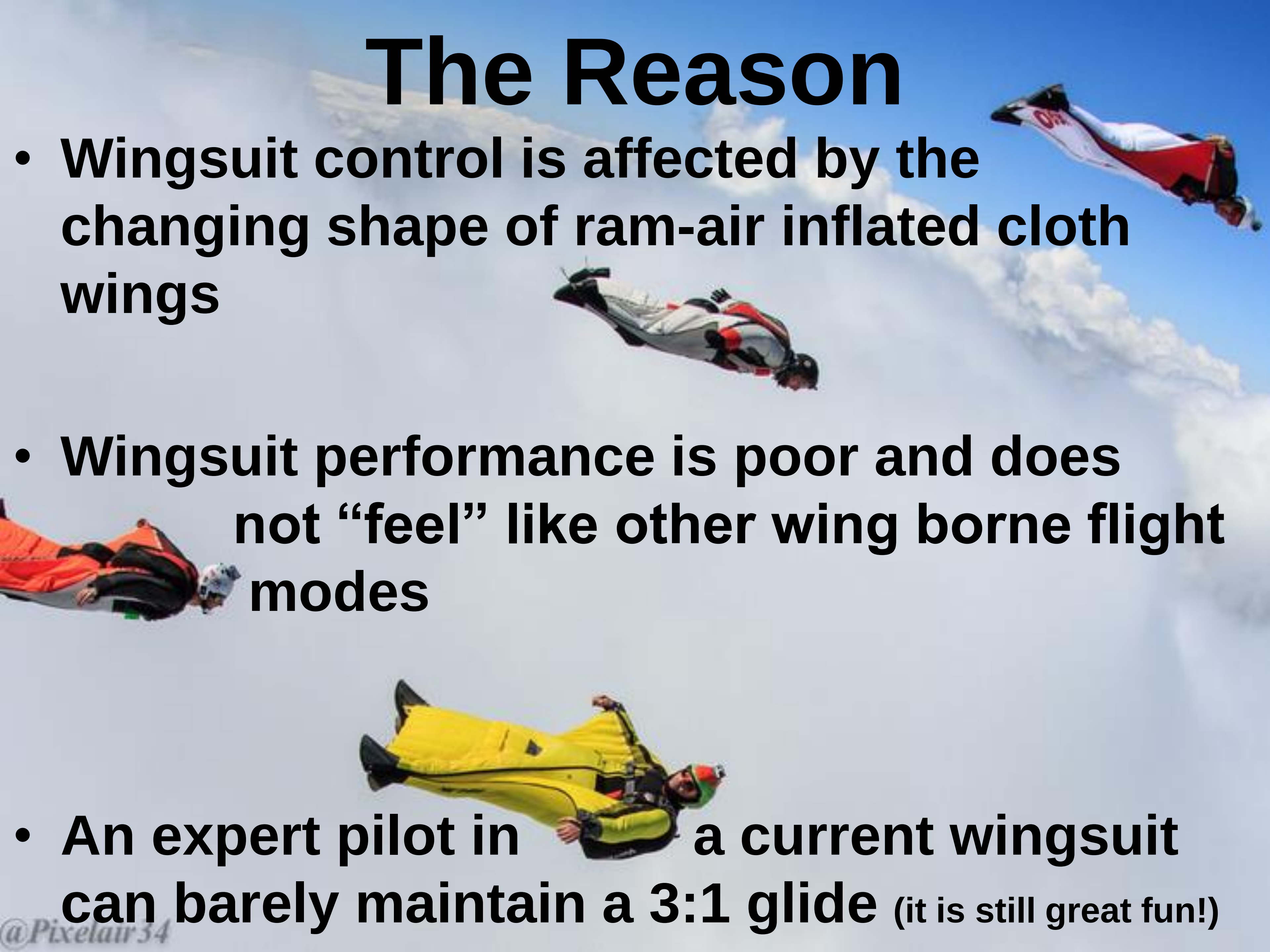
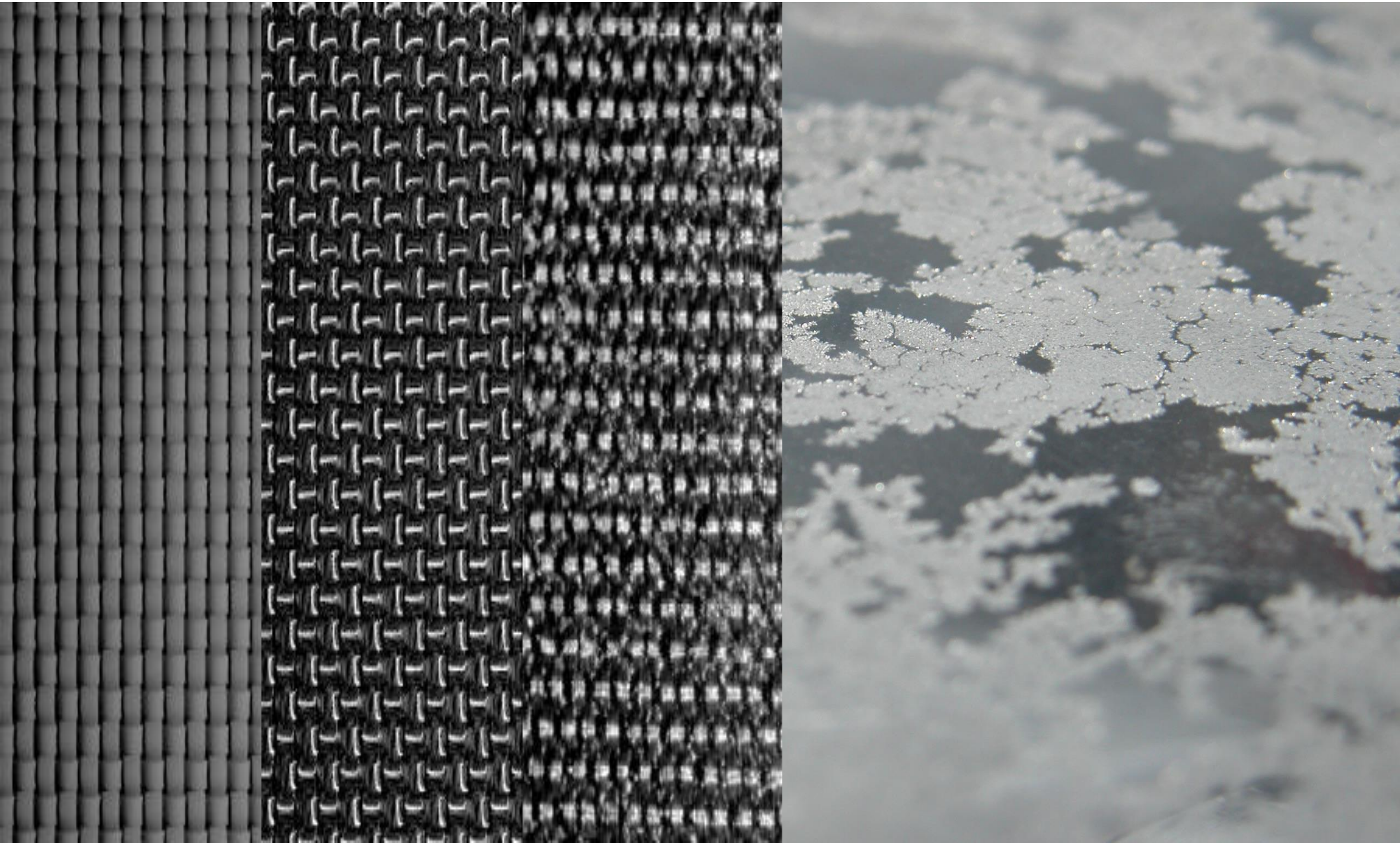
Building a Robust Wind Tunnel Balance for Wingsuit Aerodynamic Research

The Reason

- **Wingsuit control is affected by the changing shape of ram-air inflated cloth wings**
- **Wingsuit performance is poor and does not "feel" like other wing borne flight modes**
- **An expert pilot in a current wingsuit can barely maintain a 3:1 glide (it is still great fun!)**



Hypothesis #1
Woven Cloth is Like Frost



Hypothesis #2
Leading Edge Deformation Causes Problems

Dynamic air pressure deforms the leading edge and airfoil shape chaotically


Under some conditions this could be dangerous


Poor Glide Ratio
Chaotic aerodynamics


Poor Glide
Ratio

The Problem: flapping wing & fragile balance
Aeroelasticity/Flutter taken to new extremes

- **Testing ram-air inflated fabric airfoils in the wind tunnel may result in "flapping" and severe oscillation of the fabric shape that would stress a normal balance beyond its limits and damage it.**

- **Wind tunnel precision balances can easily approach a cost of $100,000. And commonly cost tens of thousands of dollars**

- **We need a balance capable of accurately measuring lift and drag, that could also withstand the forces generated by a violently oscillating fabric wing was required.**

