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# Simplifying Component and Materials Tests

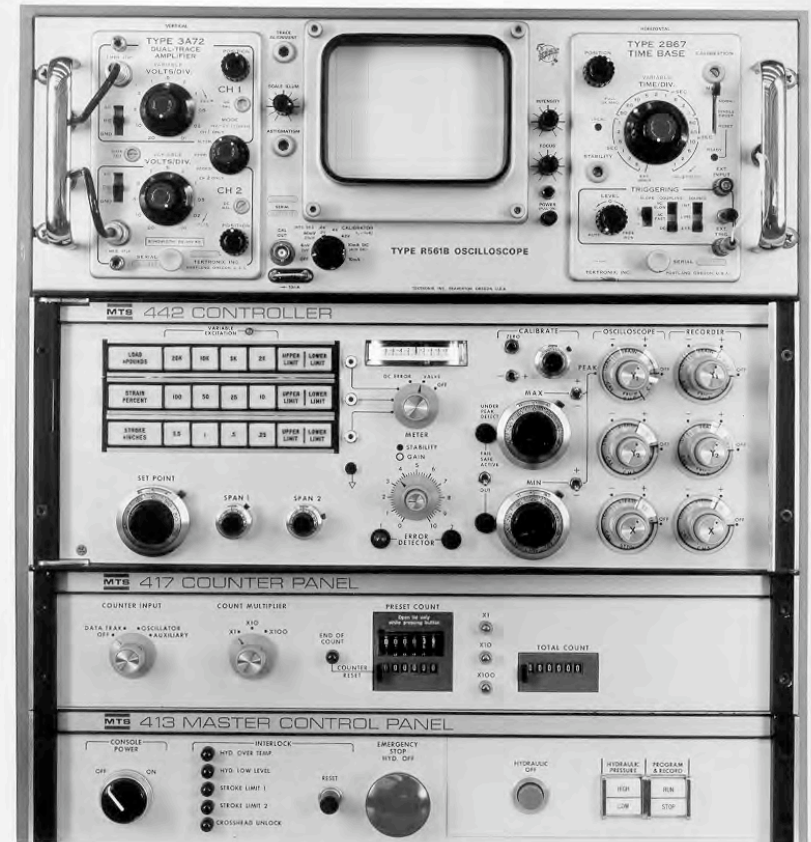
*on Modern Digital Controllers*

Presented by: Dr. Erik Schwarzkopf, MTS Systems Corporation



## The Old Way to Test

- Arrays of knob, buttons, dials, and readouts
- Strip charts
- Manual calibrations
- Manual calculations
- Operator calculations and extrapolation before, during, and after the test
- Individual devices required to perform specific tasks





## Issues with the Old Way

- All capabilities leveraged in hardware
  - Productivity hits
    - Steeper learning curve for operators
    - Requires detailed procedures
    - More mistakes
    - Inflexible configurations





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## Modern Digital Controllers





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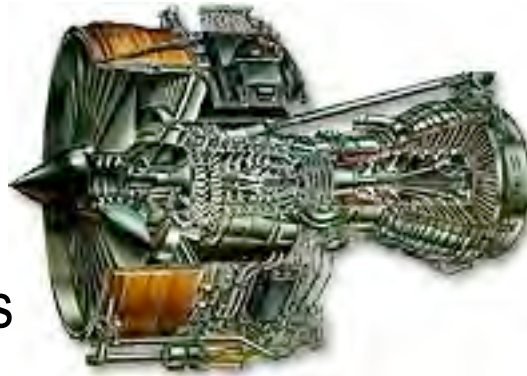


## What drives investment in new techniques and applications?

- New air frames
- New engines
- New manufacturing and repair techniques



Computer graphics by I3M



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## Applications and Techniques

- Applications

- Multi-axis Materials Testing

**Better understanding of complex loading behavior => better designs**

- Thermo Mechanical Fatigue (TMF)

**Higher operating temperature materials for Aero engines => higher efficiency, less pollution, quieter engines**



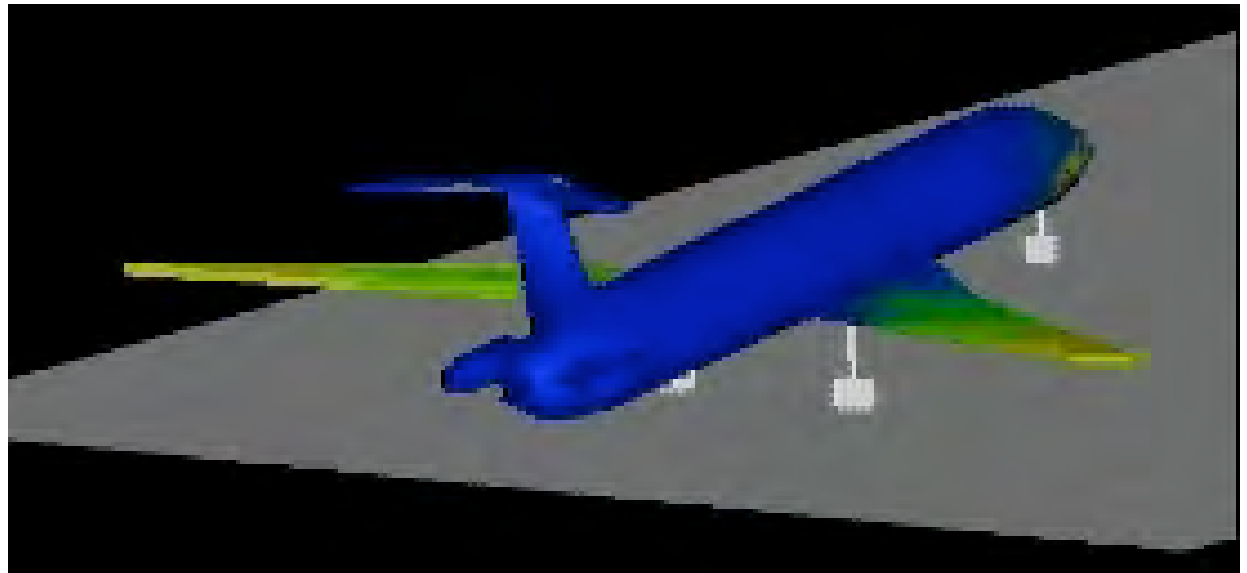
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## Multi-Axis Materials Testing

Important because.....

