Electronic Instrumentation

The Power of the Potential Divider

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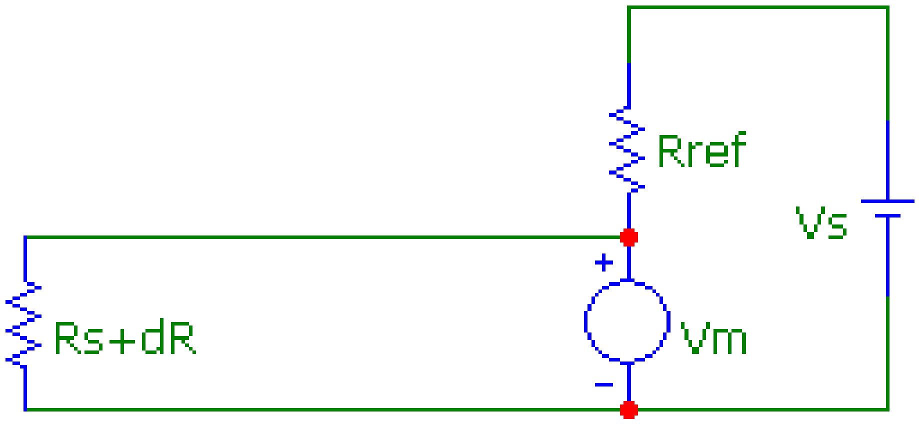
Outline

- The Circuits
  - Potential Dividers
  - Bridge Circuits
  - Cal Steps
- The Transducers
  - Strain Gauges
  - PRTs
  - Pressure Transducers
  - Load Cells
- The Application
  - Aircraft Qualification

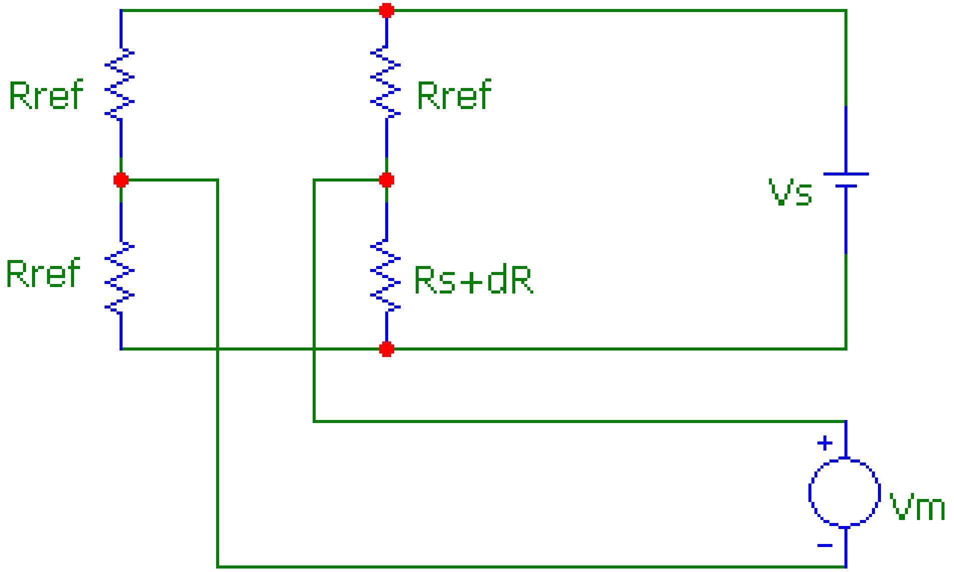
Circuits - Potential Divider



- Vm = Vs × (Rs+dR)/(Rs+dR+Rref)
- Make dR depend on measurand
- Rs≈Rref
- Measure change in Vm…

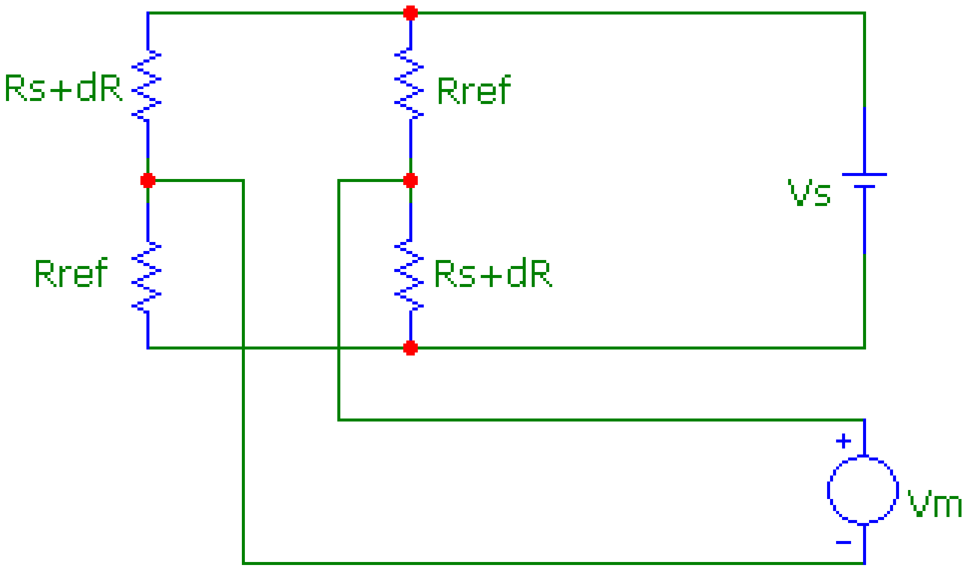
- But measuring small changes in a large voltage is difficult

Circuits - Quarter Bridge



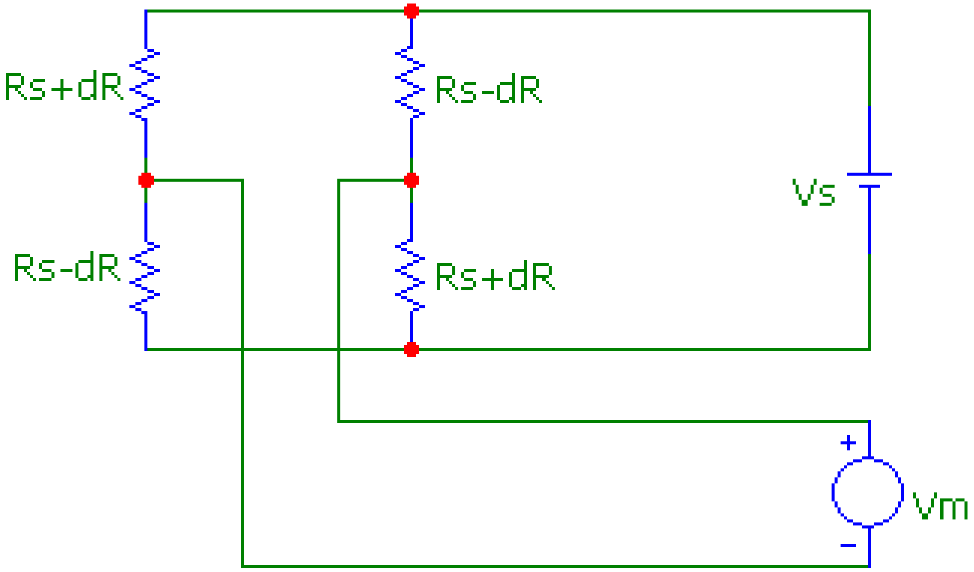
- Add a potential divider to offset static value
- Take differential value Vm as output
- Bipolar Signal
- $Vm \approx Vs \times \frac{1}{4} \times dR/Rs$

