A Single-Piece Wind Tunnel Balance with a Universal Metric End

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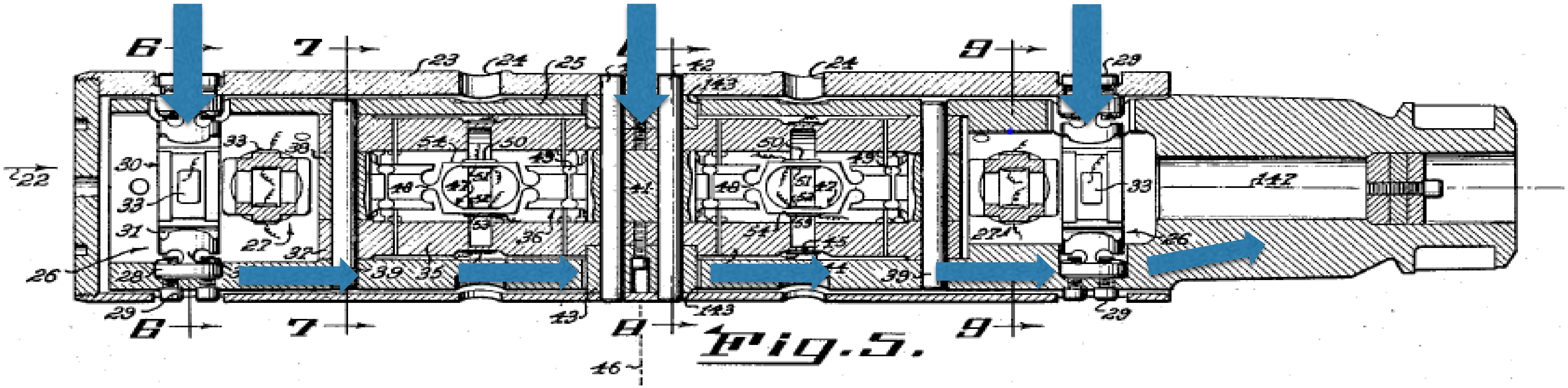
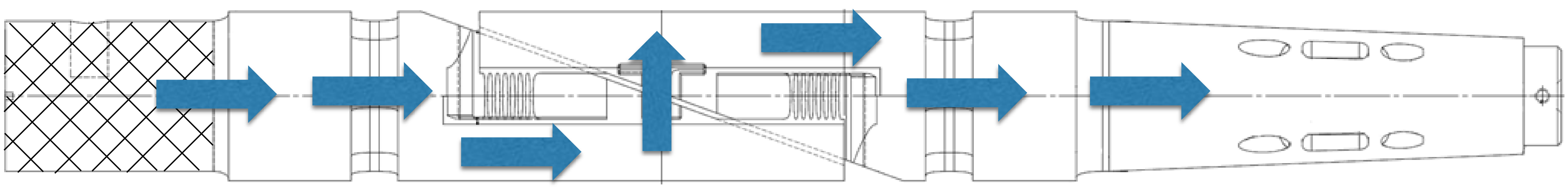
Background and Motivation