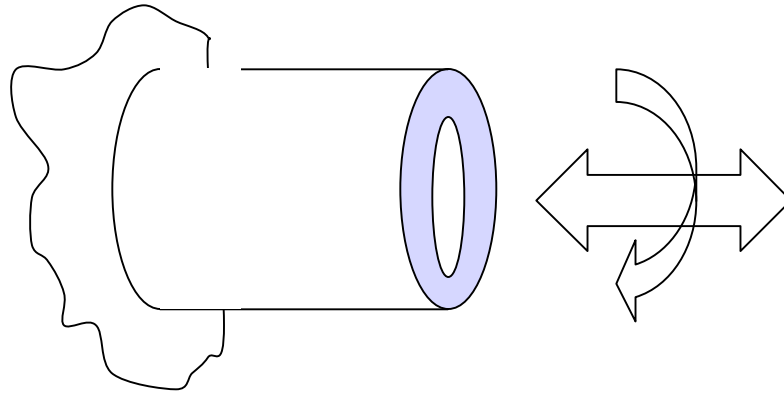
- As design becomes more sophisticated, more descriptive material models are required
- Close simulation of application loading required to test models
- Mixed mode loading in both air frames and turbines



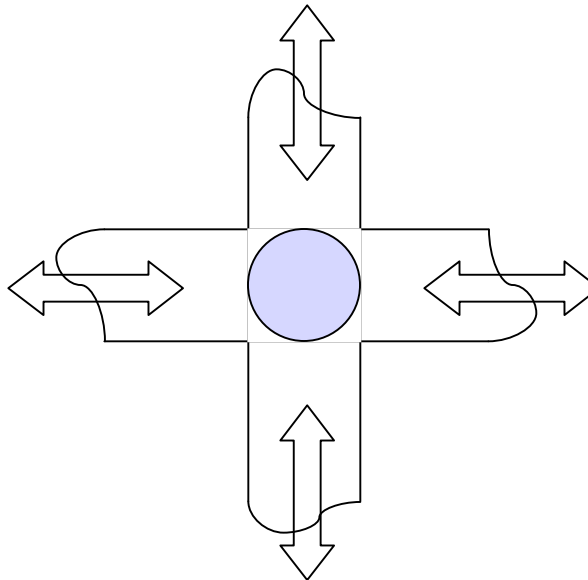


## Common forms of Multi axis testing

- Tension-Torsion



- Planar Biaxial





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## Axial-Torsion or Axial-Rotation

- MTS Model 858
  - Table top
  - 25kN



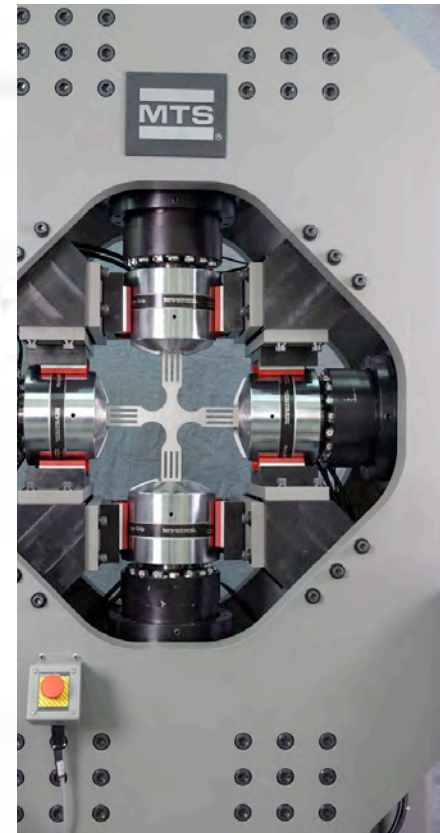
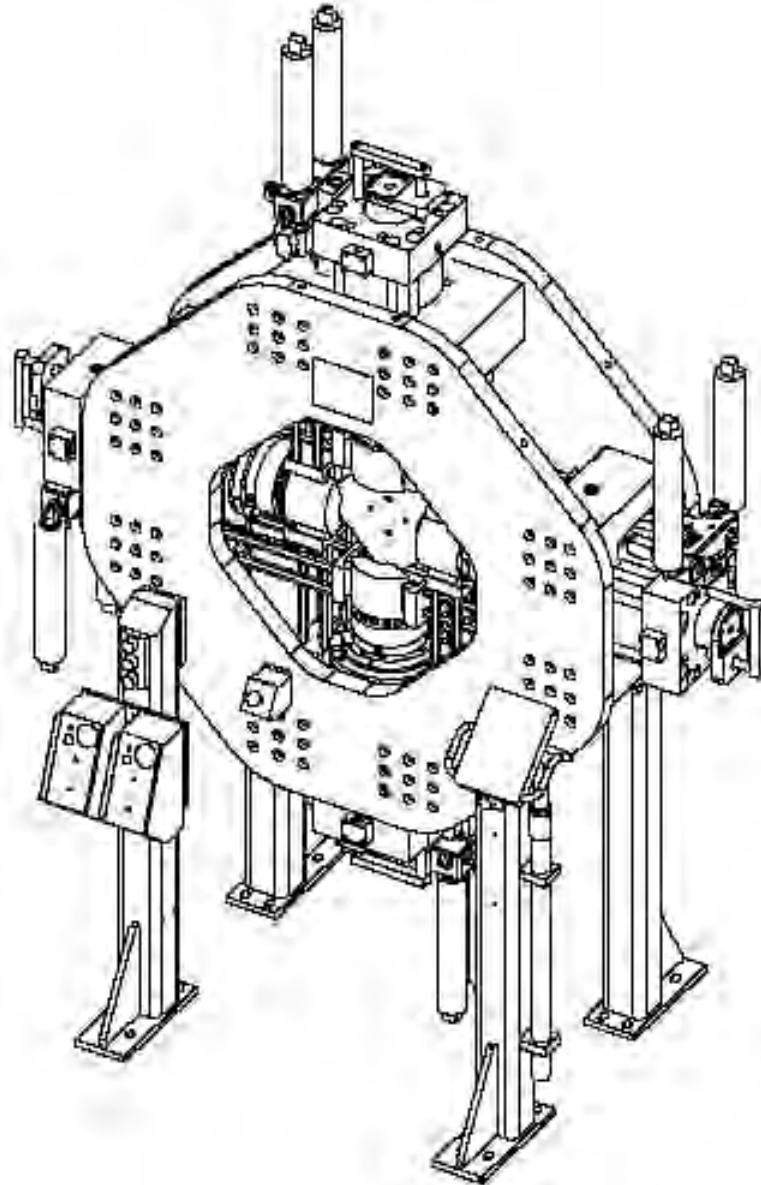
- MTS Model 809
  - Floor standing
  - Up to 1000kN





