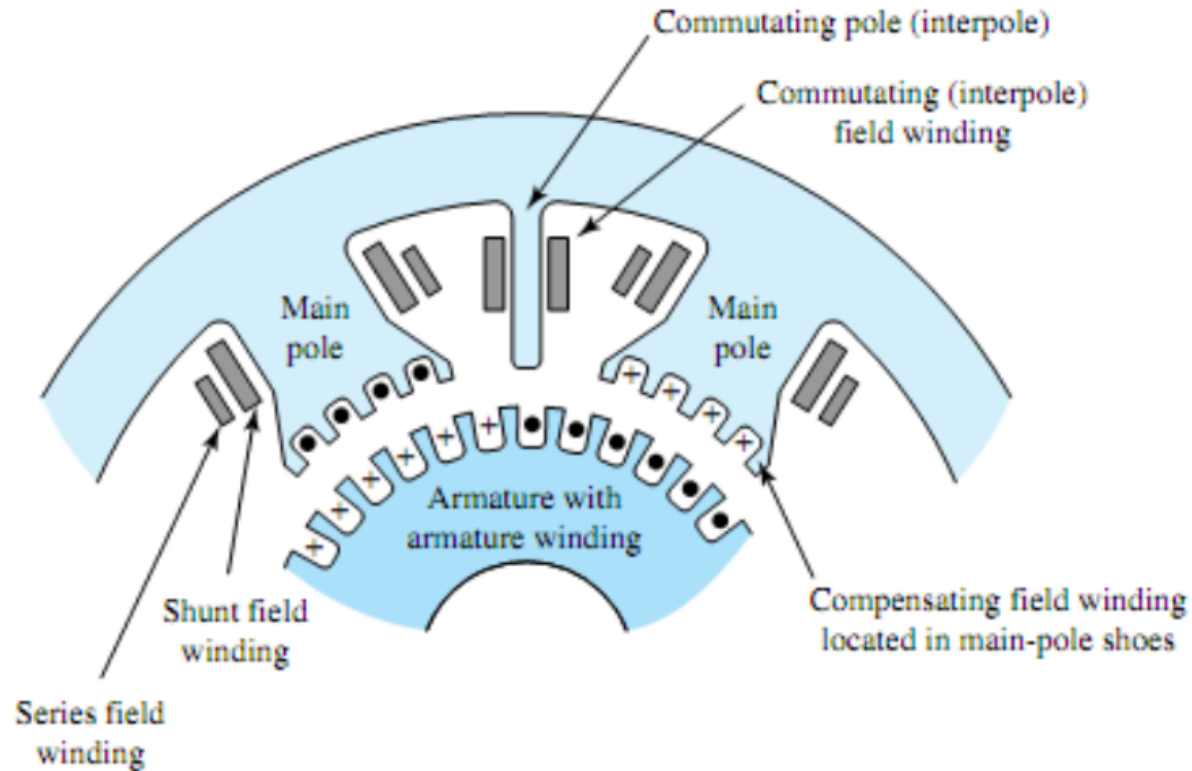


# Bell-Shaped Strain Distribution



A maximum  $1\sigma$  strain setting results in excluding the top 15.8% of the measured differential strain (or boom loadings) from OBP control. Rule of thumb, 90% of damage is done by 10% of the loads.