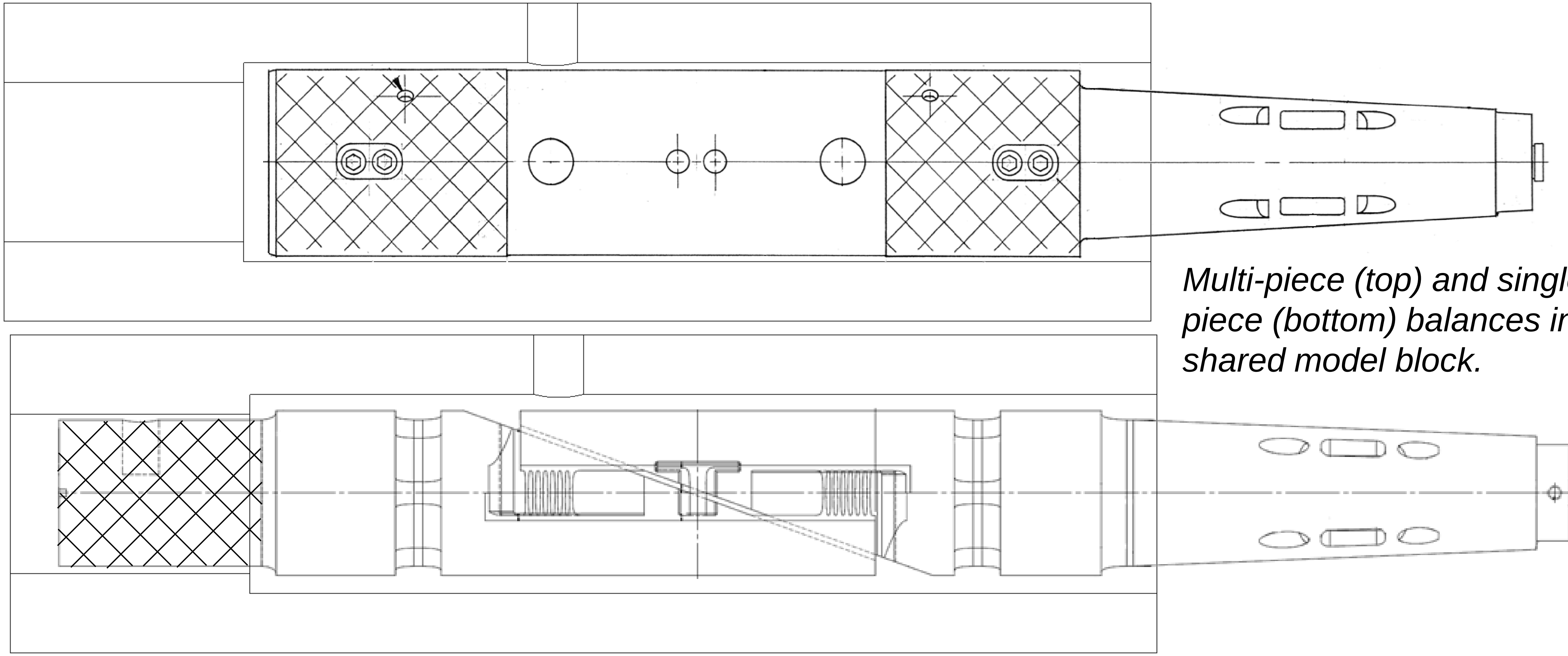
Representation of load path through a multi-piece balance.



Representation of load path through a single-piece balance.

- **Loads enter a multi-piece balance over much of its length.**
- **Loads typically enter a single-piece balance through the forward end.**