## Planar - Biaxial

- Center point control
- Biaxial Fracture Mechanics on flat plate
- Induction heating possible
- Optical and potential drop crack length measurement methods possible



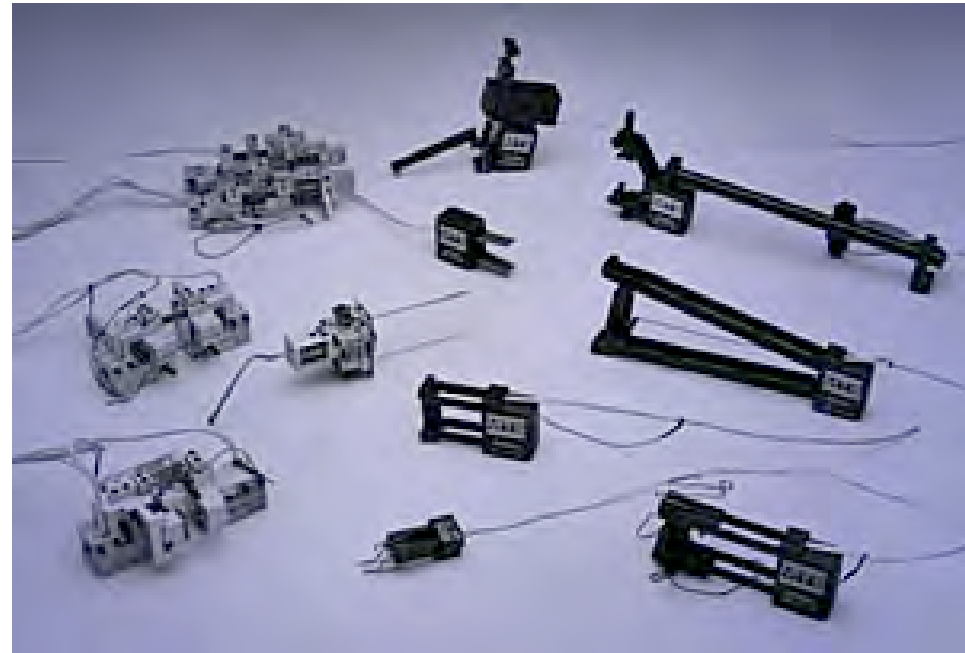


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## Physical vs. Calculated Signals

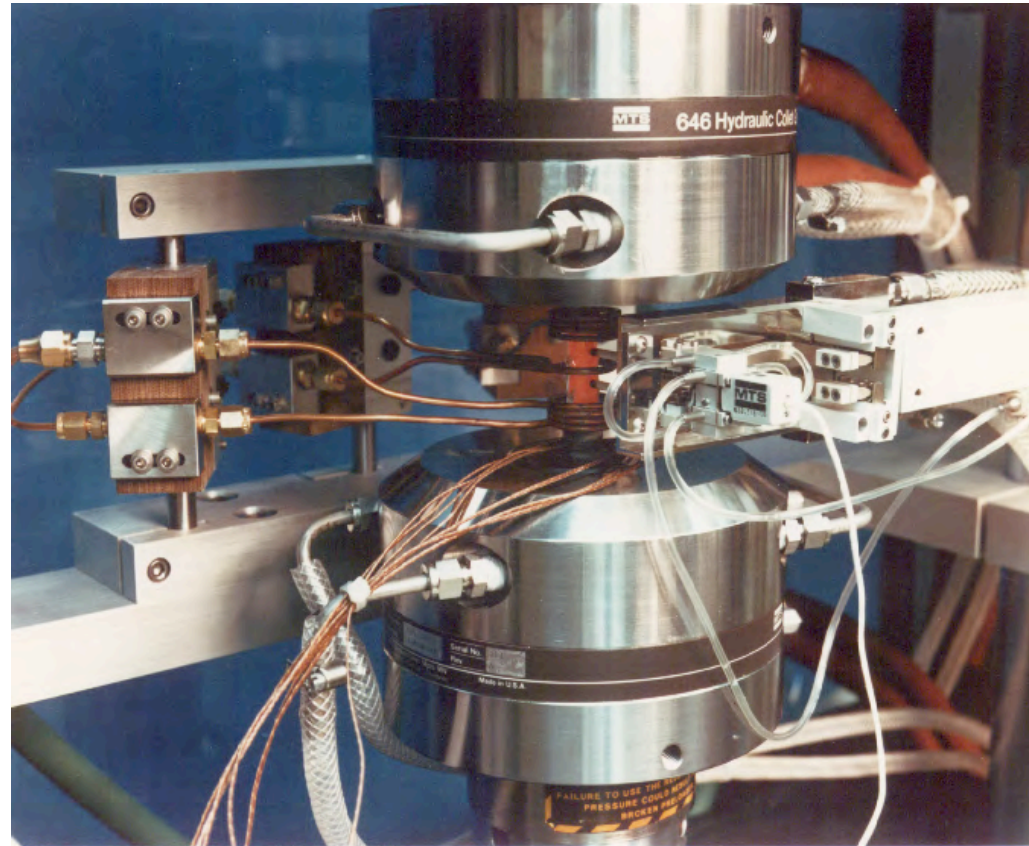
- Data acquired directly from physical sensors
  - Load (Force)
  - Strain (Extensometers)
  - Displacement (LVDT's)
  - Temperature (Thermocouples)





## Calculated Signals

- Calculated from physical inputs or other calculated inputs
  - Stress
  - Elastic, Plastic Strain
  - Thermal Strain
- Provide continuous values to the digital controller