Team Eagle Wingsuit

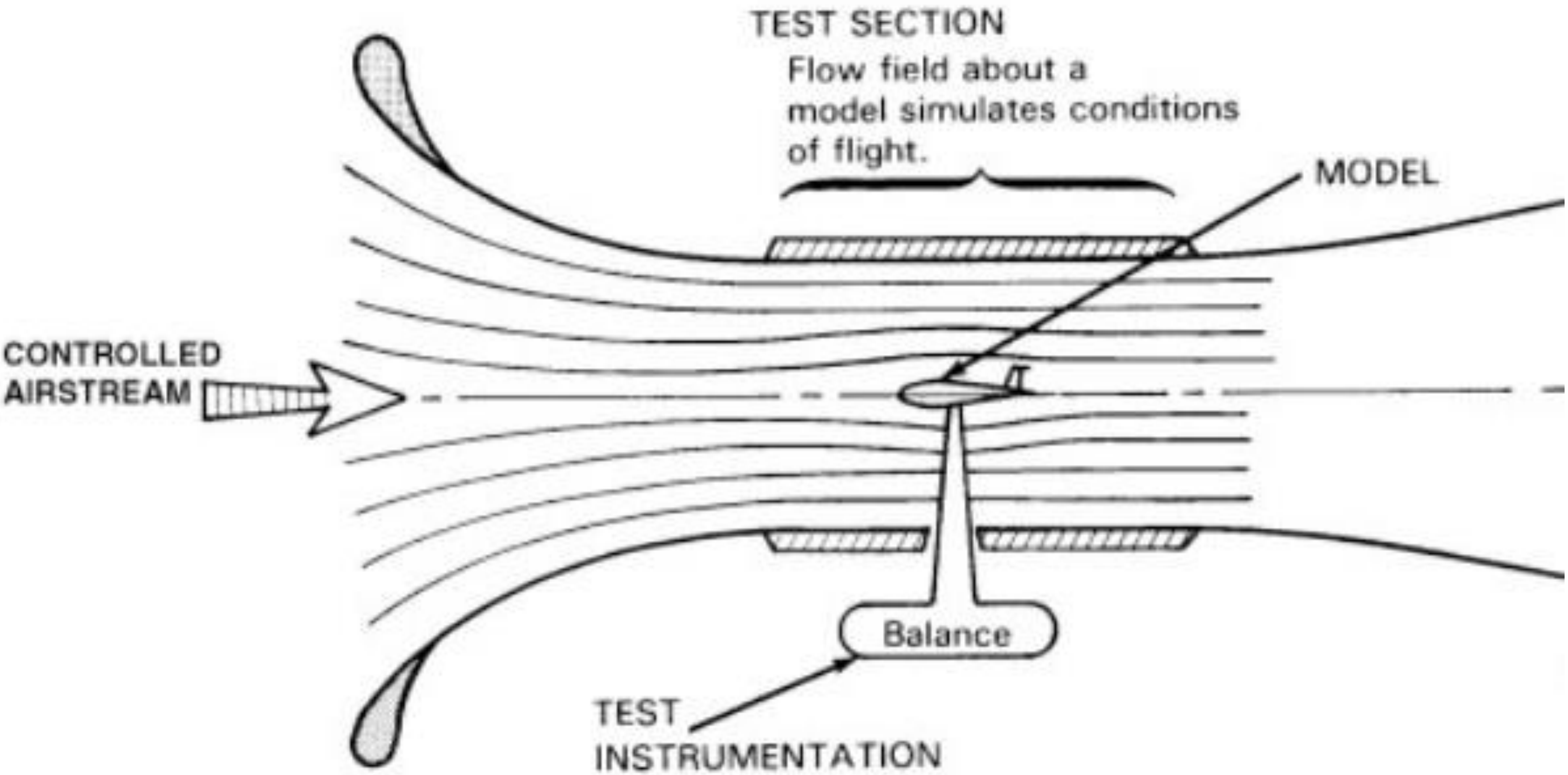
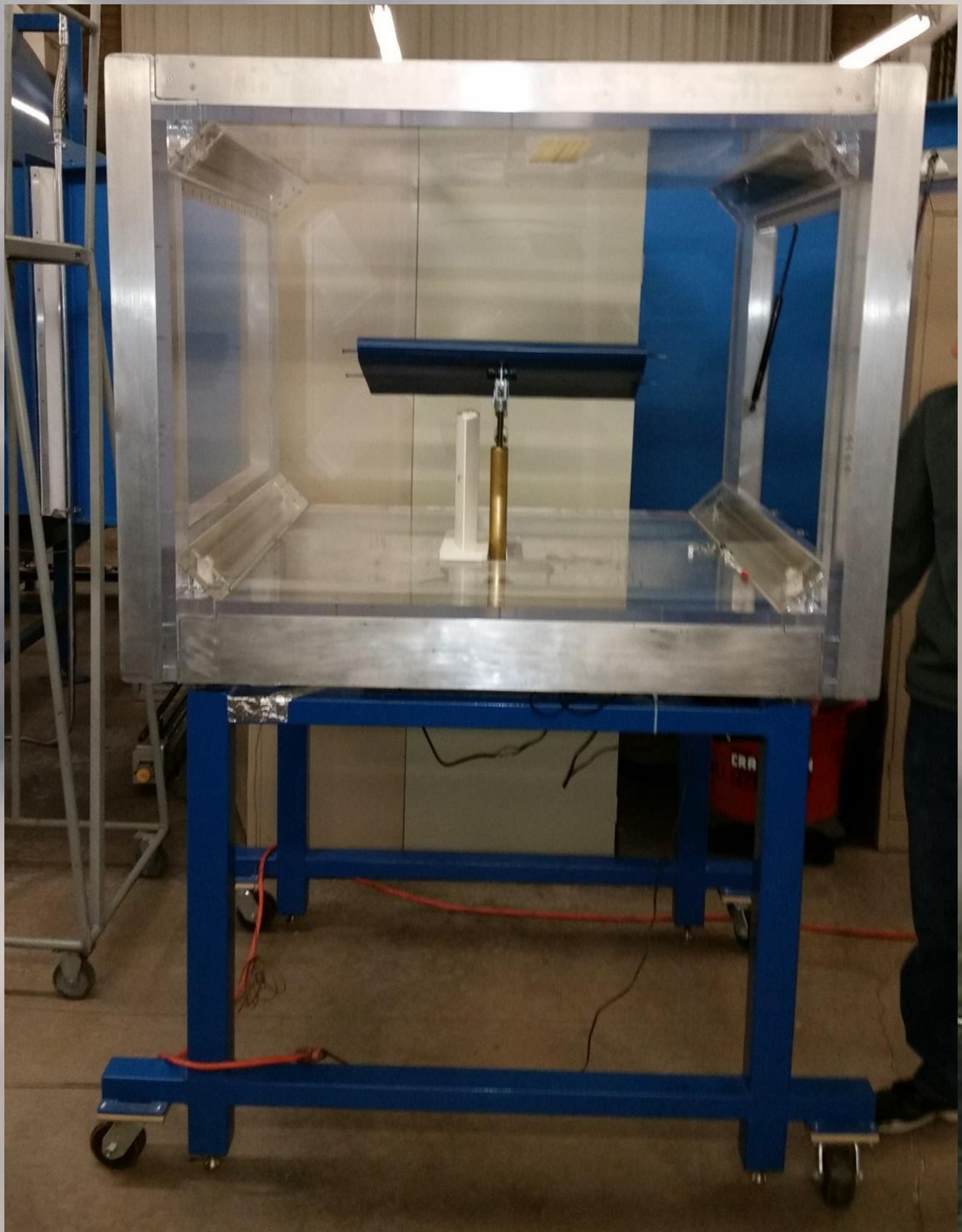


Diagram of typical wind tunnel.

ERAU Modular Test Sections



ERAU Modular Test Sections

Our Balance Requirements

- Must fit in the modular test section
- Must accurately manipulate the model
- Must provide accurate force measurements
- Must operate through the range of expected airspeeds and forces
  - 60 to 180 knots
  - 0 to 75+ lbs force

- Sensors and balance must be:
  - robust,
  - not sensitive to electromagnetic environment,
  - stable
  - Valid
  - Plug and play simplicity highly desirable
  - Fit budget < $5000

Concept Design

- A literature search revealed a variety of designs and possible sensors. Two very basic designs were combined for the stability and robust characteristics of the components
  - McMahon, H., Jagoda, J., Komerath, N., & Seitzman, J., (2009). Force measurement in a subsonic wind tunnel. Georgia Institute of Technology lesson Plan for AE3051 Experimental Fluid Dynamics
  - Morris, M., & Post, S. (2010). AC 2010-393: Force balance design for educational wind tunnels
- A two component design – Lift and Drag – was considered acceptable

Sensor Selection

- A variety of sensors were considered – USB interface was favored
  - Piezo electric
  - Strain gauge
  - Optical strain gauge
  - Capacitance

- Capacitance force sensors were chosen
  - Sensor cost $600 each
  - Sensors are large
  - Very simple plug and play DAQ