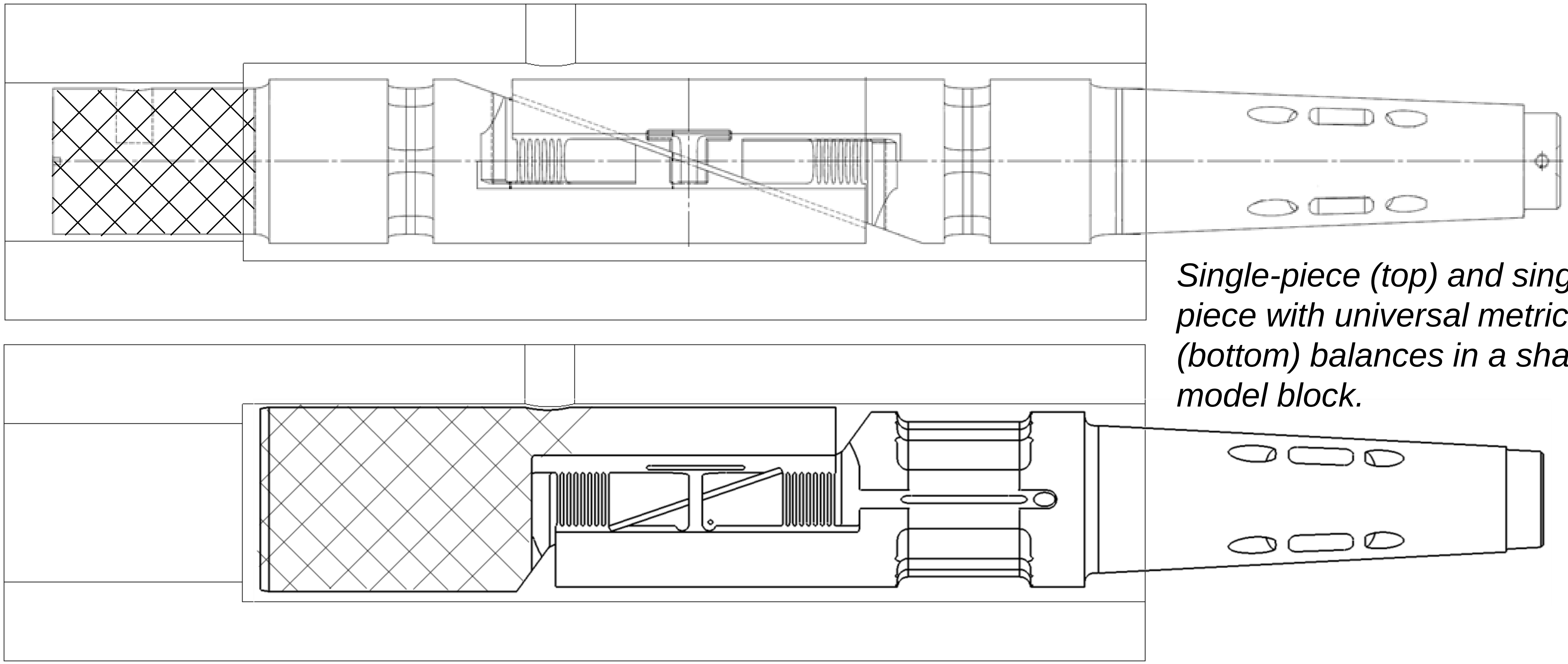
Background and Motivation



Multi-piece (top) and single-piece (bottom) balances in a shared model block.

- **Load paths typically mean the balances cannot be used interchangeably (share the same bore and dowel hole).**
- **To share the same model block, the single-piece balance must be longer and thinner than the multi-piece (with a separate forward bore).**

