THE UNIVERSITY OF TEXAS AT EL PASO
COLLEGE OF ENGINEERING

# A Guideline for the Assessment of Uniaxial Creep and Creep-Fatigue Data and Models

Calvin M. Stewart and Jack Chessa

NETL Kick-Off Meeting

October 6, 2016

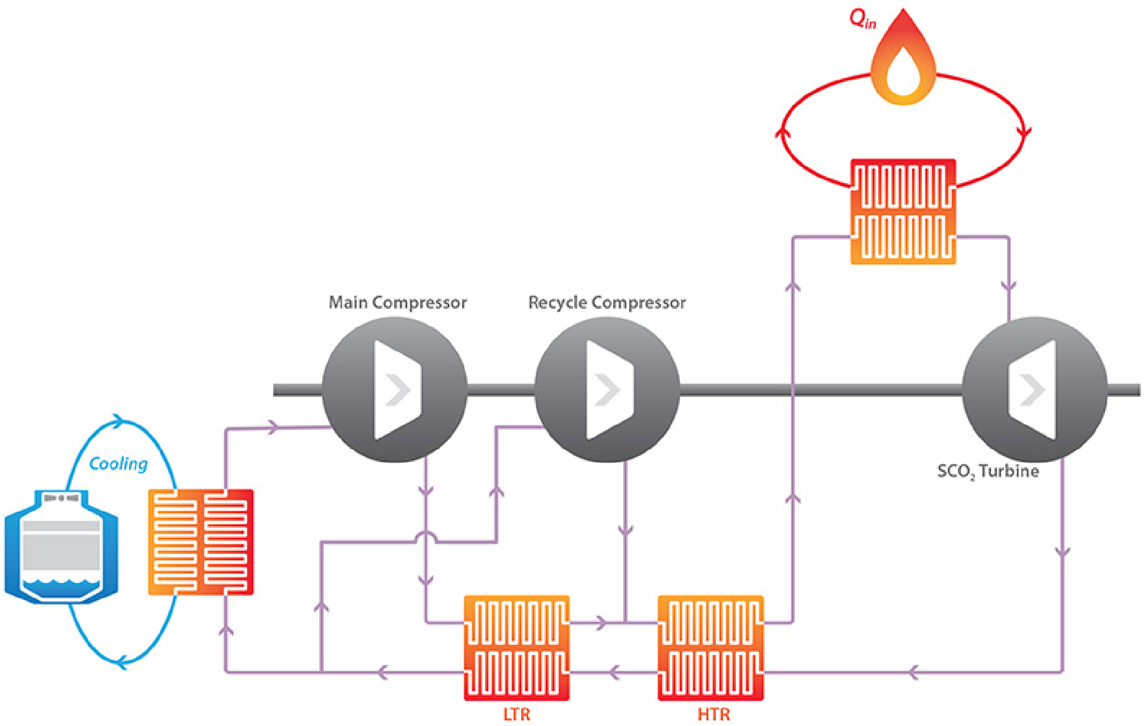
UTEP MATERIALS AT EXTREMES RESEARCH GROUP

# Outline

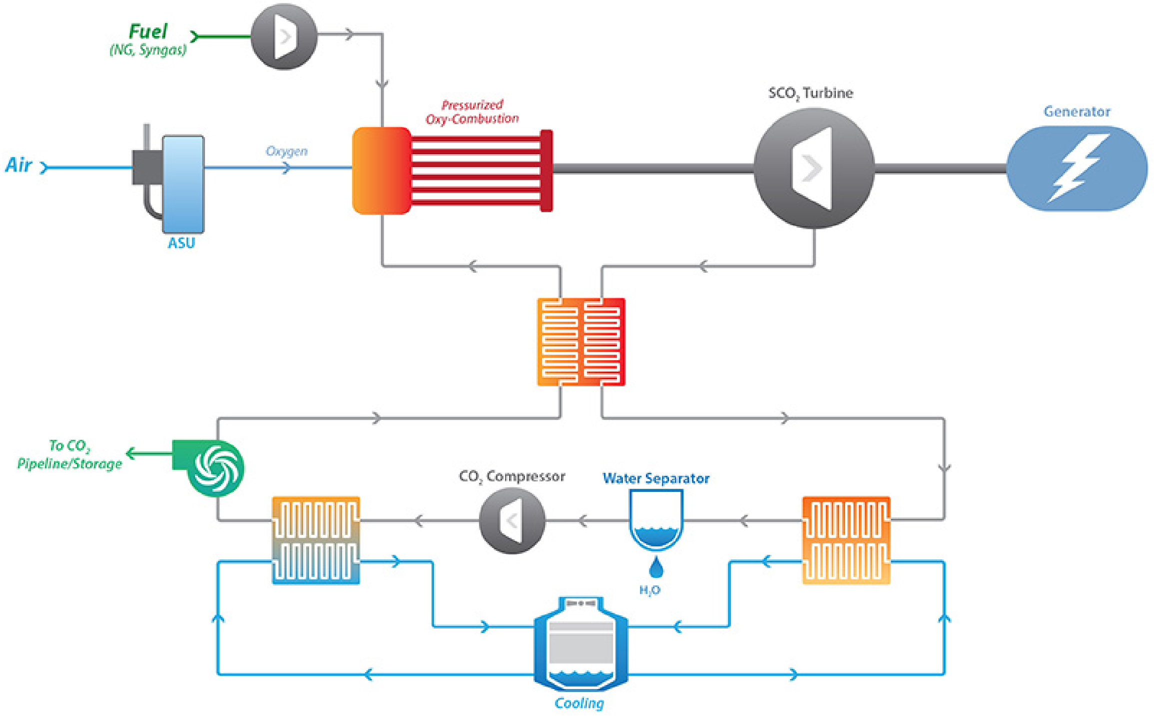
- Motivation
- Research Objectives
- Team
- Systematic Approach to Assessment
  - Task 2: Locate, Digitize, Sort, Store Experimental Data
  - Task 3: Uncertainty and Integrity of Experimental Database
  - Task 4: Mathematical Analysis and FEA of the Models
  - Task 5: Calibration & Validation – Fit, Interpolation, Extrapolation of the Models
  - Task 6: Post-Audit Validation of the Models
  - Task 7: Uncertainty Analysis of the Models
- Gantt Chart
- Milestones
- Questions

# Motivation

- Recent drives to increase the efficiency of existing fossil energy (FE) power plants and the development of **Advanced Ultrasupercritical (A-USC) power plants**, have led to designs with steam pressures **above 4000 psi** and temperatures **exceeding 1400°F**.




Indirect-Fire Supercritical $CO_2$ Recompression Brayton Cycle




Oxy-Fueled Directly-Fired Supercritical $CO_2$ Cycle



Figures via NETL

# Motivation

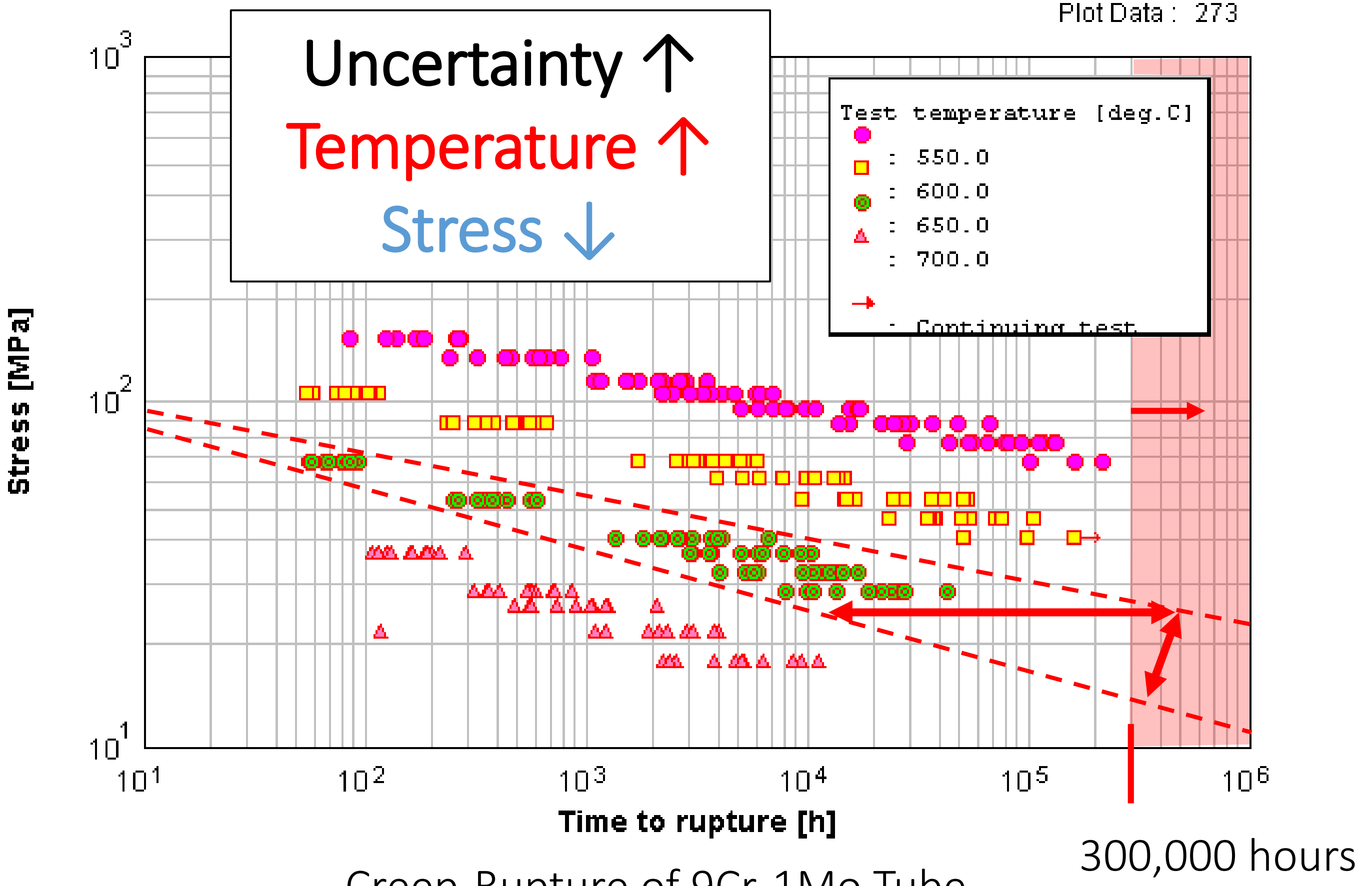
- The existing FE fleet has an **average age of 40 years**.
- The Department of Energy has outlined a strategy of life extension for US coal-fired power plants where many plants will operate for **up to 30 additional years of service**.

In Service Hours….

30 Years = 262,974 hours

40 Years = 350,634 hours

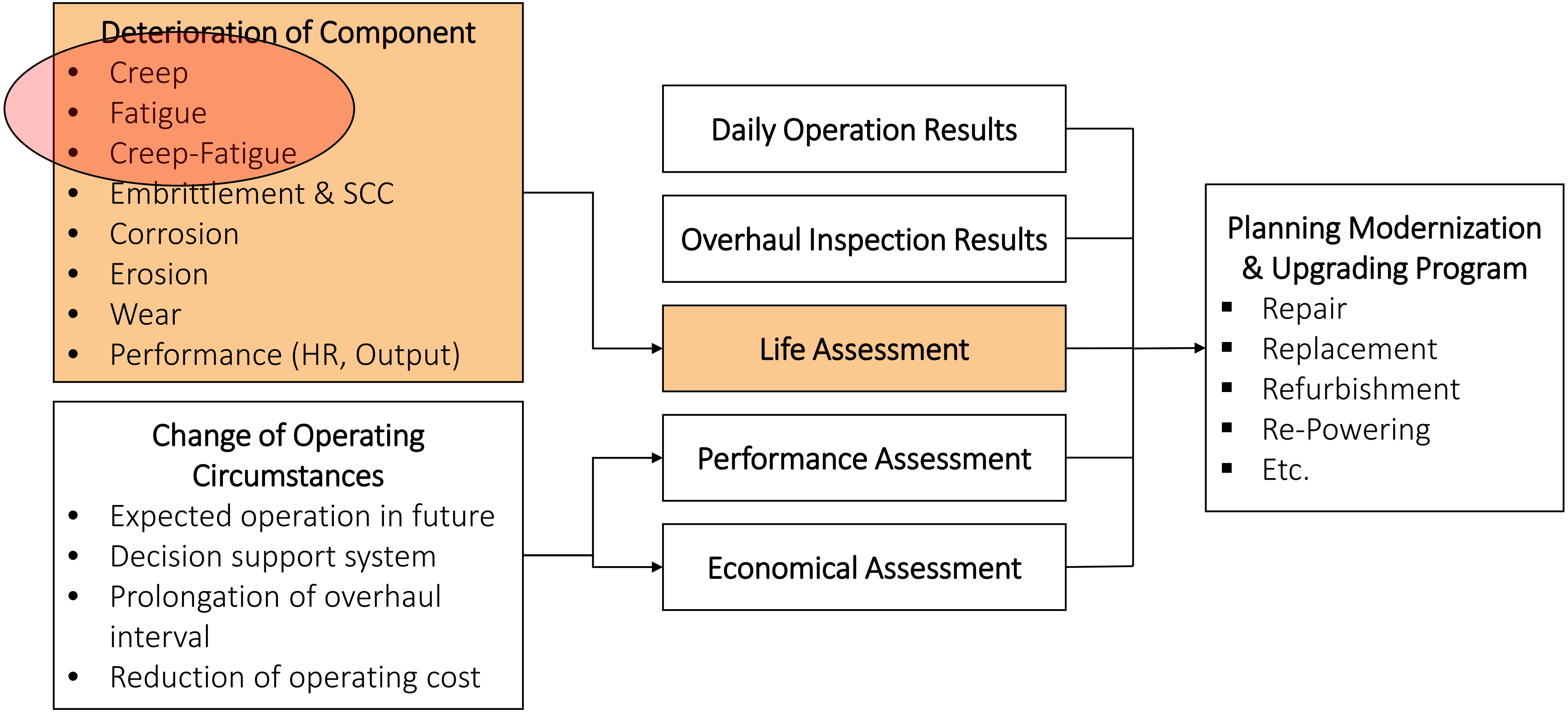
70 Years = 613,607 hours




Creep-Rupture of 9Cr-1Mo Tube

# Plant Life Extension Program

- During Life Assessment, the integrity of components is assessed and the remaining service life estimated.