Circuits - Half Bridge



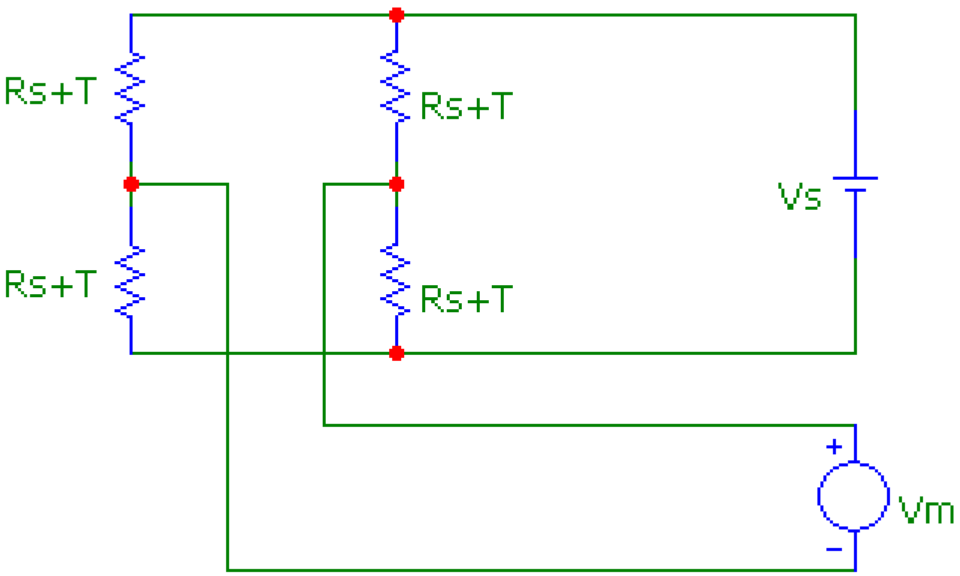
- Add a second active potential divider
- Both Vm+ and Vm- change
- Take differential change in Vm as output
- $Vm \approx Vs \times \frac{1}{2} \times dR/Rs$

Circuits - Full Bridge



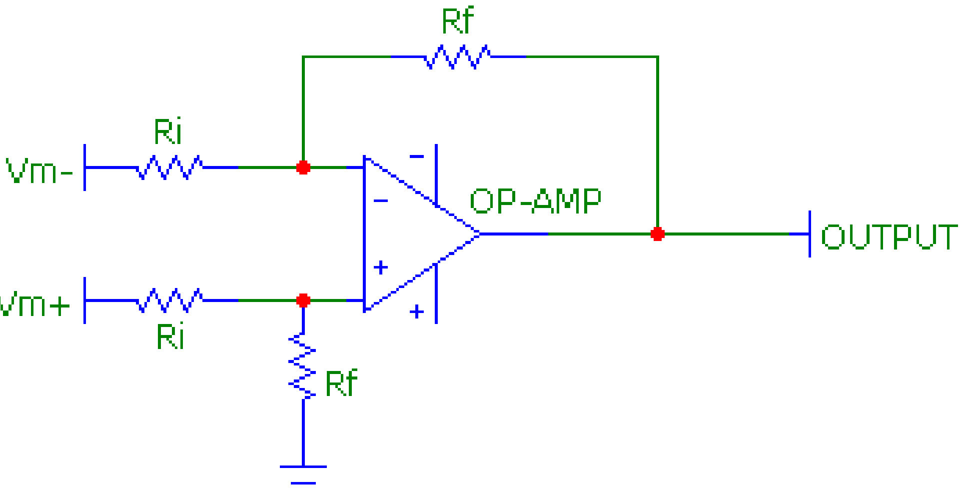
- Four elements with opposite sensitivities
- May only be possible in some installations
- $Vm \approx Vs \times 1 \times dR/Rs$
- ΔVs only changes sensitivity (slightly)

Circuits - Full Bridge (Temp)



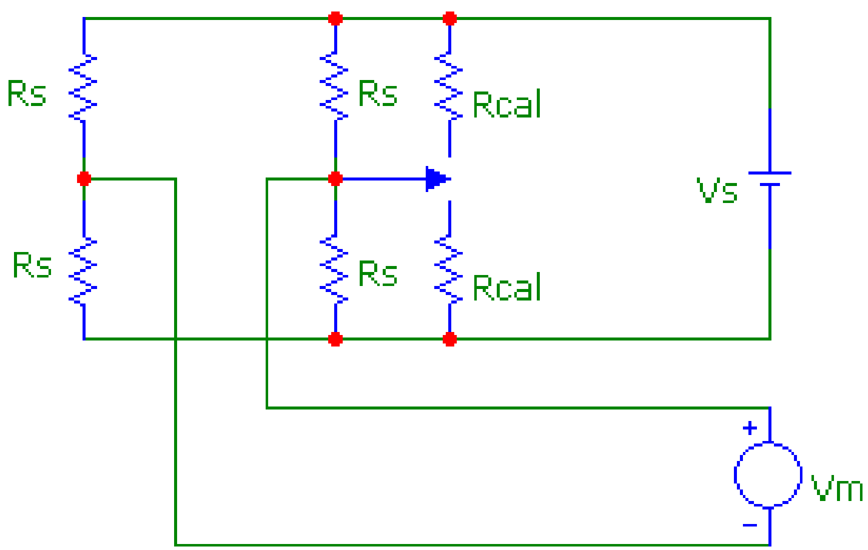
- Vm+ = Vm- = Vs/2
- No change in Vm due to temperature effect T
- Differential (mismatched) temperatures appear as error signal
- Put gauges in close (thermal) proximity