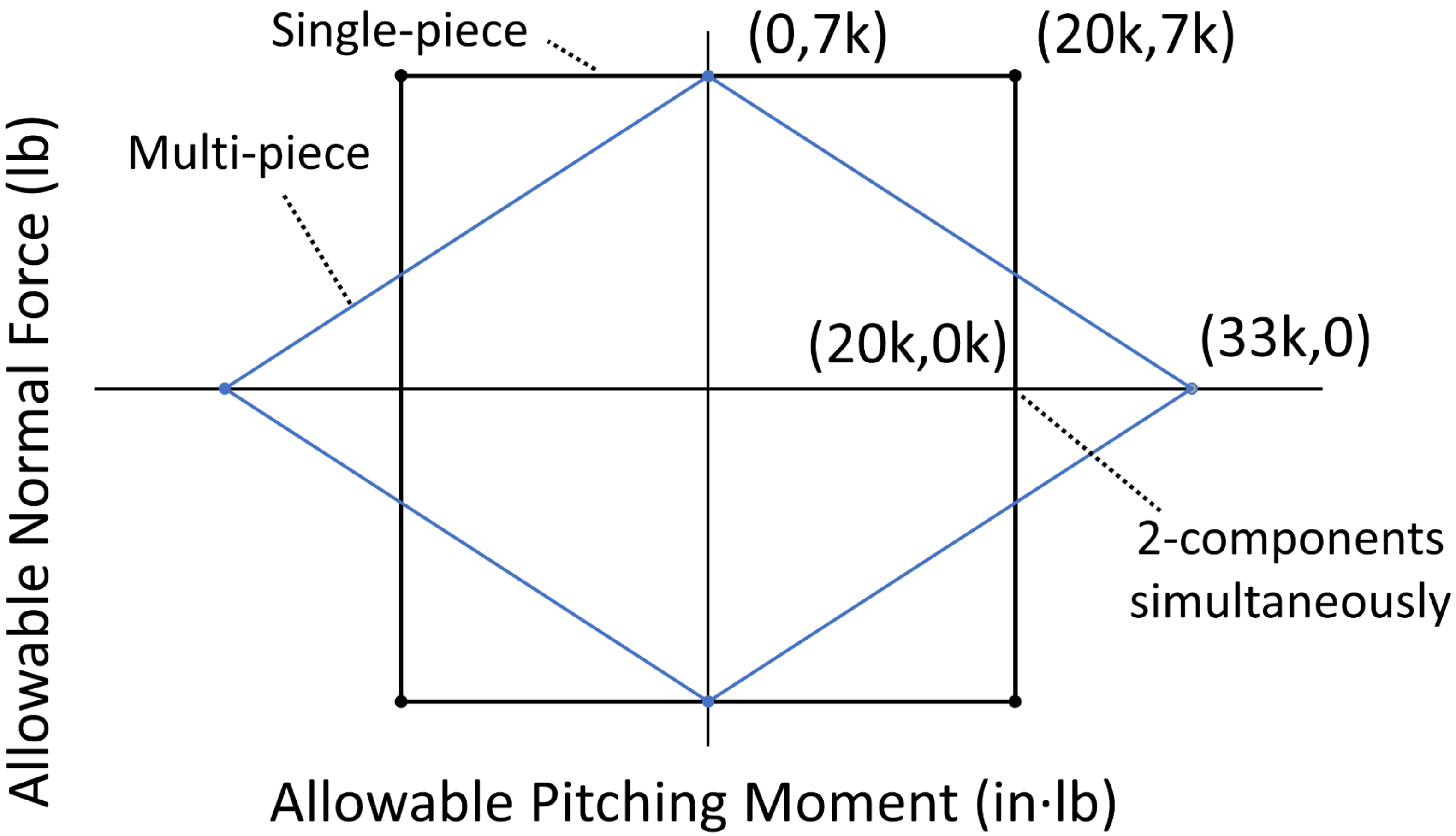
Background and Motivation



Single-piece (top) and single-piece with universal metric end (bottom) balances in a shared model block.

- **In this work, we design, manufacture, and calibrate a single-piece balance with a universal metric end (can be used interchangeably with a multi-piece balance).**
- **Motivation: target the accuracy associated with a single-piece balance and the stiffness associated with a multi-piece balance.**

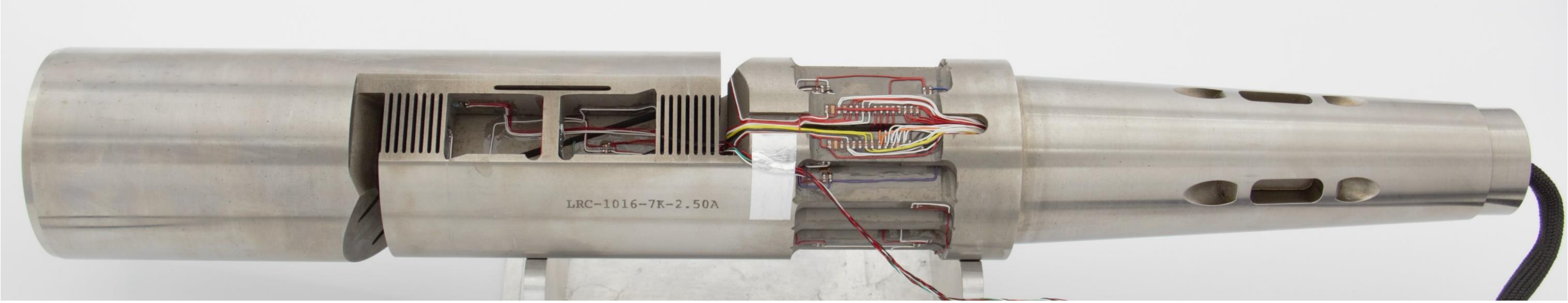
Design Loads



Component	Multi-piece	Single-Piece
Normal (lbs)	7,000	7,000
Axial (lbs)	400	400
Pitch (in-lbs)	31,500	20,000
Roll (in-lbs)	5,000	5,000
Yaw (in-lbs)	12,600	10,000
Side (lbs)	3,600	3,500

- **Single-piece balances assume all design loads are applied simultaneously whereas multi-piece trade off allowable NF/PM and SF/YM.**
- **The single-piece loads were largely adopted from an existing multi-piece balance making this one of the highest load to diameter balances in inventory.**