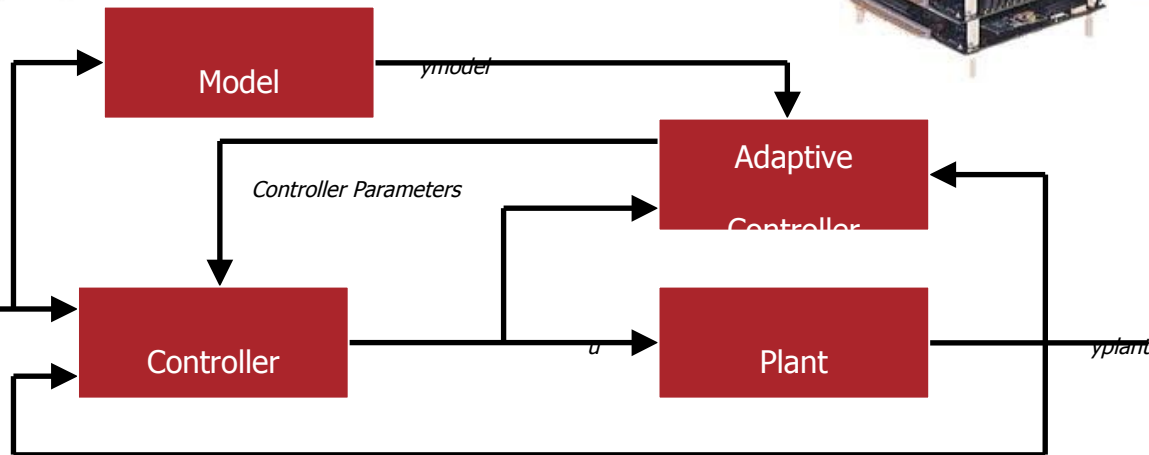
# FREEDOM Shovel Systems - Motors



Section of a dc machine illustrating the arrangement of various field windings.

# How can adaptive control help?

- Adaptive control systems technology defined:

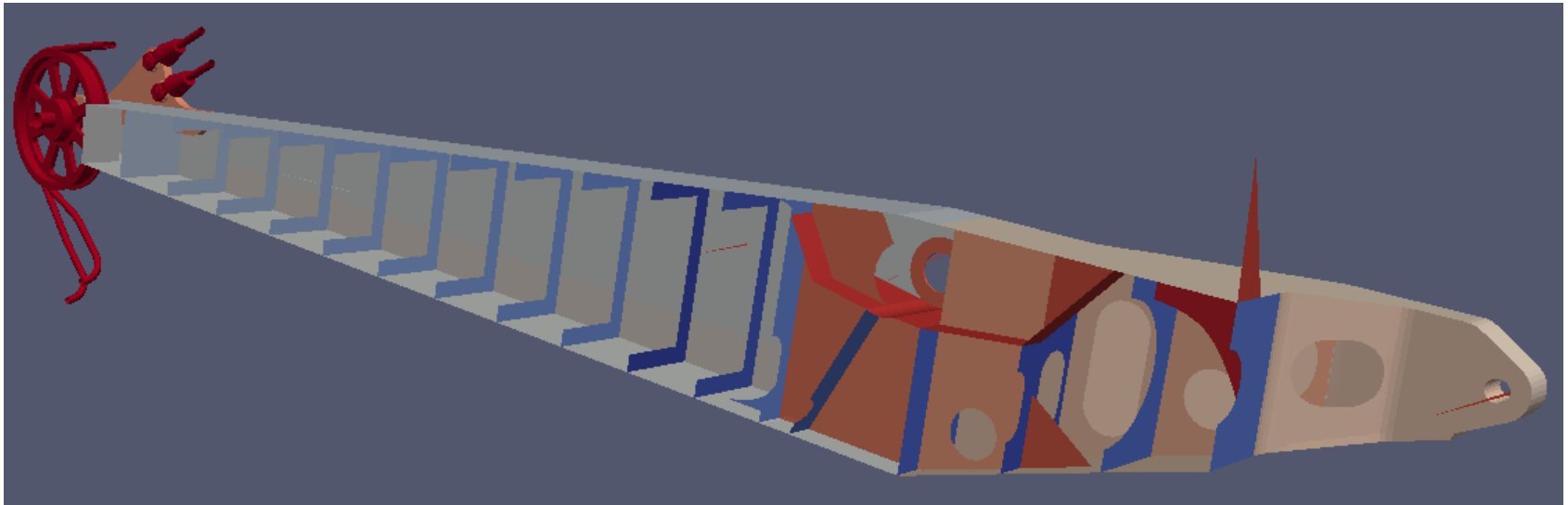


# How can adaptive control help?

- Differences between two technology platforms
  - Control parameters no longer fixed
  - Plant is expanded beyond motor to complete mining system
  - The complete mining system is computer modeled to provide feed forward signals resulting in optimized dynamic performance
  - Resulting in optimized machine performance - \$\$\$/ton