Based on Mitsubishi's Life Extension Program

# Motivation

- An immense number of models have been developed to predict the deformation, damage evolution, and rupture of structural alloys subjected to Creep and Creep-Fatigue.

**Life Prediction**

### Creep-Rupture

- Larson-Miller (1952); Manson-Haferd (1953); Sherby-Dorn (1954); Monkman-Grant (1956); Omega (1995); Theta (1992); Kachanov-Rabotnov (1967-69); Wilshire (2006); Sinh (2013); etc.

### Fatigue Rupture

- Palmgren-Miner (1924,1945); Robinson (1938); Lieberman (1962); Coffin-Manson (1953-54); Morrow-Halford (1965-66); Chaboche (1988); Scott-Emuakpor (2011); etc.

### Creep-Fatigue Rupture

- Manson (1971), British R5; Chaboche (1980), ASME B&PV III, French RCC; etc.

**Constitutive Laws**

### Creep Viscoplasticity (Zero Yield Surface)

- Primary: Andrade (1910); Bailey (1935); McVetty (1943); Garofalo (1965); etc.
- Secondary: Norton (1929); Soderberg (1936); McVetty (1943); Dorn (1955); Johnson-Henderson-Kahn (1963); Garofalo (1965); etc.
- Mixed: McVetty (1943); Graham and Walles (1955); Garofalo (1965); Kachanov-Rabotnov (1967-69); Theta (1984); RCC-MR (1985); Omega (1995); Liu-Murakami (1998); Dyson-McClean (1998); Sinh (2013); etc.

### Cyclic Viscoplasticity (Yield Surface)

- Bodner (1975); Hart (1976); Chaboche (1977); Robinson (1978); Krempl (1980);etc.

### Creep-Fatigue Viscoplasticity (Equilibrium Surface)

- Miller (1976); Walker (1981); Sinh (2013); etc.

**There are Many More!...**

# Research Objectives

- Of primary concern to FE practitioners is a determination of which constitutive models are the "best", capable of reproducing the mechanisms expected in an intended design accurately; as well as what experimental datasets are proper or "best" to use for fitting the constitutive parameters needed for the model(s) of interest.

**RO1**

Development of Aggregated Experimental Databases of Creep and Creep-Fatigue Data

**RO2**

Computational Validation and Assessment of Creep and Creep-Fatigue Constitutive Models for Standard and Non-Standard Loading Conditions

# Team

Dr. Stewart is an Assistant Professor in the Department of Mechanical Engineering at the University of Texas at El Paso. He directs the *Materials at Extremes Research Group (MERG)*. He has over 10 years of experience in the theoretical development and numerical implementation of constitutive models for creep, fatigue, oxidation, and creep-fatigue-oxidation interaction phenomenon.

Dr. Jack Chessa is currently an Associate Professor of Mechanical Engineering at the University of Texas at El Paso. His research interest has been focused on the development of novel numerical methods for solving several challenging areas such as fracture mechanics, durability of high temperature ceramics as well as oxidation are reactions of evolving interfaces.

# Recent Work

- Haque, M. S., and Stewart, C. M., 2016, "**Finite Element Analysis of Waspaloy Using Sinh Creep-Damage Constitutive Model under Triaxial Stress State**", *ASME Journal of Pressure Vessel Technology*, **138**(3). doi: 10.1115/1.4032704

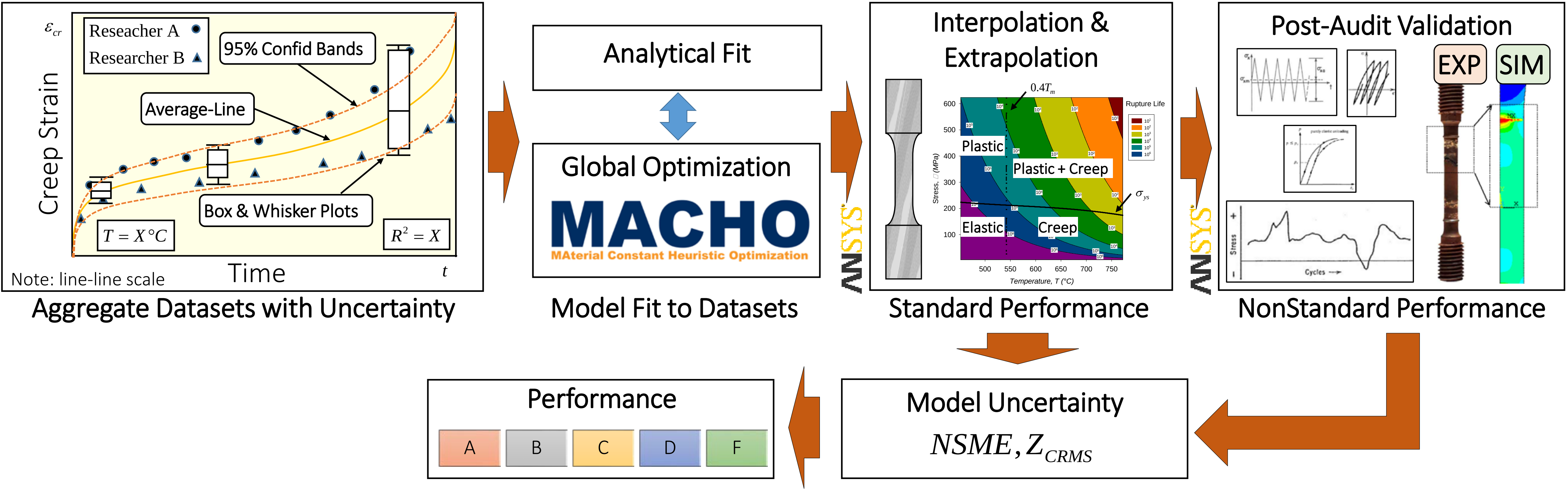
- Varela, L. A., and Stewart, C. M., 2016, "**Modeling the Creep of Hastelloy X and the Fatigue of 304 Stainless Steel using the Miller and Walker Unified Viscoplastic Constitutive Models,**" *Journal of Engineering Materials and Technology*, **138**(2). doi: 10.1115/1.4032319

- Haque, M. S., and Stewart, C. M., 2016, "**Exploiting Functional Relationships between MPC Omega, Theta, and Sinh-Hyperbolic Models**" *ASME PVP 2016,* PVP2016-63089, Vancouver, BC, Canada, July 17-21, 2016.

- Haque, M. S., and Stewart, C. M., 2016, "**Modeling the Creep Deformation, Damage, and Rupture of Hastelloy X using MPC Omega, Theta, and Sin-Hyperbolic Models,**" *ASME PVP 2016,* PVP2016-63029, Vancouver, BC, Canada, July 17-21, 2016.

# Systematic Approach to Assessment

Example for Creep Deformation



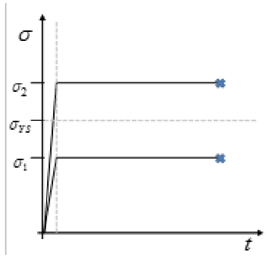
# DEF: Standard and NonStandard

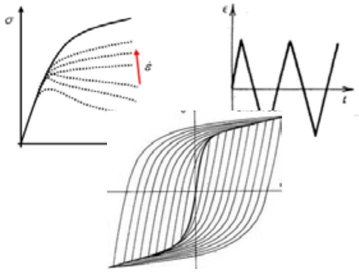
STANDARD

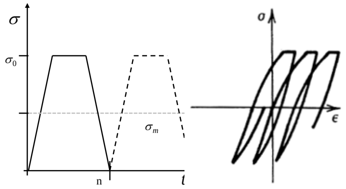
- Creep / Stress Relaxation
- Cyclic Hardening
- Creep-Fatigue

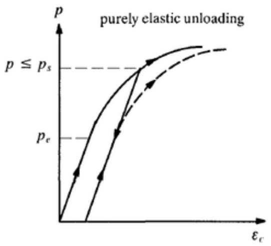
NONSTANDARD

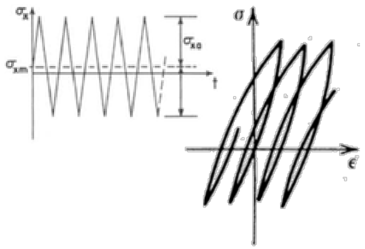
- Shakedown
- Ratcheting
- Service-Like Conditions

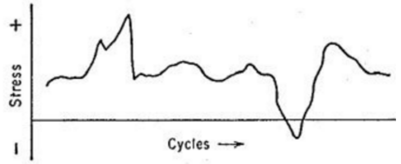



| | Standard | Nonstandard |
|---|---|---|
| **Data** | High Availability | Limited Availability |
| **Models** | Often Calibrated | Rarely Calibrated |

# Systematic Approach to Assessment

Task 1: Maintain Project Management Plan

Task 2: Locate, Digitize, Sort, Store Experimental Data

Task 3: Uncertainty and Integrity of Experimental Database

Task 4: Mathematical Analysis and FEA of the Models

Task 5: Calibration & Validation – Fit, Interpolation, Extrapolation of the Models

Task 6: Post-Audit Validation of the Models

Task 7: Uncertainty Analysis of the Models

# Locate, Digitize, Sort, and Store Data

**Creep Data**
- Creep-rupture
- Minimum creep strain rate
- Time to creep strain
- Creep deformation
- Stress relaxation

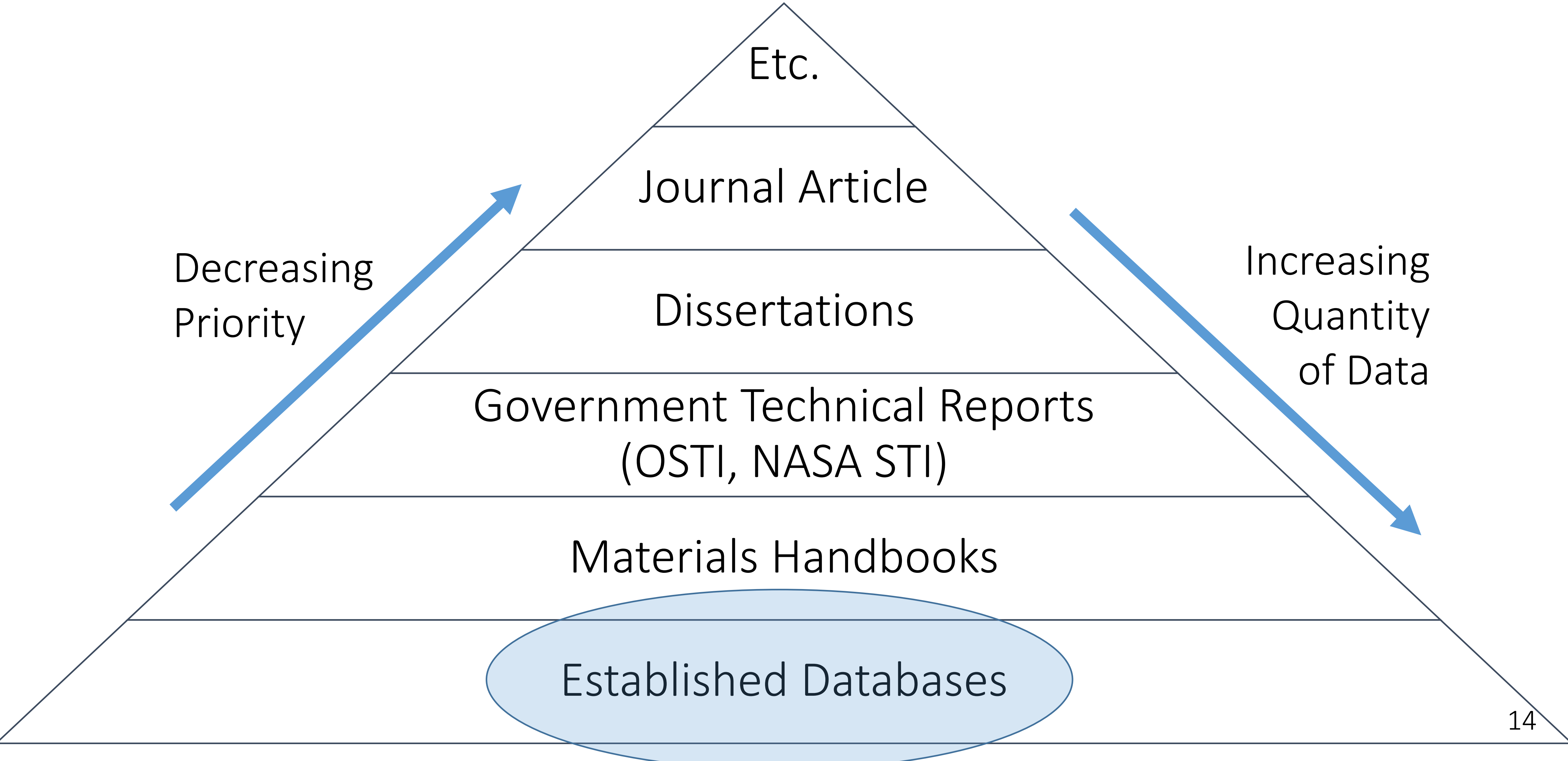
**Fatigue Data**
- Strain-Life
- Cyclic Hysteresis loops
- Stress Amplitude per Cycle