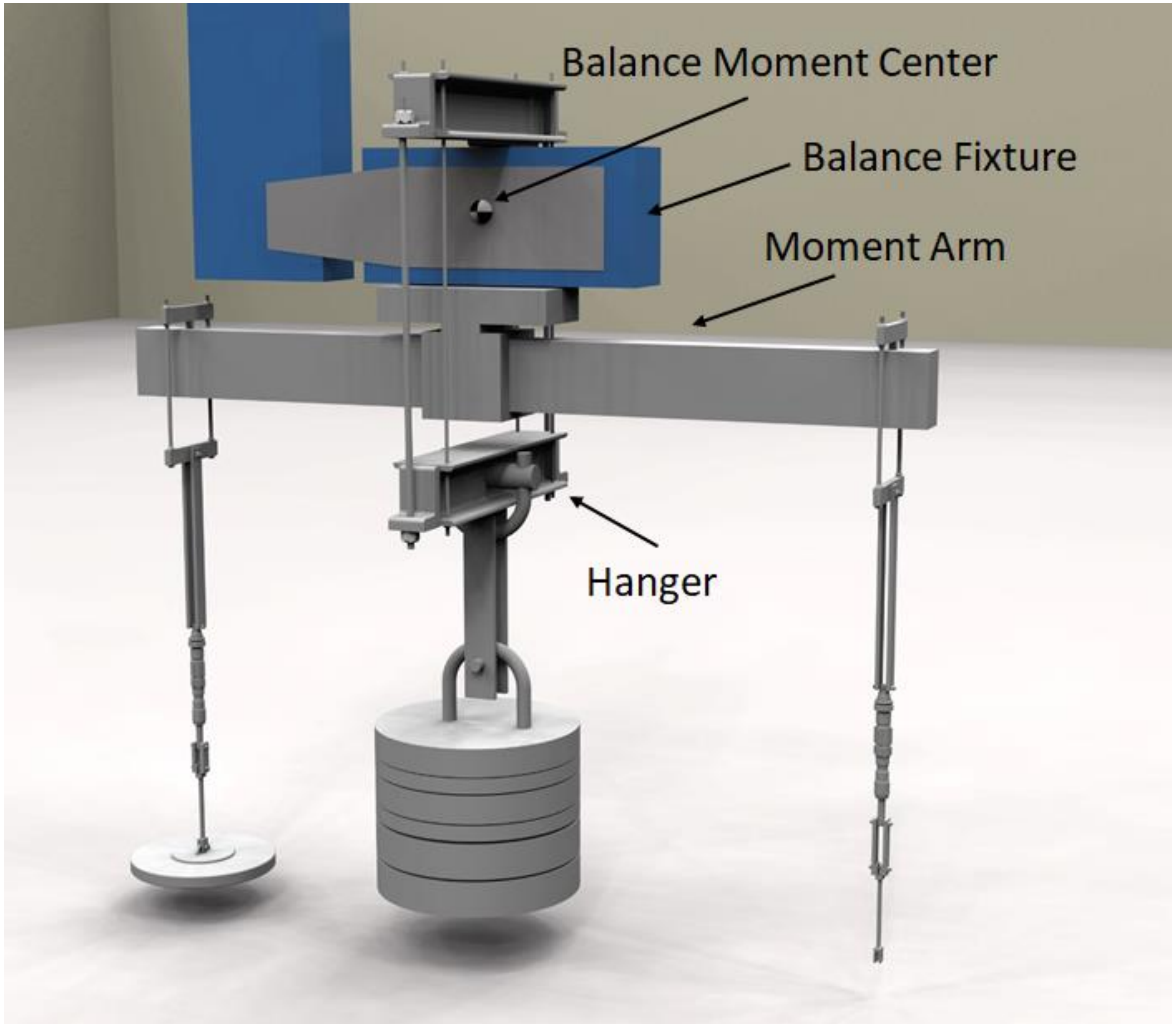
Design and Manufacturing



Single-piece balance with universal metric end following manufacturing and strain gaging.

- **Universal metric end compatible with multi-piece and maximizes diameter of the balance.**
- **Incorporates features to minimize stress concentration effects (elliptical and undercut fillets).**
- **Adopts single cage to minimize length and thus maximize stiffness.**