Morris & Post:
Force balance design for educational wind tunnels

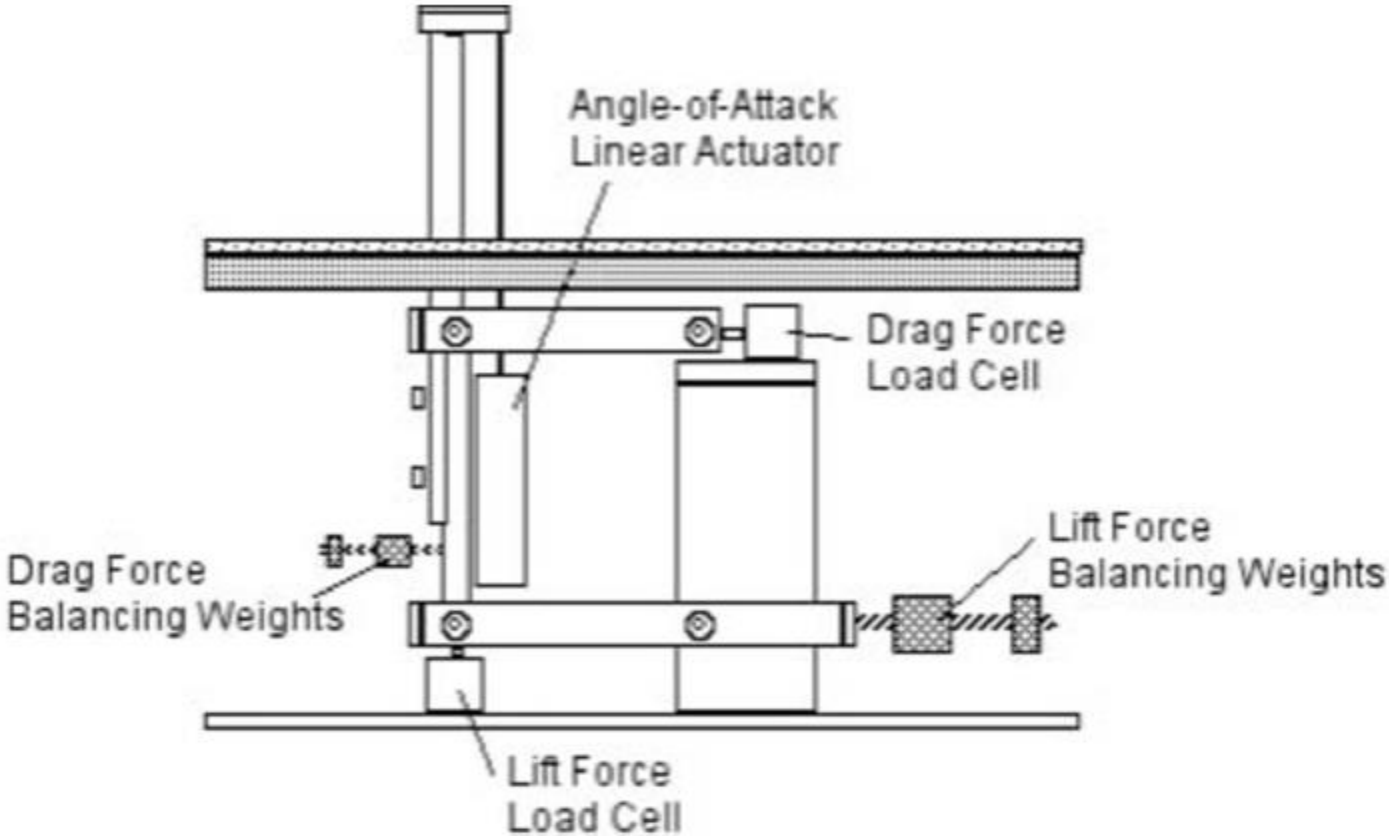


Figure 4: Diagram of Force Balance.

Morris & Post:
Force balance design for educational wind tunnels

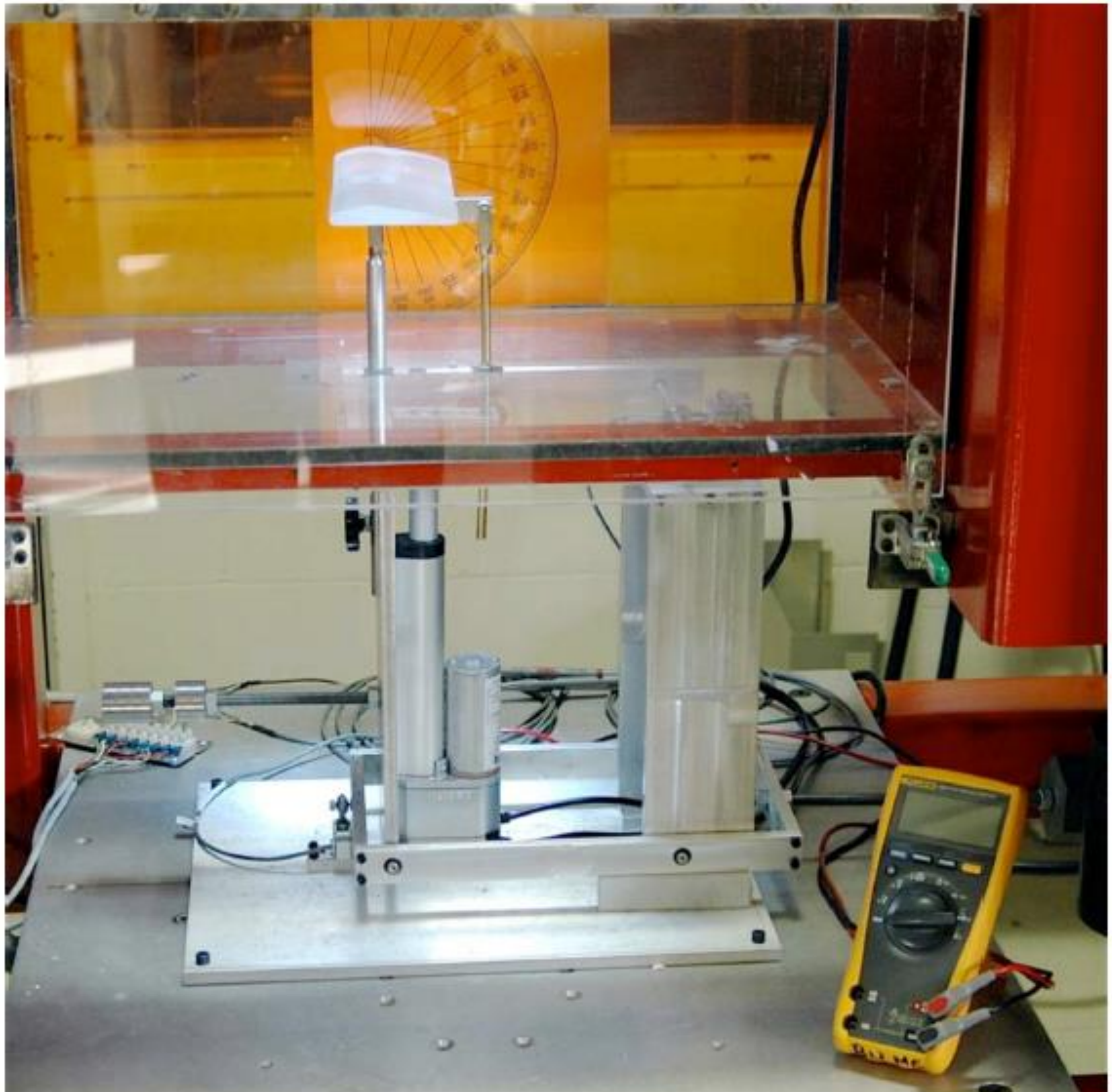
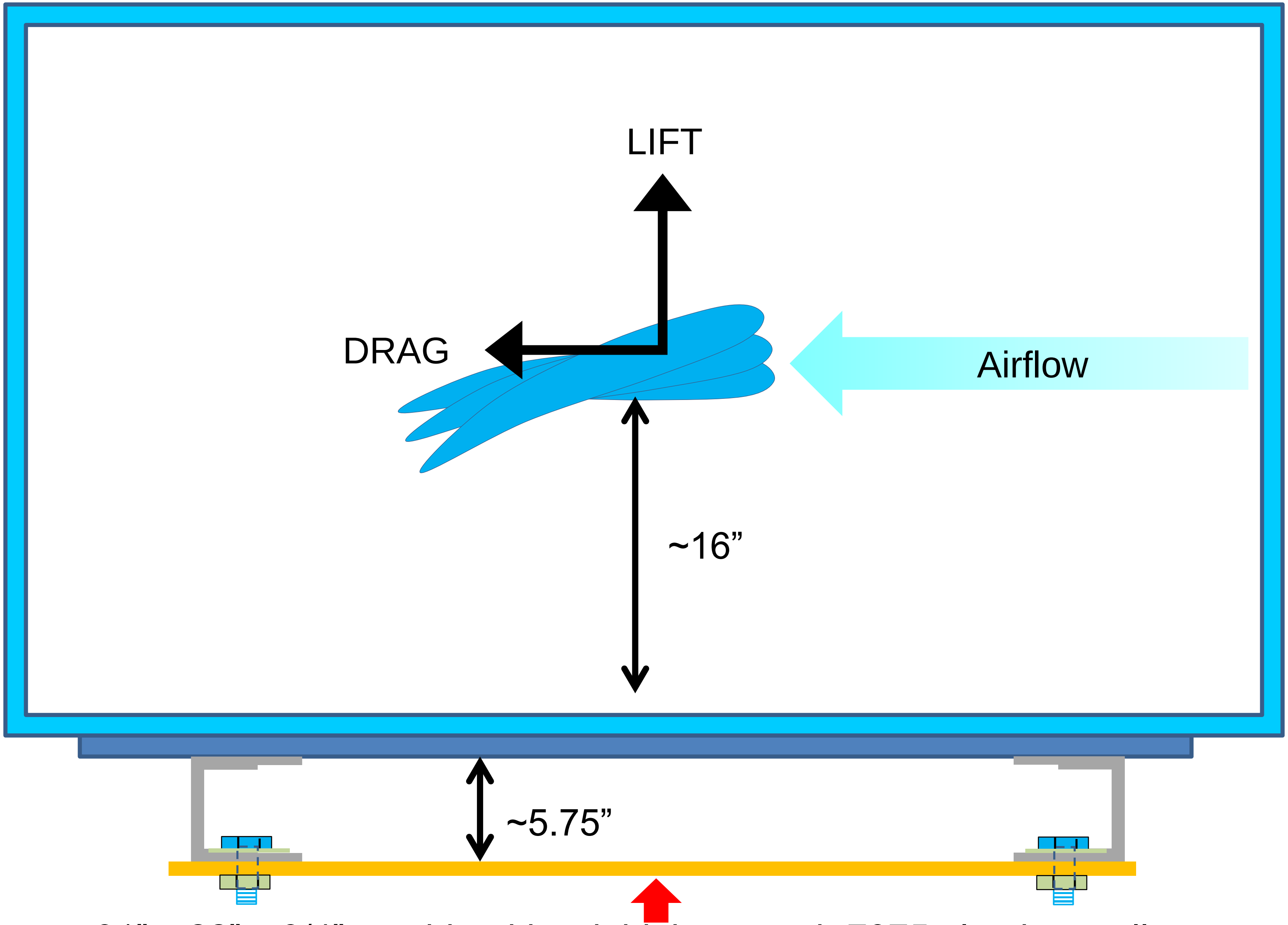


Figure 5: Picture of force balance installed in test section of wind tunnel.

