Intro to Force Balances

Overview of Concepts and Calibration

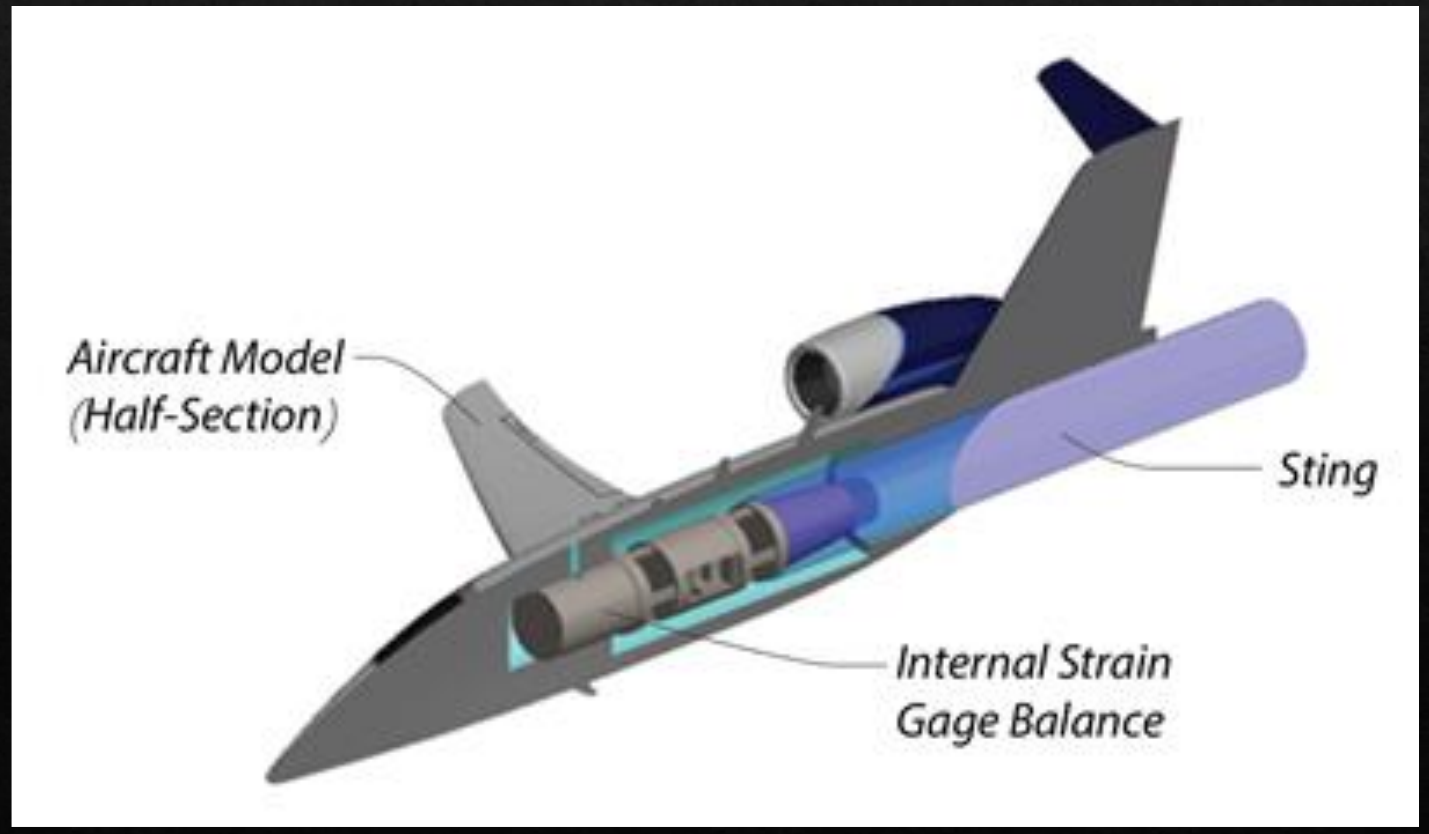
What exactly is a force balance?

Instrument that measures the forces and moments in a wind tunnel model

Different designs across a range of sizes; this presentation focuses on the "Langley Style" six component, single piece internal force balance

Can be used in semi span or full body model; connects the wind tunnel sting to the model.

Traditionally manufactured "subtractively". Newer balances are made via additive manufacturing



Images courtesy of NASA/TM-2019-220248

Wind Tunnel Forces and Moments

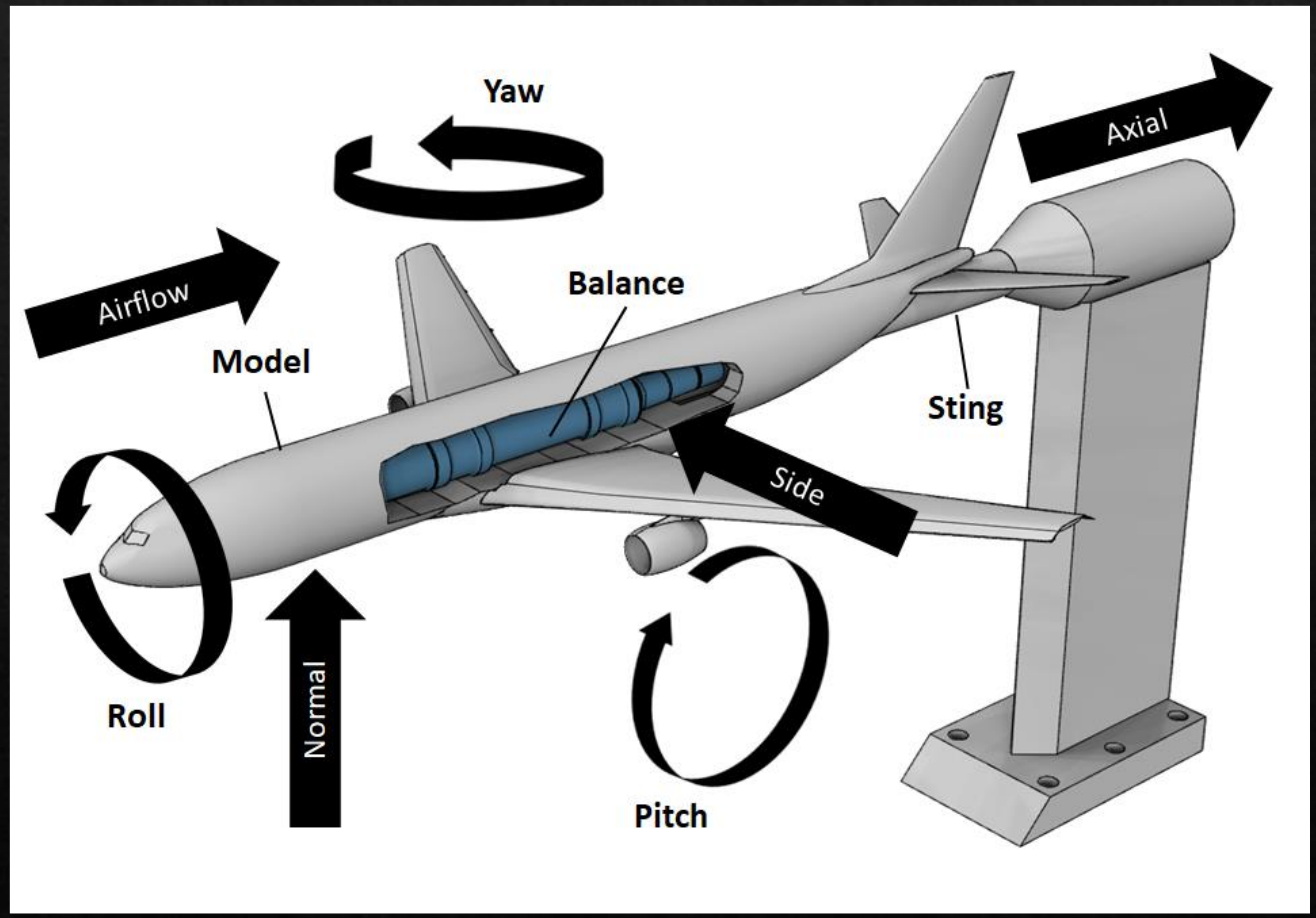
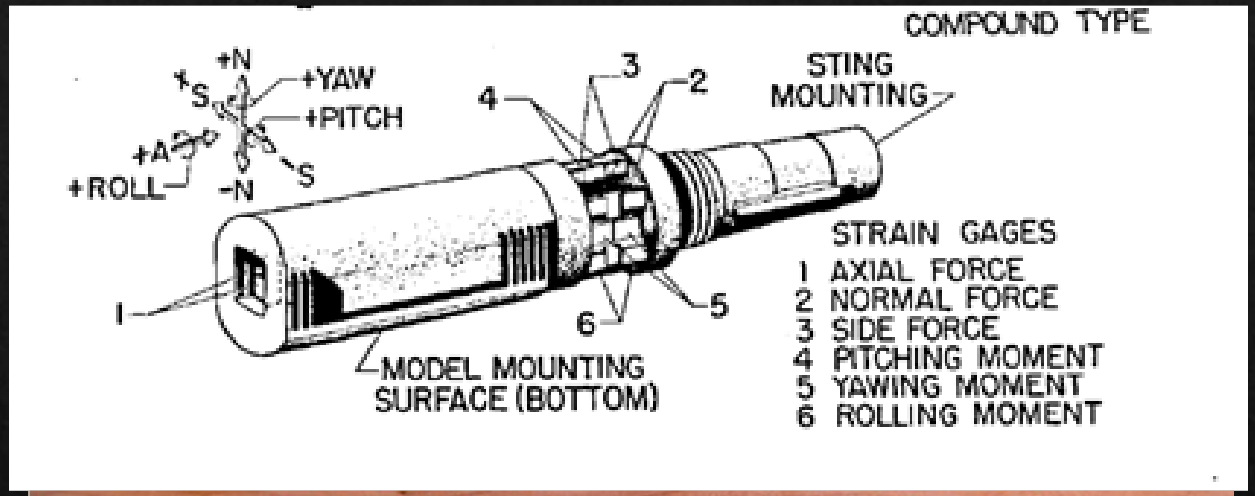
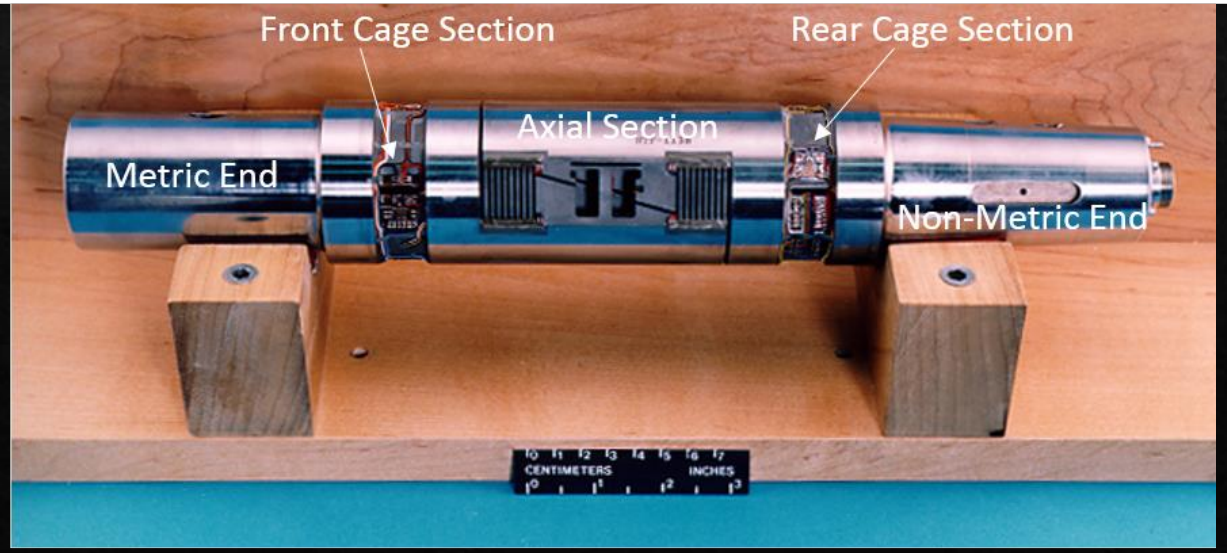