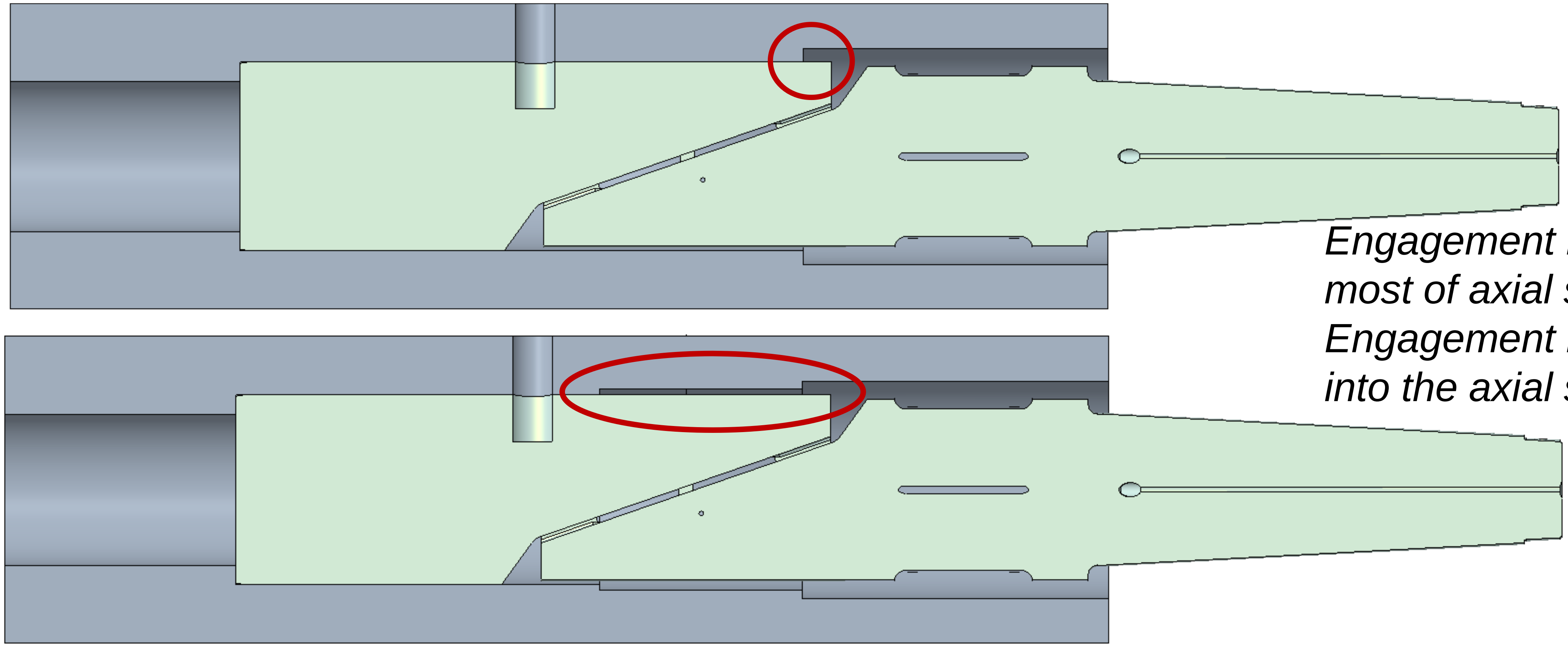
Balance Calibration



Depiction of the long-arm calibration setup.

- **Dead weight, long-arm calibration focused on axial performance.**
- **Apply known forces and moments and measure balance outputs.**
- **Math model constructed to relate applied forces and moments to balance outputs.**
- **Residuals between math model and experimental data used to quote balance accuracy.**

Evaluation of the Universal Fit



Engagement length extends along most of axial section (top). Engagement length extends slightly into the axial section (bottom).

- **Engagement length of the universal metric end with the fixture was explored:**
  - With long engagement length on top half, axial response was bifurcated as applied pitch went from negative to positive loading.
  - With shorter engagement length on top half, axial response was continuous as applied pitch went from negative to positive loading.