## Calculated Control

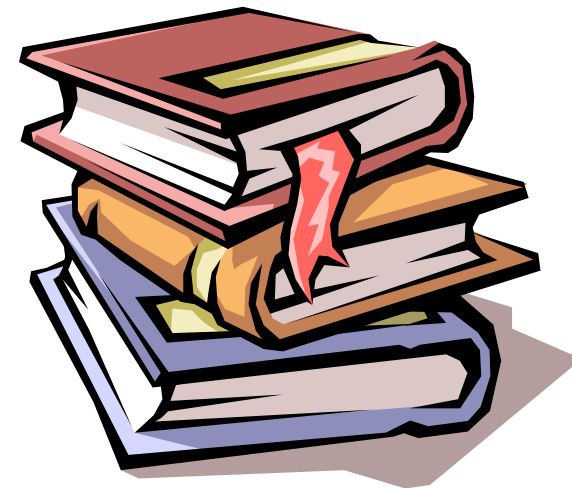
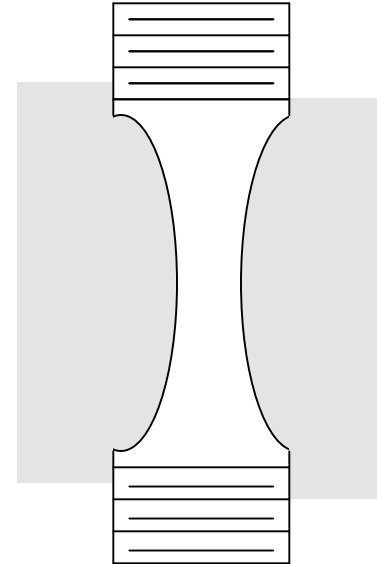
- Control mode that uses a calculated input signal

$$\sigma = \text{Load} / \text{Area}$$

$$\epsilon_{\text{True}} = \text{Ln} (1 + \epsilon)$$

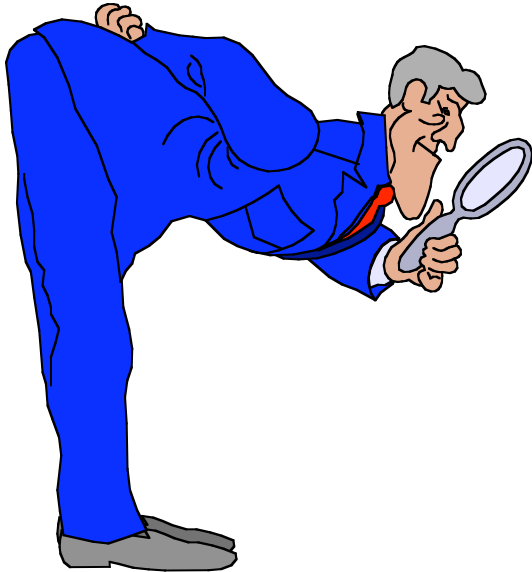
$$\epsilon_{\text{Average}} = (\epsilon_1 + \epsilon_2) / 2$$

$$\epsilon_{\text{mechanical}} = \epsilon_{\text{total}} - \epsilon_{\text{thermal}}$$





## Calculated signal examples



- Simple calculations
  - Averages of multiple strain gages
  - Digital filtering of crack length data
  - On the fly calculation of energy, etc.
- Planar Biaxial calculations
  - Center point Position Control
  - Horizontal or Vertical load control



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## Calculated signal examples

- Complex calculations
  - Periodic calculations  
(I.e. modulus in Low Cycle Fatigue)
  - “State based” calculations (If/Then)
  - Look-up table calculations  
(Feedback based command)