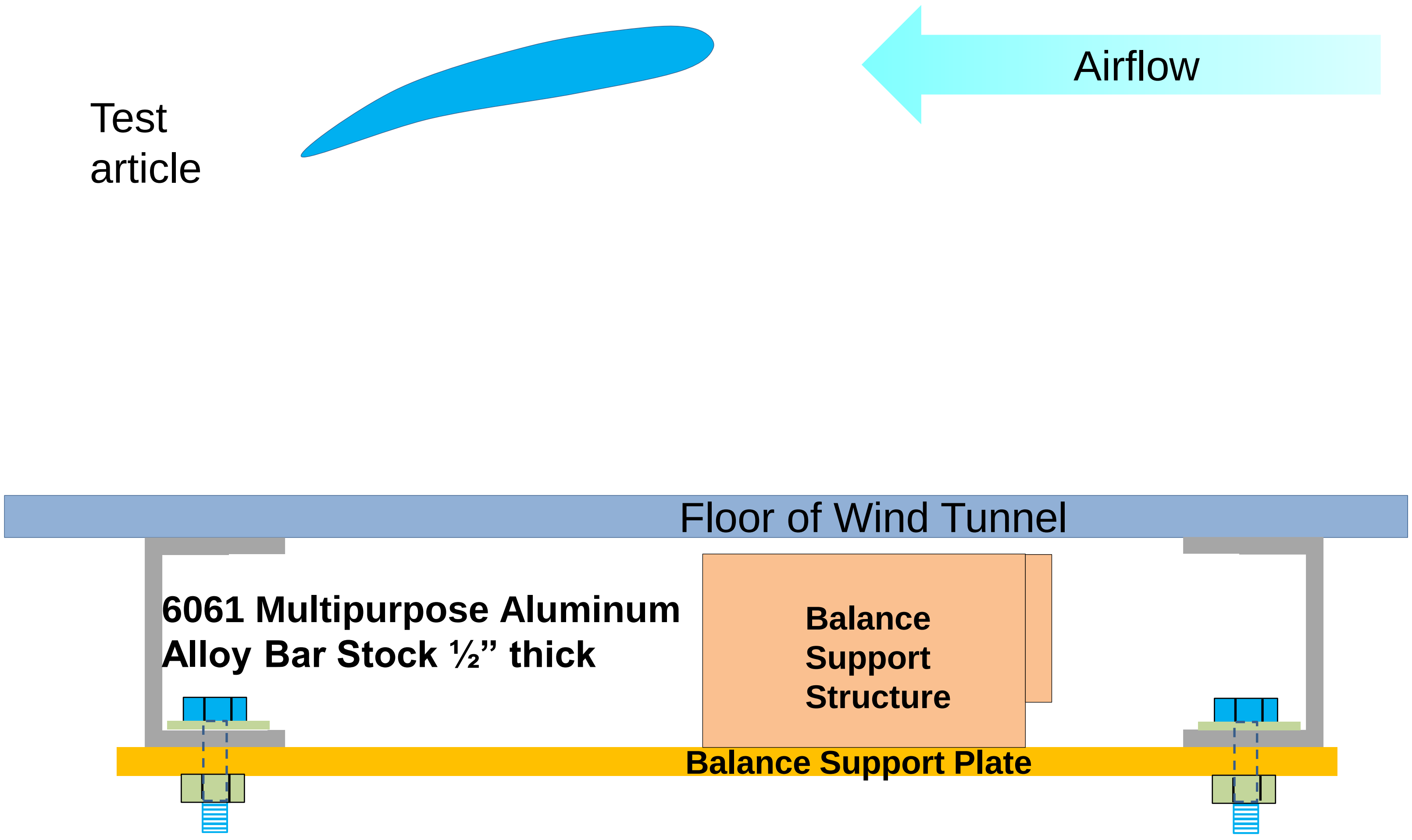
Mounting Base Plate



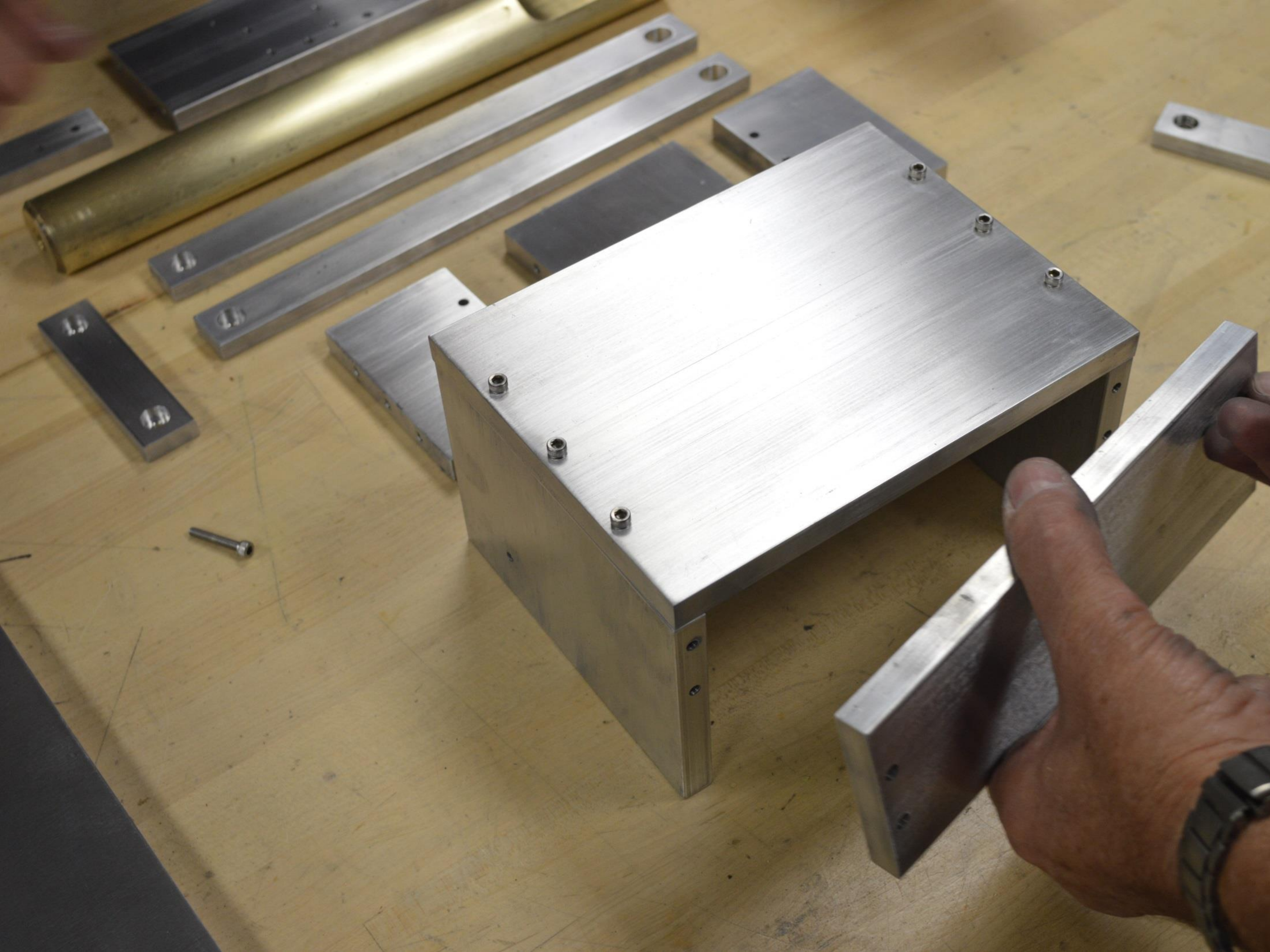
31” x 22” x 3/4” machined hard, high strength 7075 aluminum alloy

Mc=$700

Balance Support Structure

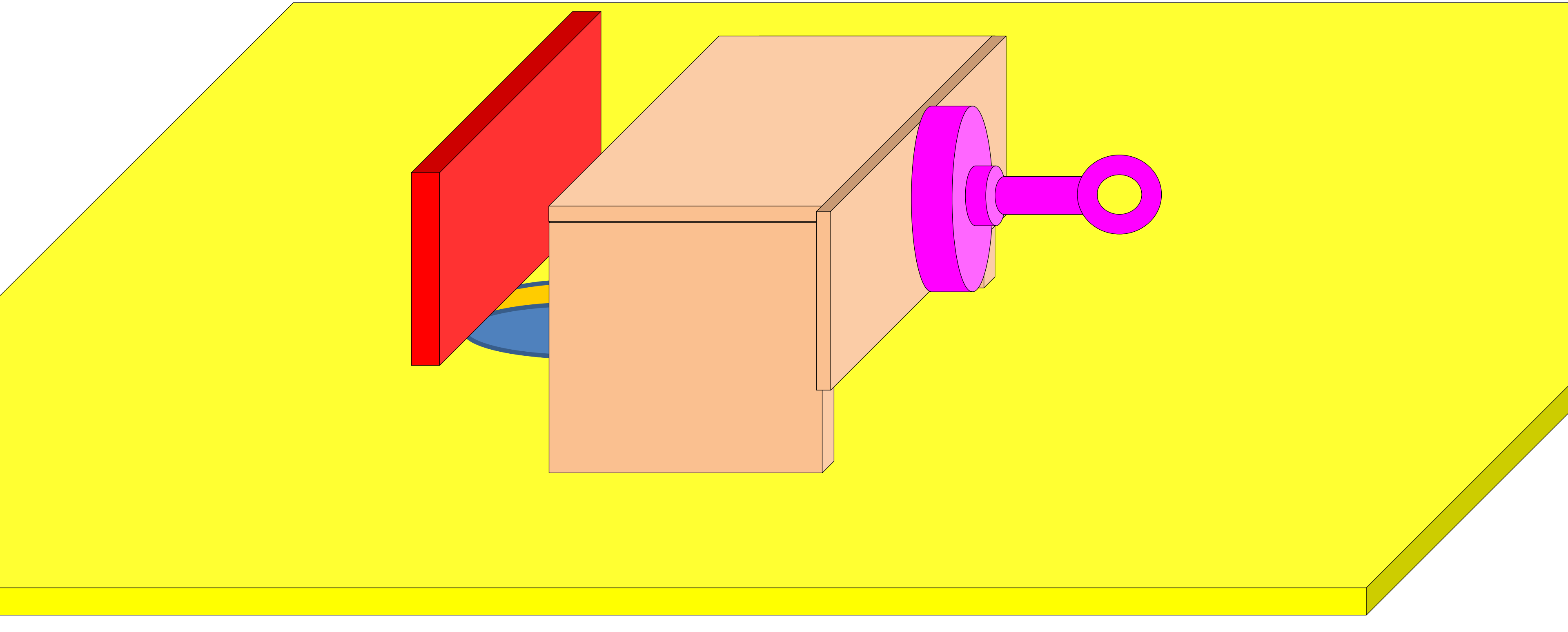



Metal Stock - ~$200 (Ebay!) +
Precision machining - $1200 =
Precision Machined Parts - $1400