Calibration Performance

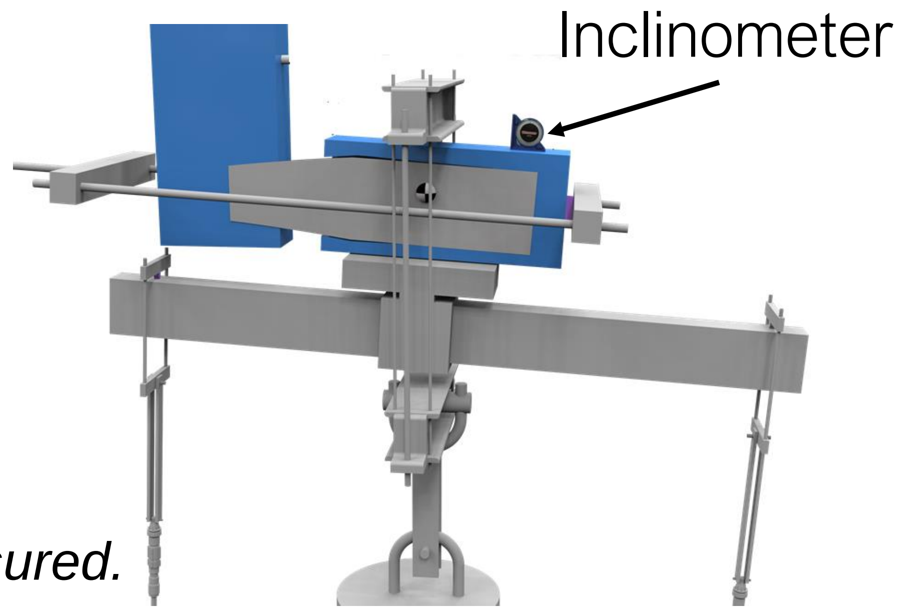
	Accuracy (% of full-scale load)					
	Normal	Axial	Pitch	Roll	Yaw	Side
Universal Metric End	0.17	0.40	0.13	0.41	0.11	0.15
Conventional Metric End	0.04	0.47	0.09	0.18	0.03	0.04

Component accuracies for single-piece balances with a universal metric end and conventional metric end.

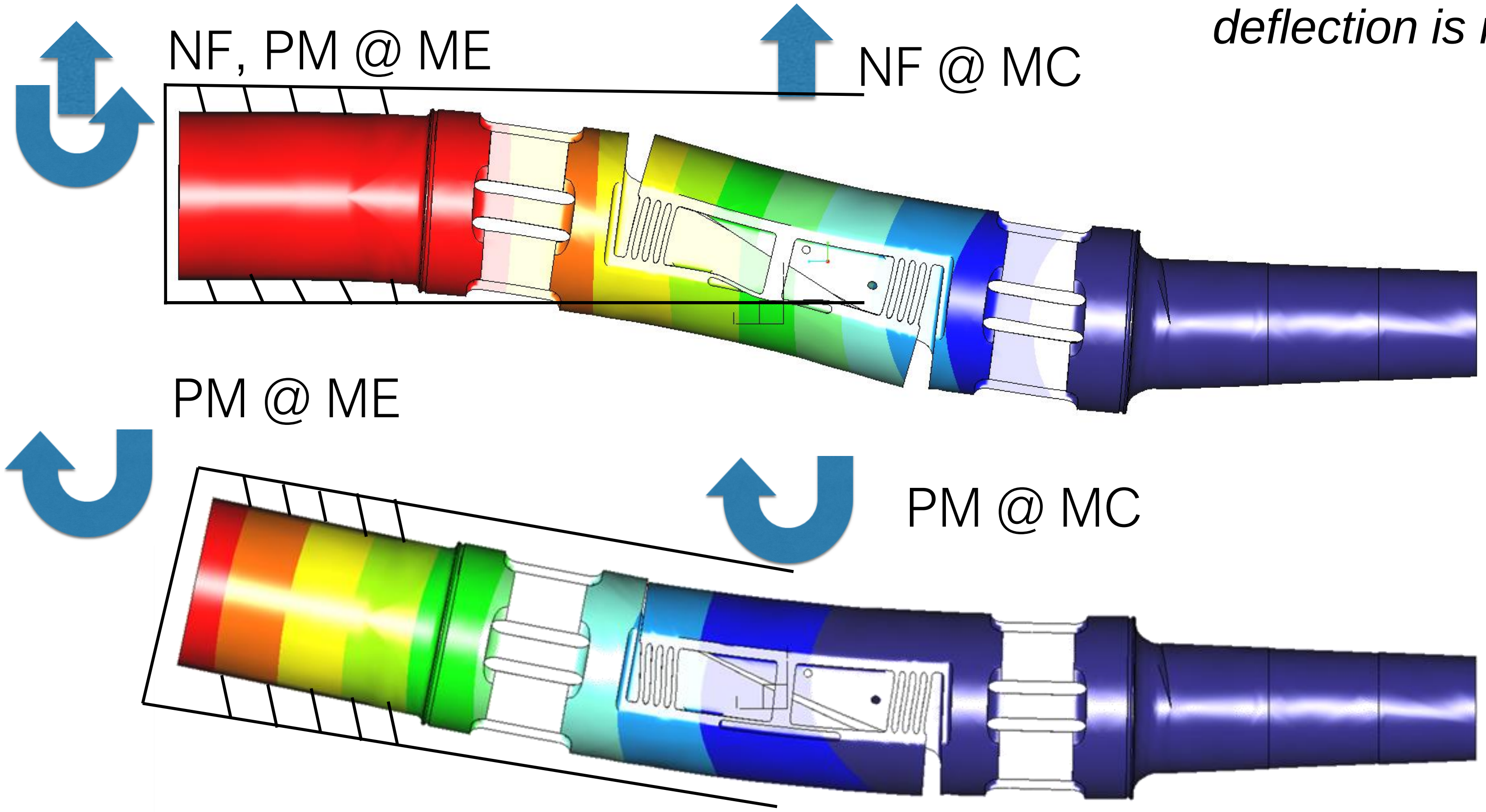
- **Comparing single-piece balances with the same design loads – one with a universal metric end the other with a conventional metric end.**
- **Except for axial force, the conventional metric end exhibits better performance than the universal metric end.**
- **Hoping to complete comparison with a multi-piece balance.**