Image courtesy of NASA/TM-2019-220248

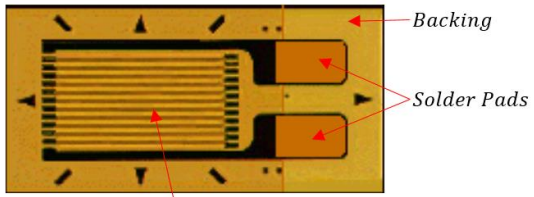
Balance Structure





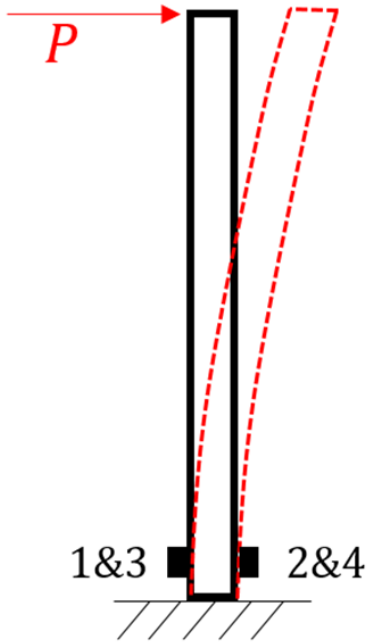
Images courtesy of NASA/TM-2019-220248

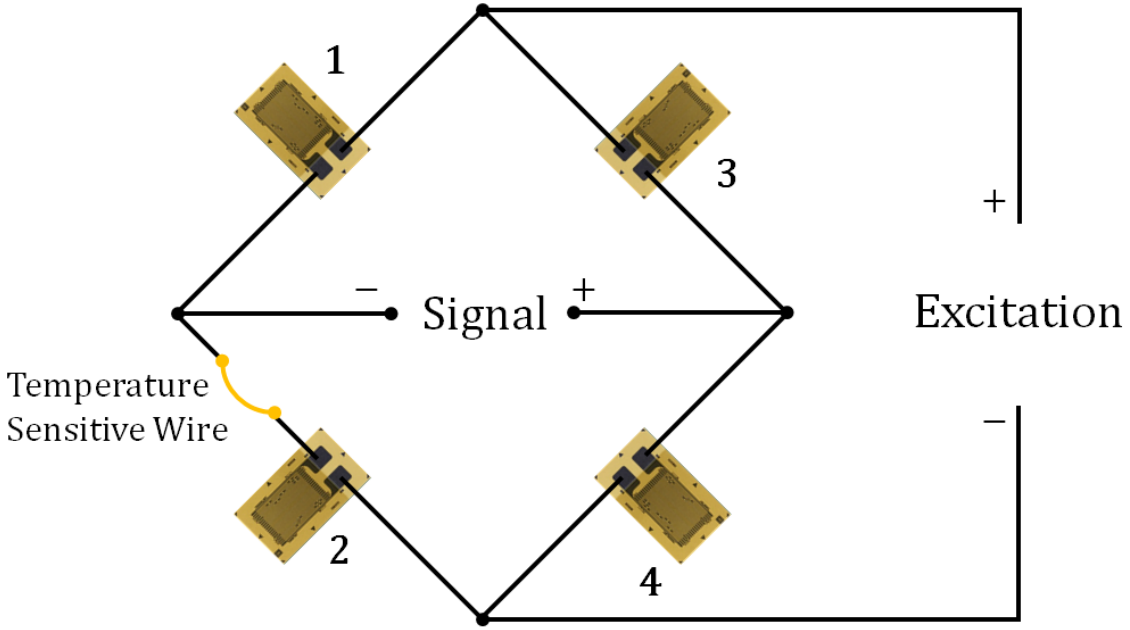
Electrical Components



$$Output\left(\frac{\mu V}{V}\right) = \sigma\,(GF/E) * 10^6$$

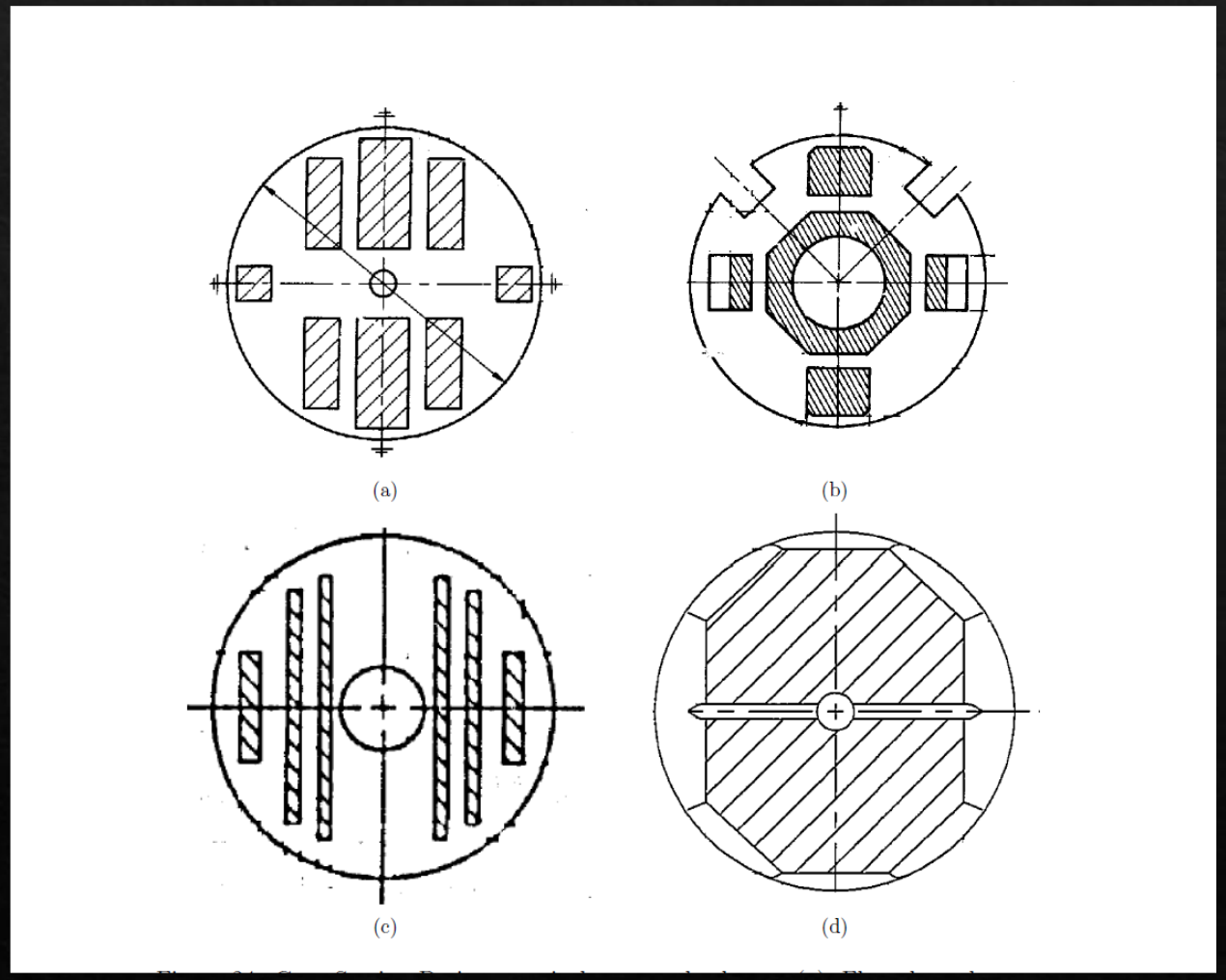
GF= Gage Factor
Sigma= Stress
E= Young's Modulus