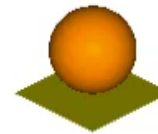
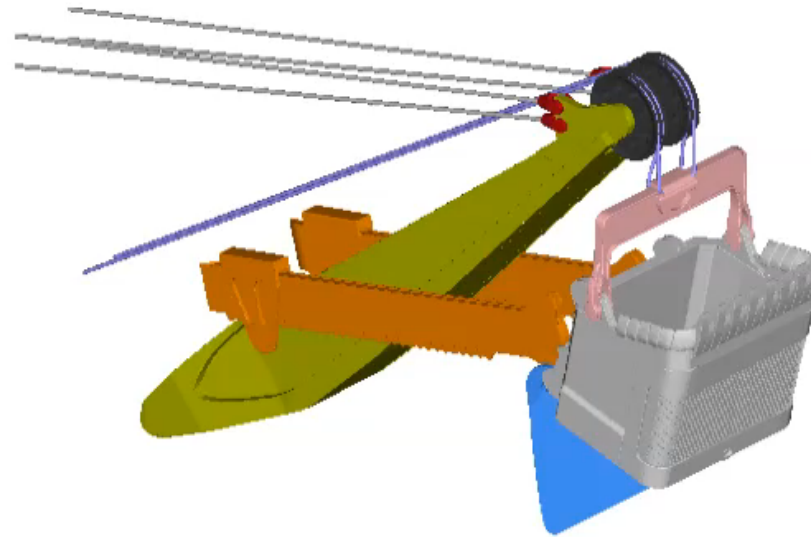
# FEA 4100 XPC Boom Model: Symmetric and Interior View



- Developed from field measurements of interior and exterior of boom
- The analysis requires the external loadings acting on the boom. The solution recovers the reaction forces and stress and strain throughout the boom structure.

# Dynamic Modeling and Fatigue Analysis

Alair Engineering – State of the Art CAE

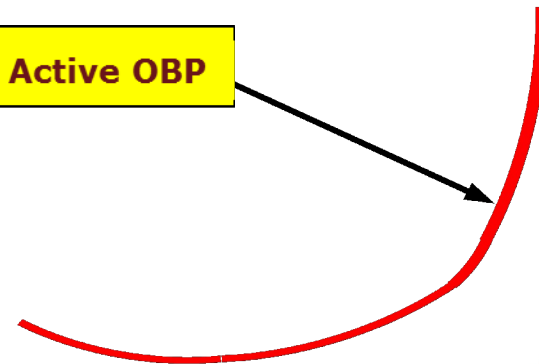


# How Does FREEDOM Work?

- Ability to monitor shovel fatigue & electrical system parameters
- Allows increased Cutting Force power **only when dig conditions allow.**
- Stay at or below conservative OEM shovel operating design parameters.