**Creep-Fatigue Data**
- Tensile Hold Tests

## Established Data Sources

## Need to Establish Connections

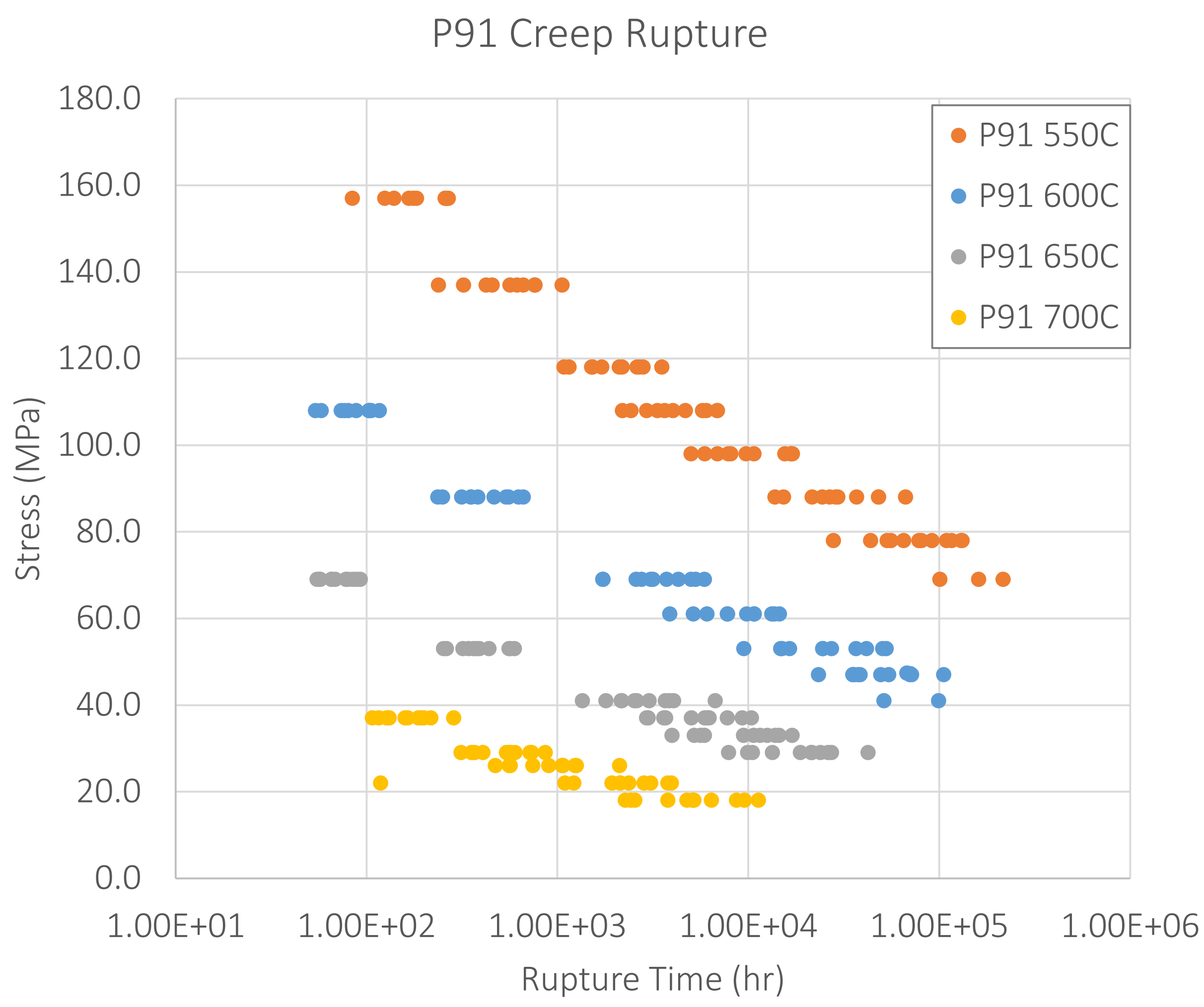
# Locate, Digitize, Sort, and Store Data



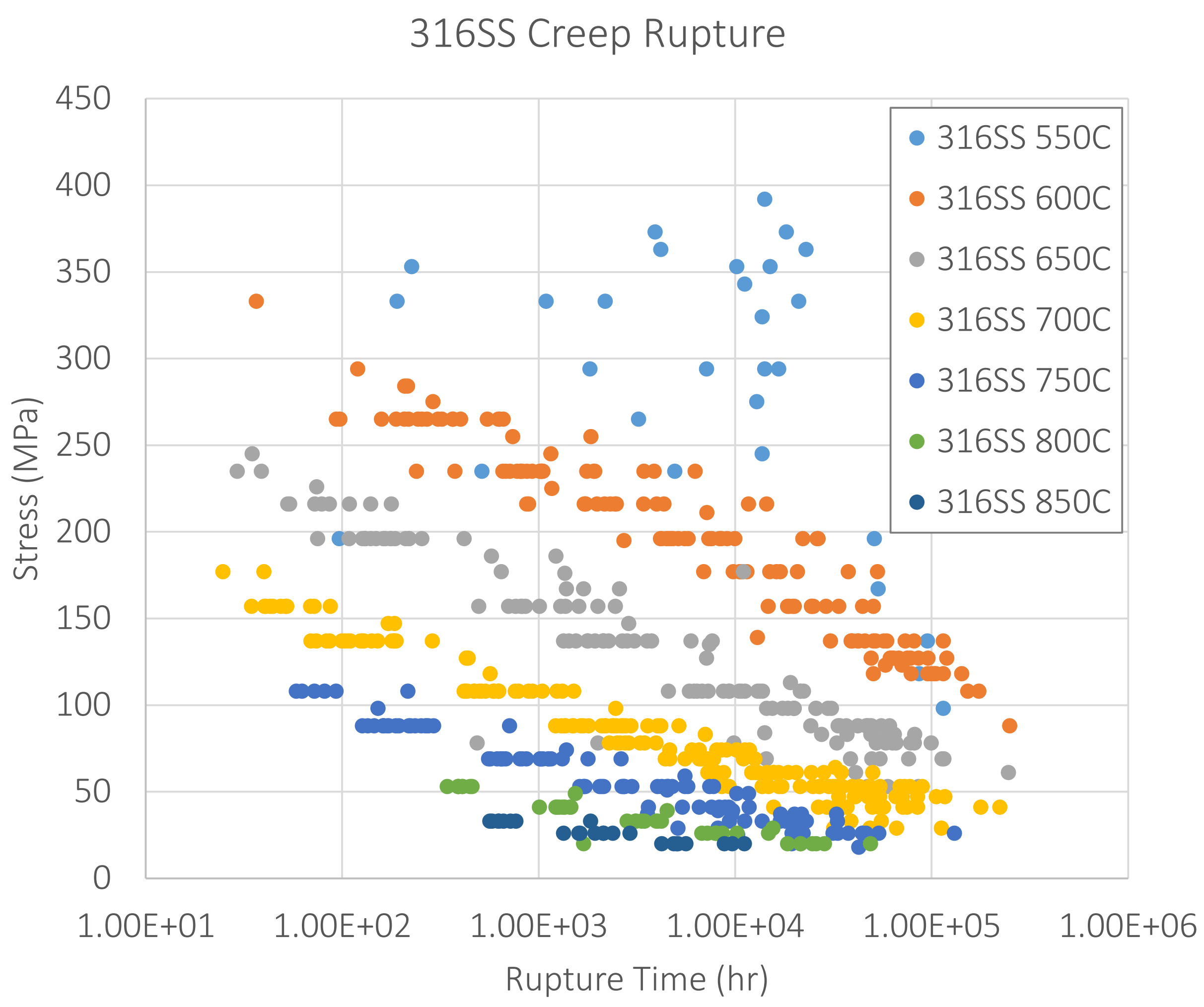
# Current & High Priority Data Sources

| Organization | Database(s) | Access | Available Metrics |
| --- | --- | --- | --- |
| National Institute of Materials Science (NIMS) | MatNavi | Granted | Material properties, monotonic, creep rupture |
| Materials and Processes Technical Information System (MAPTIS) | • NASA Databases<br>• ASM International Databases<br>• Commercial Data | Granted | Material properties, monotonic, creep deformation & rupture, fatigue curves |
| Oak Ridge National Laboratory (ORNL) | Gen IV Materials Handbook | Pending | Material properties, monotonic, creep, statistical properties |

# Creep Rupture Data (NIMS Database)




Data points: 272




Data points: 696

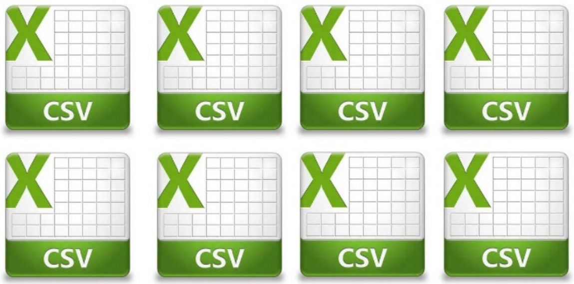
# Locate, Digitize, Sort, and Store Data

- **MetaData** – A set of data that describes the characteristic of a dataset.
- MetaData can be used to identify **sources of uncertainty** in our data.

| | | | | |
|---|---|---|---|---|
| Alloy Name | Material Code | Country Code | Laboratory Code | Material Spec / Grade |
| Chemical Composition | Thermomechanical Processing | Form | Test Type | Test Standard |
| | Specimen Geometry | Test Equipment | Environment | |

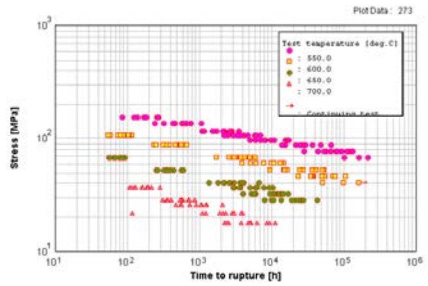
# Locate, Digitize, Sort, and Store Data