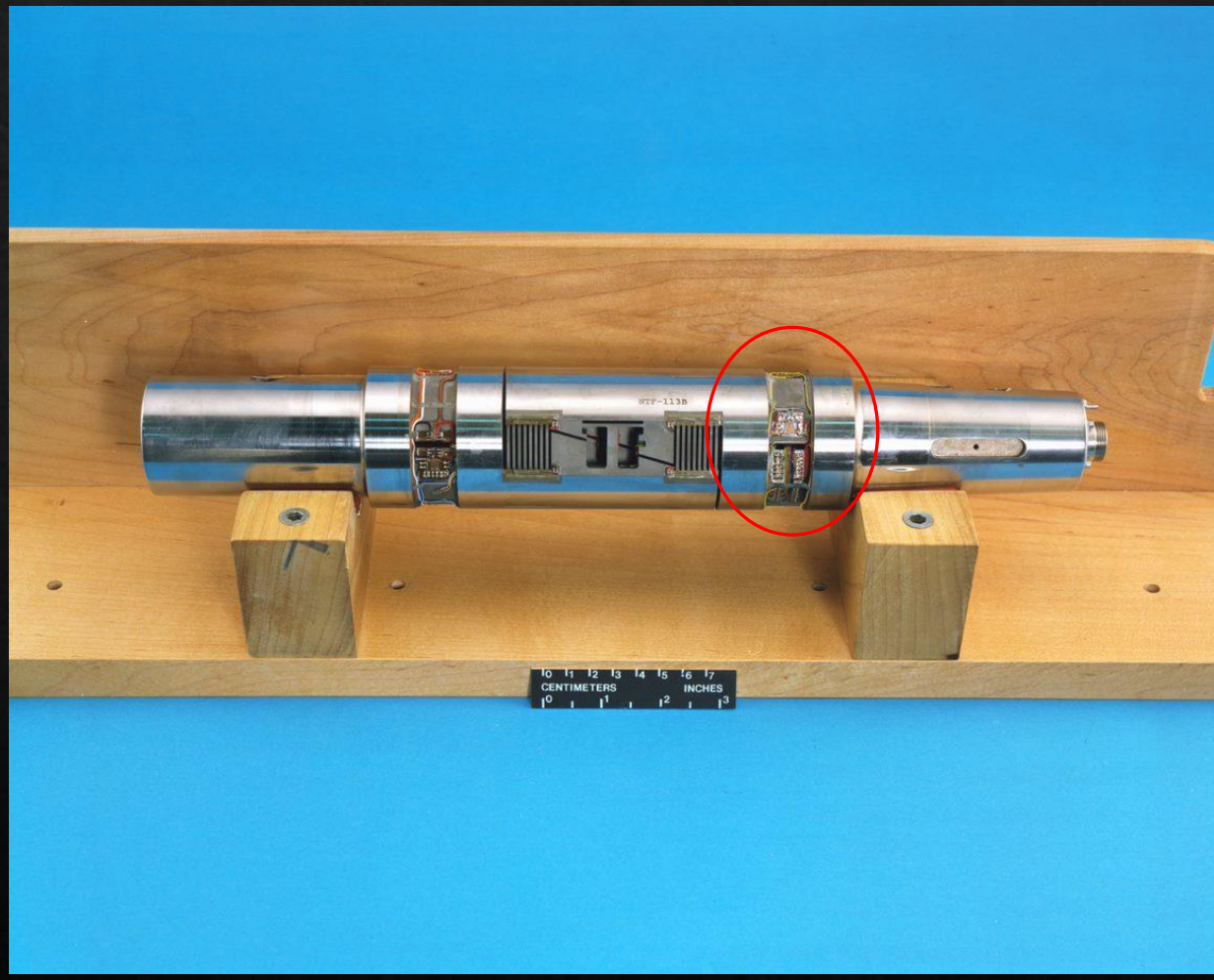




Images courtesy of NASA/TM-2019-220248

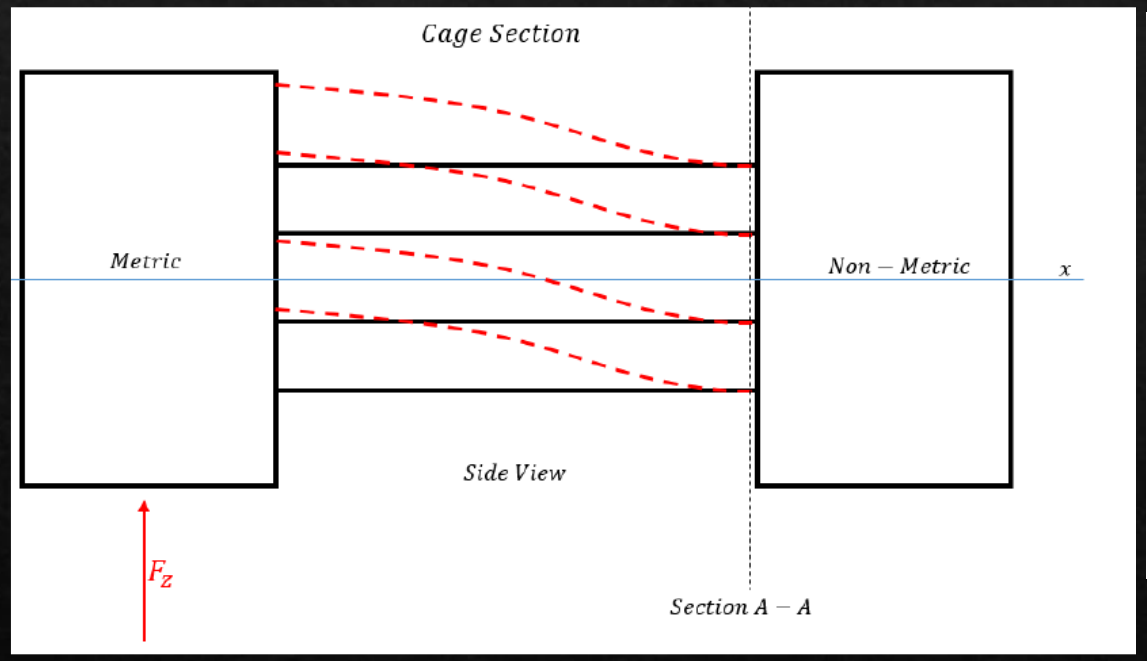
Cage Sections



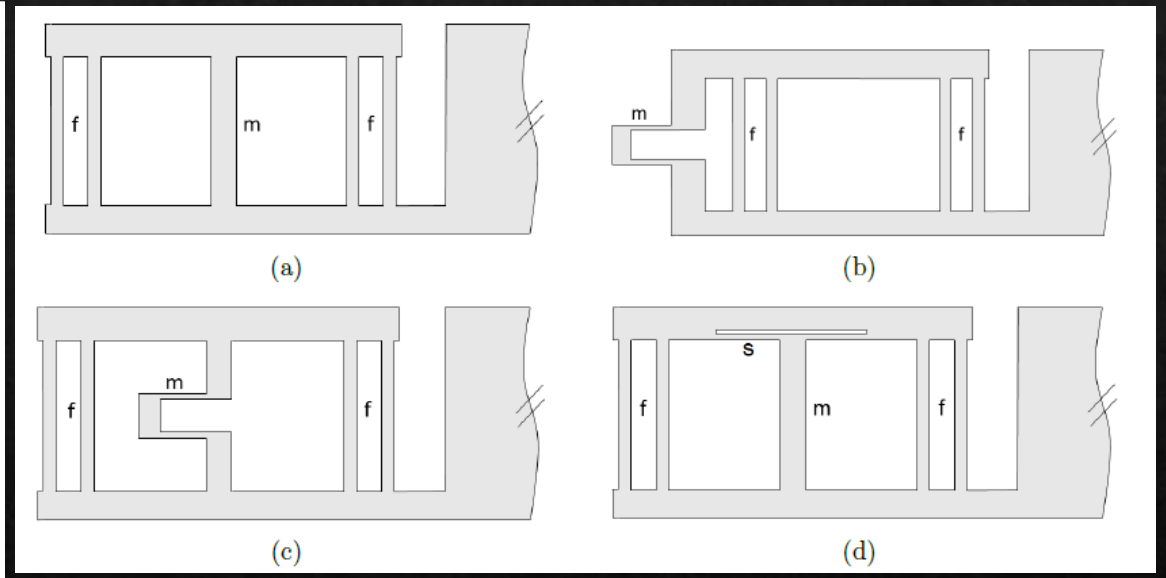


Images courtesy of NASA/TM-2019-220248

Axial Section



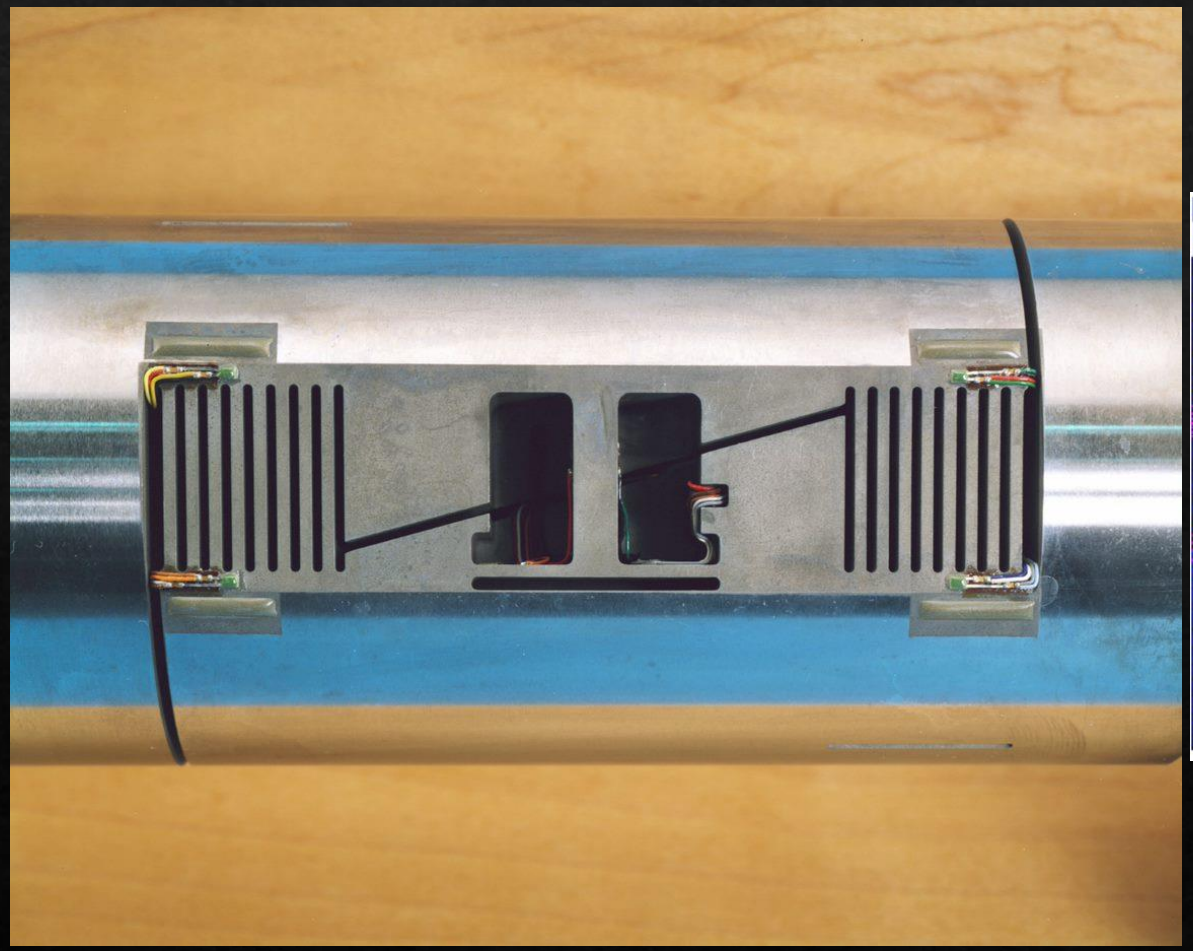
What happens in the cage sections

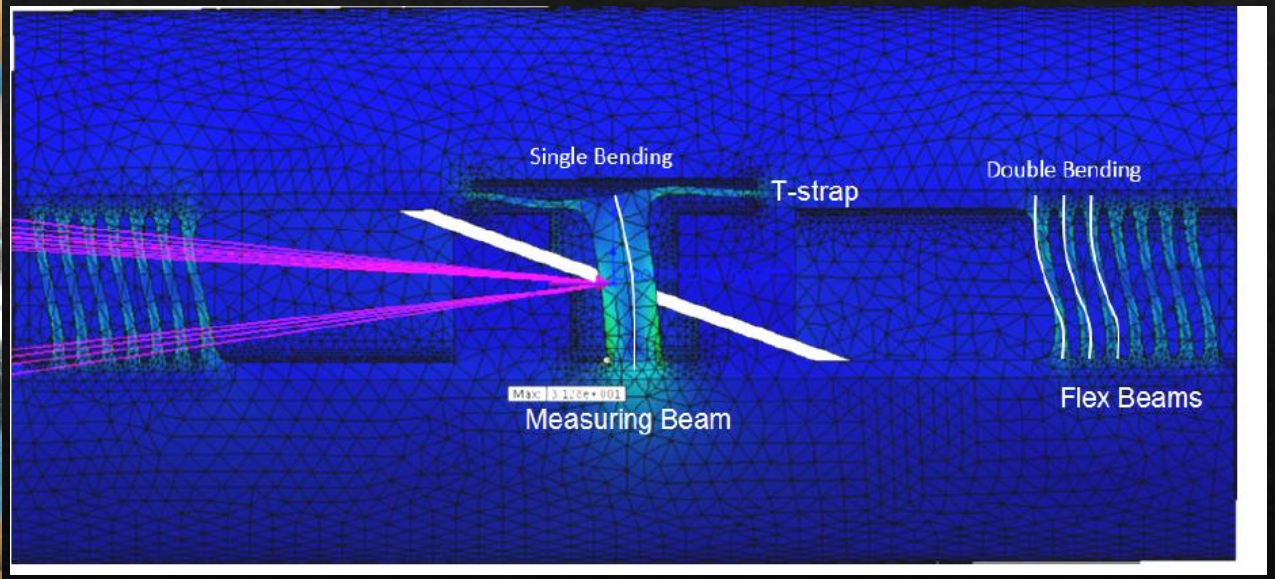


Working to avoid this in the axial section

Images courtesy of NASA/TM-2019-220248