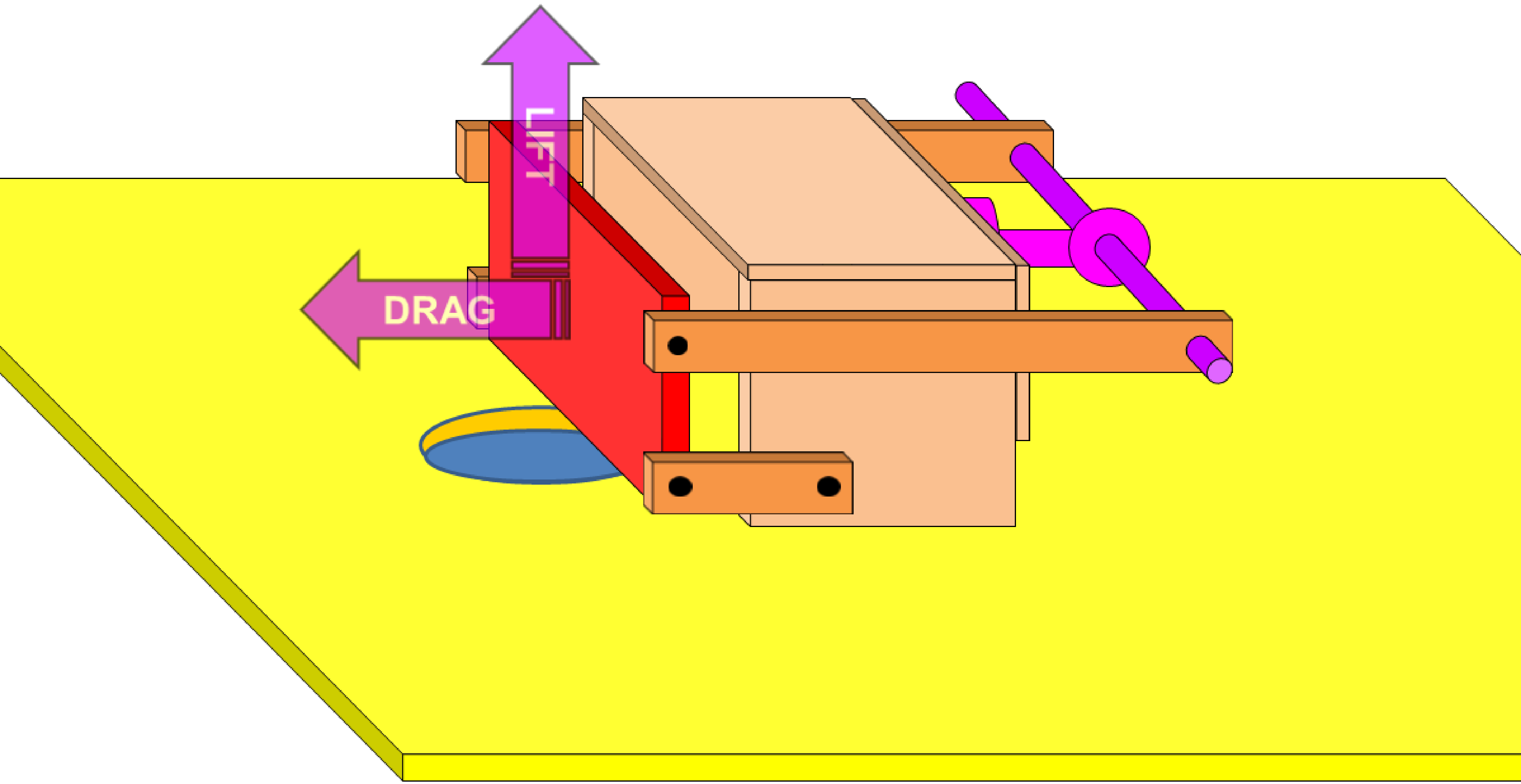


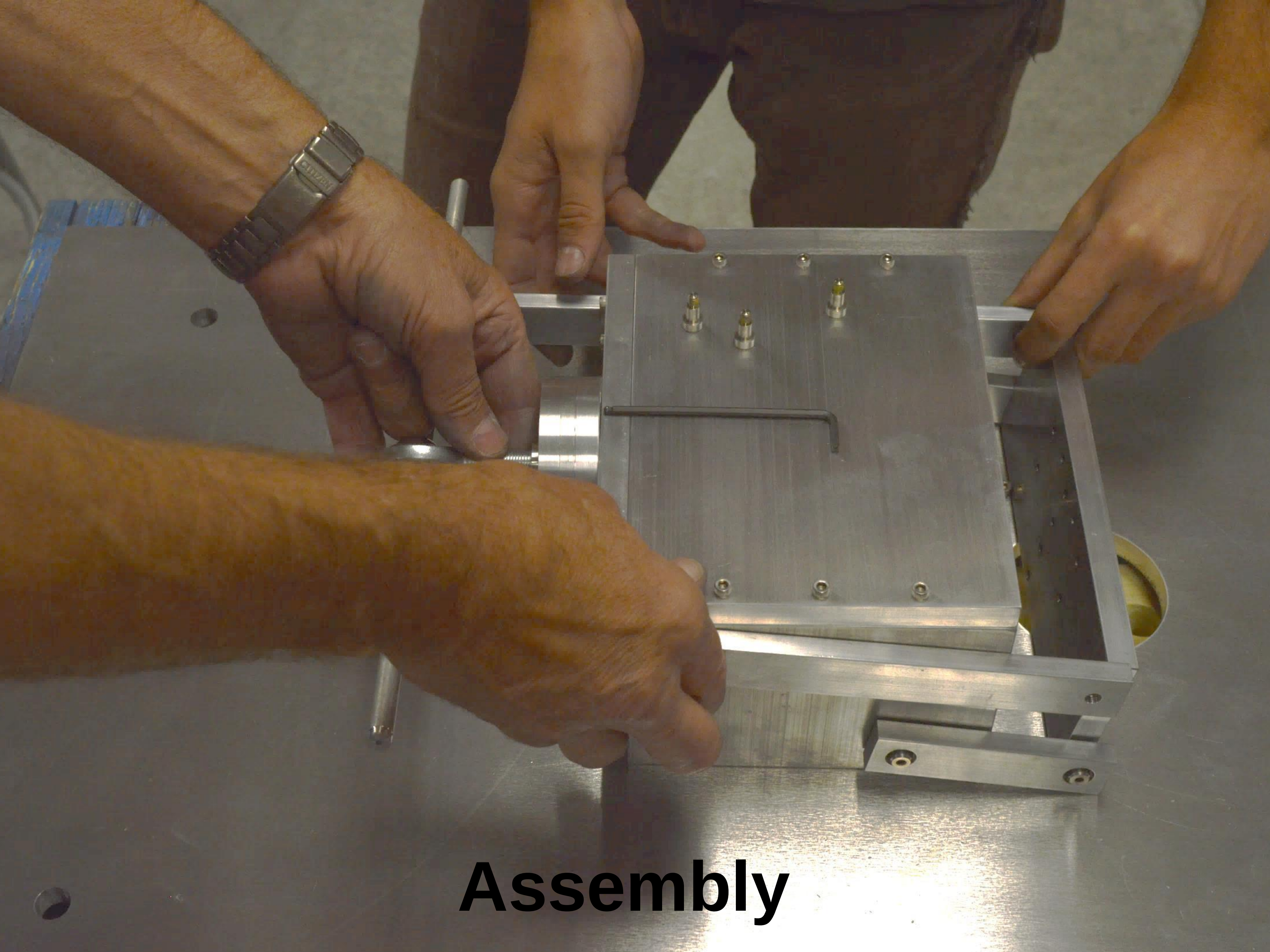
First Time Basic Structure Assembly

Placement of Drag Sensor



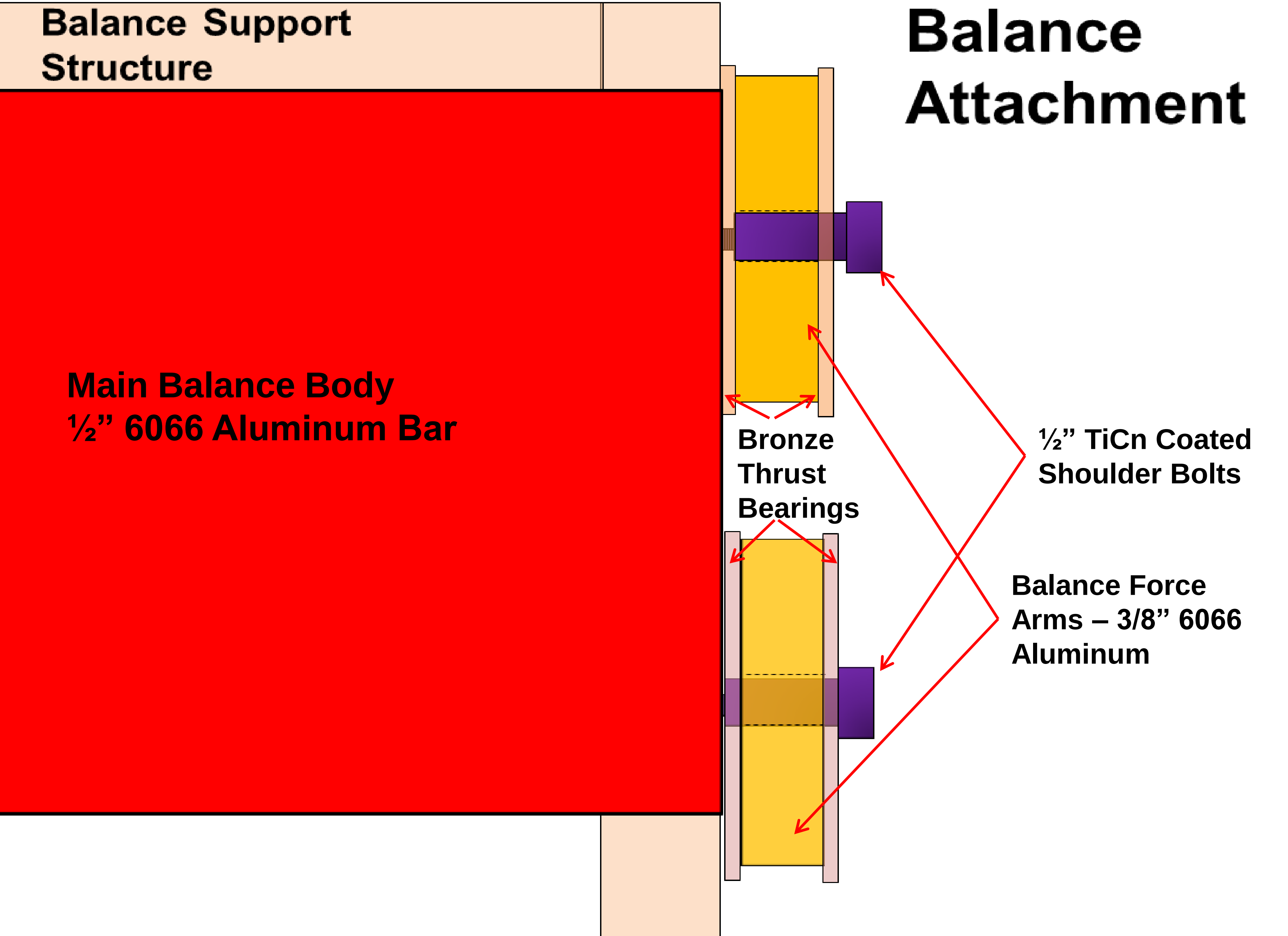