Circuits – Differential Amplifier



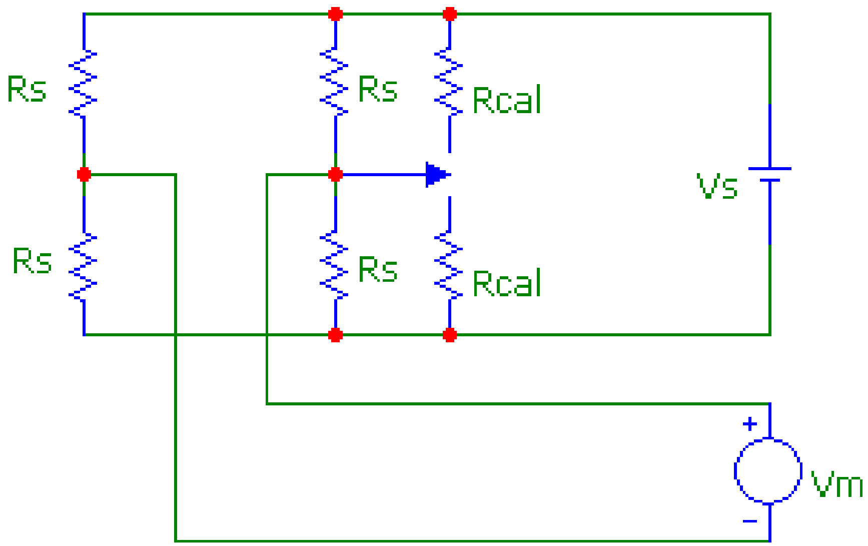
- Differential input, single ended output
- Output wrt 0V
- In practice
  - (buffers) followers between the bridge and diff. amp.
  - Well matched Rf, Ri.

Circuits - Full Bridge:Cal Step



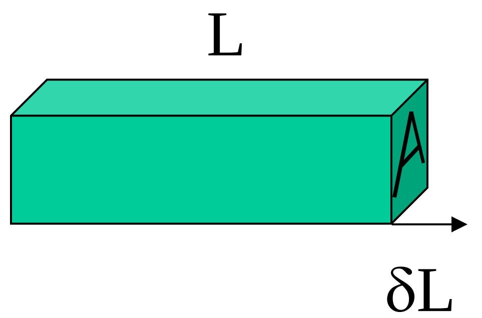
- Simulate Strain ⇒ dRs
- dRs =Rs-(Rs//Rcal)
- Choose Rcal for reqd. strain (within expected range).
- Switch in Rcal +ve or –ve for steps.
- Provides system check.

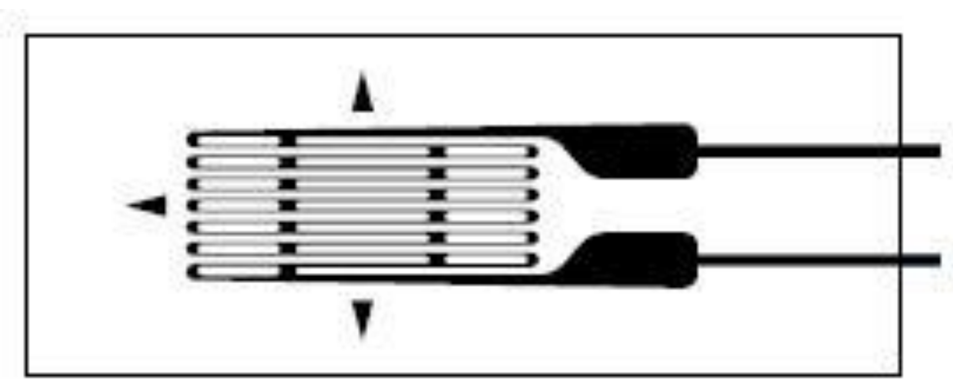
Circuits - Full Bridge:Cal Step



- Cal Step will show
  - Electronic faults
  - Change of impedance
    - Moisture
    - Wiring/connector change
- Cal Step won't show
  - Debonding
  - Incipient breakup
- Cal Step subject to external effects!

Transducers – Strain Gauges



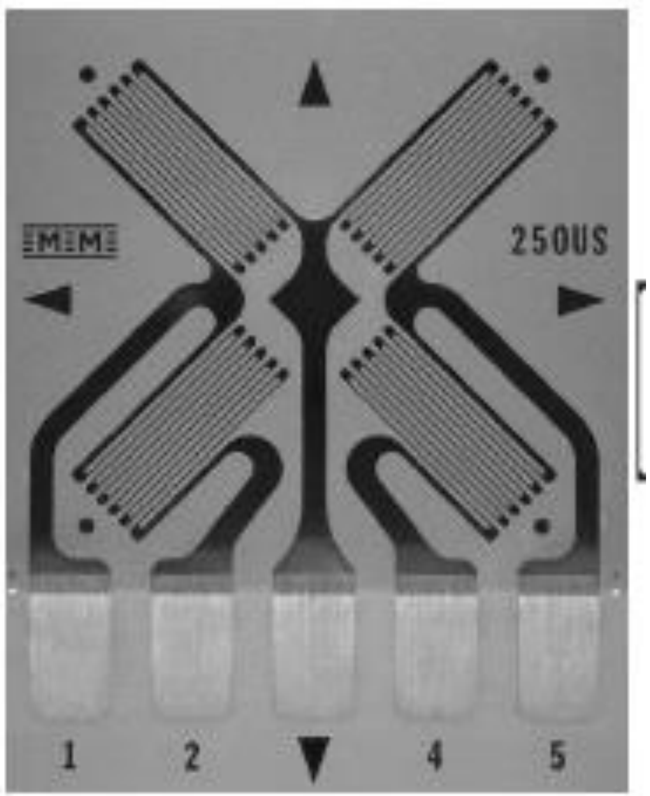


- Res. = $\rho \times L/A$
- Strain = $\delta L/L$
- δA changes with δL
- Poisson ratio for steel ≈ 0.25.
- GF = $[\delta R/R]/[\delta L/L]$

typically around 2 for metallic gauges

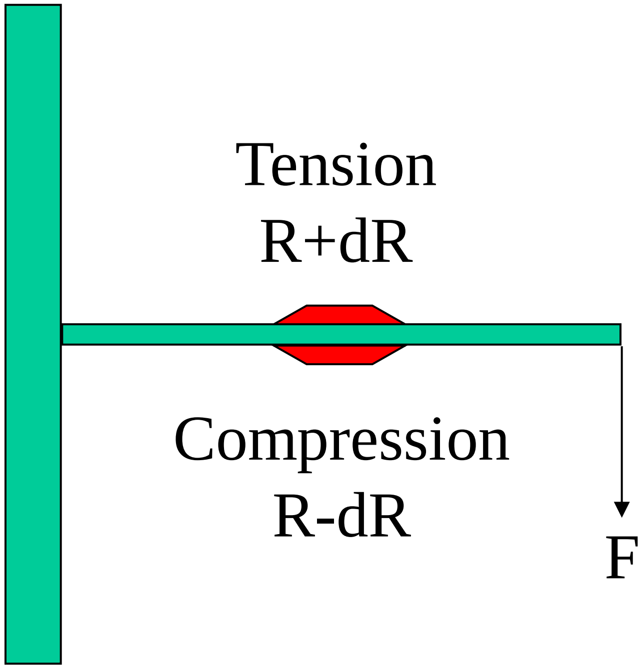
Transducers – Strain Gauges

20mm



- Conductor Foil on Insulating Substrate bonded to strain surface
- Multiple gauges for connection in bridge configurations
- Configuration depends on measurand, strain, torque, bend.
- Typically 100-1000Ω