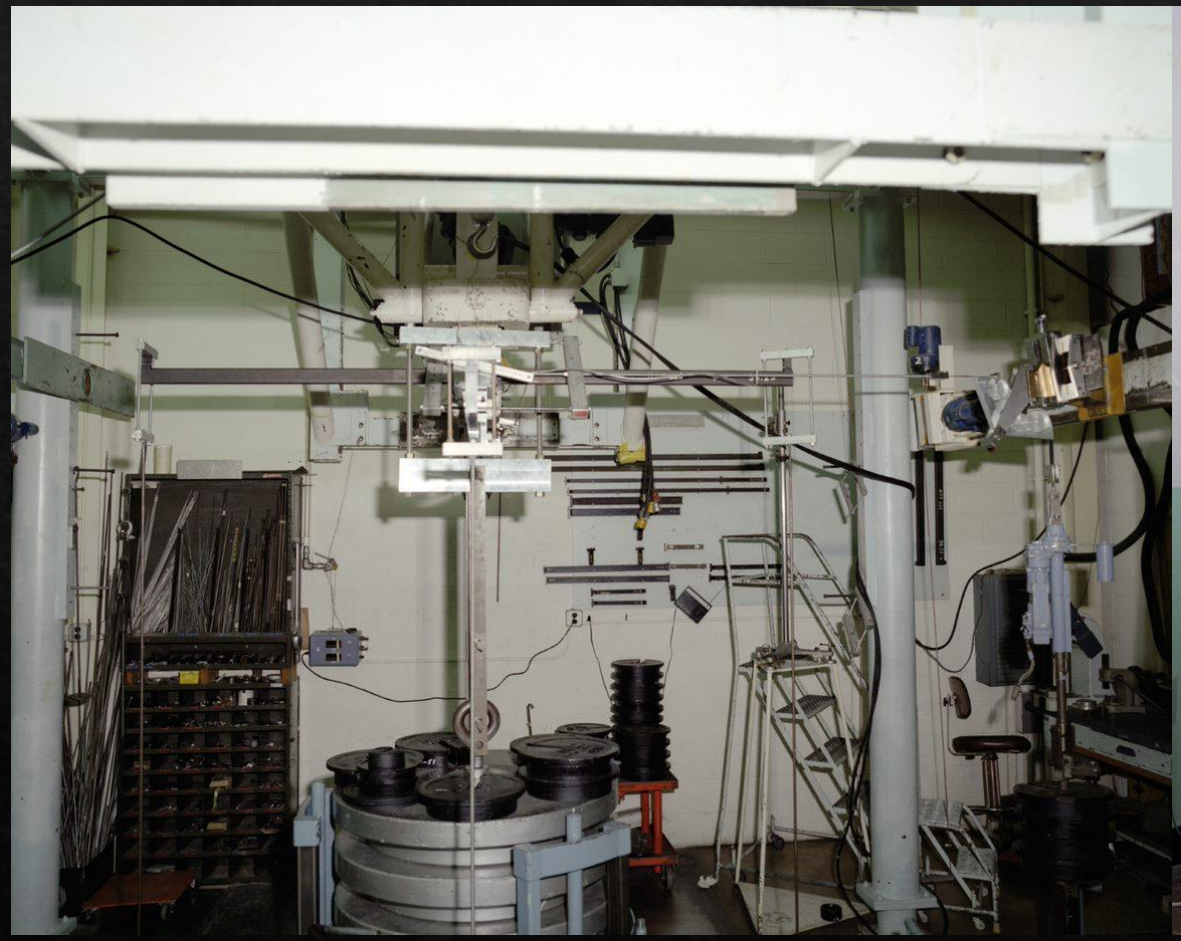
T-Slot and Strap



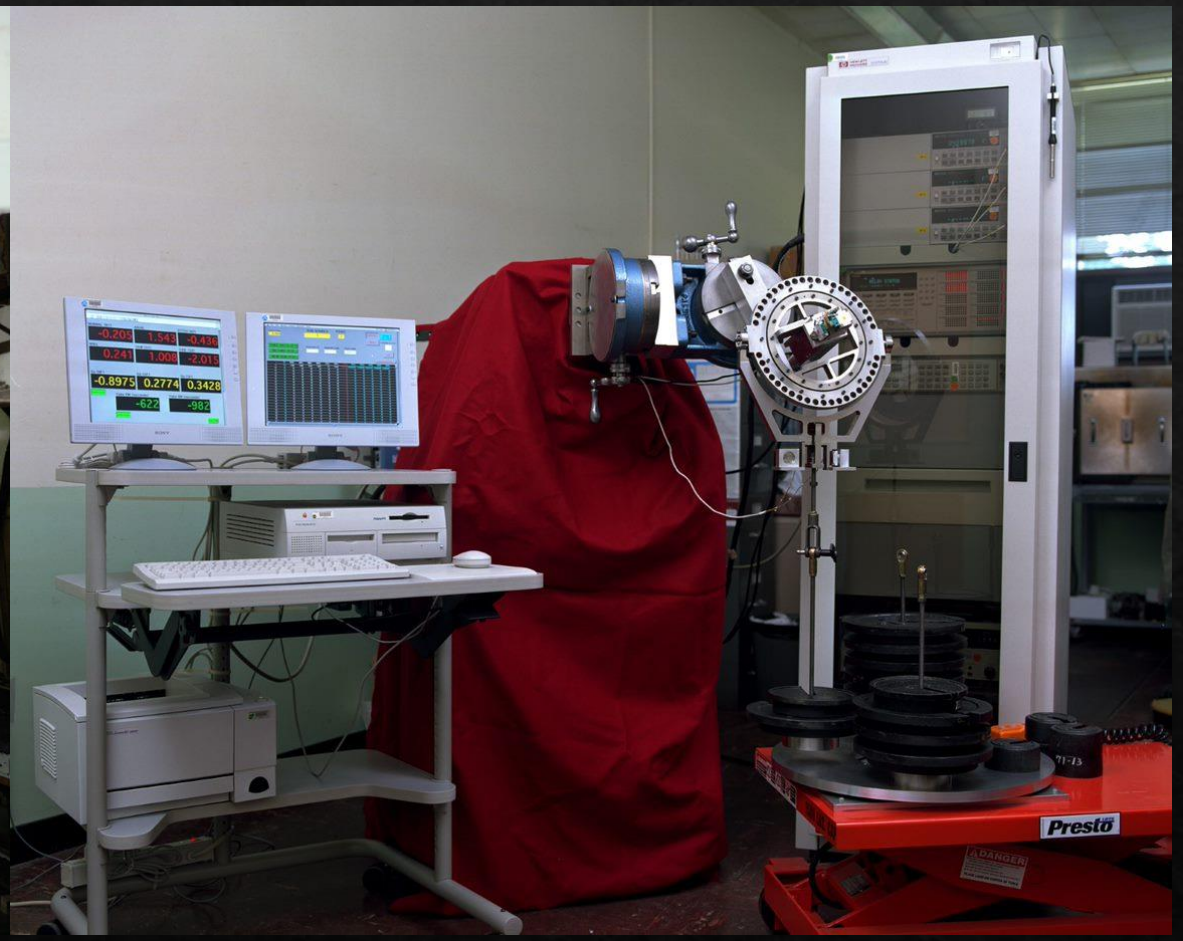


Images courtesy of NASA/TM-2019-220248 and NTF

Calibration



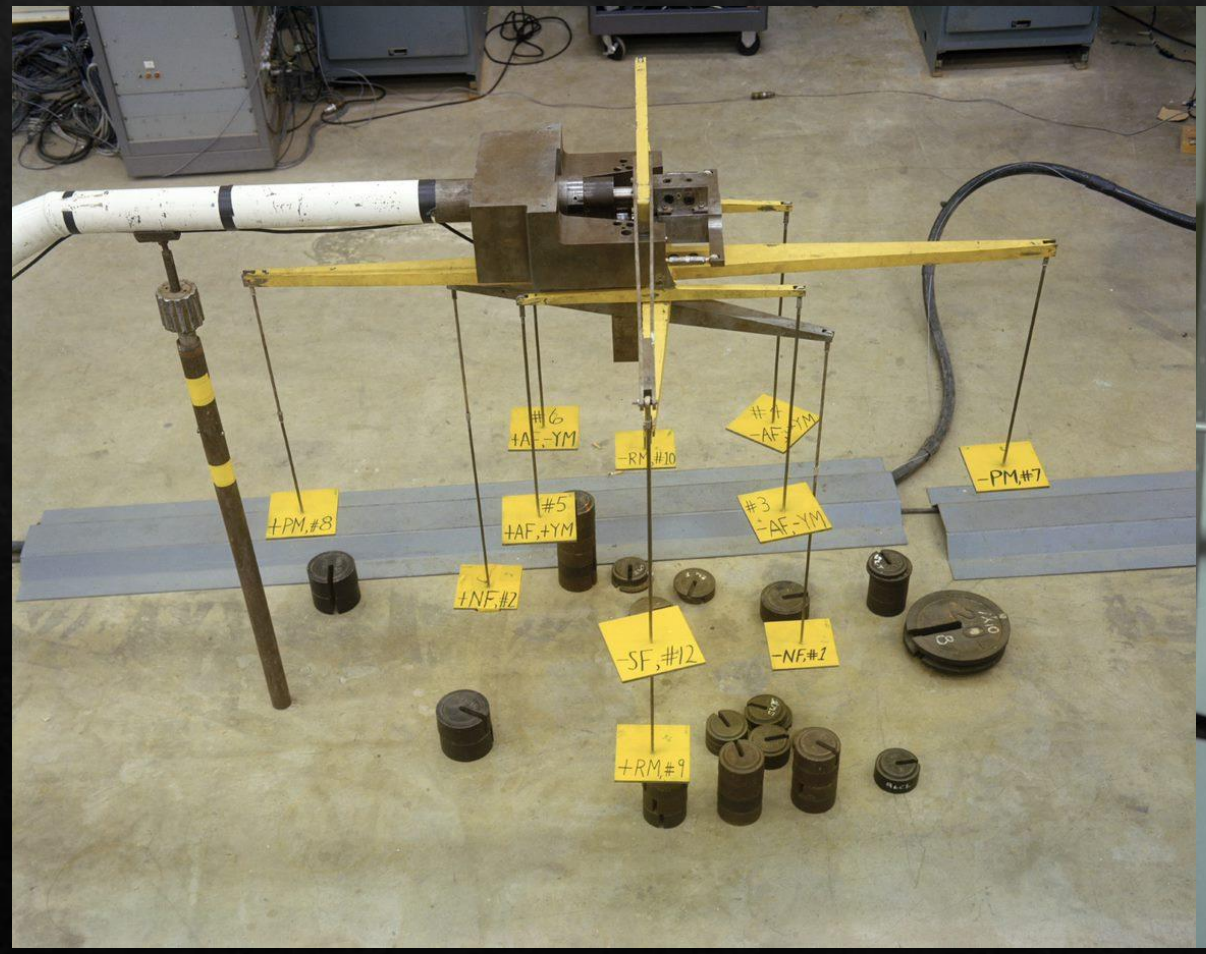
Long Arm

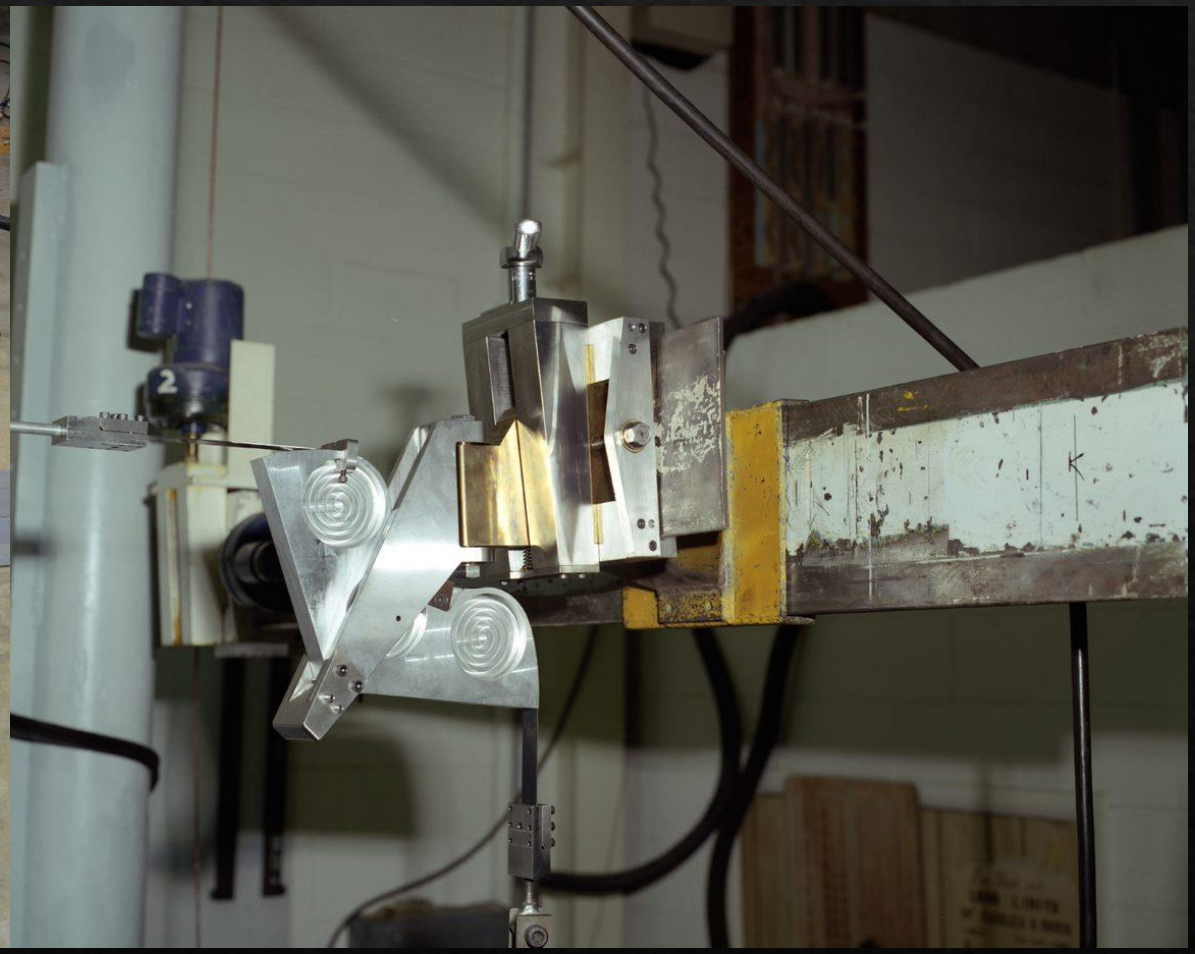


Single Vector System

Images courtesy of NASA

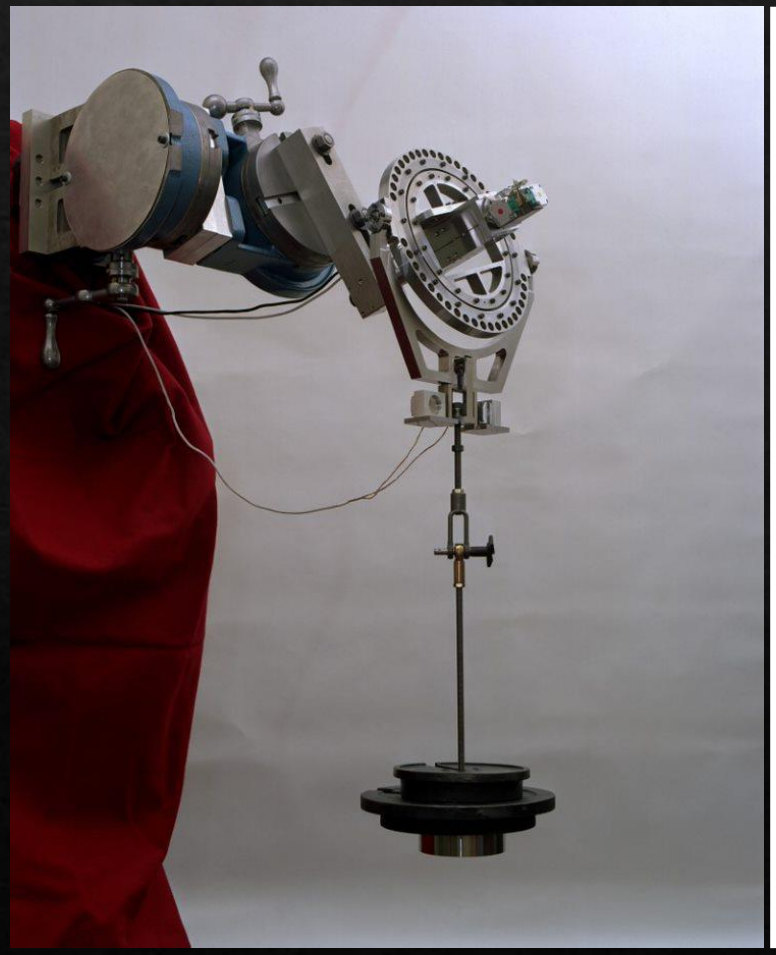
Long Arm Calibration (The Traditional Way)

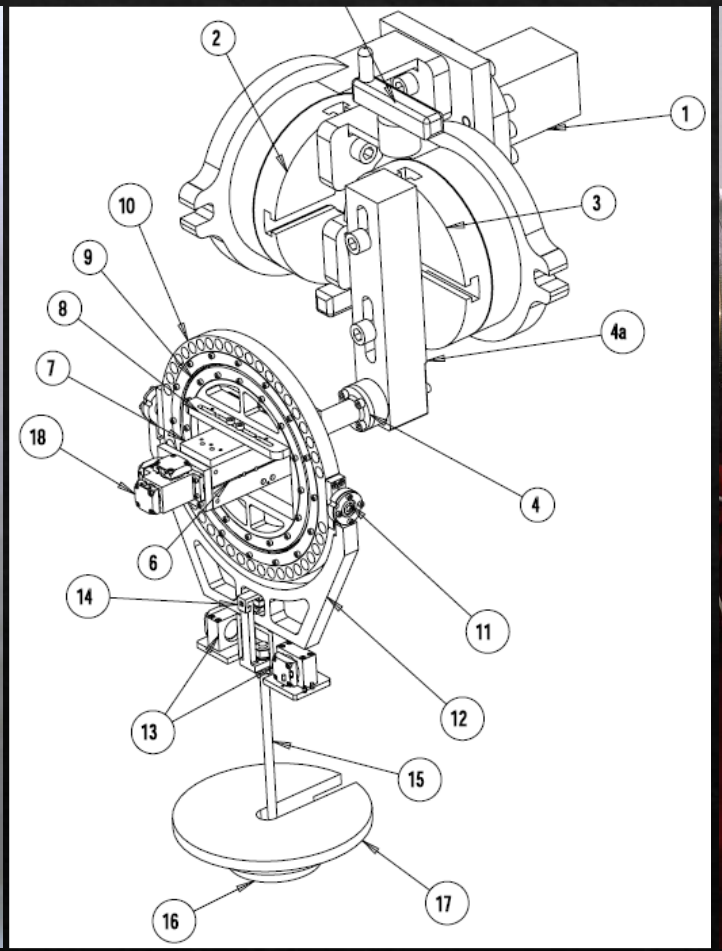