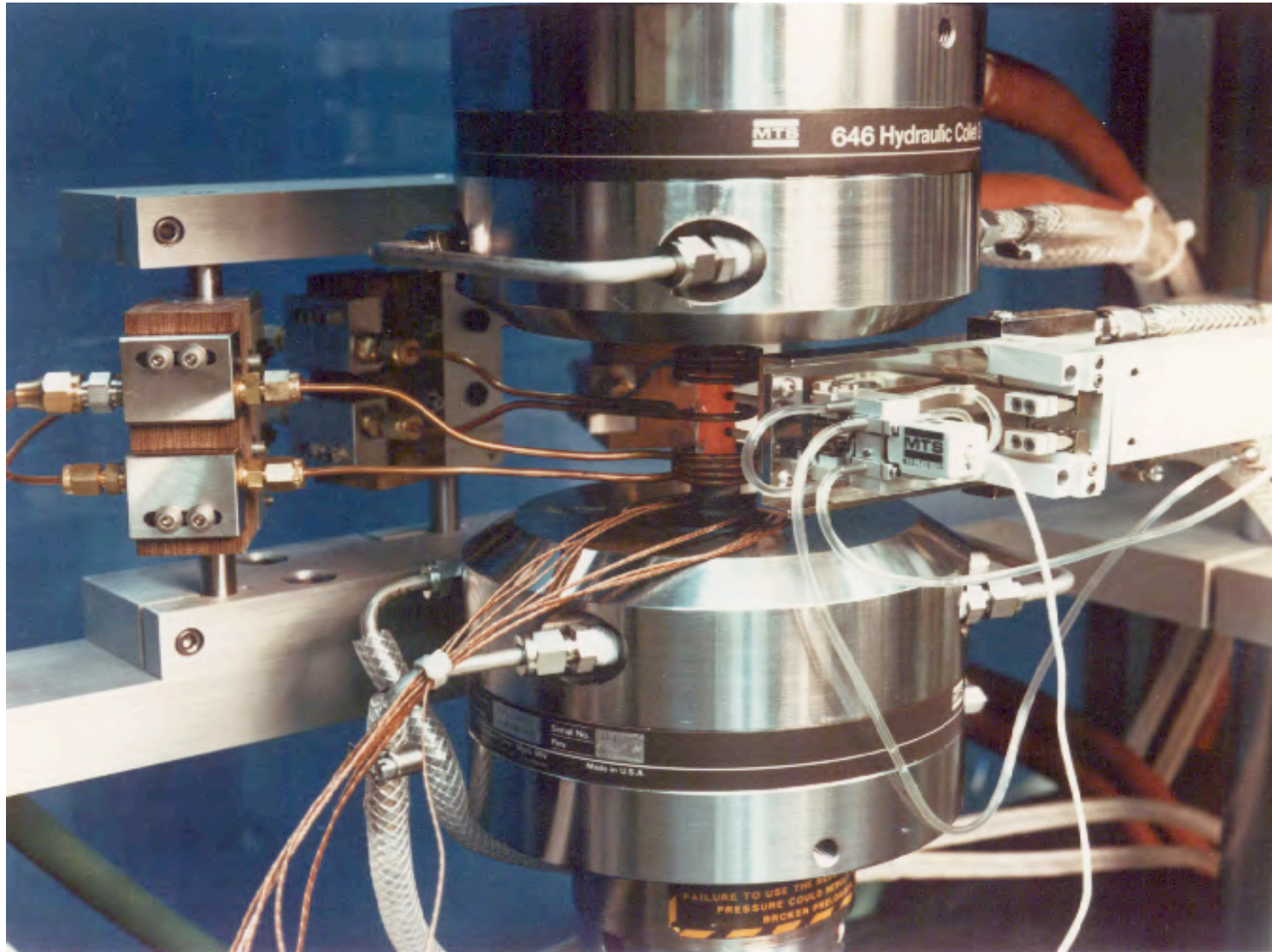




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## TMF System



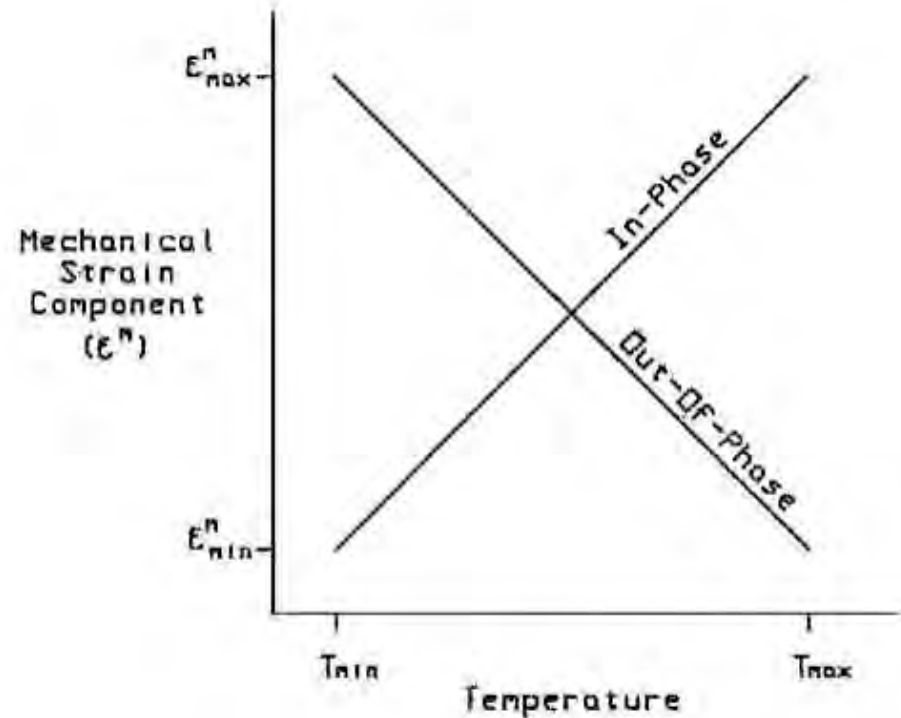


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## TMF Review

Significant studies on In-phase and Out-of-phase temperature-mechanical cycles.





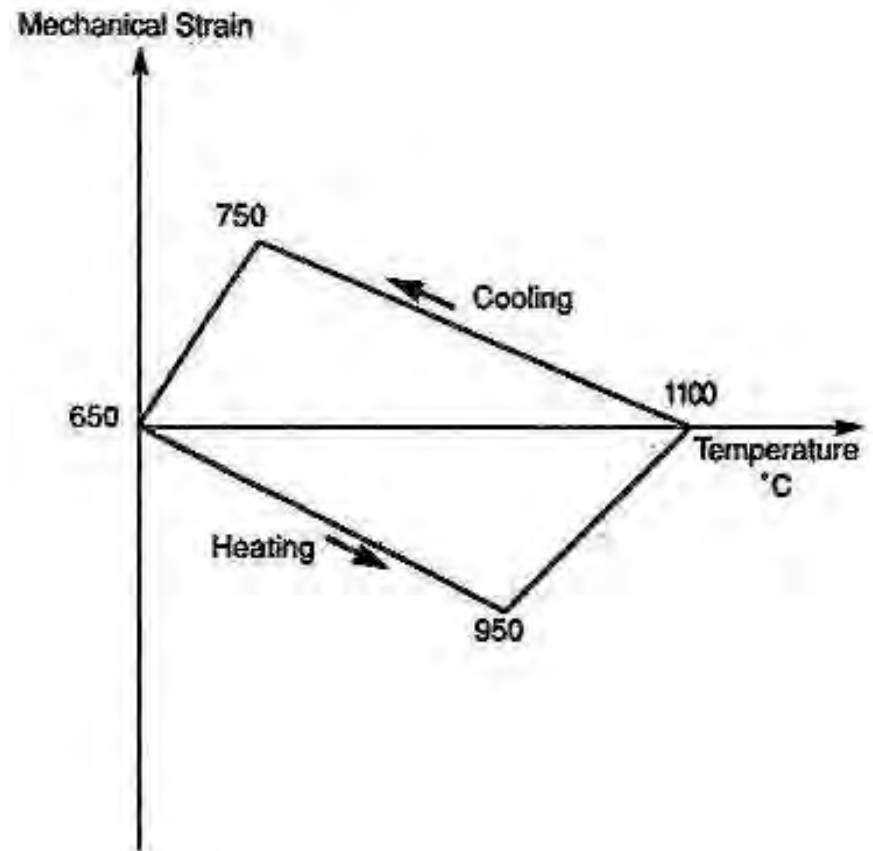
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## TMF Review

And more complicated cycles

...