Transducers – Strain Gauges



- Geometry and Installation allows gauges with both positive and negative changes.
- Strain gauges wired in a bridge configuration
- Close Proximity so temperature is uniform

Transducers – Strain Gauge

- e.g.1 milli strain fs
- 1% sensitivity
- dR/Rs

$\approx 2 \times 0.001 \times 0.01$

$= 20$ E-6

- Rs = 1kΩ,
  dR = 20 mΩ

- Large range in real terms
- GF = 2
- Small changes in Rs
- Beware connector/wiring resistances!

Transducers – Strain Gauge

- $R_s = 1k\Omega$

  $dR = 20\ m\Omega$
- $V_s = 10V$

- $V_m = 10\times1\times20E\text{-}6$
- $\Rightarrow 200\mu V$

- Large range in real terms
- Easy to maintain Vs within 1%

- Not impossible to measure,

  but not trivial!

Transducers – S.G. Cal Step

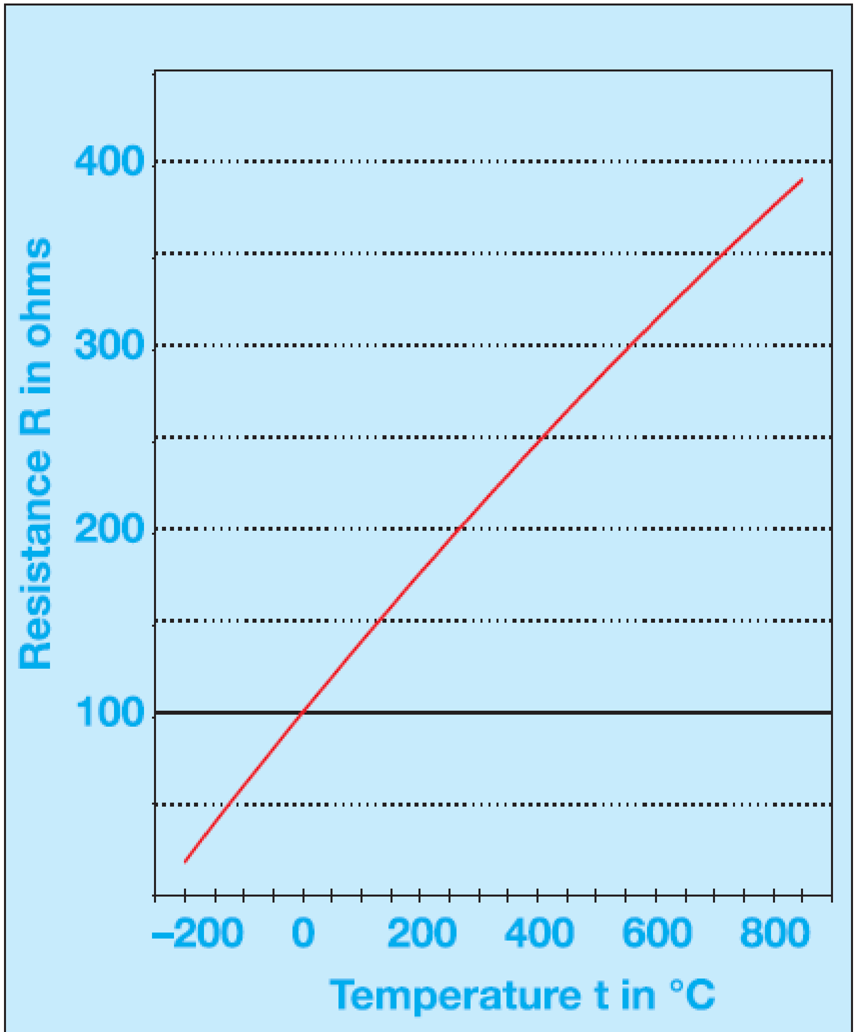
- Rs = 1kΩ
  dR = 2 Ω
- Rs – Rs//Rcal = 1·5Ω
- Rs//Rcal = 998·5Ω
- 1/Rtot = 1/Rs + 1/Rcal

Ideal Rcal = 665·7kΩ

- Use 670kΩ
- dR=1.49Ω
- Strain step = 745μ str.

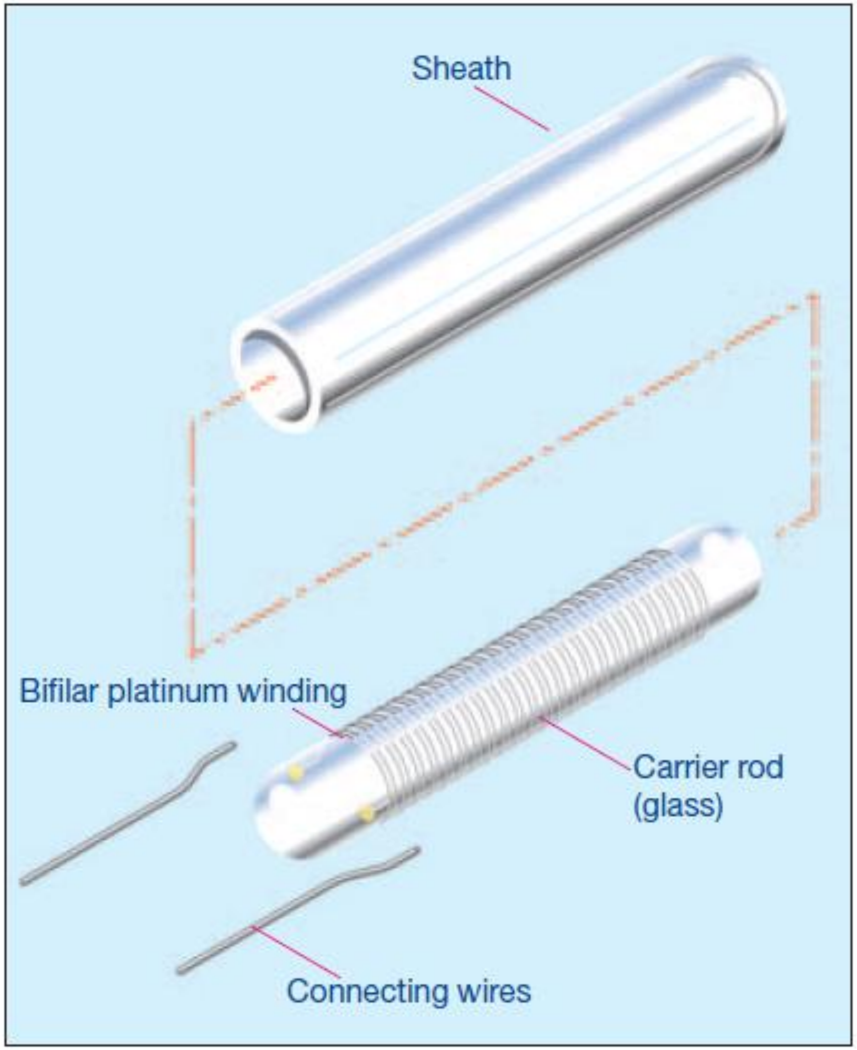
- Full scale 1 milli str.
- 75% full scale
- Can't buy ideal value.
- Use nearest available.
- Check result