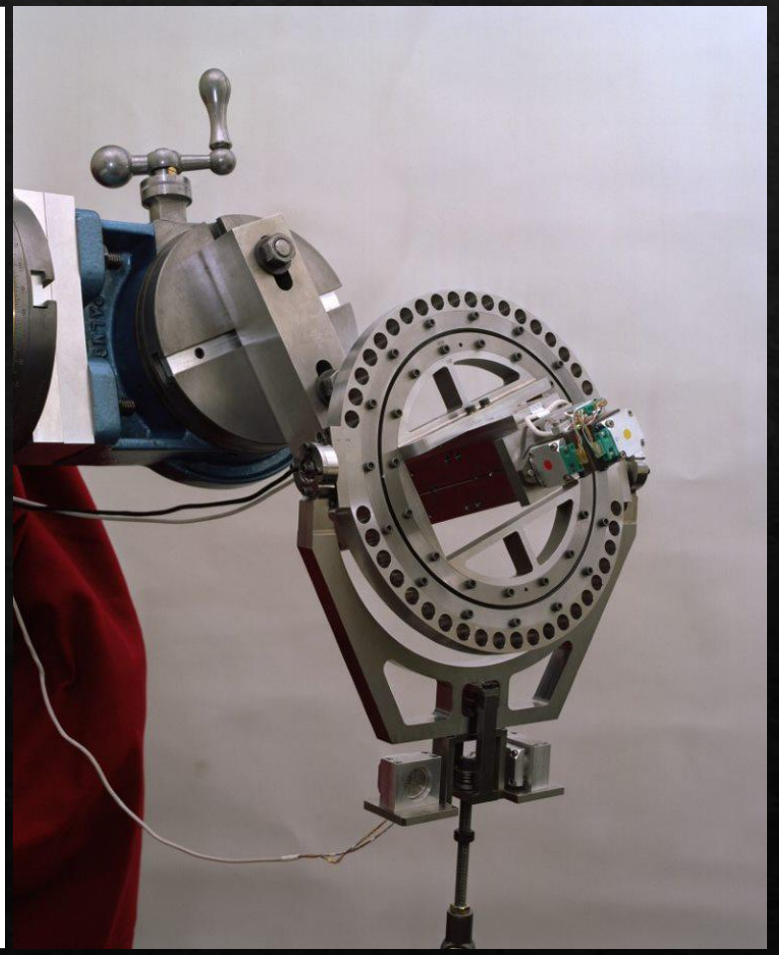


Images courtesy of NASA and NTF

Single Vector System (SVS)







Images courtesy of NASA

More Calibration Hardware

Images courtesy of NASA and NTF

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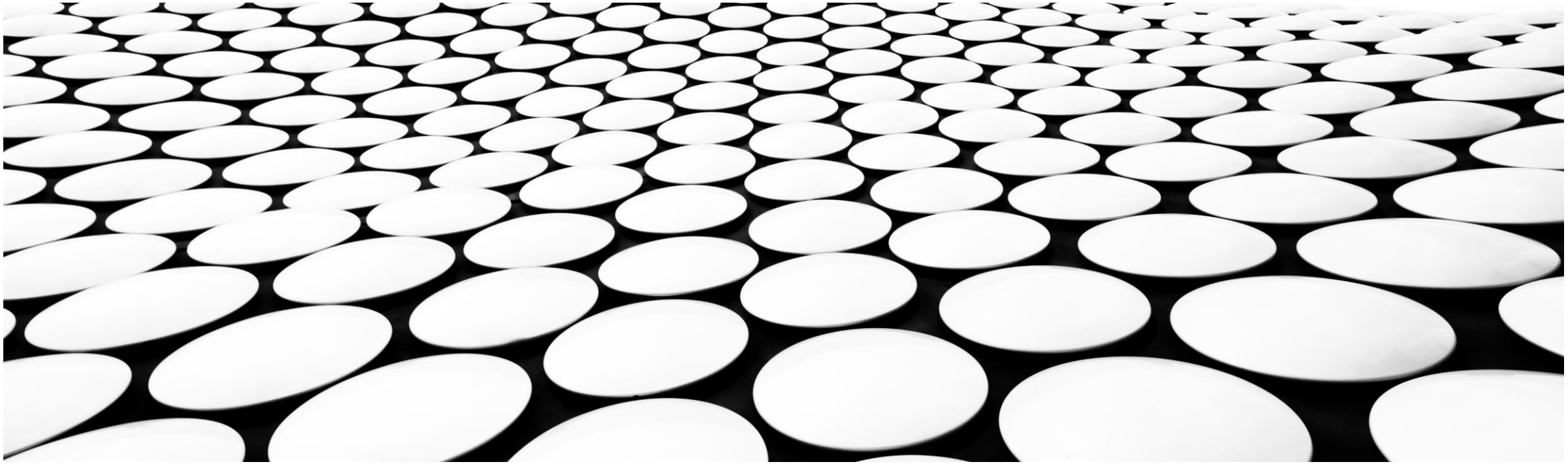
Burns DE, Parker PA, and Phillips BD. *Wind Tunnel Balance Design: A NASA Langley Perspective.* Norfolk (VA) Langley Research Center; 2019. 82 pp. NASA/TM-2019-220248