Individual .CSV Files




Single .XML Database


XML Parsed, Plotting, & XHTML Software

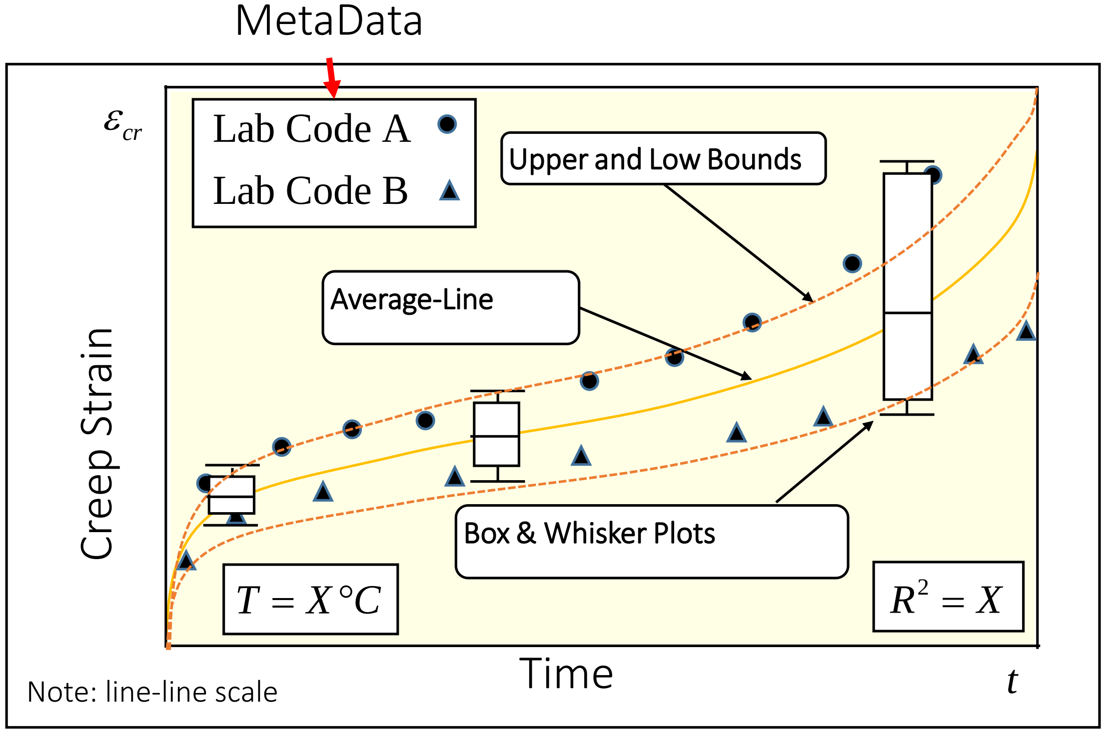



XML Database Structure – A Work in Progress

```
<?xml version="1.0" encoding="US-ASCII"?>
<!-- Possible XML format for various test data -->
<database>
<!-- here is a possible creep test data. Go to http://xmlgrid.net/ to validate the data -->
<experiment material="inconel 718" country=“USA” laboratory=“ORNL” reference="the big creep database" type="creep
deformation" name="stewart101">
<data name=“chemical composition” format="ascii" dtype="float" units=“hours" rank="1"> 52.50 1.00 19.00 3.05 17.00 0.35
0.35 0.08 0.60 0.90 0.30 0.015 0.006 0.015 5.125</data>
<data name="time" format="ascii" dtype="float" units=“hours" rank="1"> 0.0 1.0 2.0 3.0 4.0 5.0 </data>
<data name="strain" format="ascii" dtype="float" units=“mm/mm" rank="1"> .000 .001 .002 .005 .010 .020 </data>
<data name="description" dtype="string"> "This is a basic creep test conducted by Dr. Calvin Stewart" </data>
<data name="stress" dtype="float" units=“MPa" rank="0"> 2000.0 </data><data name="tbd"/></experiment>
</experiment></database>
```

# Uncertainty and Integrity of Experimental Data

- Integrity Check
  - average line
  - upper and low bounds
  - standard deviations
  - coefficient of variation
  - box and whisker plots
  - factor of 2 bands
  - confidence intervals
  - coefficient of determination




Aggregate Datasets with Uncertainty

- A parametric evaluation of the full database and individual datasets with regards to metadata will be performed to quantify the impact of experimental uncertainty on the material response.

# Mathematical Analysis and FEA of the Models

Generate Model Database

Taxonomy of Models

Material Constant Determination

# Model Database

- Model Name (Year)
- Authors
- Primary Source
- Taxonomy
- Equations
  - Count
  - Functional form
- Material Constants
  - Count
  - Physical representation
  - Functional form
- Notes
  - Advantages
  - Disadvantages
  - Special remarks
- Analytical form of the Material Jacobian matrix (pseudo-Jacobian if necessary)

$$\mathbf{C}_{TOT} = \frac{\partial \sigma_i}{\partial \varepsilon_j}$$

- USER MATerial (USERMAT) subroutine

ANSYS®

# Unification of Master Curve Models

$$P_{unified} = \frac{\log(t_r) - \alpha_0 - \alpha_3 T^r}{(T^r - \alpha_2{}^r)^q}$$

| Model | Year | Parametric equation | Condition | Attribute |
|---|---|---|---|---|
| Larson-Miller | 1952 | $P_{LMP} = T(\log(t_r) + t_a)$ | $r = -1, q = 1$, $\alpha_2 = \alpha_3 = 0$ | Linear |
| Manson-Haferd | 1953 | $P_{MH} = \frac{\log(t_r) - \log(t_a)}{T - T_a}$ | $r = q = 1$, $\alpha_3 = 0$ | Linear |
| Manson-Succop | 1953 | $P_{MS} = \log(t_r) - BT$ | $r = 1, q = 0$, $\alpha_0 = 0$ | Linear |
| Orr-Sherby-Dorn | 1954 | $P_{OSD} = \log(t_r) - Q/RT$ | $r = -1, q = 0$, $\alpha_0 = 0$ | Linear |
| Goldhoff-Sherby | 1968 | $P_{GS} = \frac{\log(t_r) - \log(t_a)}{1/T - 1/T_a}$ | $r = -1, q = 1$, $\alpha_3 = 0$ | Linear |
| Modified Manson-Haferd | 2016 | $P_{MMH} = \frac{\log(t_r) - \log(t_a)}{T}$ | $r = 1, q = 1$, $\alpha_2 = \alpha_3 = 0$ | Linear |
| Manson-Brown | 1953 | $P_{MB} = \frac{\log(t_r) - \log(t_a)}{(T - T_a)^n}$ | $r = 1, \alpha_3 = 0$ | Non-Linear |
| Graham-Walles | 1955 | $P_{GW} = \frac{\log(t_r)}{T - T_a}$ | $r = q = 1$, $\alpha_0 = \alpha_3 = 0$ | Linear |
| Chitty-Duval | 1963 | $L_{CD} = T - m\log(tr)$ | $r = q = 1$, $\alpha_0 = 0$, $T = \alpha_2 - \alpha_3$ | Linear |
| White le may | 1978 | $P_{WM} = \frac{1/T - 1/T_a}{\log(t_r) - \log(t_a)}$ | Inverse of Goldhoff-Sherby | Linear |
| Mendelson-Roberts-Manson | 1965 | $P_{MRM} = \frac{\log(t_r)/\sigma^q - \log(t_a)}{(T - T_a)^n}$ | Special Manson-Brown | Non-Linear |

| Name: Larson-Miller | Authors: Larson and Miller | Year: 1952 |
|---|---|---|

| Model Equations: | Attribute: |
|---|---|
| $P_{LMP} = T(\log(t_r) + t_a)$ | • Creep-Rupture<br>• Master curve<br>• Time-Temperature Parameter<br>• Linear iso-stress line |
| Number of constants: 2 | |

Constant terms, definition, unit:

$P_{LMP}$, $t_a$ : Larson-Miller parameter, Point of convergence respectively, both are unitless

Sample plot:

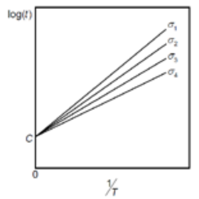
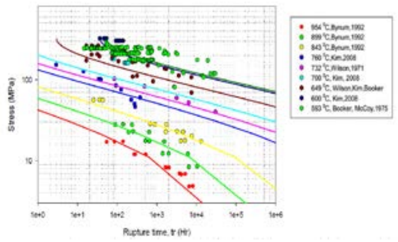



Figure 1. Larson-Miller creep parameterization.




Note: (advantages/limitations/special remarks)

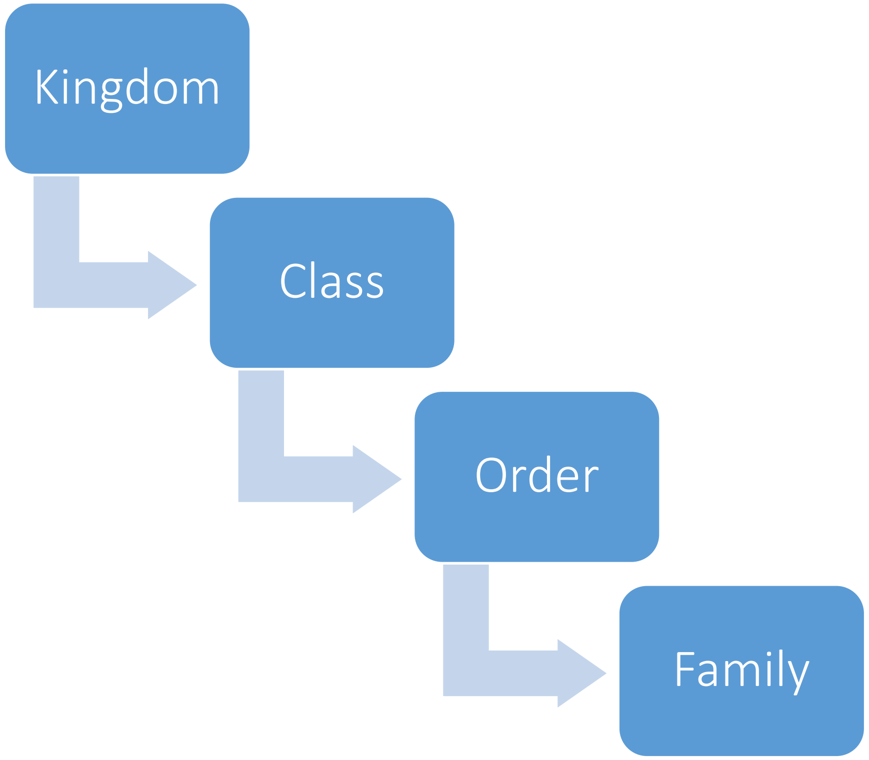
Linear iso-stress line.
For wide range of data exhibits inflection point.

References:

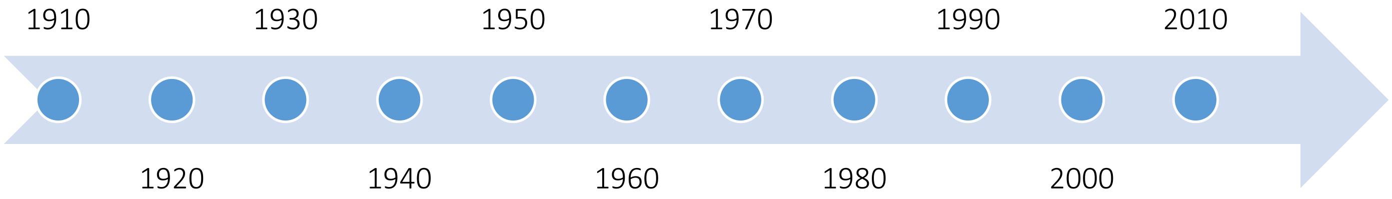
1. F.R. Larson, J. Miller Trans. ASME, 74 (1952), p. 765

# Taxonomy of Models

Taxonomy




**Development Timeline**




KINGDOM: Phenomenological, Mechanistic, Multiscale

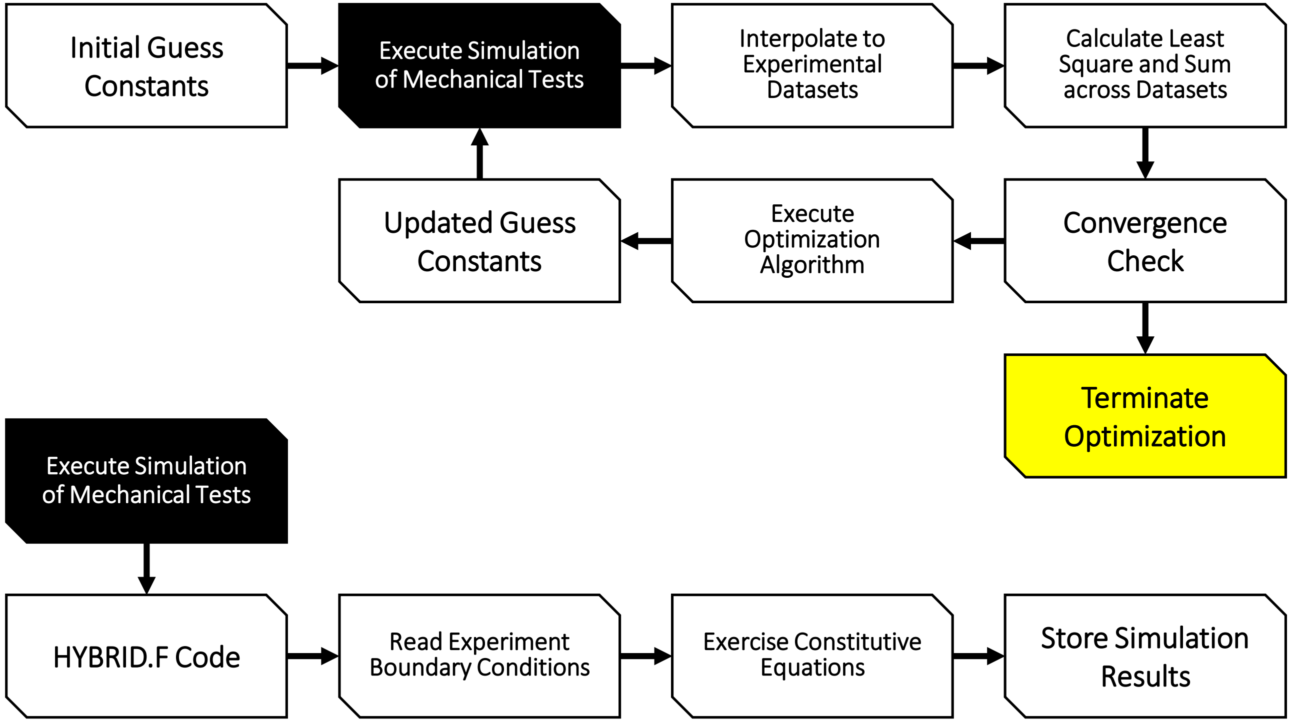
- CLASS:
  - Deformation
    - ORDER
    - Minimum creep strain rate
      - FAMILY: Originating Model/Author
    - Primary creep
    - Secondary creep
    - Tertiary creep
    - Mixed
    - Creep Viscoplasticity
    - Viscoplasticity
    - Unified Viscoplasticity
    - Zero-Yield Unified Viscoplasticity
  - Damage & Rupture
    - ORDER
    - Classic damage mechanics / Ratios
    - Continuum damage mechanics
    - Microstructural damage mechanics
  - Combined