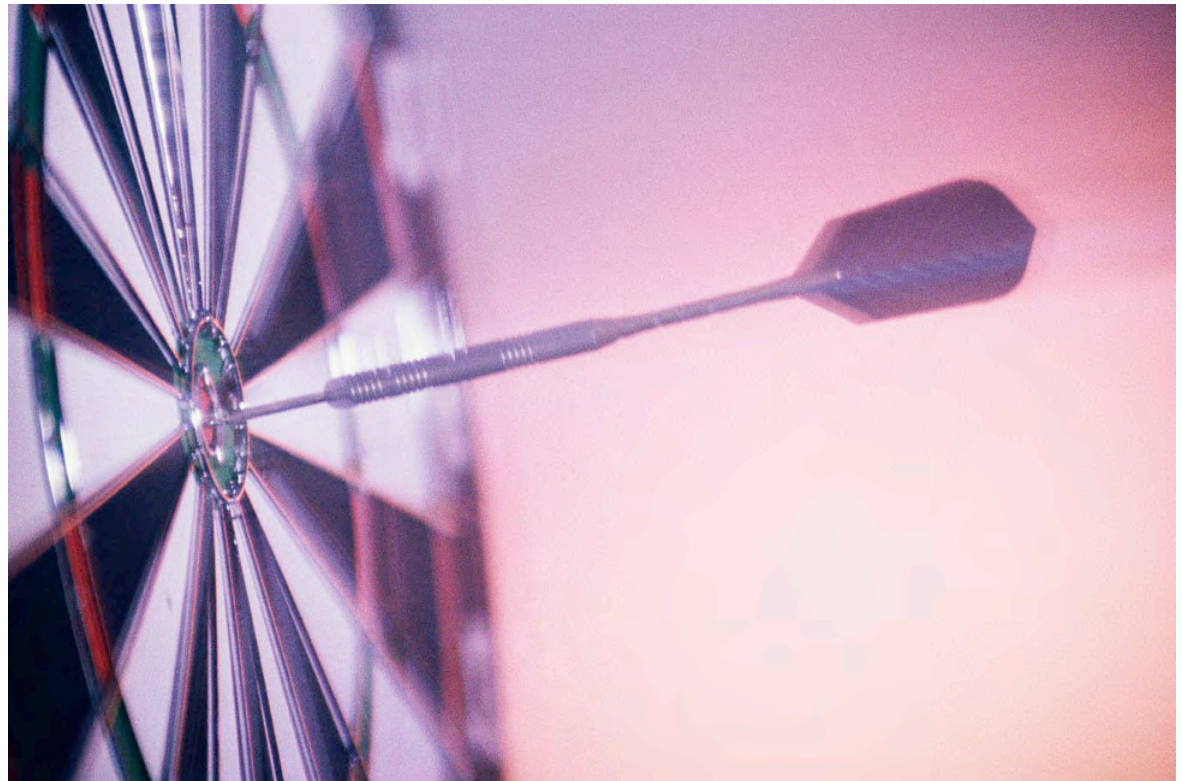


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## TMF Test Procedure

Simplify Testing by Targeting the Test Procedure





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## Calculated Inputs

**Stress**

$$\sigma = \text{Force/Area}$$

**Elastic Strain**

$$\varepsilon_{elastic} = \sigma / E$$

**Plastic Strain**

$$\varepsilon_{plastic} = \varepsilon_{total} - \varepsilon_{elastic}$$

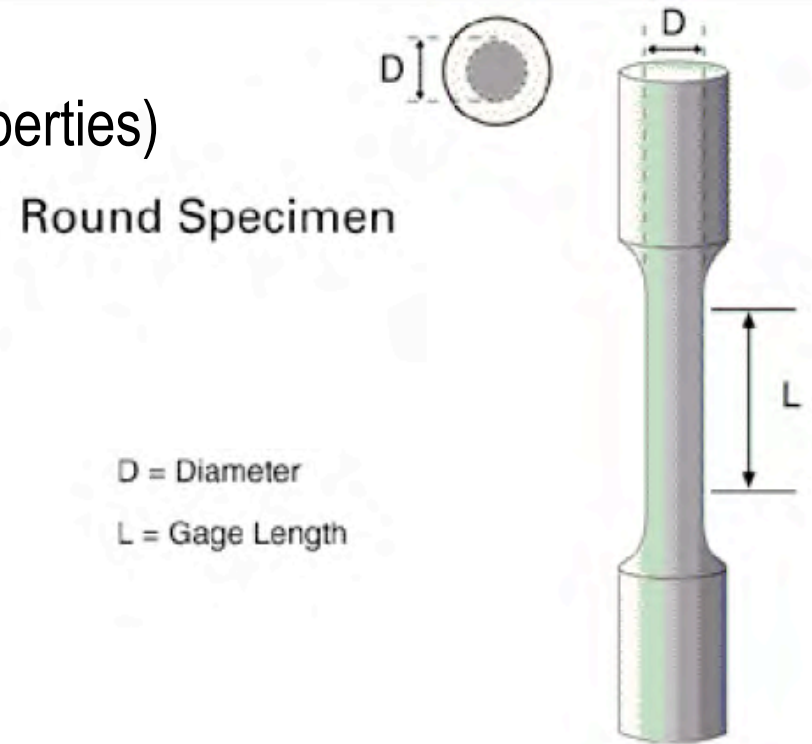
**Thermal Strain**

$$\varepsilon_{Thermal} = c + \alpha T + \beta T^2 + K$$



## Calculation Constants

- Values used in calculations (typically specimen dimensions or properties)
  - Area
  - Diameter, Width, Thickness
  - Gage length
  - Elastic Modulus
  - Thermal expansion coefficient





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## TMF Calculated Inputs

**Mechanical  
Strain**

$$\epsilon_{mech} = \epsilon_{Total} - \epsilon_{thermal}$$

**Thermal  
Strain**

$$\epsilon_{Thermal} = c + \alpha T + \beta T^2 + K$$

**Measure “Total Strain” or  
calculate from “Total Extension”**



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## Mechanical Strain Calculated Input

- Mechanical strain is simply the difference between total strain and thermal strain.

The screenshot shows the 'Calculation Editor' window for a file named 'TMF.cfg'. The left pane shows a tree view with 'Station' expanded to 'Calculated input signals', where 'Axial Mechanical Strain' is selected. The right pane shows the 'Axial Mechanical Strain' configuration, with the expression:  $\text{"Axial Mechanical Strain"} = \text{"Axial Total Strain"} - \text{"Axial Thermal strain"}$ . Below the expression are 'Insert' buttons for mathematical operators and a table of functions and signals.