Parker, Peter A. SVS Class Notes, 2002

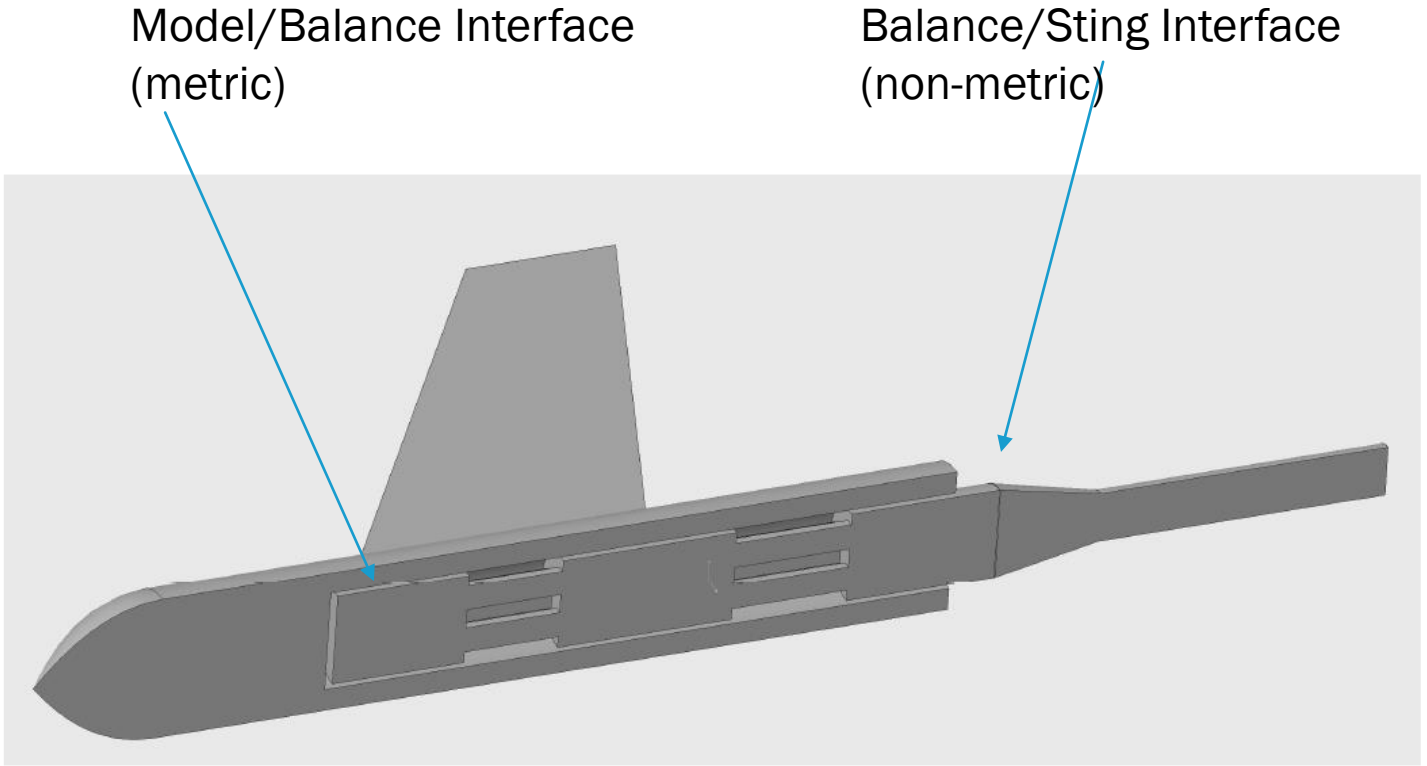
INTEGRATED WIND TUNNEL MODEL CONCEPT

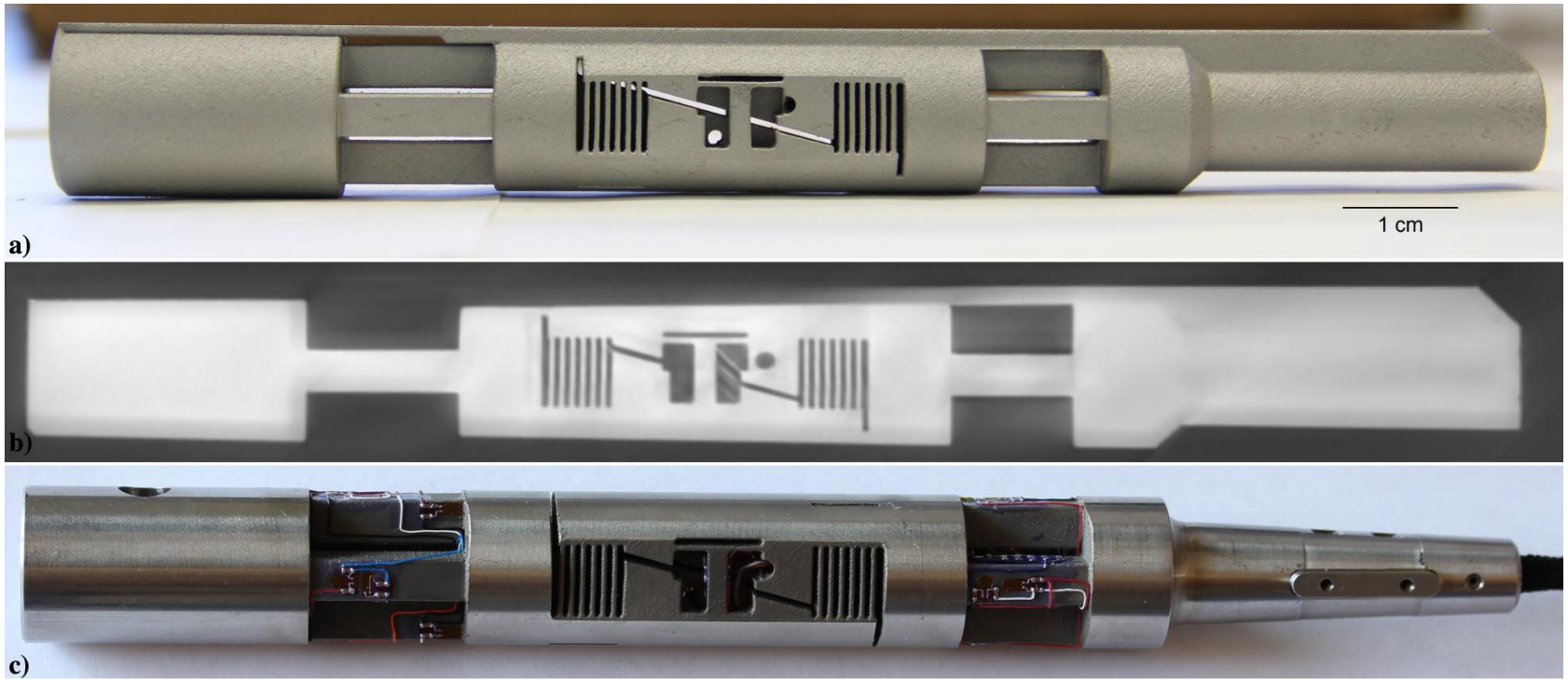
WITH ADDITIVE MANUFACTURING



TRADITIONAL MODEL

- Wind tunnel model manufactured separately, interface designed to work with existing balance and wind tunnel hardware
- Two distinct interfaces; interface between sting and balance, and between balance and model.





Additively Manufactured Balance, Image Courtesy of NASA (Burns & Parker, 2020)

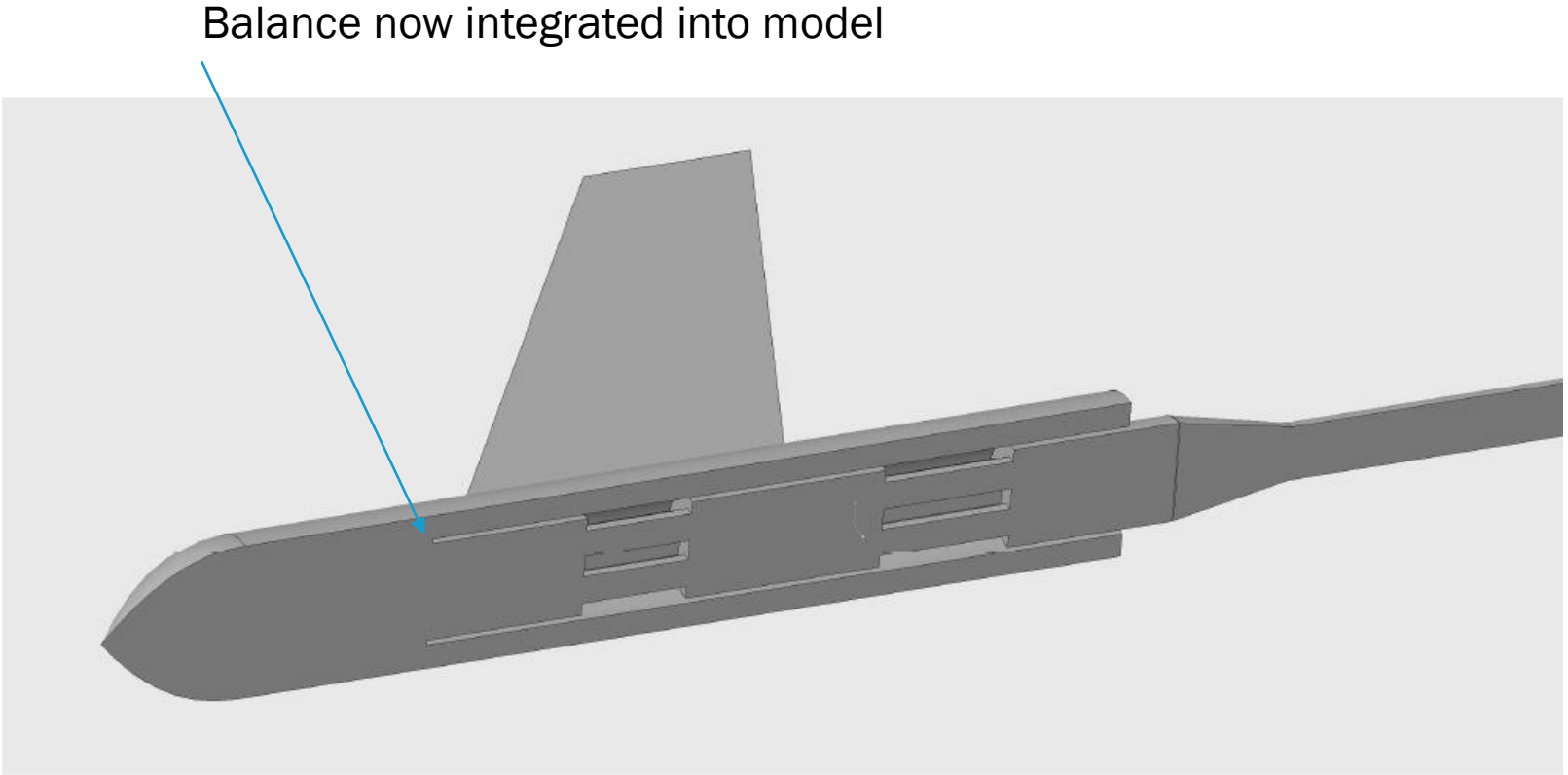
ADDITIVELY MANUFACTURED BALANCE

- Additive manufacturing of wind tunnel balances is a new concept that shows great promise in reducing manufacturing time, and increasing availability
- This method of fabrication also permits geometry that is otherwise unattainable via standard manufacturing methods

ADDITIVELY MANUFACTURED MODEL WITH INTEGRATED BALANCE

Integration of the balance within the wind tunnel model presents several benefits:

- Removal of one interface (that between model and balance) removes one potential source of error.
- Model includes own instrumentation
- Integrated balance may be designed around model intent, omitting search for a balance that is both appropriate and available



BENEFITS AND CHALLENGES OF THE DESIGN

- Additive manufacturing permits a significant reduction in cost and secondary machining of the model
- Permits construction of geometry that would otherwise be very difficult or even impossible with traditional machining techniques
- Limitations on AM technique, particularly in terms of overhang and/or perpendicular geometry
- Balance electronics and other instrumentation must be accessible for installation and troubleshooting

AGARD-B MODEL & UT-63A BALANCE

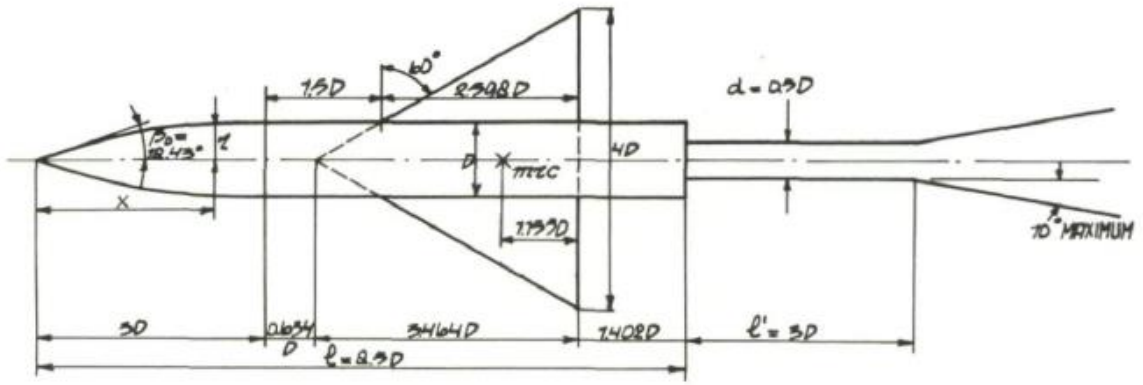


Image courtesy of AGARD (Hills, 61)