Angular Deflections

- **Deflections reflect angle of the metric end of the balance relative to horizontal (as measured by an inclinometer).**



Depiction of how balance angular deflection is measured.

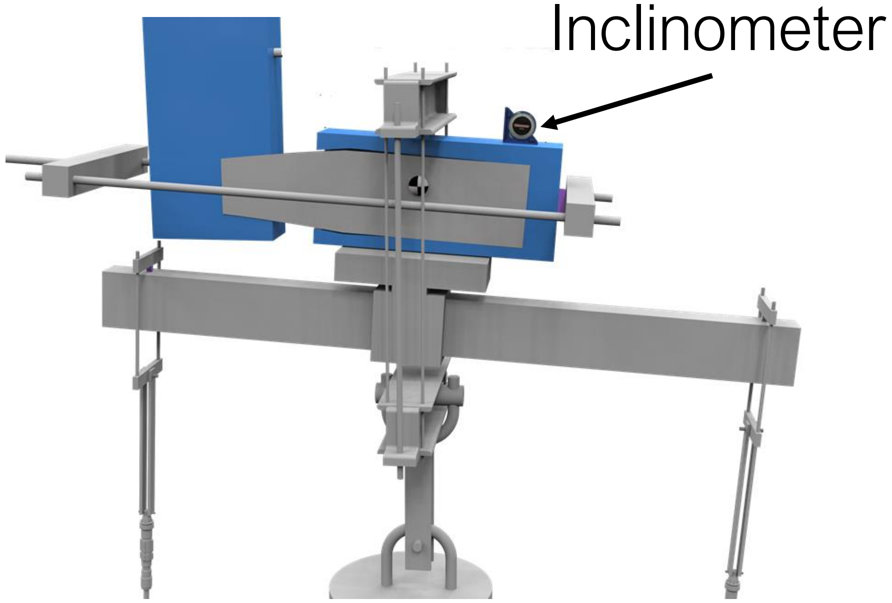


Depiction of balance deflection due to an applied force (top) and an applied moment (bottom).

- **Forces generally produce minimal angular deflection for balances that have longitudinal geometric symmetry.**
- **Moments tend to induce largest angular deflections.**

Angular Deflections

	Angular Deflection (minutes)				
	Normal	Pitch	Roll	Yaw	Side
Universal Metric End	42	63	32	31	20
Conventional Metric End	18	86	51	42	7



Angular deflections for single-piece balances with a universal metric end and conventional metric end.

- **Single-piece balance with universal metric end is consistently stiffer than the conventional metric end balance.**
- **Conventional metric end balance has approximately 40% more deflection with pitch and yaw applied and approximately 70% more when roll is applied.**
- **Balance diameter and length are the primary drivers of global deflection.**
- **Hoping to complete comparison with a multi-piece balance.**

Summary

- **Axial response is sensitive to the termination point of the universal metric end.**
- **Comparing single-piece balances:**
  - Accuracy of universal metric end was worse (except for axial force).
  - Stiffness of universal metric end was higher.
- **Single-piece balance with universal metric end is a compelling replacement of aging multi-piece balances.**
- **Future work – compare performance to multi-piece balance.**