Transducers - PRTs



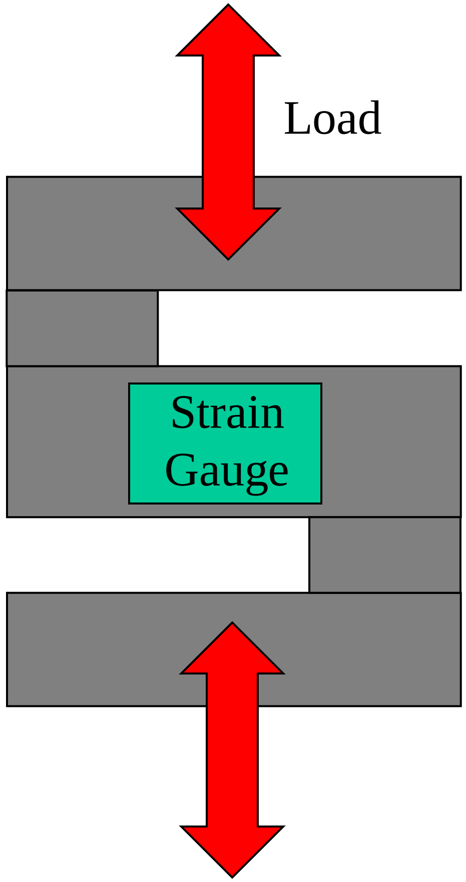
- Platinum resistance temp coeff well characterised
- $\delta R/R \approx 0.4\%/K$
- Well characterised$\rightarrow$ standard tables/eqns.
- Available in standard resistances, 100, 1k, etc.

Transducers - PRTs



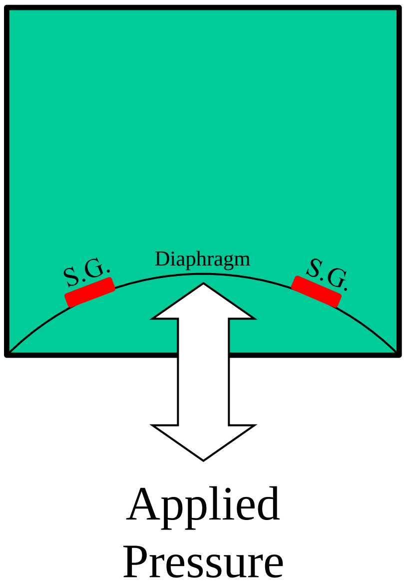
- Construction based on Platinum wire
- Various designs to reduce spurious effects such as self-heating, strain, vibration

Transducers – Load Cells



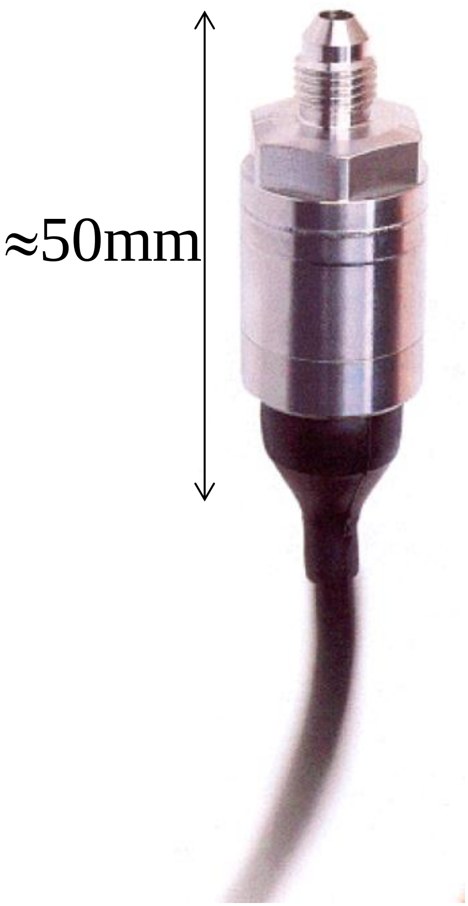
- S-Beam Load Cell sensitive to tension/compression
- other configurations available, torque, compression, shear…
- Strain Gauge element wired as a bridge configuration

Transducers – Pressure



- Strain Gauged aneroid barometer
- May include internal signal conditioning amplifiers
- Open/Closed chamber for Relative /Absolute Measurement

Transducers – Pressure



- Robust housing with pressure fitting(s).
- May be passive bridge, 4-20mA or 1-5V output.
- Ideally no change due to temperature

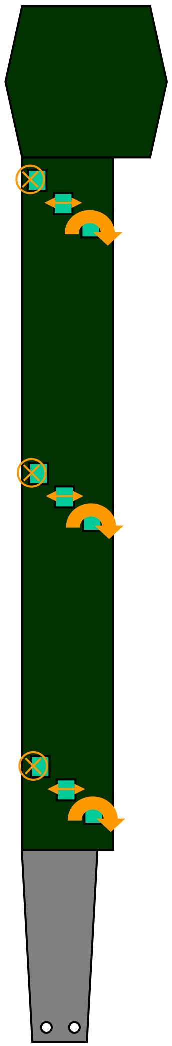
Applications – Aircraft Testing

- Explore Performance Envelope
  - Measure actual loads during manoeuvers
- Validate Model
  - Model predicts component loading
  - Confirm anticipated loading
  - Refine models/life components
- Calibrate Systems
  - Aircraft Air Data vs Instrumentation Air Data
- Certification
  - CAA/FAA/EASA require documented testing