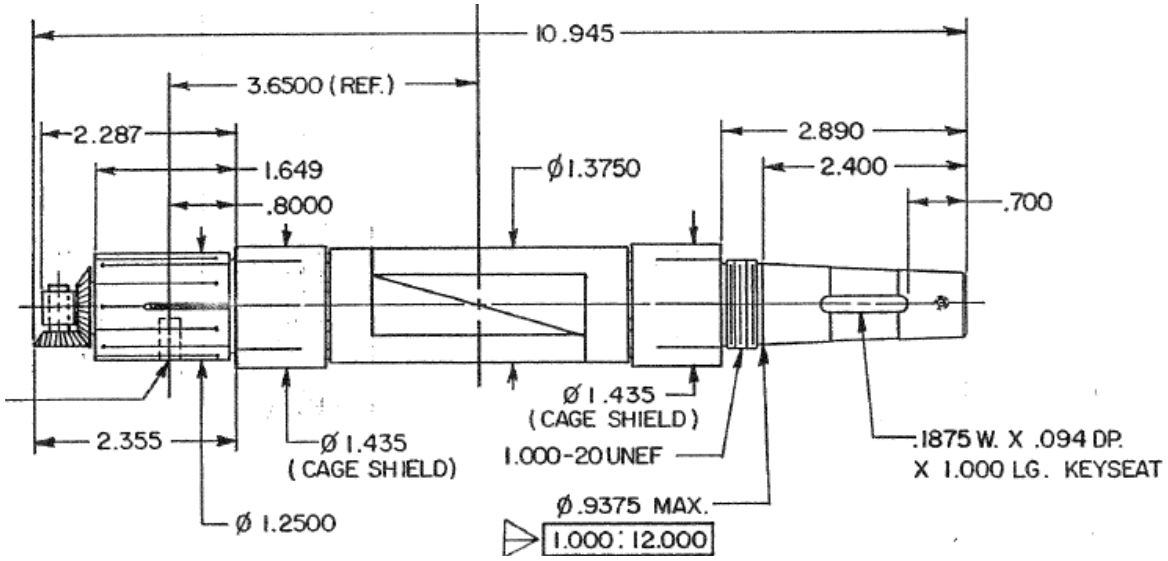
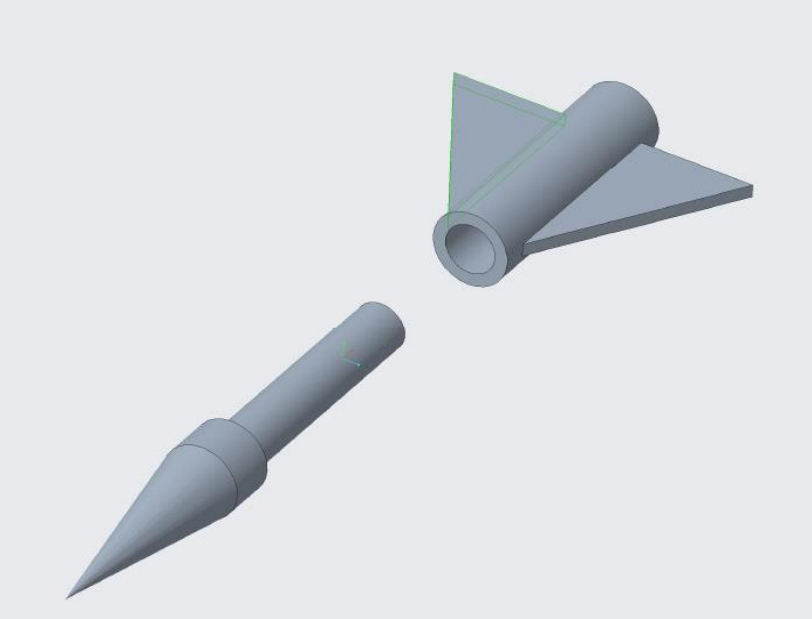
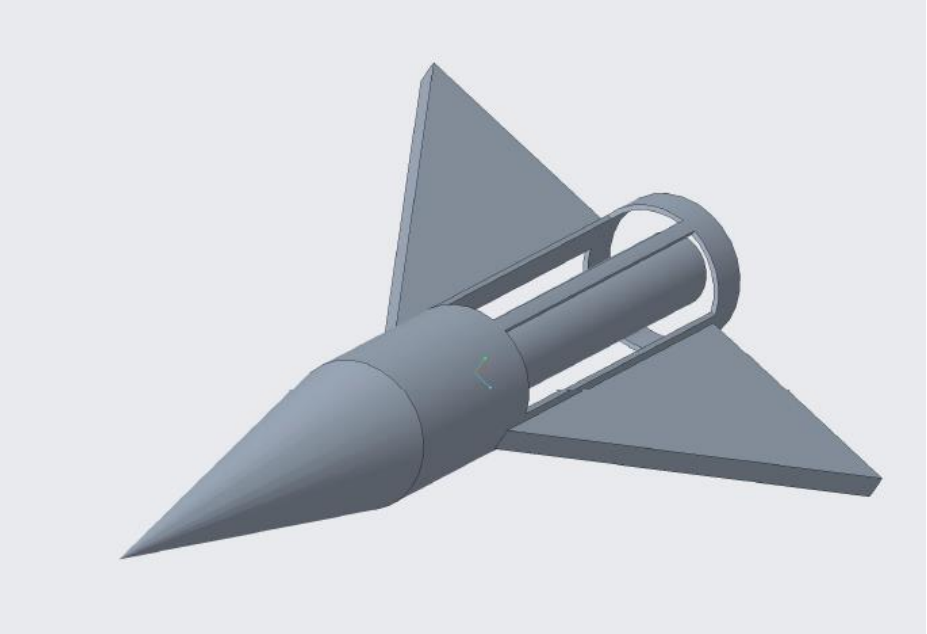


Image courtesy of NASA (Parker, 91)

INITIAL CONCEPTS



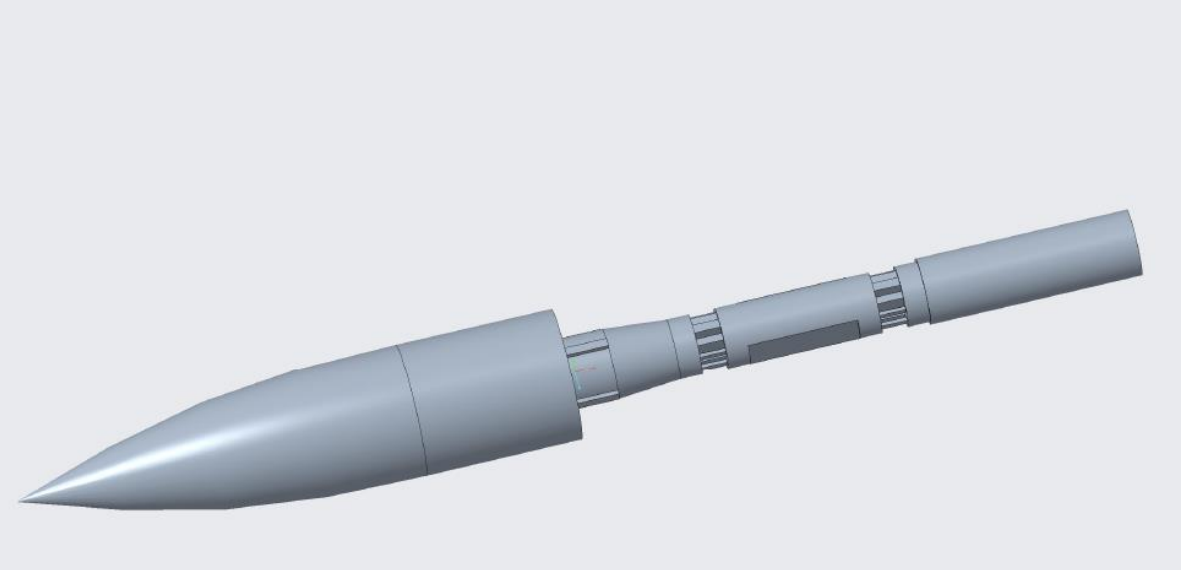
Two-piece model with separate wing module

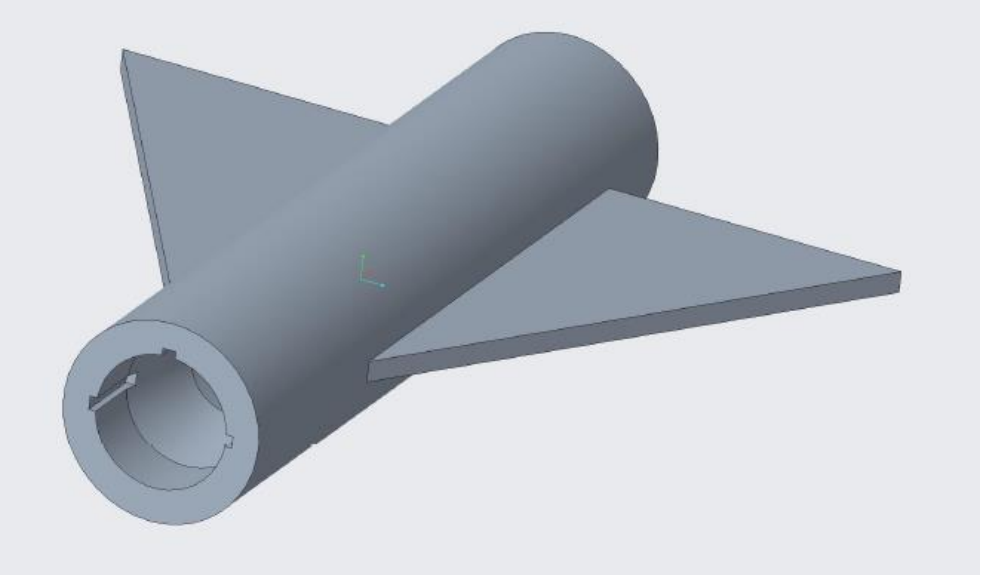


One-piece model with removable access panels

FIRST MODEL

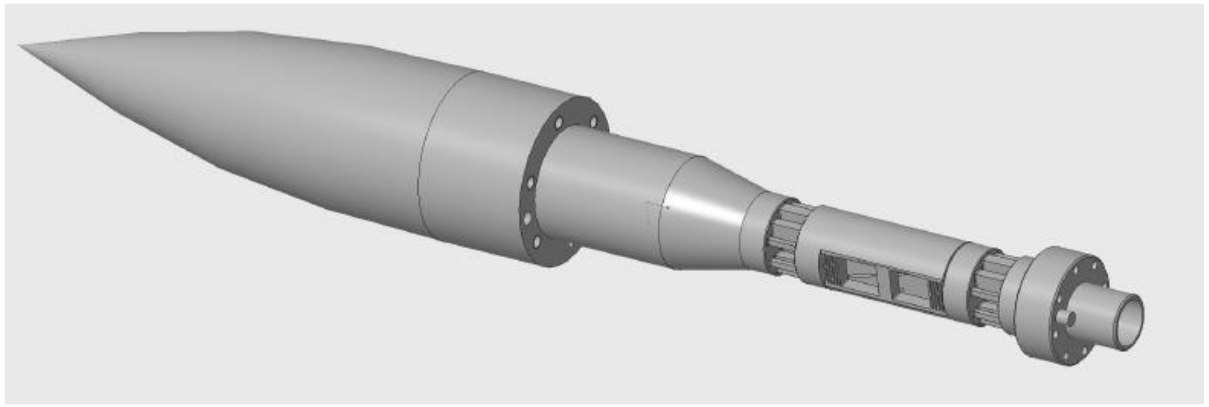
- Two-piece model featuring integrated balance and nose cone, taper for interfacing with sting
- Wing module at this stage does not have airfoil camber rendered. Alignment is provided via keyslots