# Material Constant Determination

- Analytical Optimization for Simple Models
- Numerical Optimization for Complex Models (# of Matl Constants >> Variables)

MACHO
MAterial Constant Heuristic Optimization

| Features |
| --- |
| • Global Optimization Routine (uphill and downhill moves)<br>• Suitable for a high number of variables (tens of thousands)<br>• Internal FEM Code<br>• 64-bit, multi-core, multi-CPU<br>• scalable memory allocation |



# Calibration and Validation

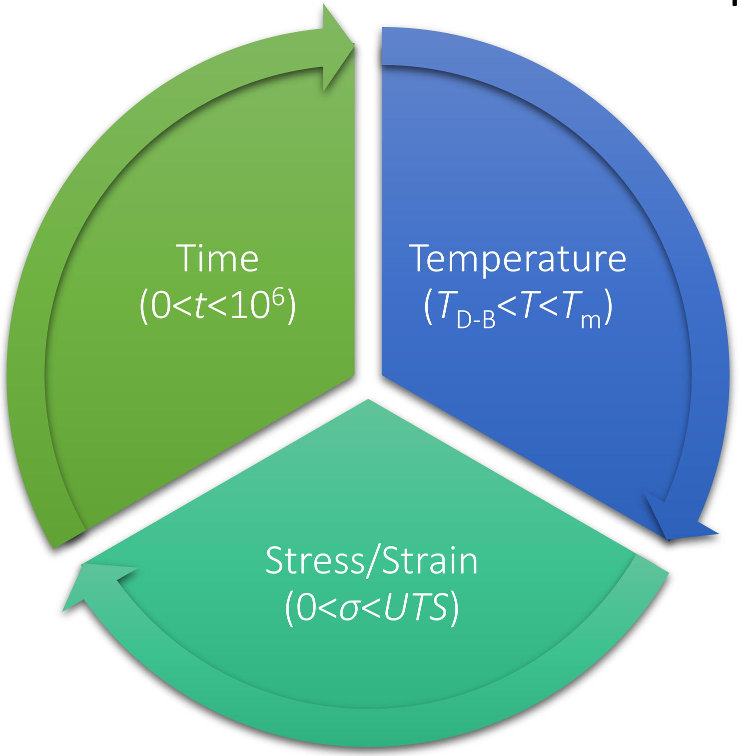
- The calibrated models will be parametrically simulated across a full range of temperature, stress, and time to testing for **fit**, **interpolation**, and **extrapolation ability** of the models.
- Evaluate the credibility of **characteristic curves** produced by the models.
- Ideally, the best models will be able to predict **extreme conditions** and pass **physical realism requirements**

Parametrically explore the

**Time-Temperature-σ/ε Map**

and

**Time-Temperature-Δσ/Δε Map**



# Calibration and Validation

## Extreme Conditions for Creep

| Condition | Creep Rupture | Deformation |
|---|---|---|
| $\sigma<0$ | $t_r \approx \infty$ | $\dot{\varepsilon}_{cr} \approx 0$ |
| $\sigma = 0$ | $t_r = \infty$ | $\dot{\varepsilon}_{cr} = 0$ |
| $0 < \sigma < UTS$ | $t_r \propto f\left(\sigma, T\right)$ | $\dot{\varepsilon}_{cr} \propto f\left(\sigma, T\right)$ |
| $\sigma = \text{UTS}$ | $t_r \approx 0$ | $\dot{\varepsilon}_{cr} >> 1$ |
| $T \Rightarrow T_{\text{D-to-B}}$ | $t_r \approx \infty$ | $\dot{\varepsilon}_{cr} \approx 0$ |
| $0.3T_m < T < T_m$ | $t_r \propto f\left(\sigma, T\right)$ | $\dot{\varepsilon}_{cr} \propto f\left(\sigma, T\right)$ |
| $T_m$ | $t_r = 0$ | $\dot{\varepsilon}_{cr} >> 1$ |

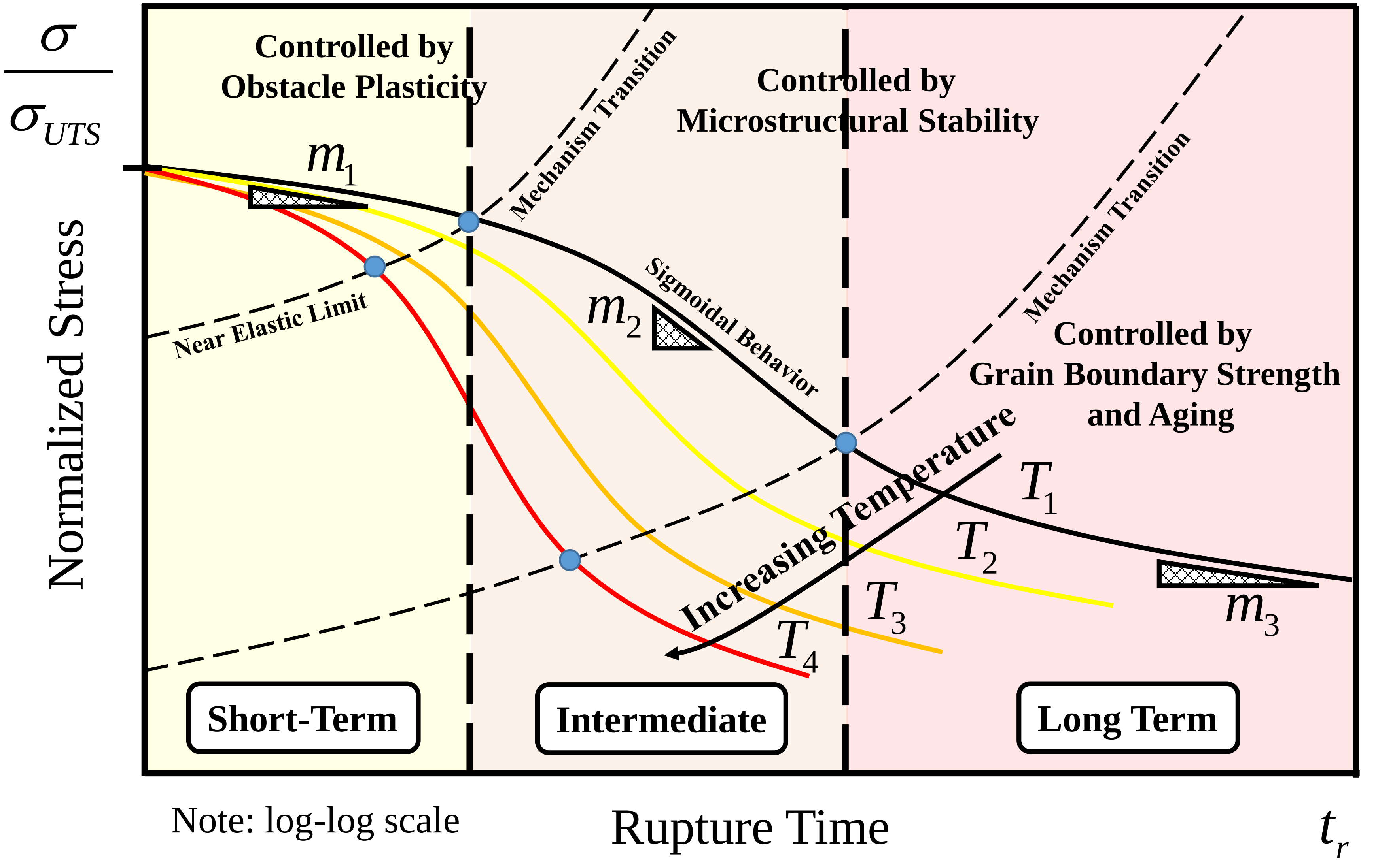
Note: $\sigma$ is equivalent stress

# Calibration and Validation

**Physical Realism Requirements**

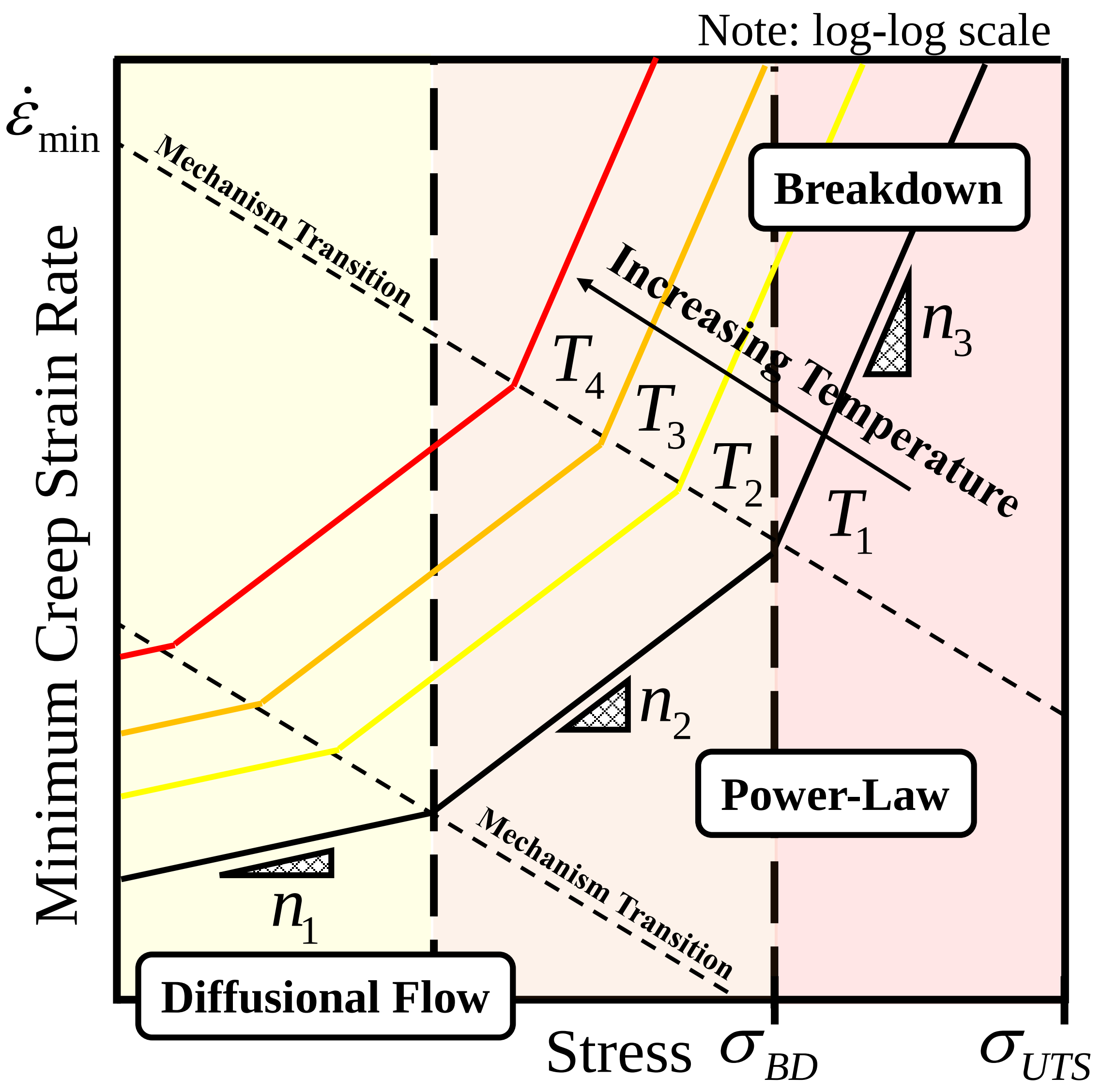
| *Creep Rupture Requirements* | *Creep Deformation Requirements* |
| --- | --- |
| • The isotherms do not cross-over, come-together, or turn back;<br>• The extrapolated isotherms produce a sigmoidal behavior if a sigmoidal response is expected in material;<br>• Both mechanism transition stresses decrease with temperature;<br>• $T_{\text{D-to-B}} < T < 0.3T_m$, the isotherms for creep-rupture are tightly bunched together;<br>• $0.3T_m < T < T_m$, the isotherms become more dispersed. | • Minimum creep strain rate isotherms<br>  o do not cross-over, come-together, or turn back;<br>  o transitions from power-law creep to breakdown;<br>• Creep deformation<br>  o growths with $\sigma$ and $T$; isostress lines do not cross-over, come-together, or turn back;<br>  o regime dominance (primary at low stress and temperature, secondary at intermediate stress and temperature, tertiary at high stress and temperature) depends $\sigma$ and $T$;<br>  o Increasing $\sigma$ and $T$ coincidences with increased rupture strain as the creep deformation mechanisms change. |