Drag Sensor and Balance



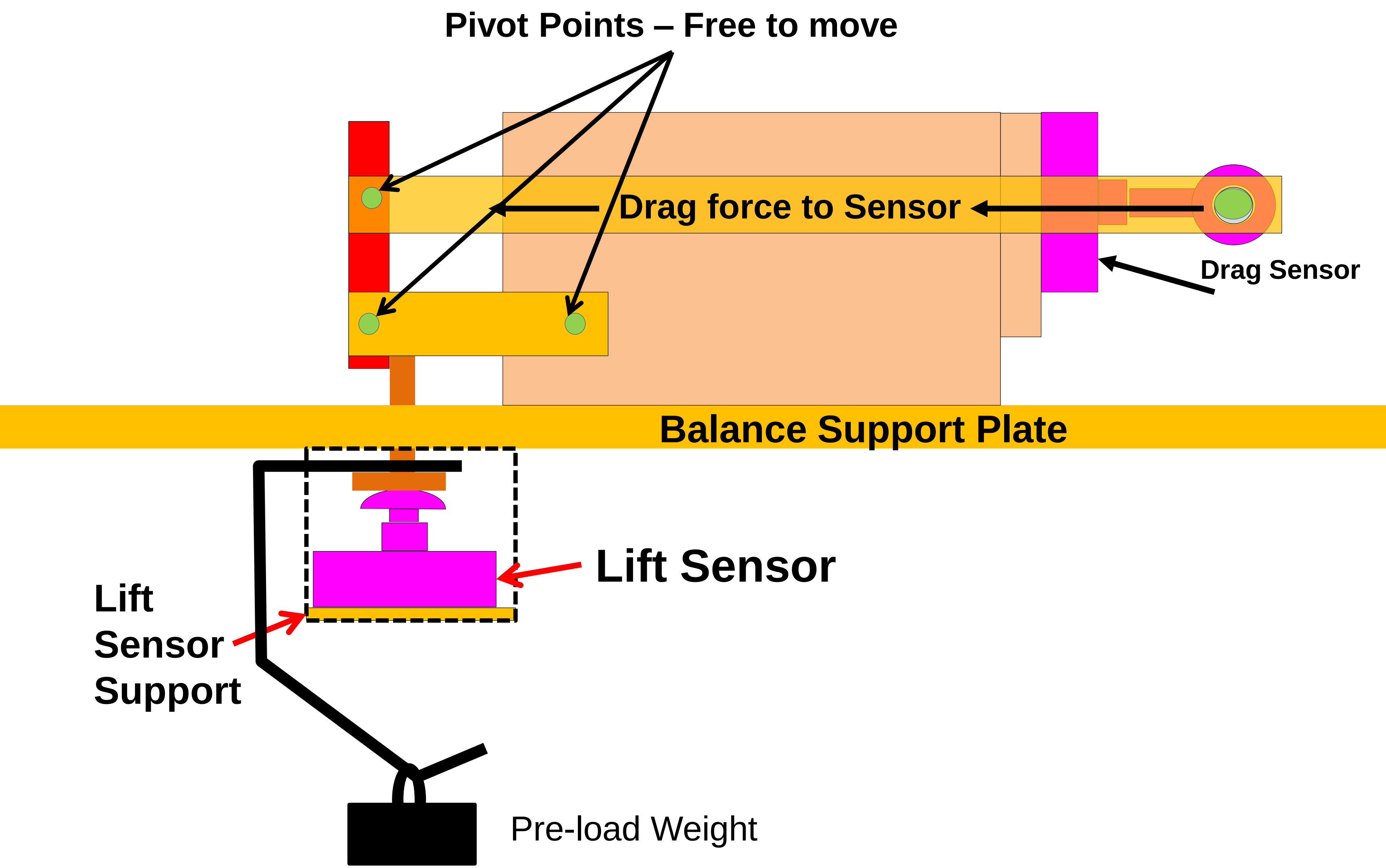


Assembly

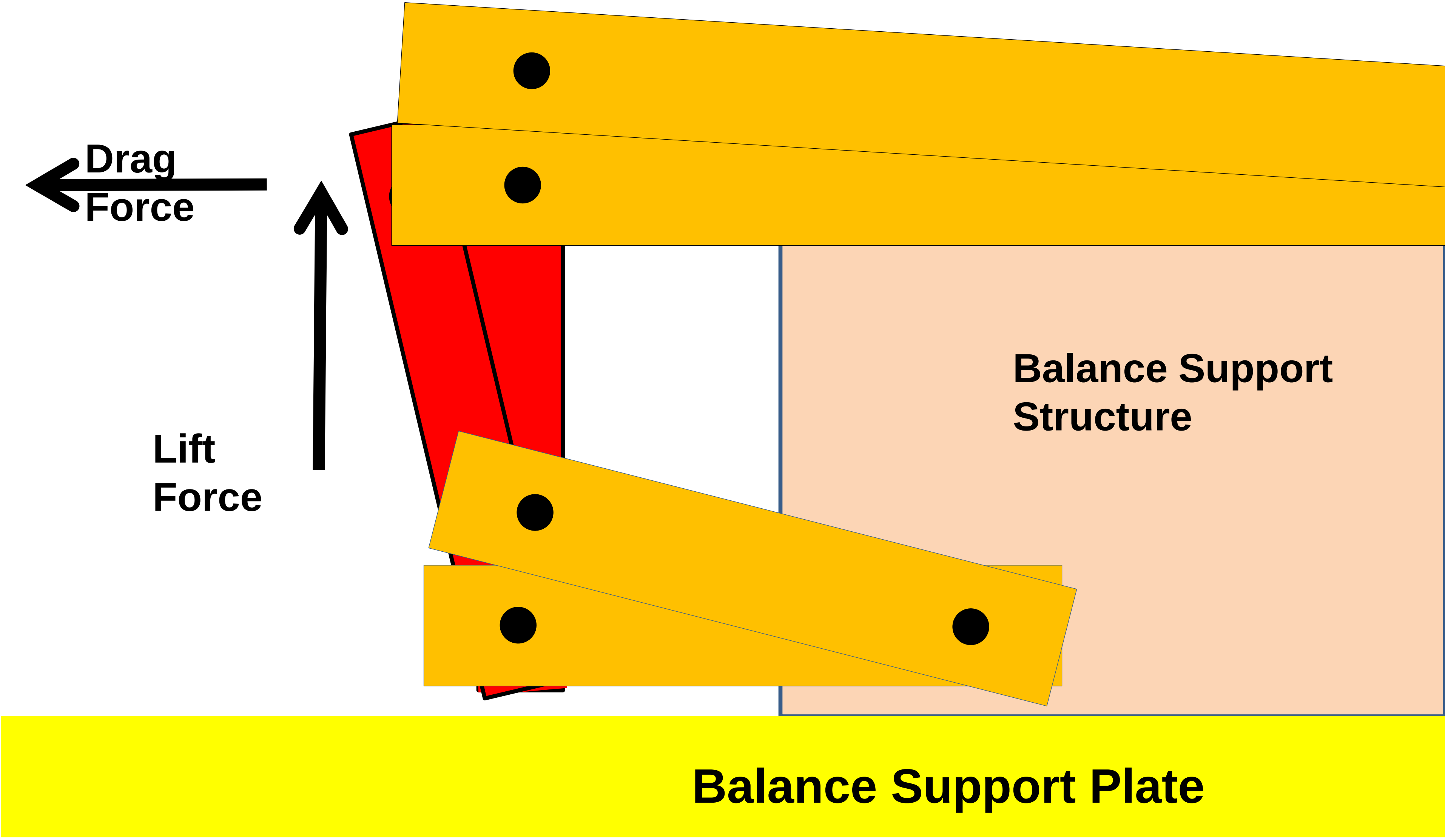
Friction Reducing Titanium carbonitride (TiCN) Coated 18-8stainless steel Shoulder Bolts