Applications – Aircraft Testing

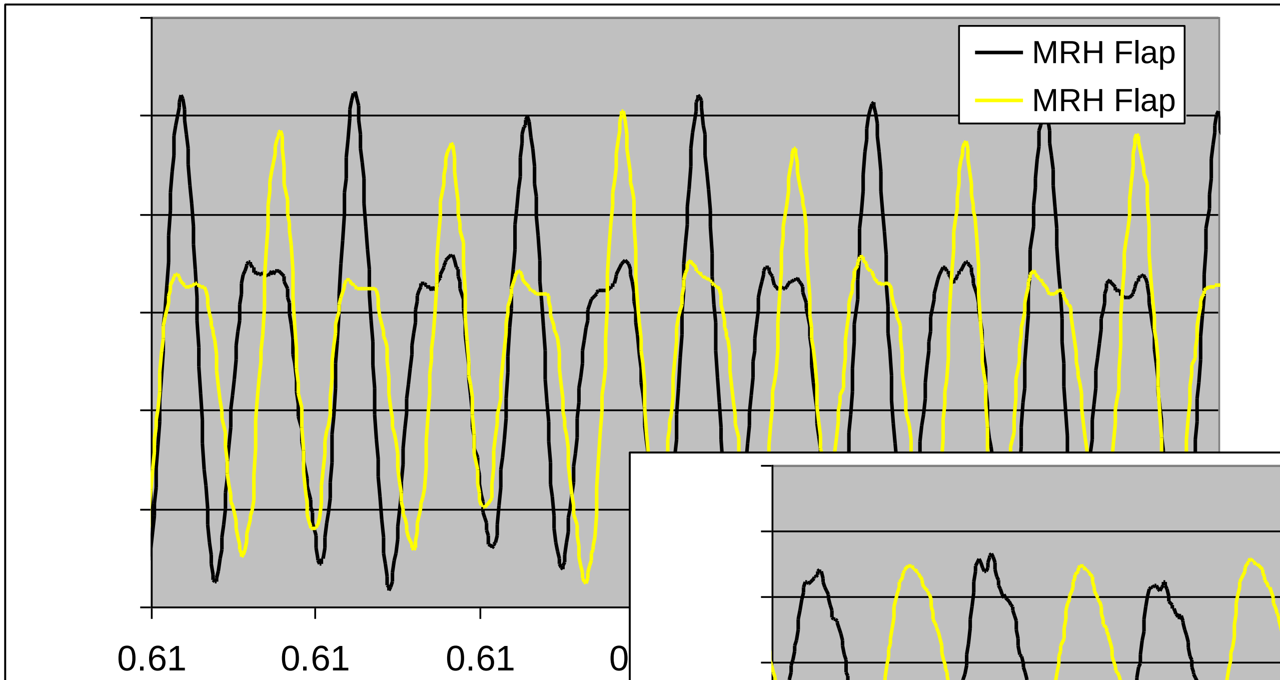
- Gauged Blades
  - Main and Tail, rotating components
- Gauged Airframe Components
  - Lifting Frames, Tail Cone
  - Undercarriage
- Air data Pressure and Temp Transducers
  - Pitot – Airspeed
  - Static Pressure – Altitude
  - OAT – Outside Air Temperature

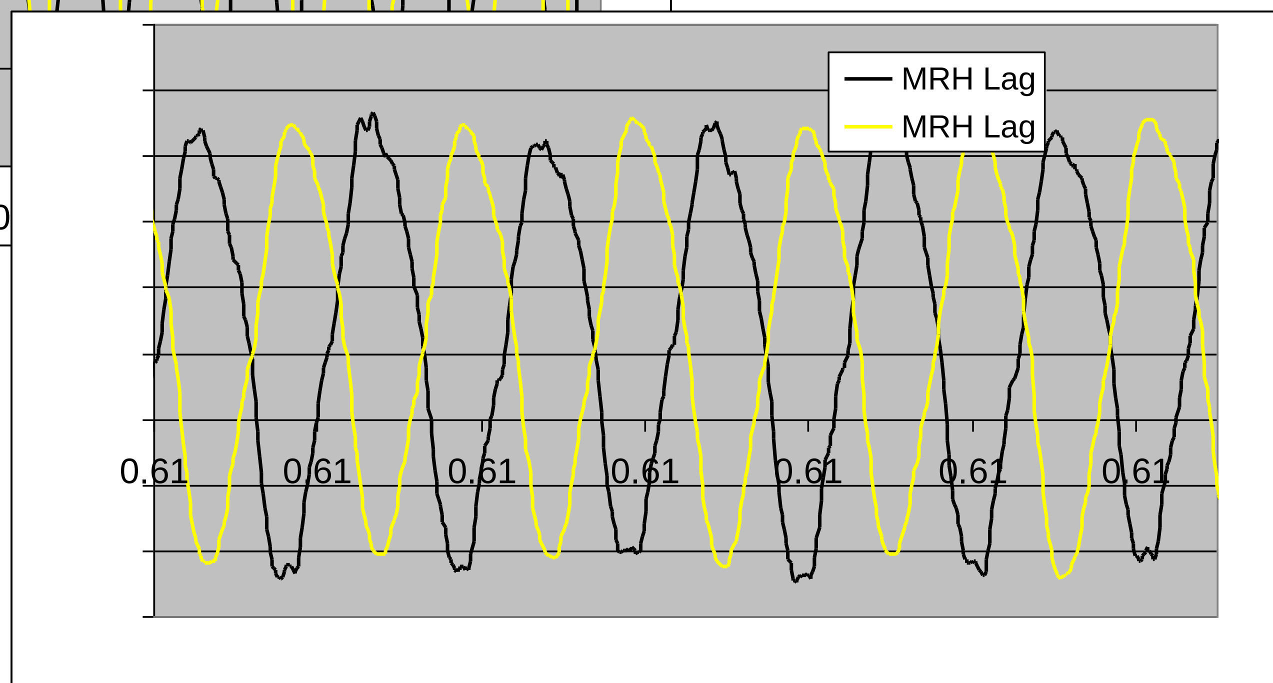
Blade Gauging



- Strain Gauged Blades
- Flap, Lag, Torsion at each station
- Record and Map Blade Motion During Flight
- Determine blade life