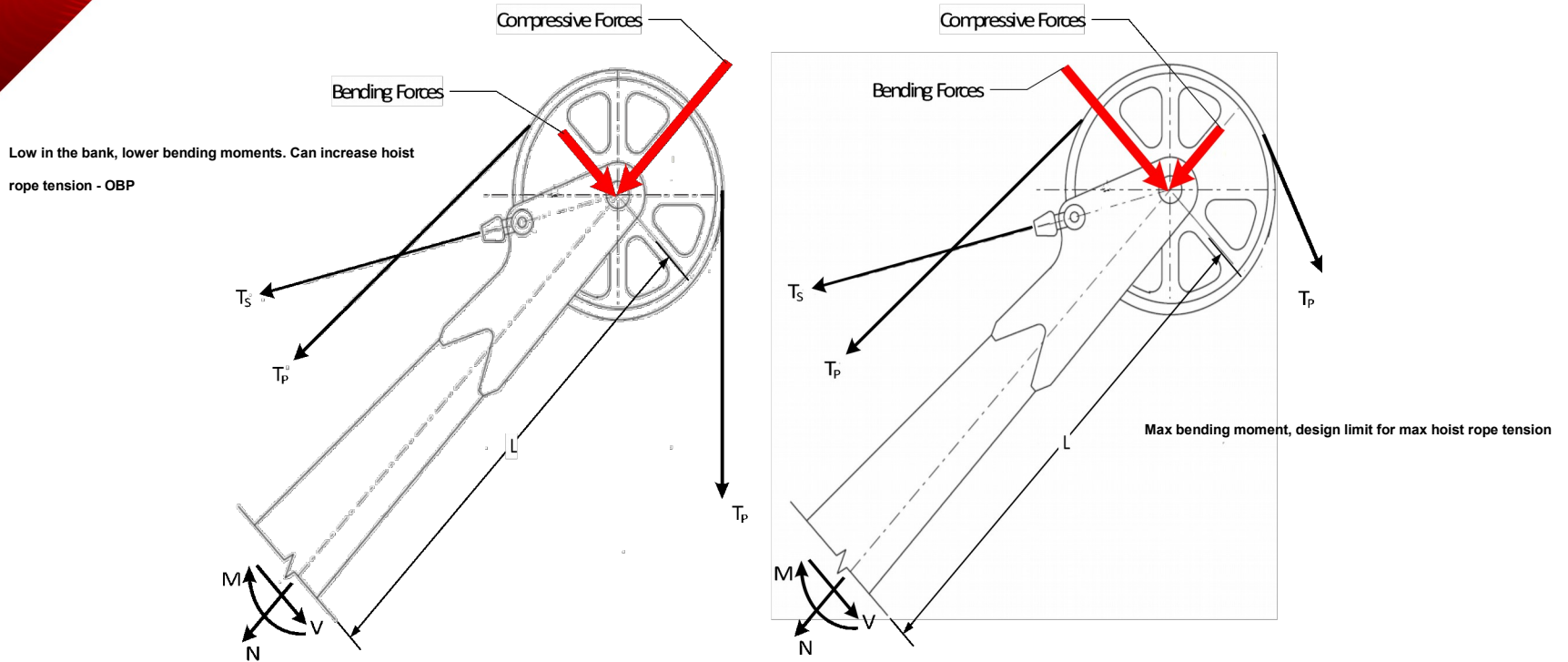


Active OBP





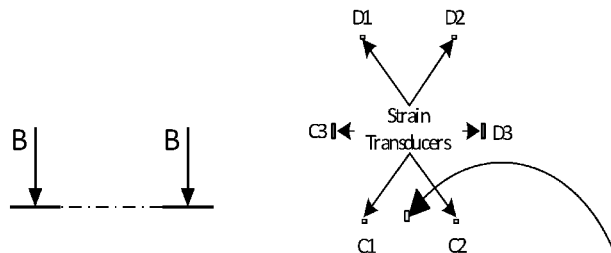
# Structural Design Forces



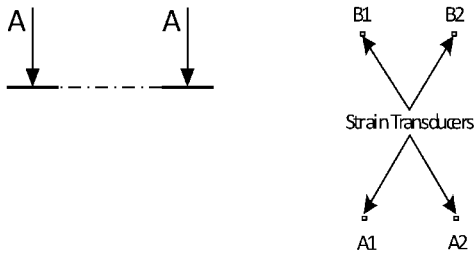
- Magnitude and direction of components changes throughout the dig cycle
- Bending forces generally are the limiting factor in design and fatigue
- Boom protection requires a real time recovery of the two components, compressive and bending