# Calibration and Validation




$\sigma \Rightarrow \sigma_{UTS} \quad t_r \Rightarrow 0 \qquad m_3 \Rightarrow 0 \quad \sigma \Rightarrow 0 \quad t_r \Rightarrow \infty$

# Calibration and Validation

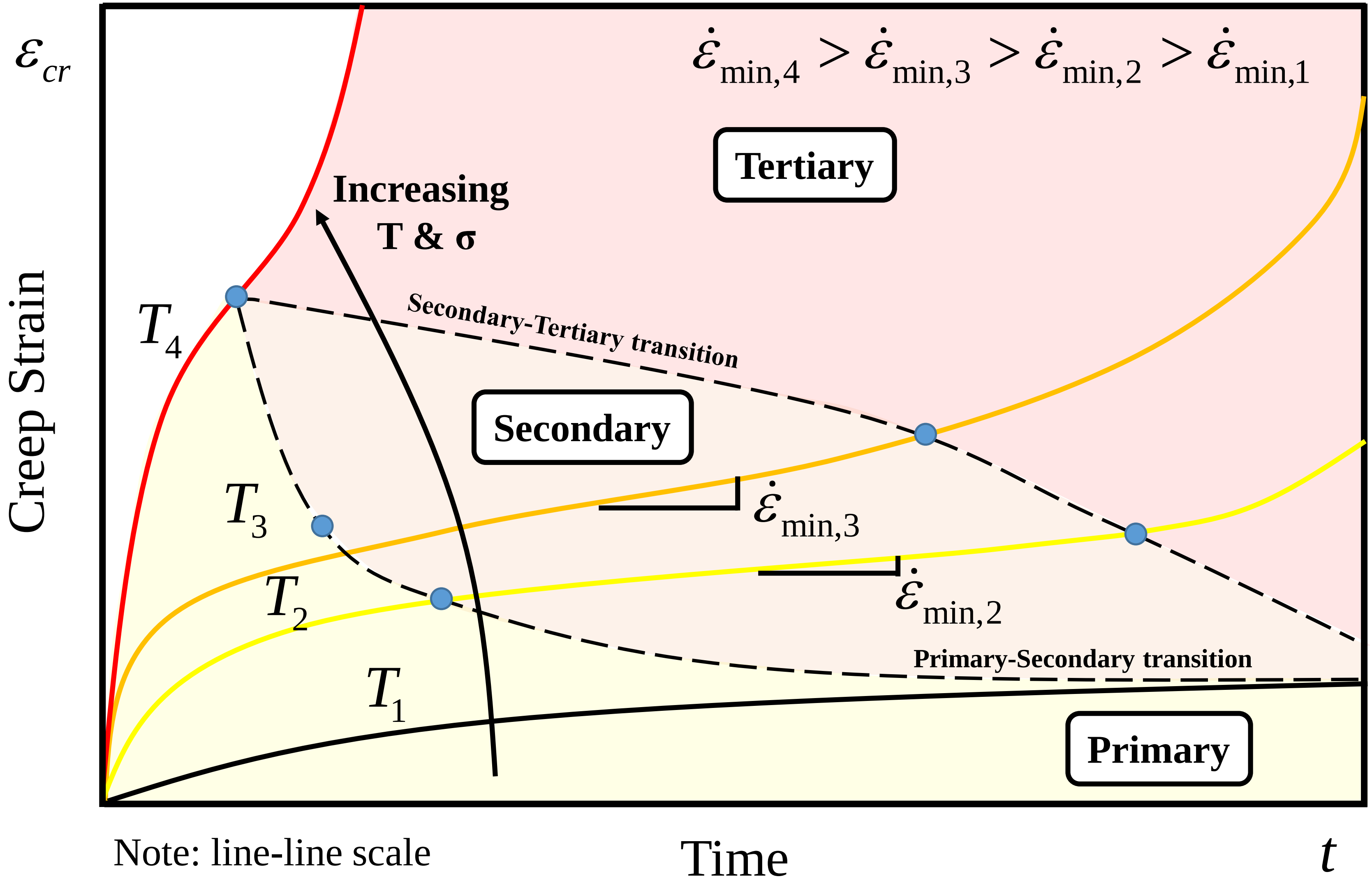



Diffusional Flow / Harper Dorn Controversy

Kassner, Kumar, and Blum 2007

Blum and Maier 1999

# Calibration and Validation




Note: line-line scale

# Post-Audit Validation

- Post-audit validation will provide insight into the ability of the constitutive models to reproduce various **non-standard** test responses.

## POST-AUDIT VALIDATION

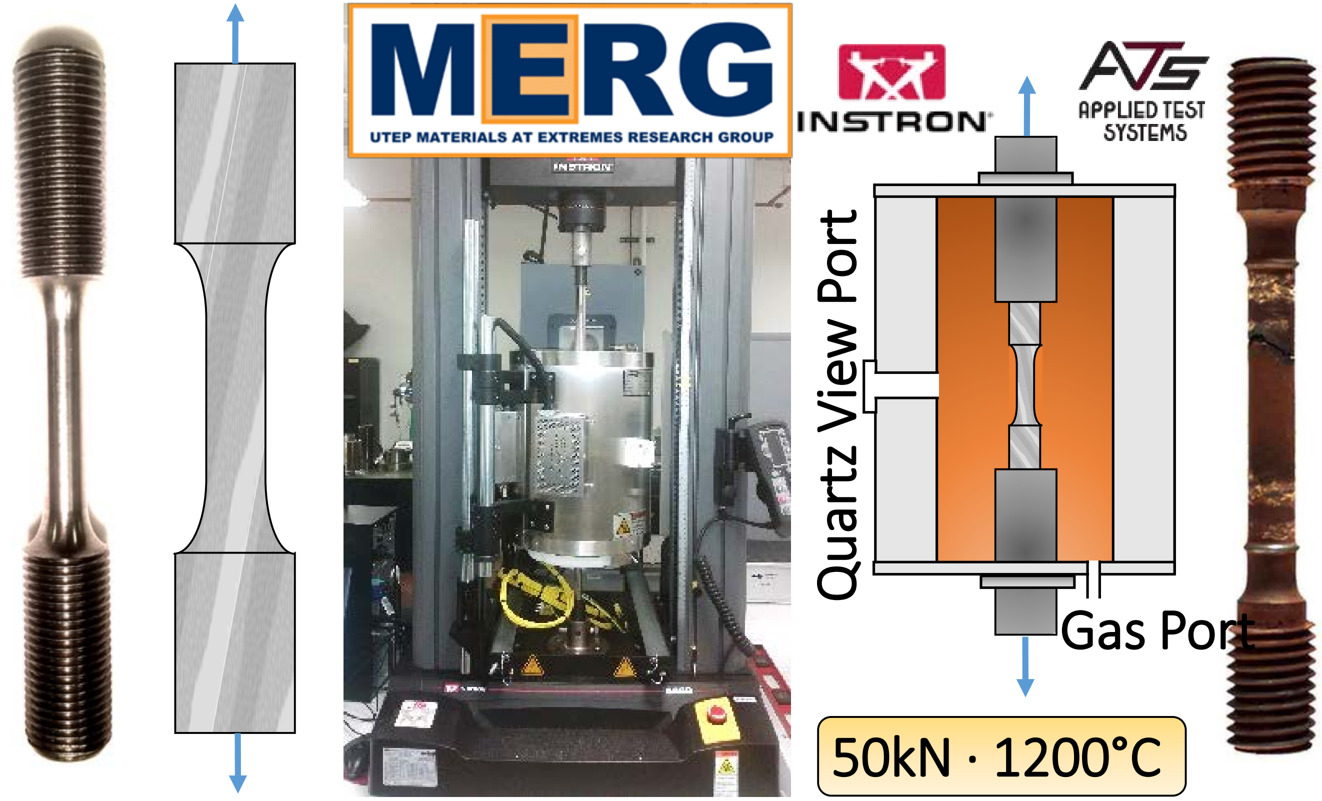
Calibrated Model Simulation

NonStandard Test Data

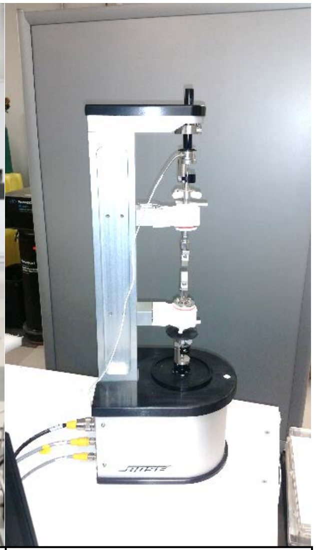
**Literature** and/or **Experiments**

Shakedown
Ratcheting
Stepped Isostress
Stepped Isothermal
Variable Amplitude Loading
Etcetera…

NonStandard Performance



# Experimental Capabilities



| Team MERGe | 100 kN | 50 kN | 50 kN | 5 kN | 200 N |
|---|---|---|---|---|---|
| | | -150 to | Rm to | | BioReactor Liquid/Gas |
| | | Gas Env. | Gas Env. | | |

**Challenger-Columbia Structures and Materials Research Facility**

This 5,500 $ft^2$ facility houses state of the art materials synthesis, processing, and testing equipment for developing advanced materials research for next generation energy and aerospace systems. Dr. Stewart’s Materials at Extreme Research Group (MERGe) is housed in this facility and he maintains the equipment above.