Blade Data


MRH Flap
MRH Flap
0.61
0.61
0.61

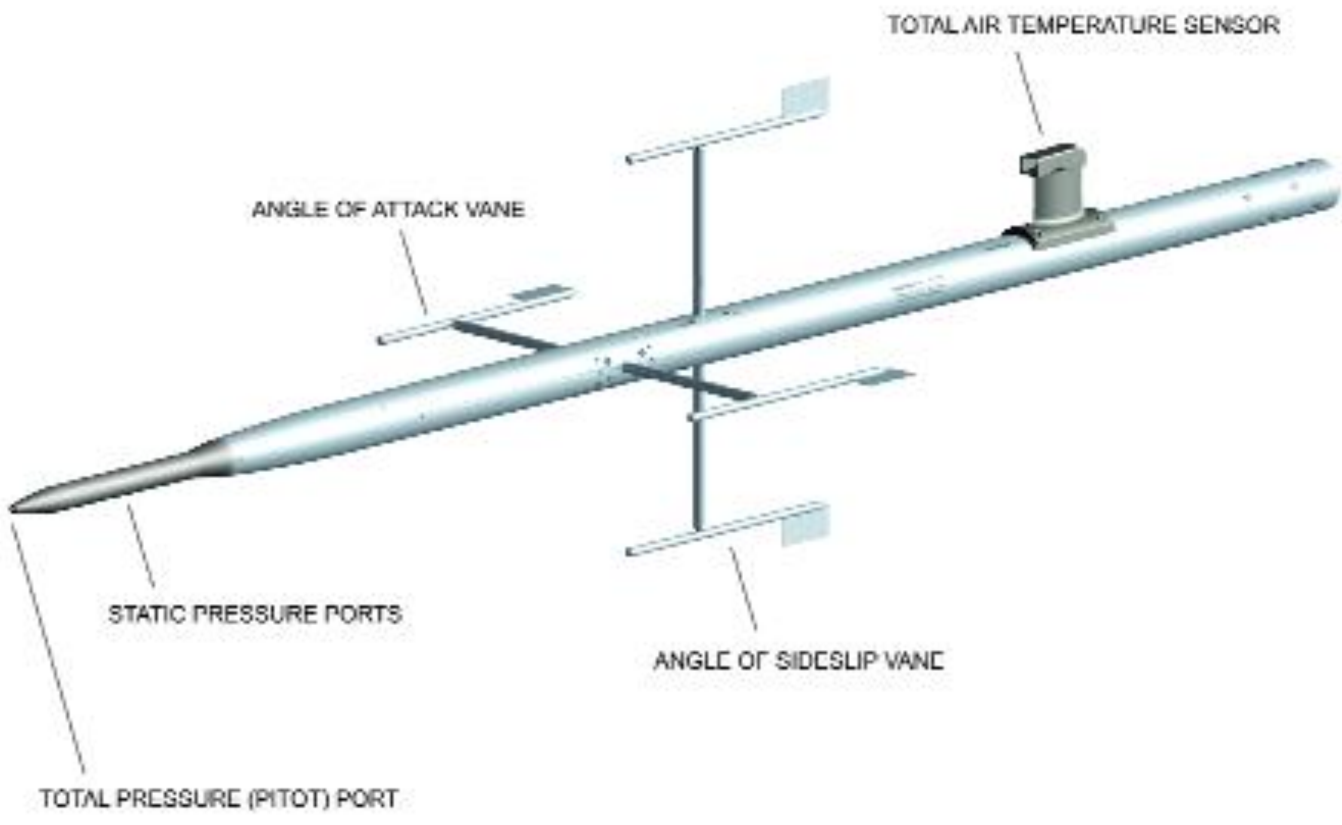

MRH Lag
MRH Lag
0.61
0.61
0.61
0.61
0.61
0.61
0.61

Blade Data: Typical Faults

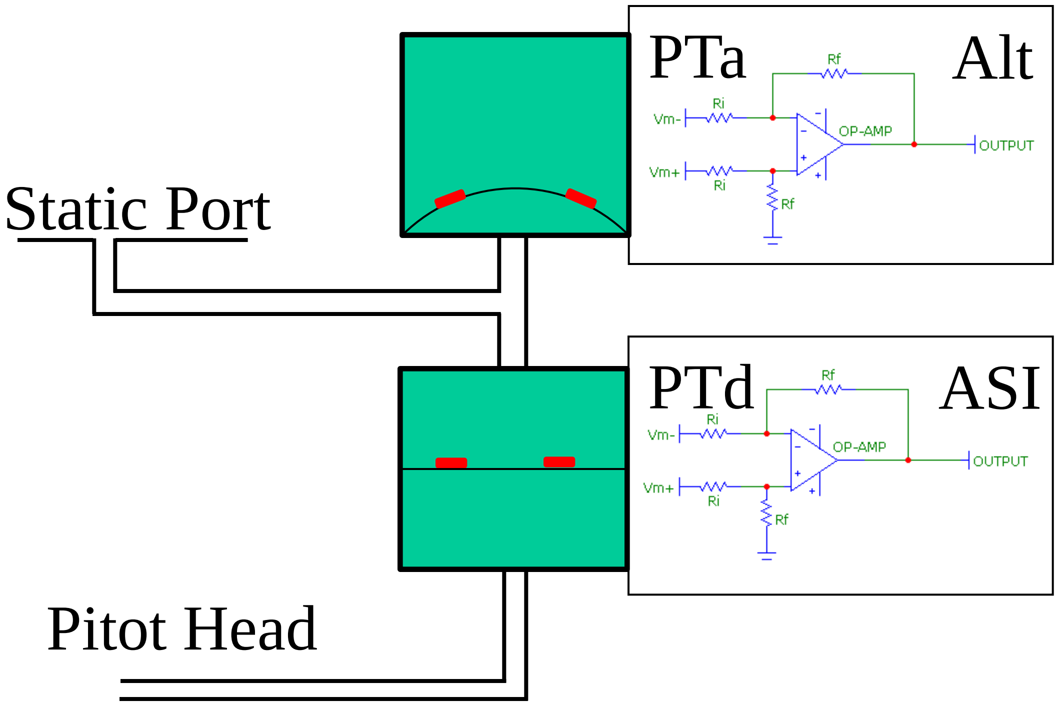
- Moisture
  - Change in CalStep
  - Zero drift
  - Unpredictable/variable
- Breakup
  - Spikes in traces
  - Often only in certain flight conditions

Air Data Instrumentation

- Air data boom
  - Clear (as possible) from disturbing airflow

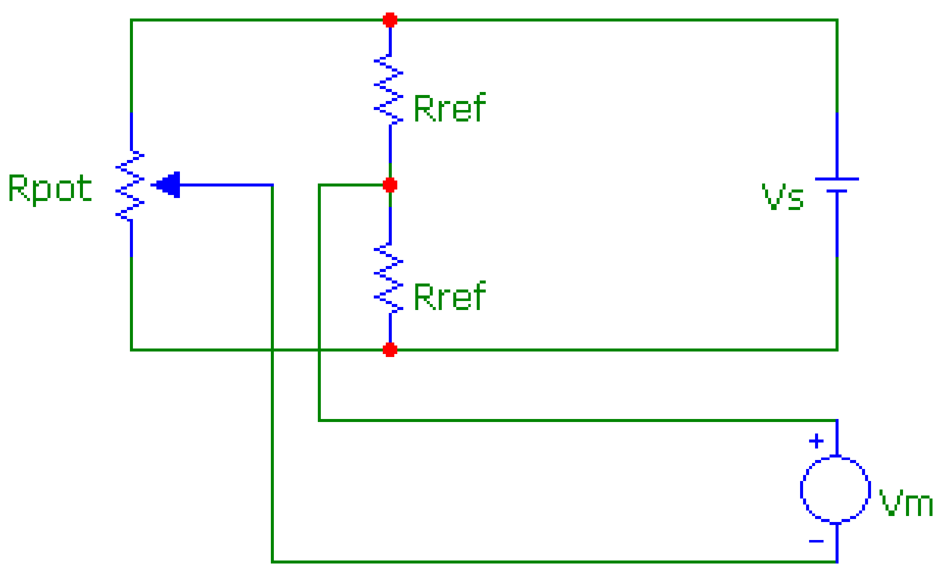


Air Data Instrumentation



- Air data boom
  - Clear (as possible) from disturbing airflow
  - Instrumentation is orange
- Pitot-Static System
  - Differential/Air Speed
- Static Pressure
  - Absolute/Altitude
- PRT/Air Temperature