# Sensor Locations

## Boom Instrumentation



Instrumented Cross-Section B-B



Instrumented Cross-Section A-A

Triaxial Accelerometer

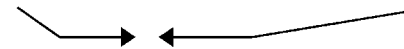
## A-Frame Tension Leg Instrumentation

Outside Edge  
Left and Right Legs

Bottom Edge  
Left and Right Legs

A1

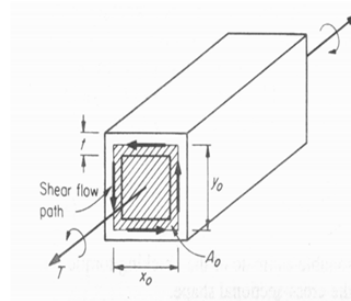
A2



A4

A3

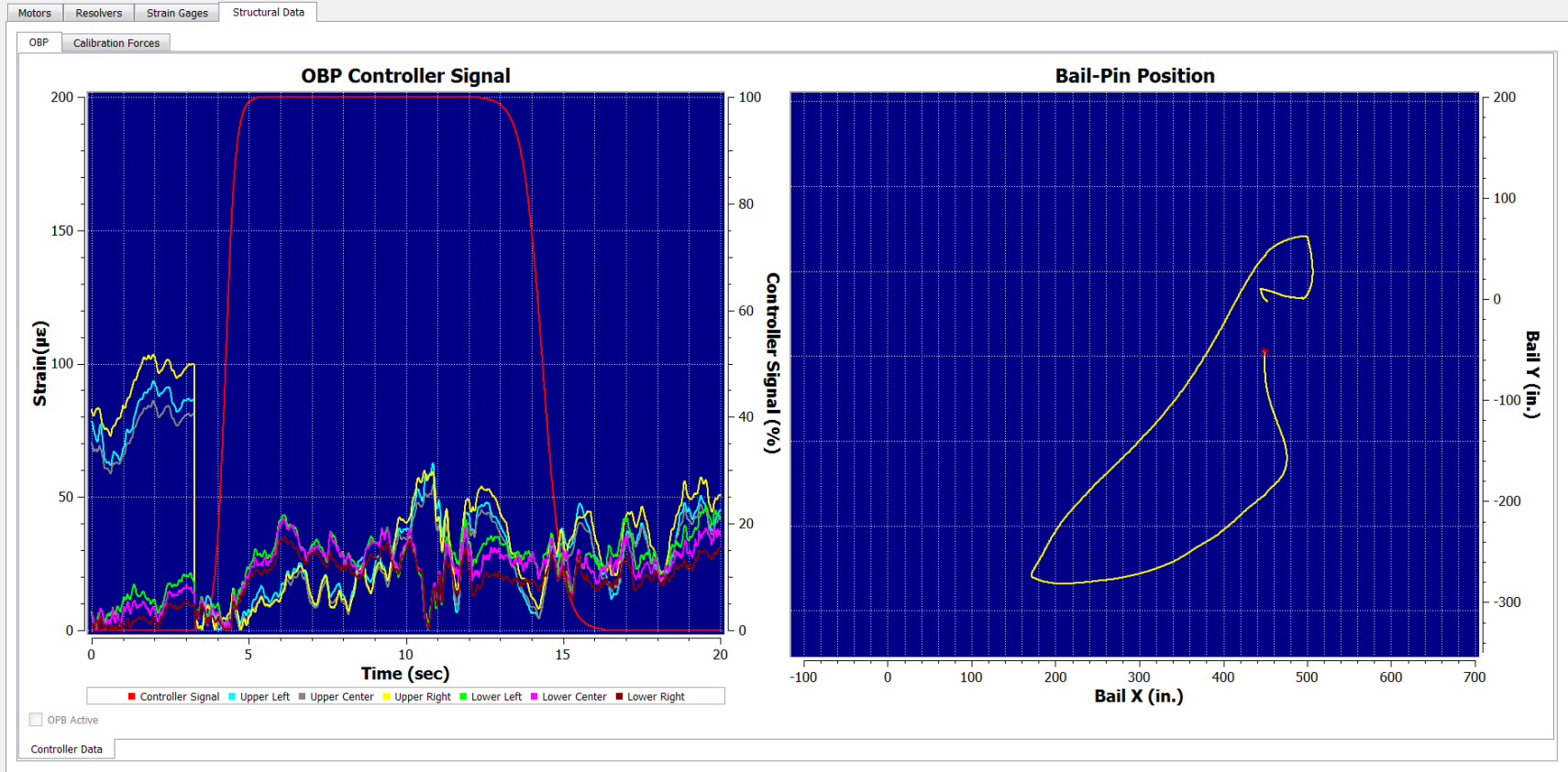
C3 and D3 measure shear flow assuming St. Venant torsion.