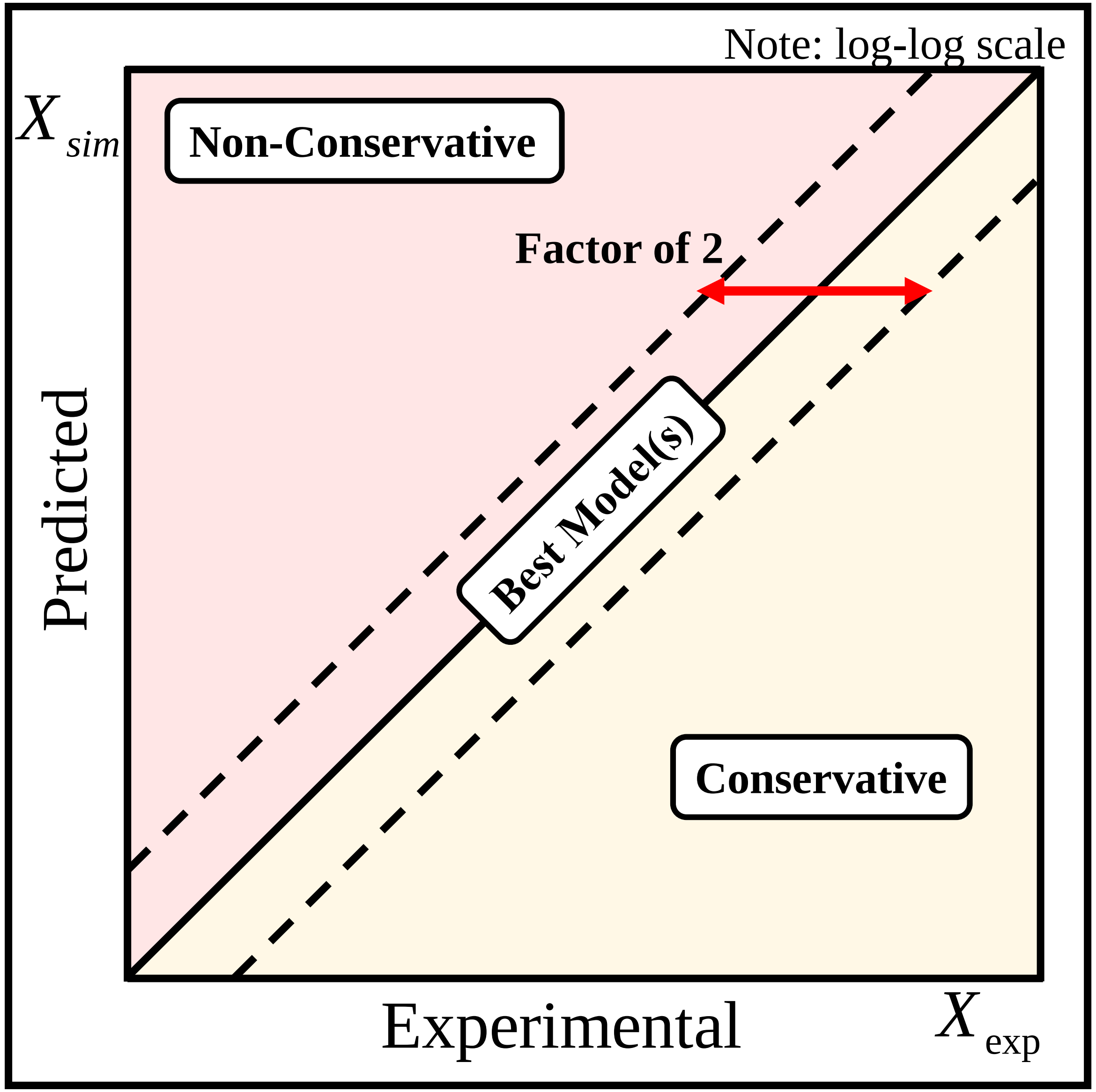
MERG

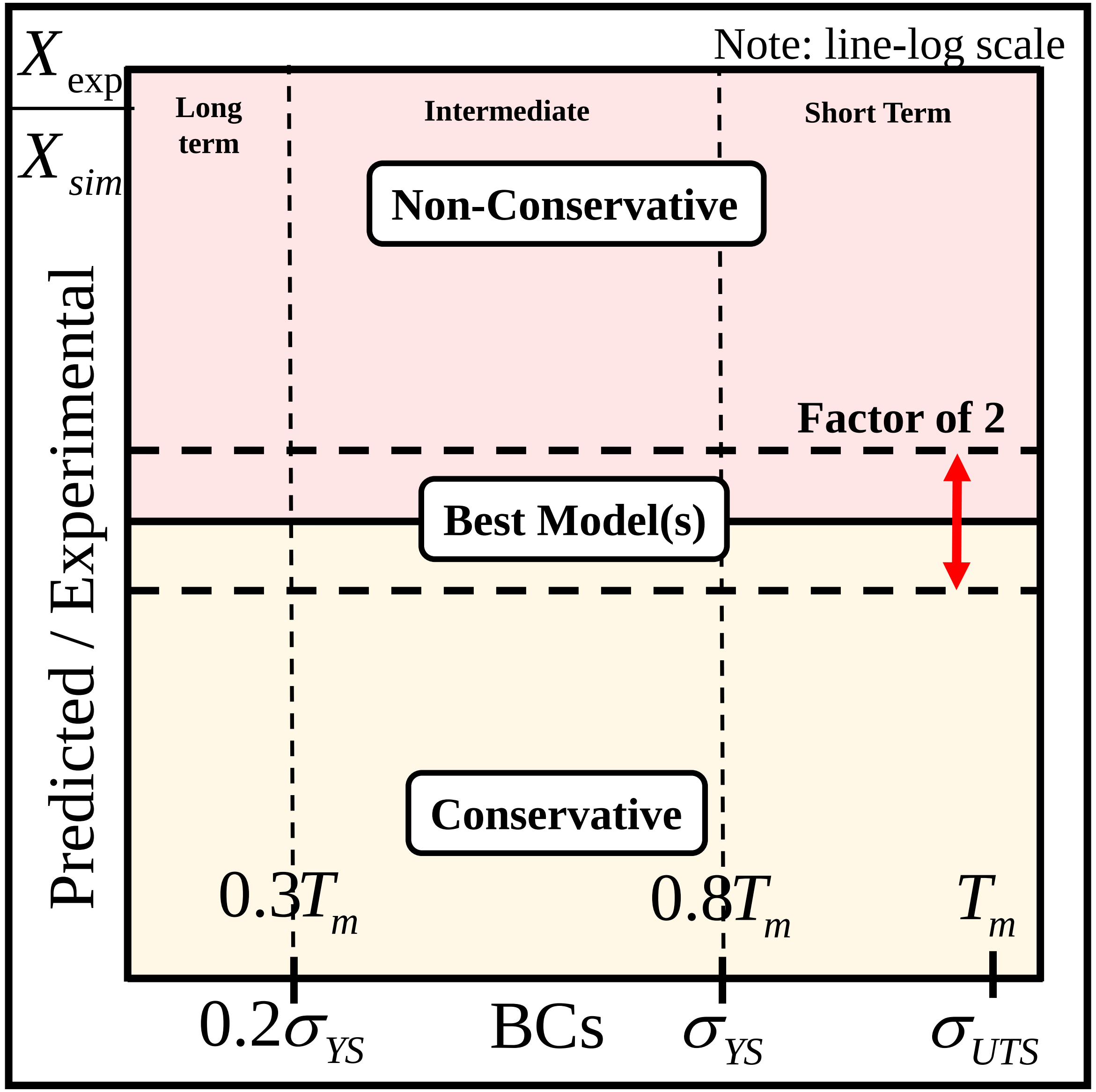
UTEP MATERIALS AT EXTREMES RESEARCH GROUP

# Uncertainty Analysis of the Models

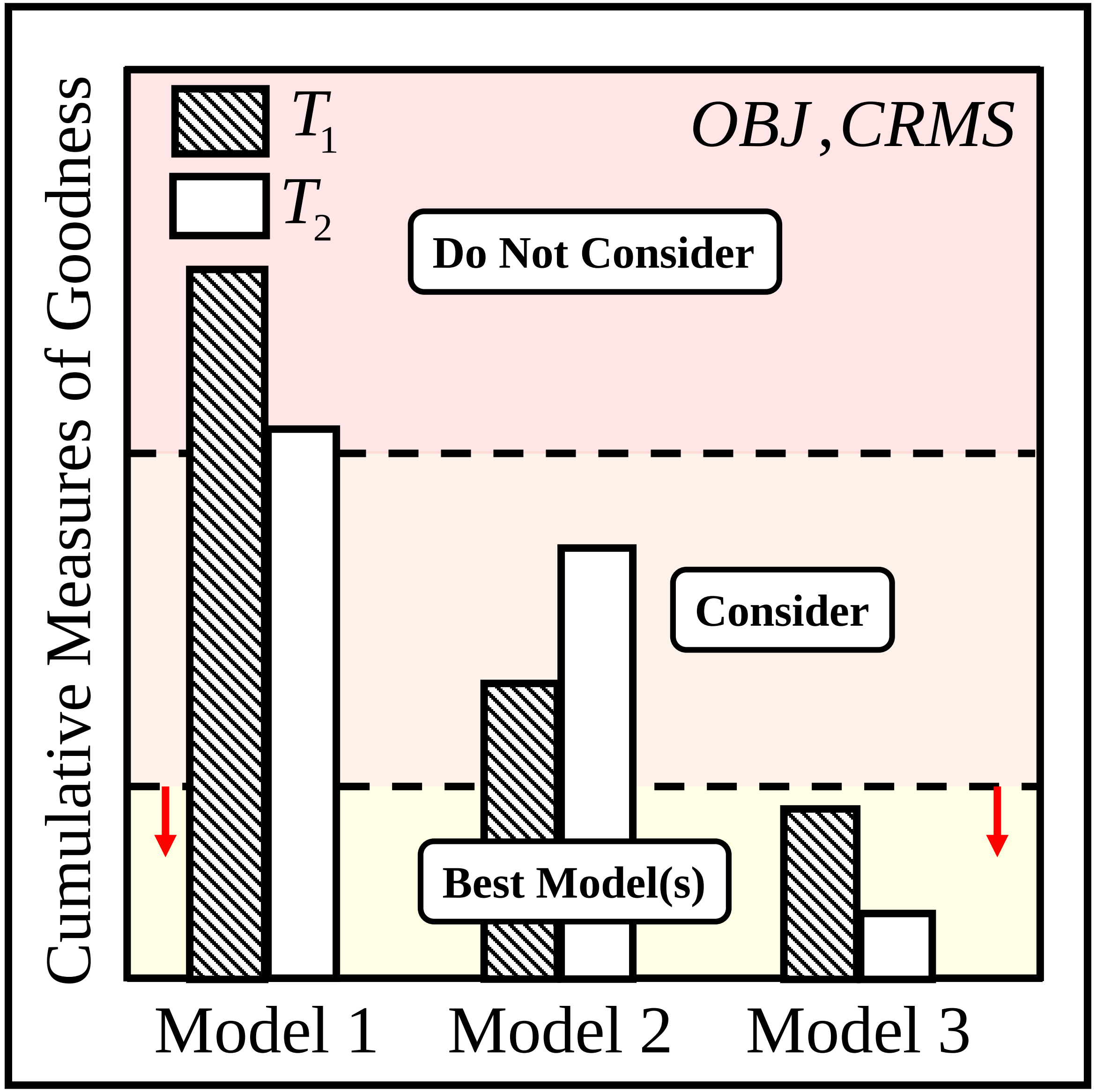
- The model performance will be evaluated with respect to experiment uncertainty.
- The repeatability and stability of extrapolations using the models will be tested across boundary conditions regimes (short term creep, long term creep, low cycle fatigue, high cycle low frequency fatigue, creep-fatigue interaction, etc.) and when the database is culled by 50% overall and 10% in the long term creep and creep-fatigue interaction regime.
- By breaking the data and model performance into categories and executing this uncertainty matrix, the bias in the experimental data can be separated from model performance.

# Uncertainty Analysis of the Models



# Uncertainty Analysis of the Models




## Creep Deformation / Hysteresis Loops

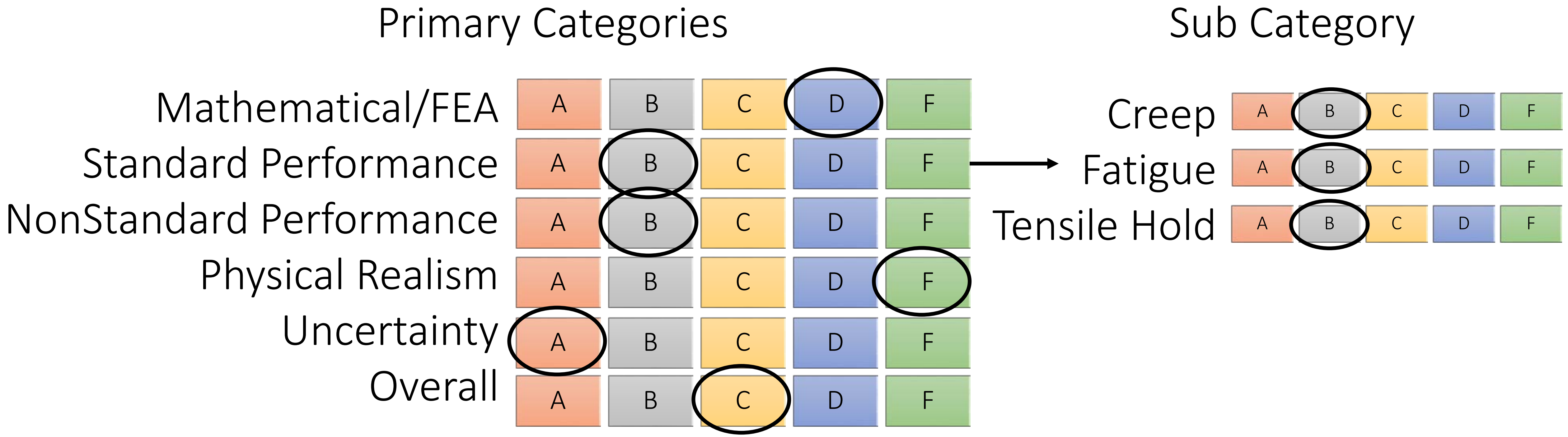
$$NMSE = \frac{1}{n}\sum_{i=1}^{n}\left[\left(X_{sim,i} - X_i\right)/X_{\max}\right]^2, \quad OBJ = \sum_i NMSE_i;$$

## Rupture and/or Cycles to Failure

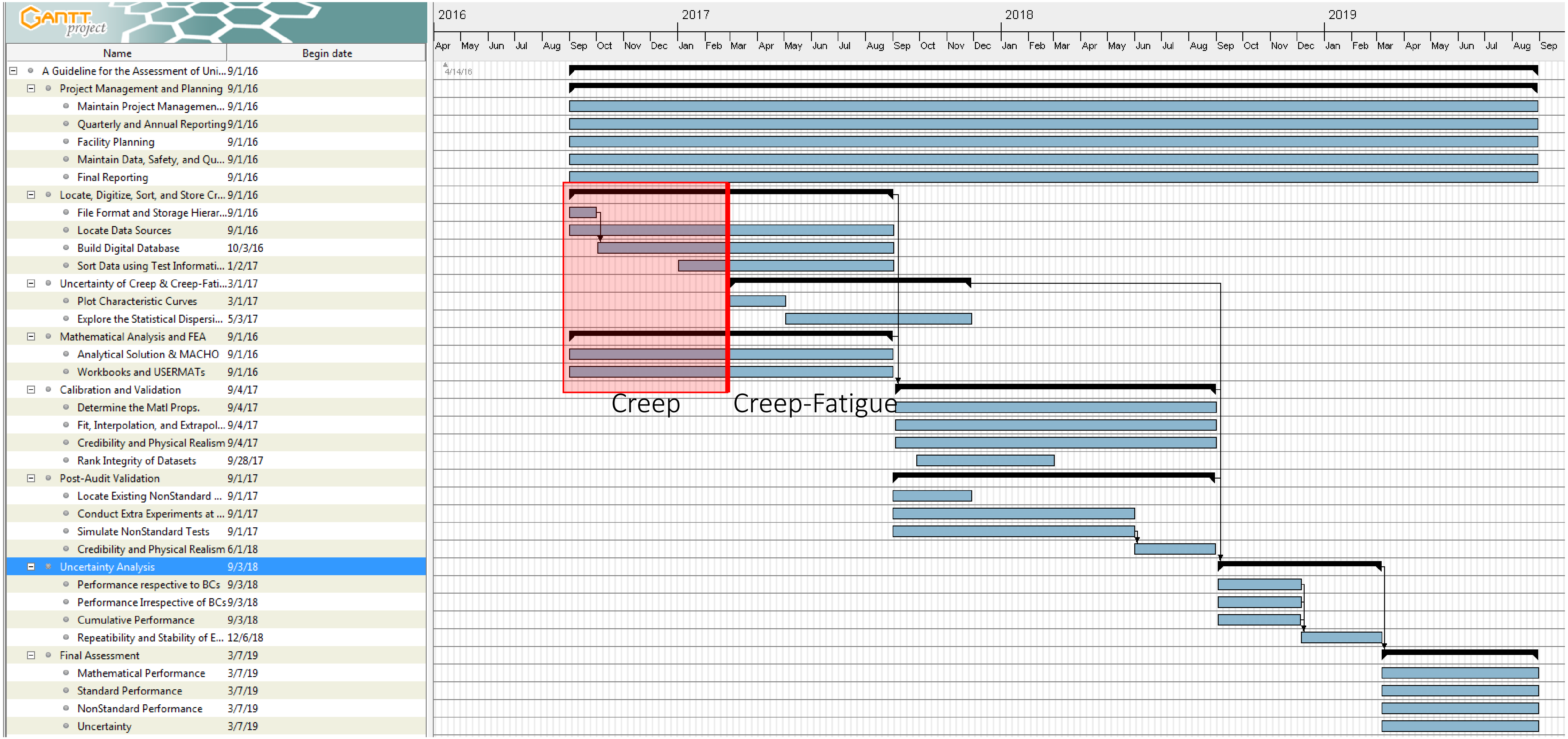
$$Z_{CRMS} = 10^{2.5CRMS}, \quad CRMS = \sqrt{\frac{\sum\left[\log\left(t_r\right) - \log\left(t_{r,sim}\right)\right]^2}{n-1}};$$

# Final Assessment

- The results of the mathematical/FEA, standard, nonstandard, and uncertainty analysis will be used to assign performance letter grades **(A, B, C, D, or F)** to each model for each loading condition, phenomena, and regime of interest.