Air Data Instrumentation



- Angle of Attack (α)
  - Potentiometer
- Angle of Sideslip (β)
  - Potentiometer
- Travel
  - Electrical 340°
  - Mechanical 360°
  - Deadstop
- Multiple Pots
- Resolver

Applications – Videos

- Ground Running
  - New Design of Tail Rotor
    - 30 hours ground run
    - Fully Instrumented
    - Visual and NDT checks between runs
  - Wireless AirCraft Demonstrator (WACD)
    - Ride along to rotor tests
    - Zigbee(WiFi) link between rotor and airframe

Application - Videos

New Tail Rotor - Ground Run

Application – Videos

- Aircraft Pacing
  - Fill in a matrix of speeds, headings and heights
  - Road Vehicle sets ground speed
    - Aircraft matches ground speed
    - Aircraft heading set to required angle
  - Require low wind for accurate data
    - Early morning no mixing of lower/upper winds
    - Early in the day to avoid runway thermal activity

Application - Videos

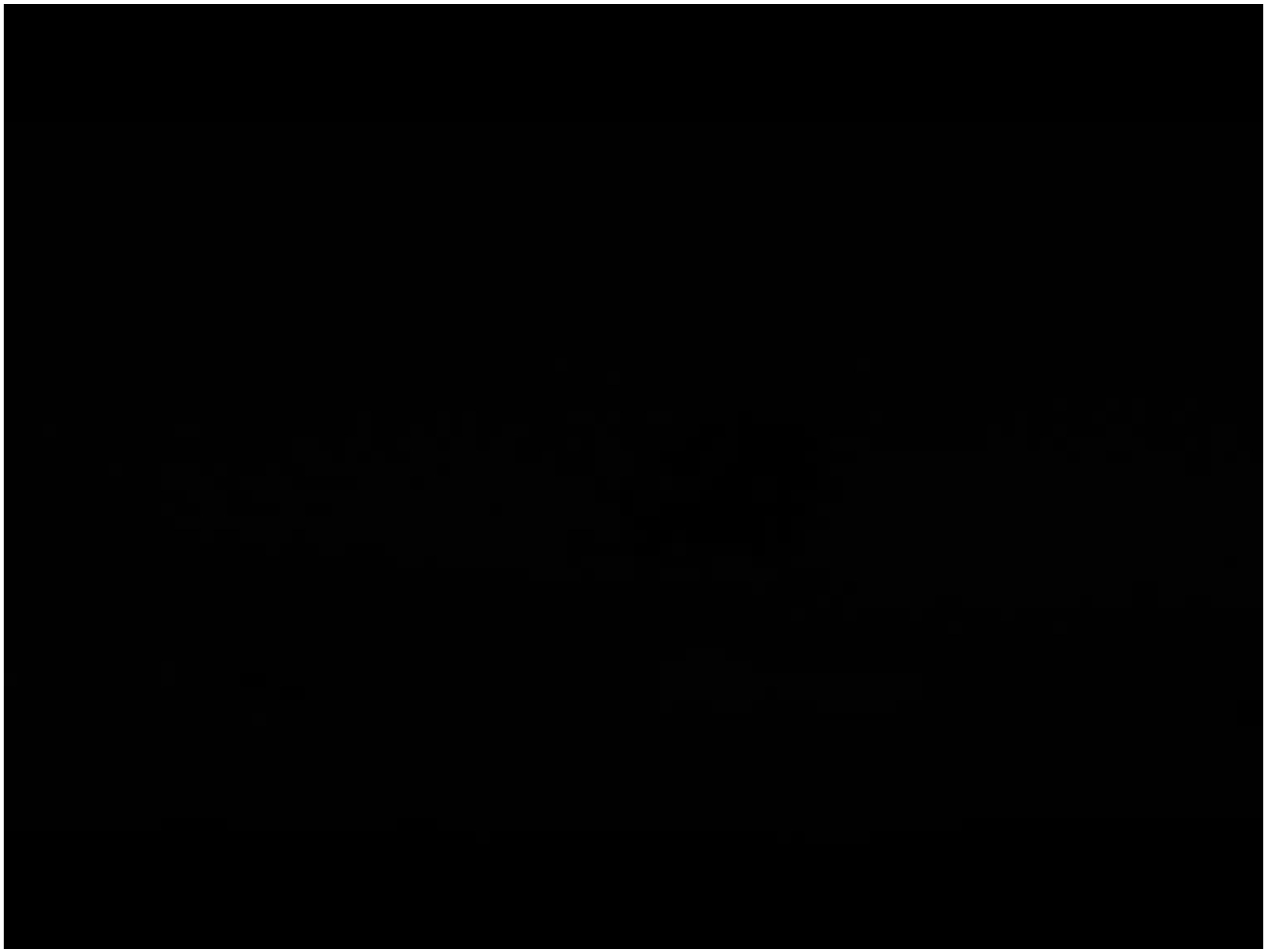
AW159 WildCat - Paced

Application – Videos

- Tethered Hover
  - Aircraft tethered to fixed anchor point
    - Load Cell measures lifting force directly
    - Instrumention measures aircraft loads
    - Different length tethers
  - Require low wind for accurate data and safety!
    - Lateral force on aircraft changes cable loading
    - Early morning no mixing of lower/upper winds
    - Early in the day to avoid ground thermal activity

Application - Videos

AW159 WildCat - Tethered Hover



Application - Pics

Some of the Flight Trials Team

Acknowledgements

- Aircraft Testing
  - Slides and Video reproduced with kind permission of AgustaWestland (Yeovil) Ltd.
  - Tethered hover video by Gary Howell, Instrumentation, AgustaWestland.
- Other Stuff
  - Manufacturers' data, Vishay, Druck, Jumo, Space Age Control, etc.

Conclusion

- Even elementary circuits have an important place in real world applications.
- However glitzy and fancy the displays, the numbers are only as good as the original measurement.
- The original measurement depends on application of fundamental principles.