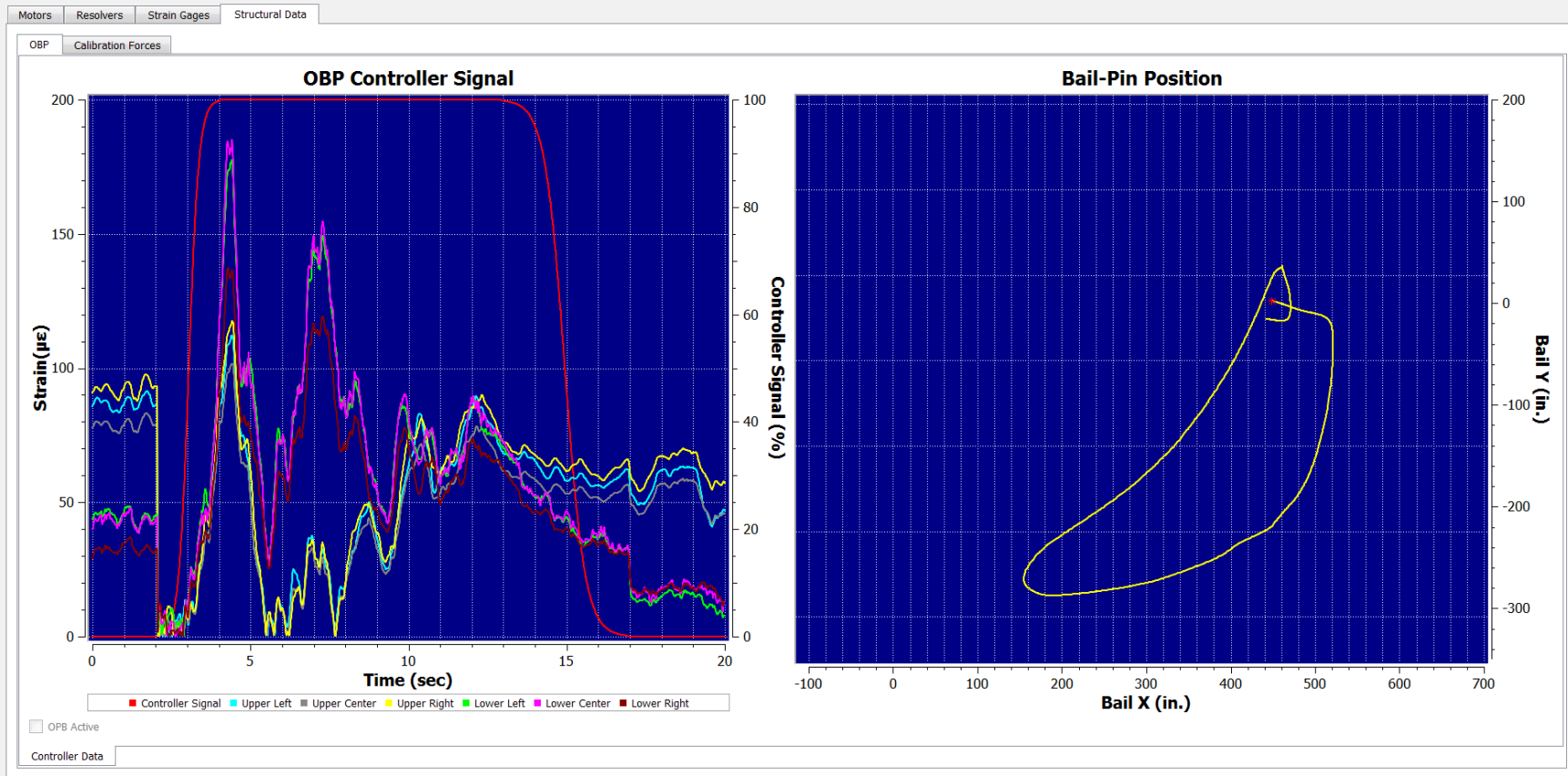
# Upper Boom Remote IO Box



# Minimal Strain During Dig Cycle



# Hoist Unload then Reload Cycle

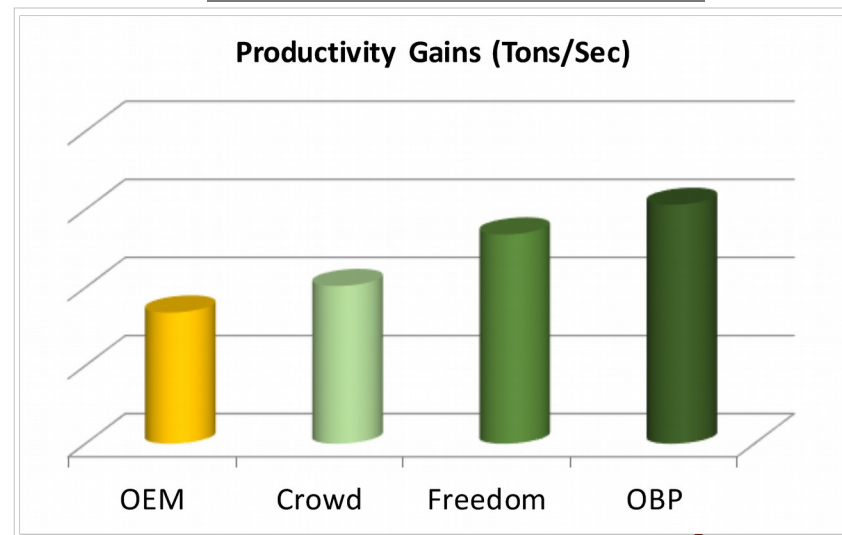


# FREEDOM ROI

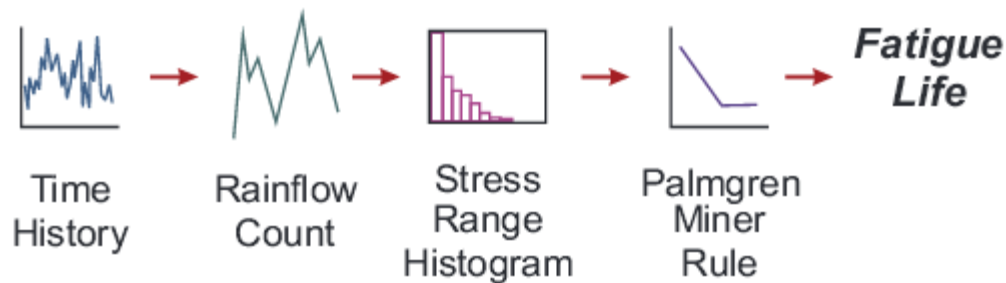
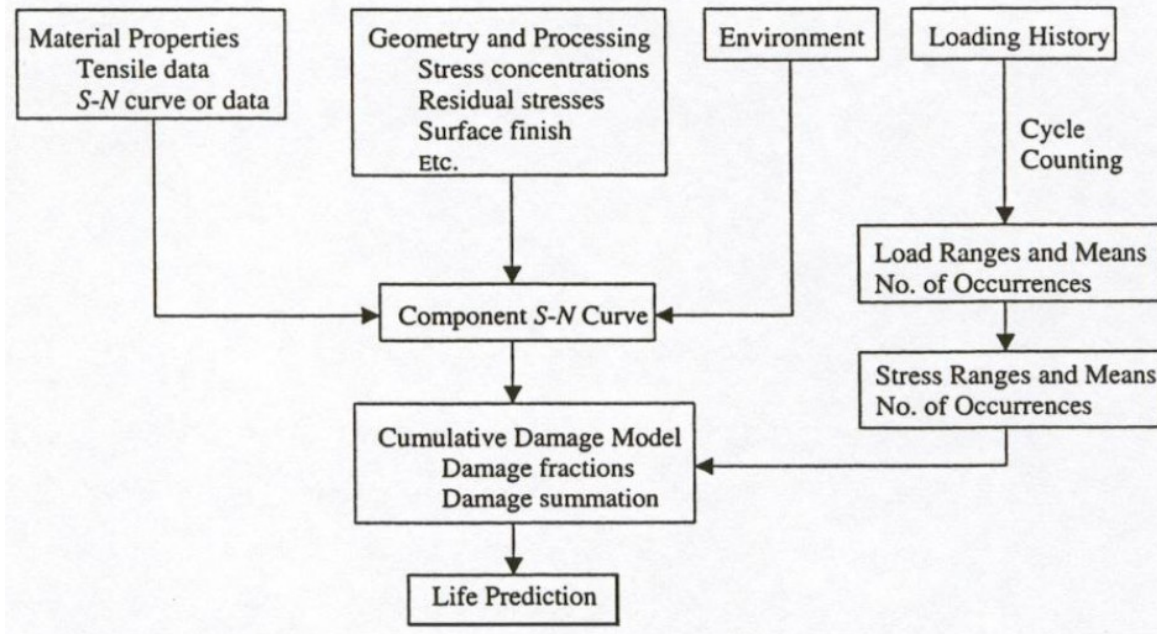
**Shovel productivity enhancement example currently in operation: (P&H 4100XPC in coal application)**  
 Performance results may vary depending on a variety of external conditions – i.e.: shovel utilization, dig conditions and truck dedication.