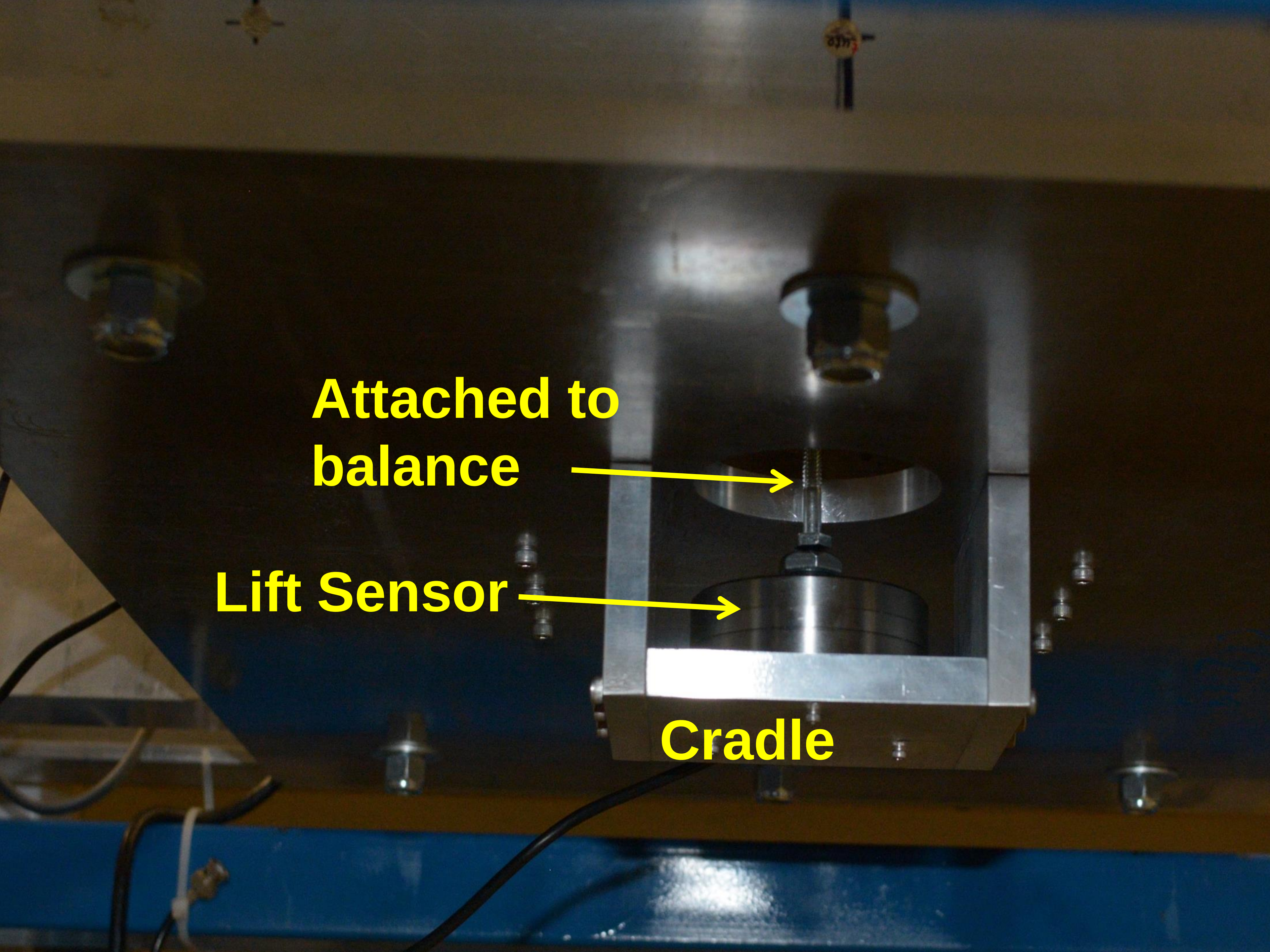

Balance Support
Structure
Balance
Attachment
Main Balance Body
½” 6066 Aluminum Bar
Bronze
Thrust
Bearings
½” TiCn Coated
Shoulder Bolts
Balance Force
Arms – 3/8” 6066
Aluminum

Installation of Lift Sensor

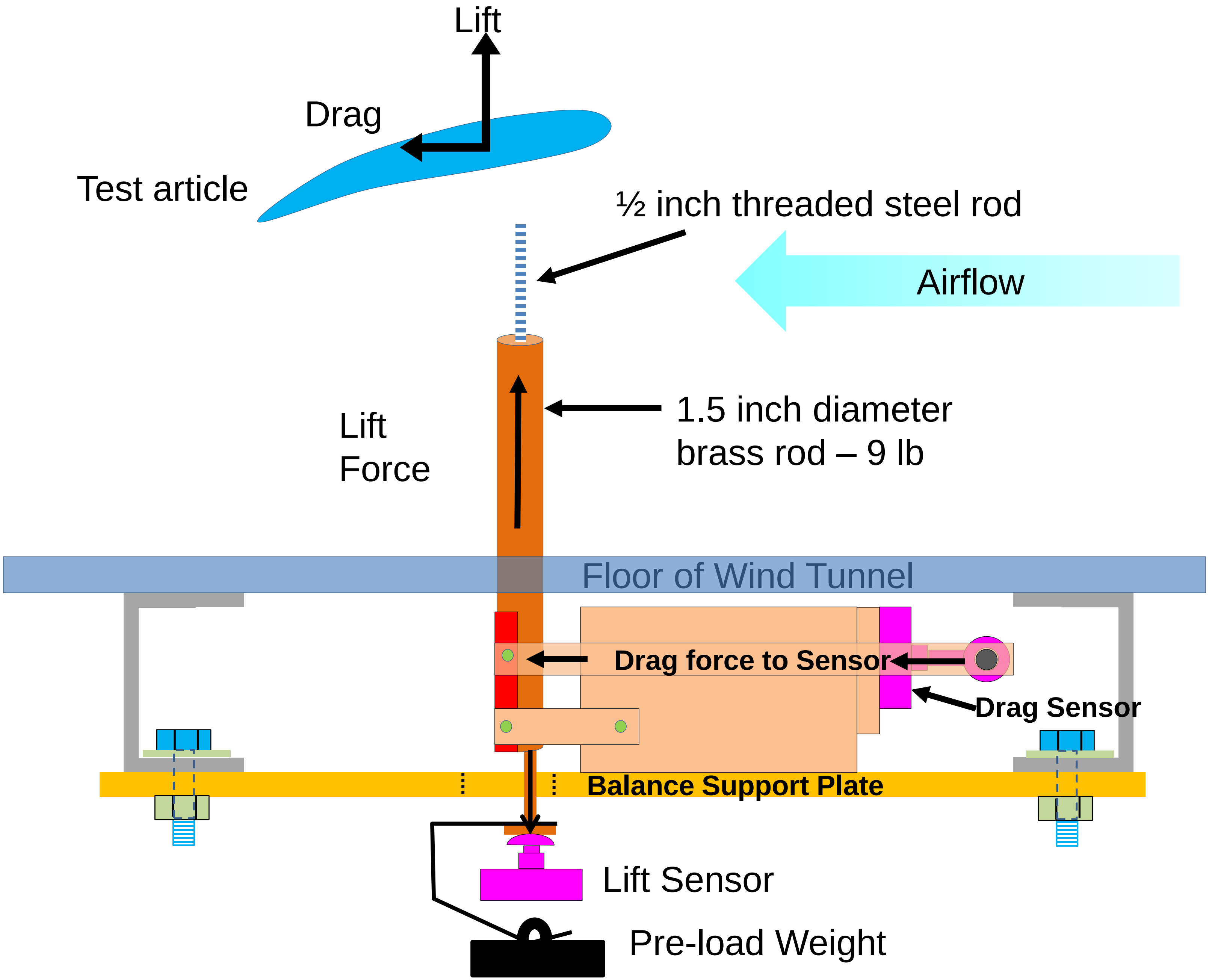


Balance Action (greatly exagerated)