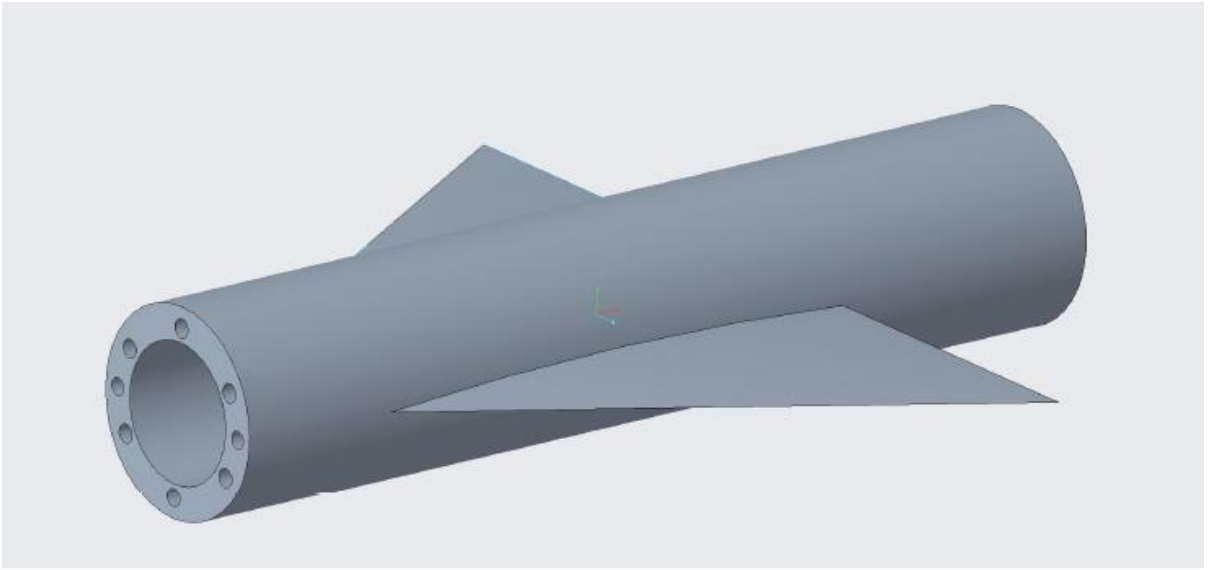




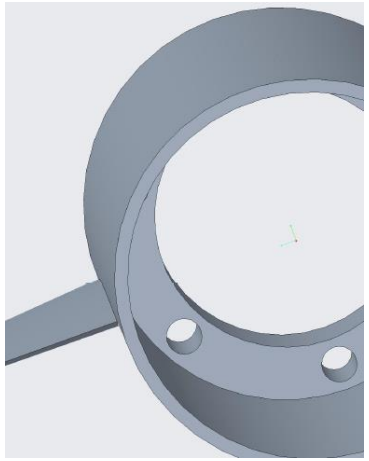
FIRST MODEL REFINED

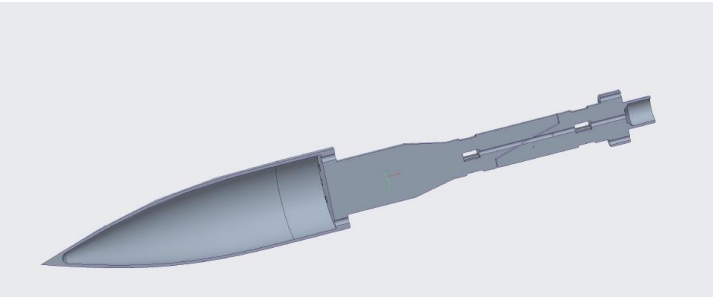
- Keyslots for alignment of wing module replaced with dowels
- Taper at aft of core section replaced with flange to interface with sting, reducing secondary machining requirements
- Wing module has basic airfoil camber formed





CONCERNS WITH FIRST MODEL

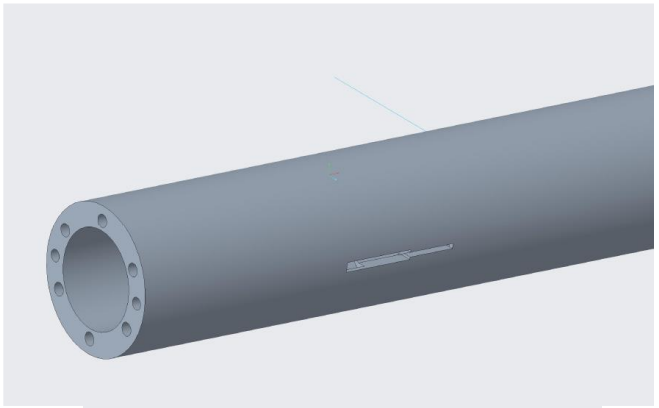


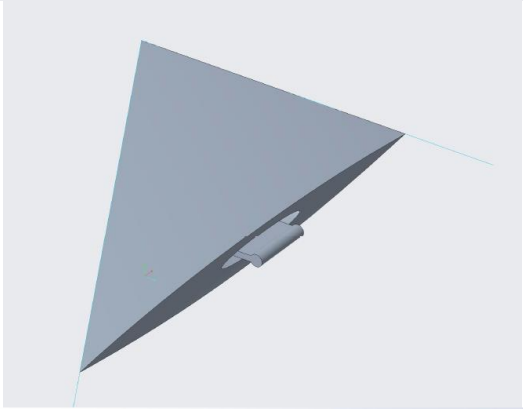


- Wing airfoil camber and cross section not accurately modeled; anomalies in the joining of the wings to fuselage prevented accurate rendering. Also concern regarding strength of wing/fuselage connection
- Large hollow nose cone integrated into model presented difficulties in both additive manufacturing, and unused space that could potentially be used to house instrumentation

IMPROVEMENTS TO BE MADE

- In addition to resolving previous issues, the question was raised; Can we do more with this concept?
- Two areas of interest explored, focusing on wing features for testing
- Force sensors integrated into separate wing pieces
- Pressure ports running through structure





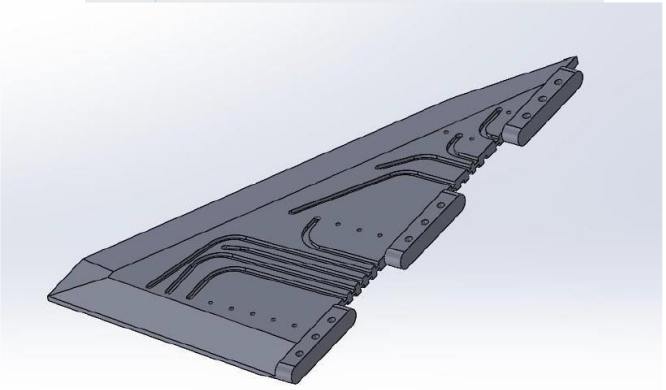
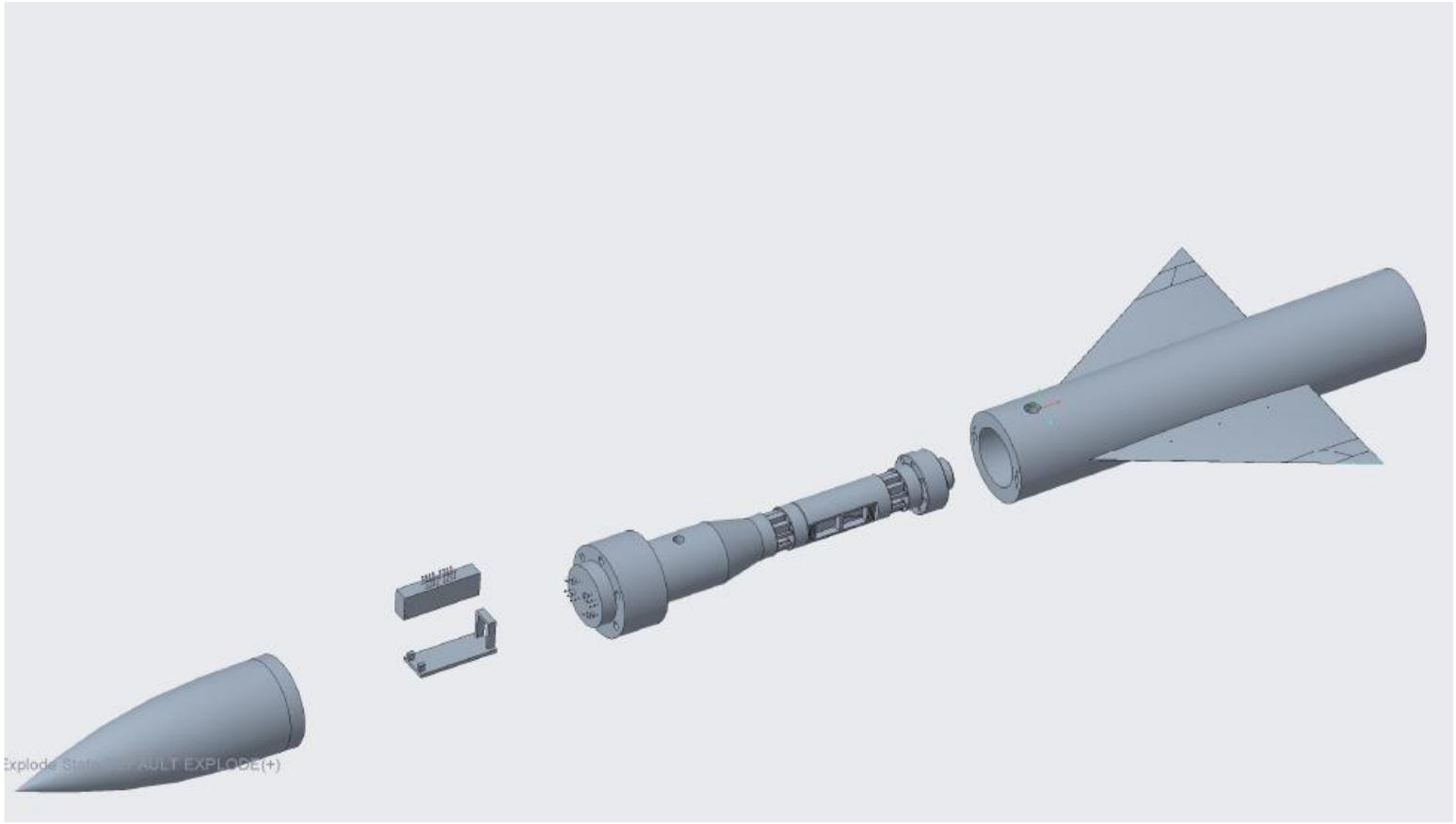


Image courtesy of National Aerospace Laboratories. (Shivam and Verma, 2019)

FINAL DESIGN

- Features include:
  - Integrated UT-63A balance within core section
  - Integrated pressure lines along MAC of wings, allowing pressure sampling at 1/4, ½, ¾ chord on dorsal and ventral surfaces
  - Hollow nose cone for installation of pressure sensing equipment (mockup shown)
  - Design is built for easy assembly within wind tunnel, as pressure line connections are either tubeless, or may be connected prior to final assembly



PROPOSED PATH OF ADVANCEMENT

Current implementation

Broad review of current AGARD-B integrated prototype, including input from researchers and fabrication technicians

Manufacture of demonstration prototype

Refinement

Development of model with integrated balance specifically designed for model

Exploration of larger models with more features

Exploration of alternate build structures (wings, single piece model)

Future development

Exploration of models with circuitry and instrumentation integrated during manufacture

ACKNOWLEDGEMENTS

I would like to give my sincere thanks to my mentor Devin Burns for his assistance with this project. In addition to providing the spark from which this started, his daily feedback and advice has been invaluable in the design process.

Furthermore, I would like to thank Peter A. Parker and Kenneth G. Toro for providing their insights on current technology and instrumentation for balances and wind tunnel models, as this provided the needed background for additional developments within the model

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Burns, D. E. & Parker, P. A. “Additively Manufactured Wind-Tunnel Balance.” *Journal of Aircraft,* Vol. 57, No. 5, 2020 pp . 958-963.
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Shivam, S., & Verma, S. B. Study of Vortex Breakdown and Pitch Up on a Compound delta wing. *INCAS BULLETIN,* Vol. 11, No. 2, 2019, pp 171-178.
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