- **Baseline results (shovel OEM settings)**
- **After crowd motor installation**
  - ✓ **4.2% improvement**
- **Level 2: Freedom installation with crowd motor**
  - ✓ **12.3% improvement**
- **Level 3: Freedom installation with crowd motor and Optimized Bank Performance (OBP)**
  - ✓ **24.3% improvement**

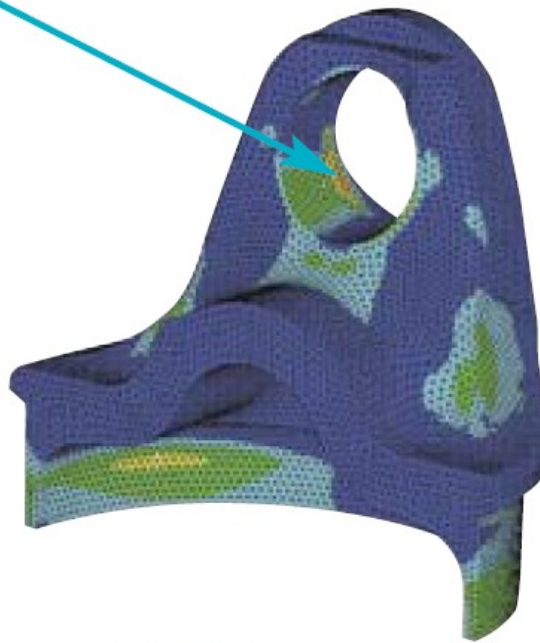
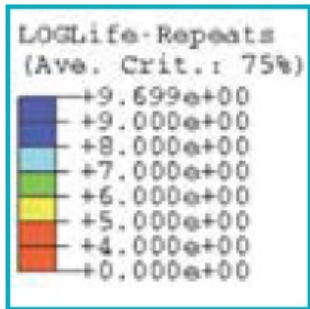


# Procedure for Fatigue Analysis



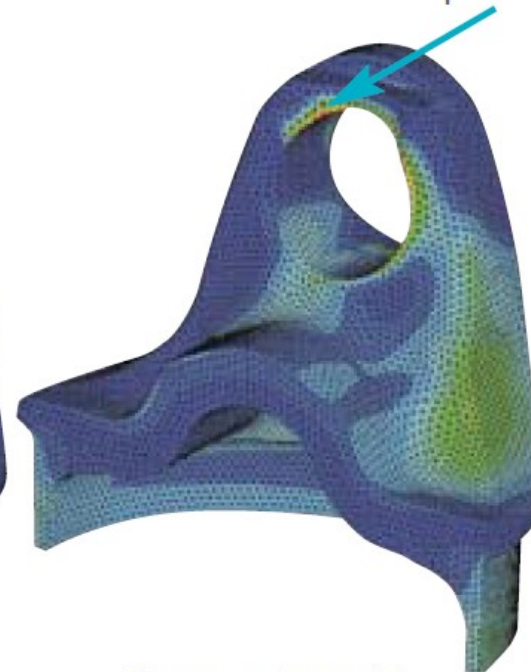
# Example FEA-Fatigue Coupled Analysis

Shortest life

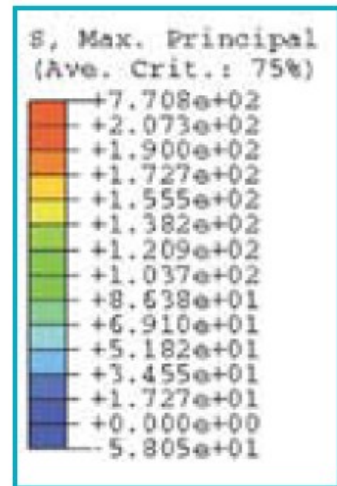


fe-safe® fatigue life contour plot

Maximum principal stress



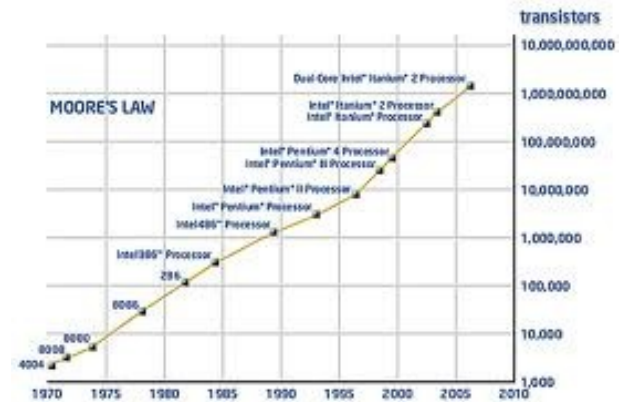
Stress contour plot





# Why now?

- Moore's law – the power of the computer
- Sensor technology
- Control theory
- Mining industry culture
- Competition and free market dynamics



Questions?