# Gantt Chart


GANTT project
Name
Begin date
A Guideline for the Assessment of Uni... 9/1/16
Project Management and Planning 9/1/16
Maintain Project Managemen... 9/1/16
Quarterly and Annual Reporting 9/1/16
Facility Planning 9/1/16
Maintain Data, Safety, and Qu... 9/1/16
Final Reporting 9/1/16
Locate, Digitize, Sort, and Store Cr... 9/1/16
File Format and Storage Hierar... 9/1/16
Locate Data Sources 9/1/16
Build Digital Database 10/3/16
Sort Data using Test Informati... 1/2/17
Uncertainty of Creep & Creep-Fati... 3/1/17
Plot Characteristic Curves 3/1/17
Explore the Statistical Dispersi... 5/3/17
Mathematical Analysis and FEA 9/1/16
Analytical Solution & MACHO 9/1/16
Workbooks and USERMATs 9/1/16
Calibration and Validation 9/4/17
Determine the Matl Props. 9/4/17
Fit, Interpolation, and Extrapol... 9/4/17
Credibility and Physical Realism 9/4/17
Rank Integrity of Datasets 9/28/17
Post-Audit Validation 9/1/17
Locate Existing NonStandard ... 9/1/17
Conduct Extra Experiments at ... 9/1/17
Simulate NonStandard Tests 9/1/17
Credibility and Physical Realism 6/1/18
Uncertainty Analysis 9/3/18
Performance respective to BCs 9/3/18
Performance Irrespective of BCs 9/3/18
Cumulative Performance 9/3/18
Repeatibility and Stability of E... 12/6/18
Final Assessment 3/7/19
Mathematical Performance 3/7/19
Standard Performance 3/7/19
NonStandard Performance 3/7/19
Uncertainty 3/7/19
2016
2017
2018
2019
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
4/14/16
Creep
Creep-Fatigue

# Milestones

| Mile-stone | Title | Description | Success Metrics | Reporting | Qtr | Date | Done? |
|---|---|---|---|---|---|---|---|
| Phase 1 | | | | | | | |
| M1 | P91 and 316SS Database Compiled | An exhaustive database of high integrity data. | Sorted excel workbooks | Summarized in Quarterly Report | Y1-Q4 | 9/1/2017 | NO |
| M2 | Uncertainty Analysis of Databases | The databases are analyzed according to material and equipment/test related uncertainties | Separation of systematic and random variables | Summarize results in Quarterly Report | Y2-Q2 | 3/1/2018 | NO |
| M3 | Topical Report | "A Guideline for the Assessment of Creep and Creep-Fatigue Data" | Submission | Emailed to Program Manager | Y2-Q2 | 3/1/2018 | NO |
| Phase 2 | | | | | | | |
| M4 | Mathematical Analysis Report | Document describing the mathematical form and material constant determination procedure of all models | Completed Document | Summarize results in Quarterly Report | Y1-Q4 | 9/1/2017 | NO |
| M5 | Calibration and Validation | Fit, Interpolation, and Extrapolation of Models | Material constants and characteristic creep curves | Summarize results in Quarterly Report | Y2-Q4 | 9/1/2018 | NO |
| M6 | Post-Audit Validation | Simulations and Experiments under complex loading conditions | Blind Simulations compared to the experimental data | Summarize results in Quarterly Report | Y2-Q4 | 9/1/2018 | NO |
| M7 | Model Uncertainty | Parametric exercise of models against creep data uncertainty | characteristic creep curves for different datasets | Summarize results in Quarterly Report | Y3-Q2 | 3/1/2019 | NO |
| M8 | Final Assessment | Letter Grade score of models for mathematical/FEA, calibration validation, and post-audit validation | A table listing the performance of each model under different boundary conditions and regimes of interest | Summarize results in Quarterly Report | Y3-Q4 | 9/1/2019 | NO |
| M9 | Topical Report | "A Guideline for the Assessment of Creep and Creep-Fatigue Models" & "Recommendations for Improved Creep-Fatigue Models" | Submission | Emailed to Program Manager | Y3-Q4 | 9/1/2019 | NO |
| Outside Budget Periods | | | | | | | |
| M10 | Final Report | Summary of experimentation, findings and data | Final | Report | Y4-Q1 | 12/31/2019 | NO |

# In Preparation. The Next 6 months…

- ASME PVP 2017
  - Time-Stress Parameters in Continuum Damage Mechanics
  - A Guideline to Representative Stress Model Selection for Multiaxial Creep
  - Development of a Stepped Iso-Stress Method Accelerated Creep Test for Metallics

- Nuclear Material Design
  - Model Transformations of Theta Projection, MPC Omega, and Sin-Hyperbolic Creep Deformation, Damage, and Life Prediction Models

- ASME Journal of Pressure Vessel Technology (Special Issue)
  - A Review of Master Curve Models for Creep-Rupture

# Questions?

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*Assistant Professor*
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The University of Texas at El Paso
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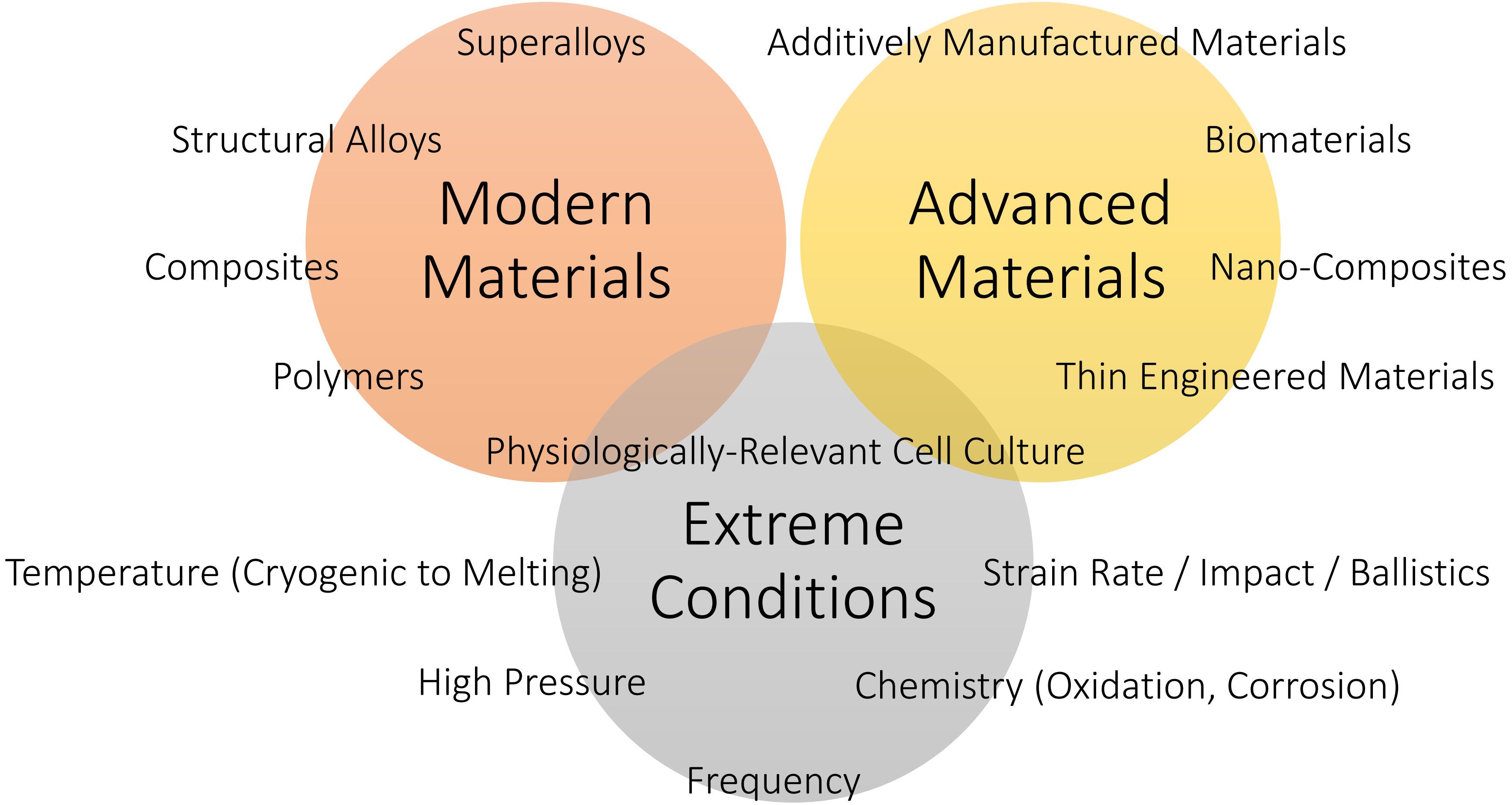
# MERG

UTEP MATERIALS AT EXTREMES RESEARCH GROUP



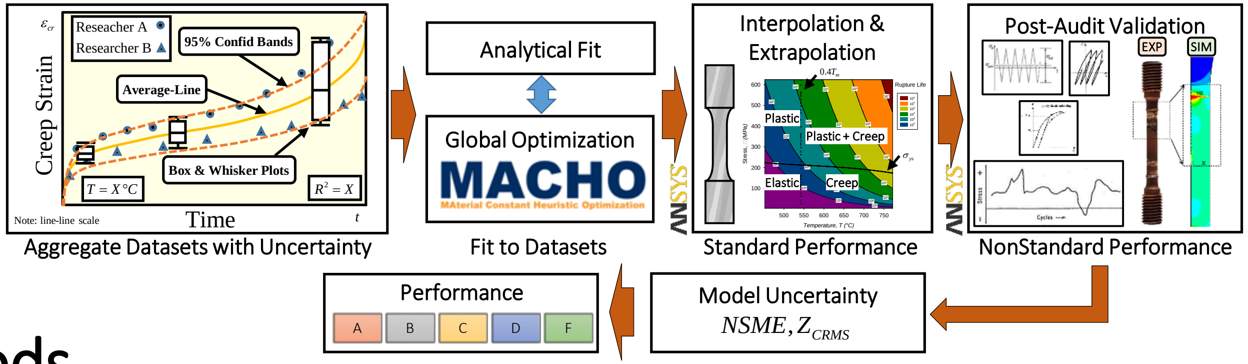
The goals of MERG are to:

- Expand the UTEP's capability to conduct **experimental research** that replicate the extreme boundary conditions experienced by modern and advanced materials.

- Develop **theoretical models** that capture the key phenomena (at appropriate time- and length-scales) that enable the prediction of constitutive response, damage evolution, and component life at a high fidelity.

- Design **numerical tools** to facilitate the rapid implementation of theory into academia, government, and industry.

# From Materials to Models




## Experimental Methods

- Subjecting small samples to mechanical test conditions bearing similarity to larger structures

## Theory Development

- Applying of theories of elasticity, plasticity, viscoplasticity, etc.
- Developing constitutive models and life prediction equations from the experimentally observed behavior

## Numerical Modeling

- Using appropriate continuum and/or non-continuum mechanics based numerical codes to simulate the materials response

## Post-Audit Validation

- Evaluate the physical-realism of simulations through parametric simulations compared to blind experimental data.

## Design

# Outcomes

- Experimental Database of Standard and NonStandard Data
- Library of Validated Creep and Creep-Fatigue Models
- Topical Report – A guideline to the assessment of creep and creep-fatigue data
- Topical Report – A guideline to the assessment of creep and creep-fatigue models
- Final Report
- Conference papers
- Journal articles