Functions:	Signals:
exp(x)	Axial True Strain
fabs(x)	Axial Thermal strain
ln(x)	Axial Mechanical Strain
log10(x)	Axial Total Strain
constant	Axial Current Gage Length

Buttons: Apply, Cancel, Clear



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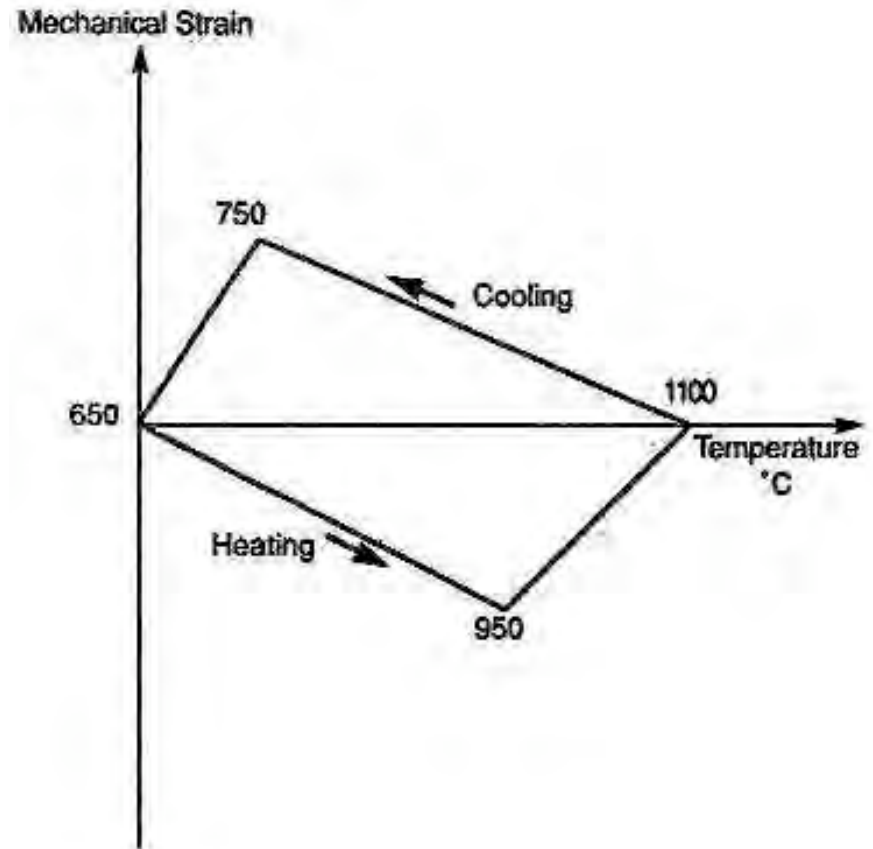
## Simplified TMF Test Generation

- Digital controllers come with a variety of application programs
  - general purpose programs for ultimate flexibility
  - application specific programs for ease of use and advanced data reduction and reports.
- TMF requires great flexibility



## Turbine Blade cycle

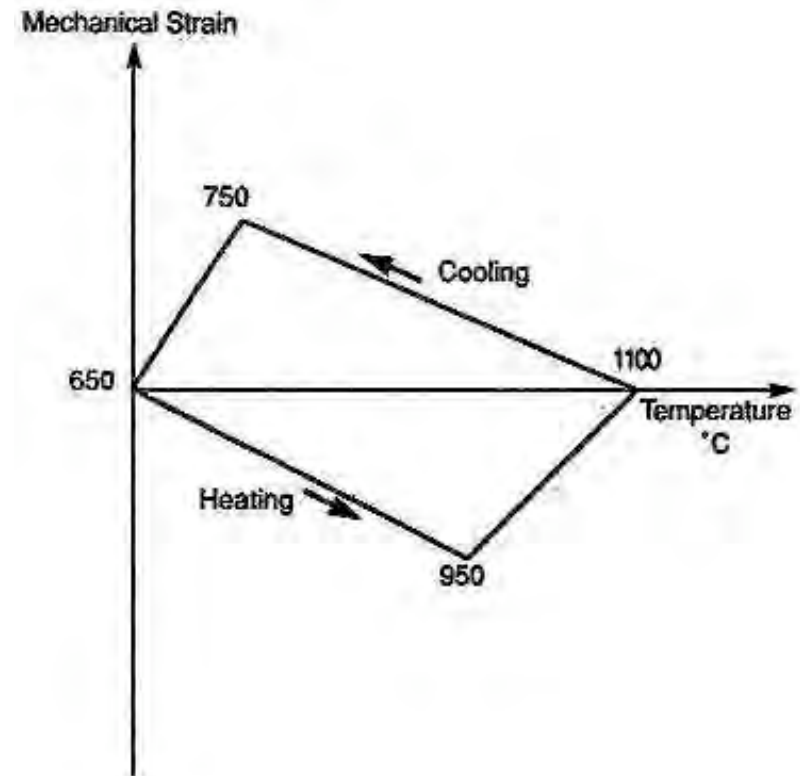
- Create a mechanical strain control mode as described above





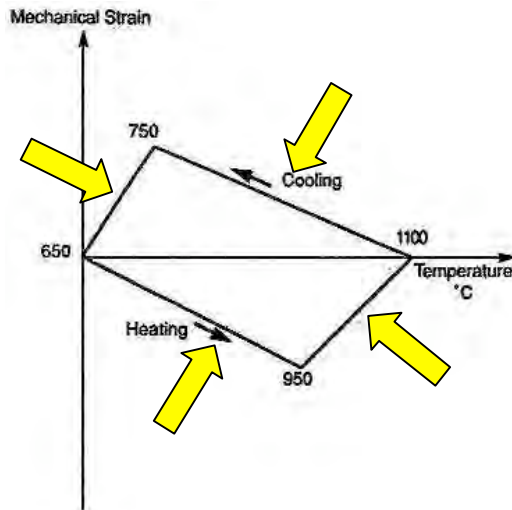
## Typical Turbine Blade Cycle

- Create a block with the four ramp segments using appropriate
  - mechanical strain control
  - temperature control
- Run the block simultaneously with data acquisition





## Turbine blade leading edge cycle



MPT < TMF.cfg > Test Procedure

File Edit Group Display Tools Window Help

Procedure

Type	Name	Start	Interrupt
	cycle mech & temp	<Procedure>.Start	
	acquire data	<Procedure>.Start	

Procedure / cycle mech & temp

Type	Name	Start	Interrupt
<input checked="" type="checkbox"/>	heat & unload to 950	<Group>.Start	
<input checked="" type="checkbox"/>	heat & load to 1100	heat & unload to 950.Done	
<input checked="" type="checkbox"/>	cool & load to 750	heat & load to 1100.Done	
<input checked="" type="checkbox"/>	cool & unload to 650	cool & load to 750.Done	

Group is done when cool & unload to 650.Done

Ready

Process T

Com

Data Ac



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## Turbine blade leading edge cycle

Ramp segment with appropriate mechanical strain control mode and end level

The screenshot displays the MPT software interface for configuring a turbine blade leading edge cycle. The main window is titled "MPT < TMF.cfg > TMF.000" and features a menu bar (File, Edit, Group, Display, Tools, Window, Help) and a toolbar with various icons. Below the toolbar, there are two procedure tables. The first table, titled "Procedure", lists a procedure named "cycle.mech & term" starting at "<Procedure> Start". The second table, titled "Procedure / cycle.mech & term", lists a segment named "heat & unload to 950" starting at "<Group> Start". A dialog box titled "heat & unload to 950 - Segment Com..." is open, showing the configuration for this segment. The "Segment Shape" is set to "Ramp", the "Time" is "120.00 (Sec)", and the "Control Mode" is "Mech Strain Heating". The "Absolute End Level" is set to "-0.40000 %".

Type	Name	Start	Interrupt
	cycle.mech & term	<Procedure> Start	

Type	Name	Start	Interrupt
	heat & unload to 950	<Group> Start	
	he		
	co		
	co		

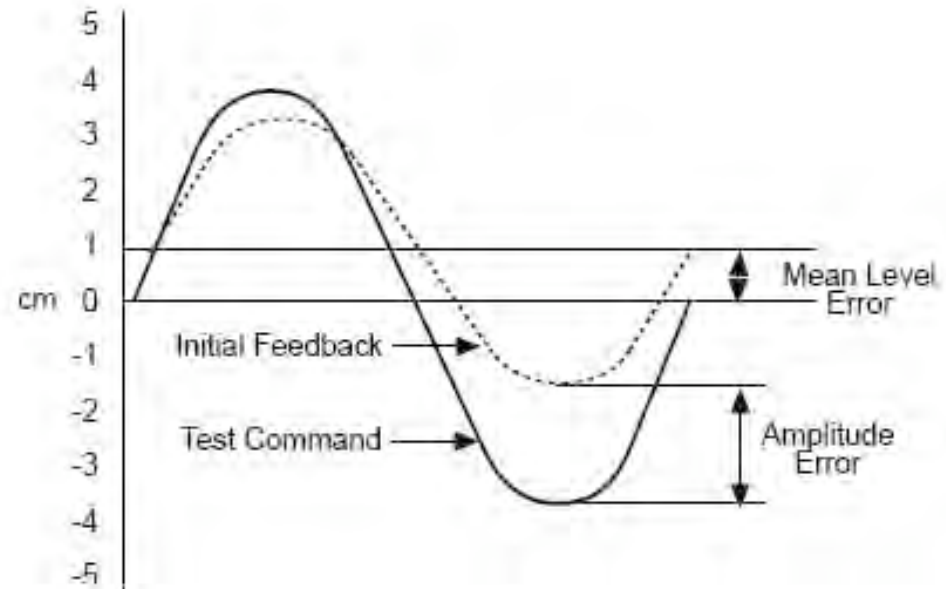
Property	Value
Segment Shape	Ramp
Time	120.00 (Sec)
Adaptive Compensators	None
Relative End Level	<input type="checkbox"/>
Channel	Axial
Control Mode	Mech Strain Heating
Absolute End Level	-0.40000 %



## Simplifying End Level Assurance (using compensation)

### Various compensation

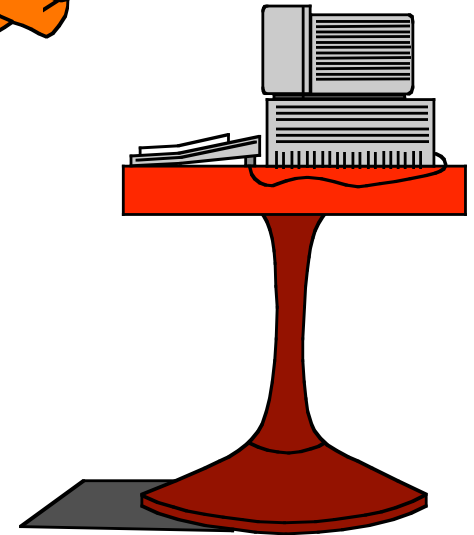
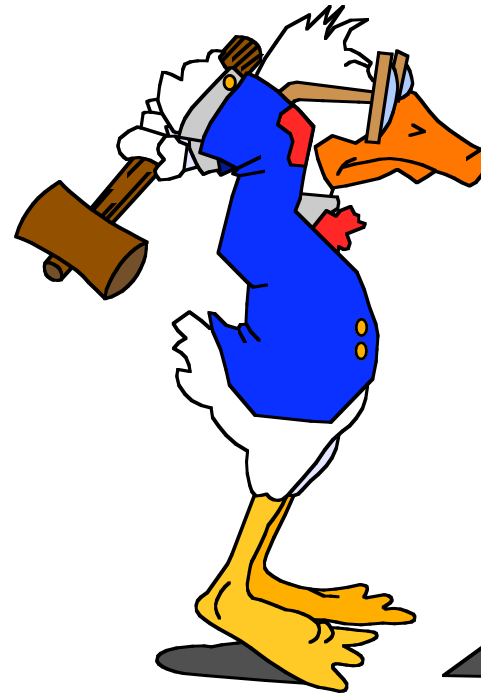
- Command based
- # of channels based
- Peak / Valley “over programming” most commonly used for Fatigue
- Various algorithms for Spectrum





## Simplifying End Level Verification

- Peak / Valley “change” ranges for constant amplitude command and spectrum command
- Missed end level counting and storage





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## End level assurance and verification for flight spectra

- Assurance = > “Get what you desire”
  - Sophisticated compensation techniques to enhance typical PID control
  - “Smart” Techniques that “learn”
- Verification = > “Know what you got”
  - Count and record end levels missed by a small amount
  - Shut down test when end levels are missed by a large amount.



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## End level assurance and verification for flight spectra

- Advantages
  - Speed up test frequency and loading rates to shorten test time
  - Repeatable loading on many specimen sizes and geometries
  - Minimize variation of results
  - Simplifies audit trails and quality recording
  - Prevents “ruined” test by dramatic under- or over-loading
- MTS proprietary methods
  - SAC (Spectrum amplitude control)
  - ALC (Arbitrary end level control)



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## End Level Verification

- Using Calculated signals
  - Find peak on Command
  - Find peak on Feedback
  - If the difference between the peaks is greater than minimum allowable window, Store the data
- Multiple “If” calculations can be created for Storage, Test hold or Test shutdown



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Questions?