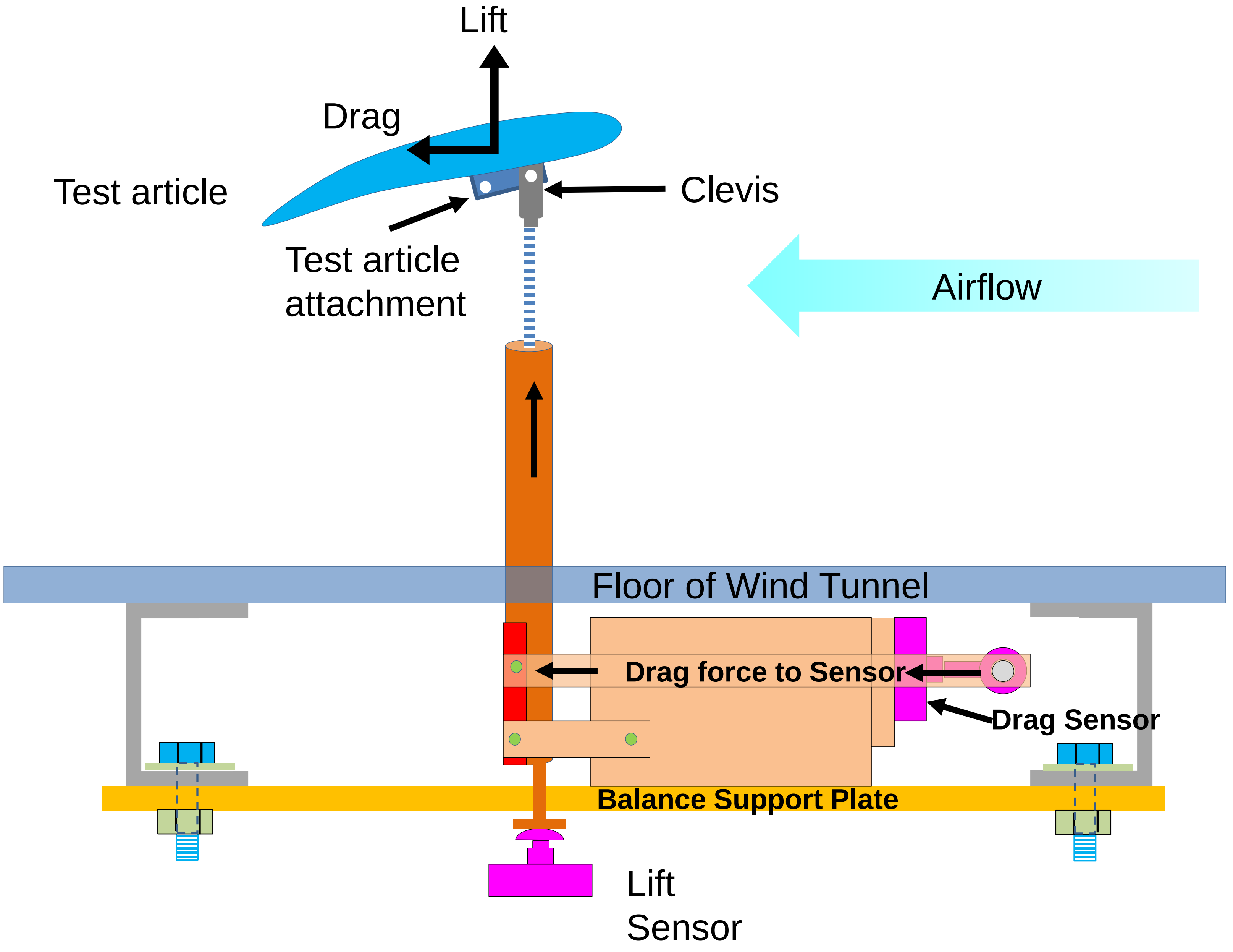



Attached to balance
Lift Sensor
Cradle

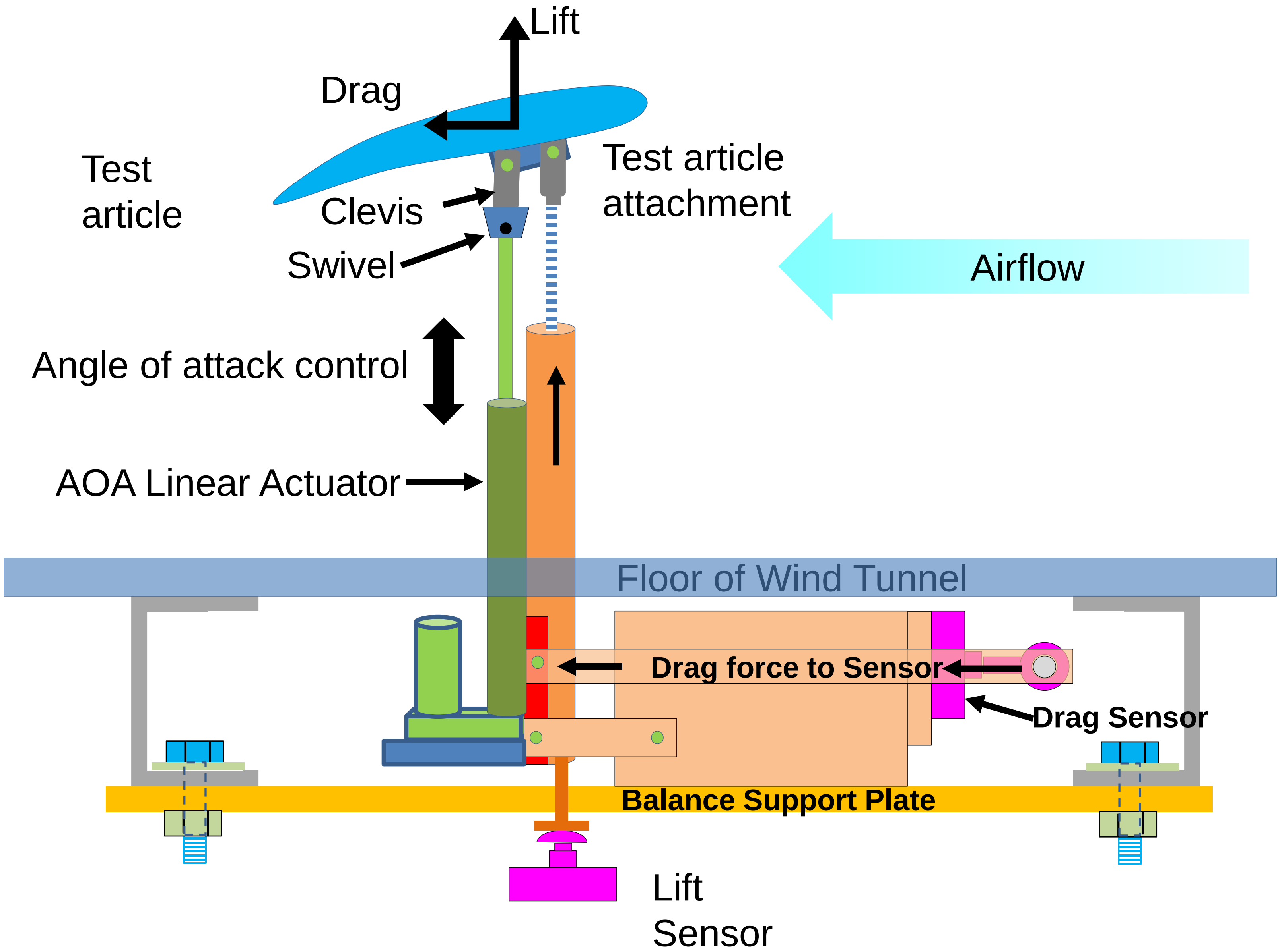
Test Article Attachment Post



Test Article Attachment Post



Angle of Attack Control

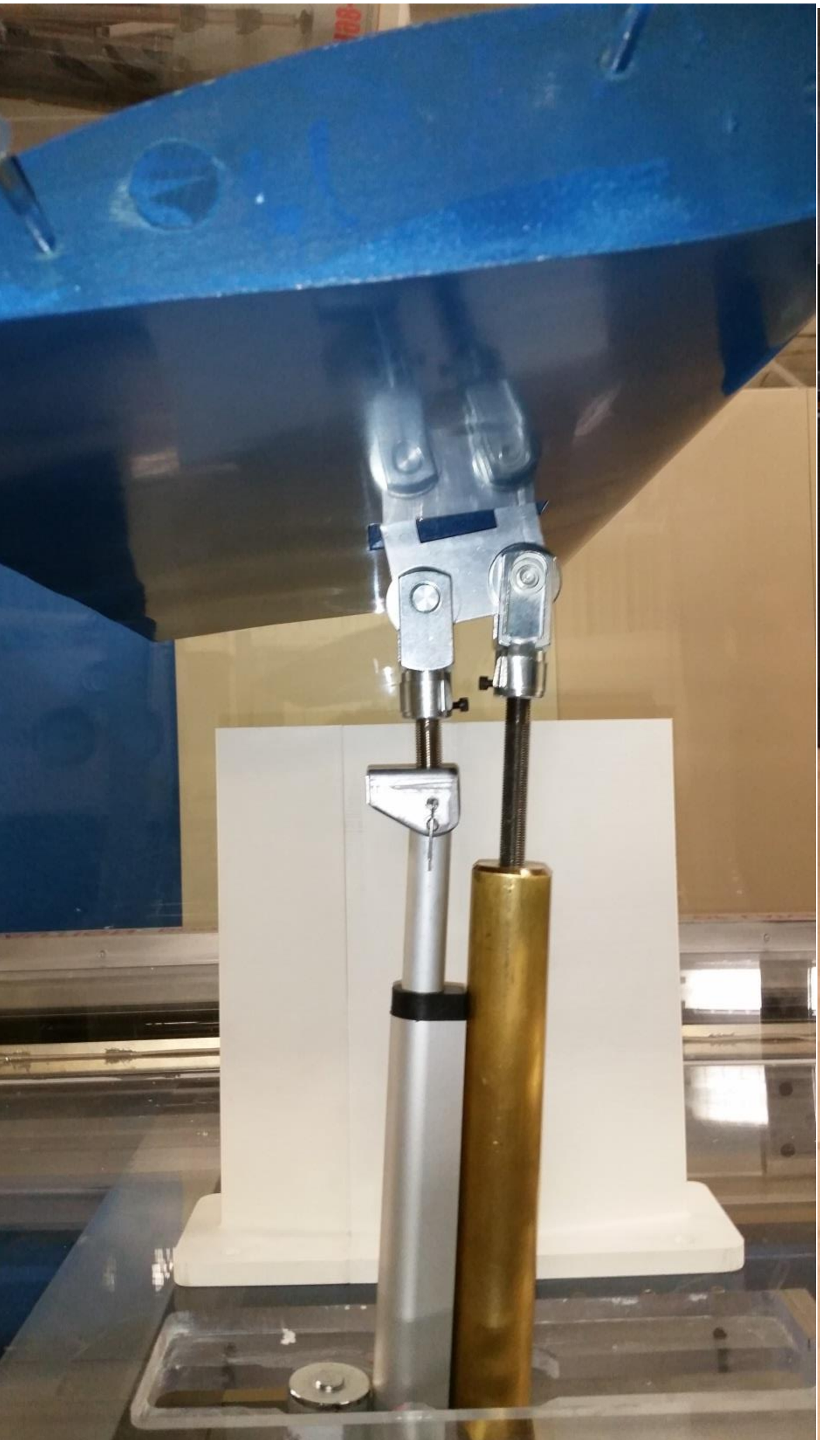


Balance

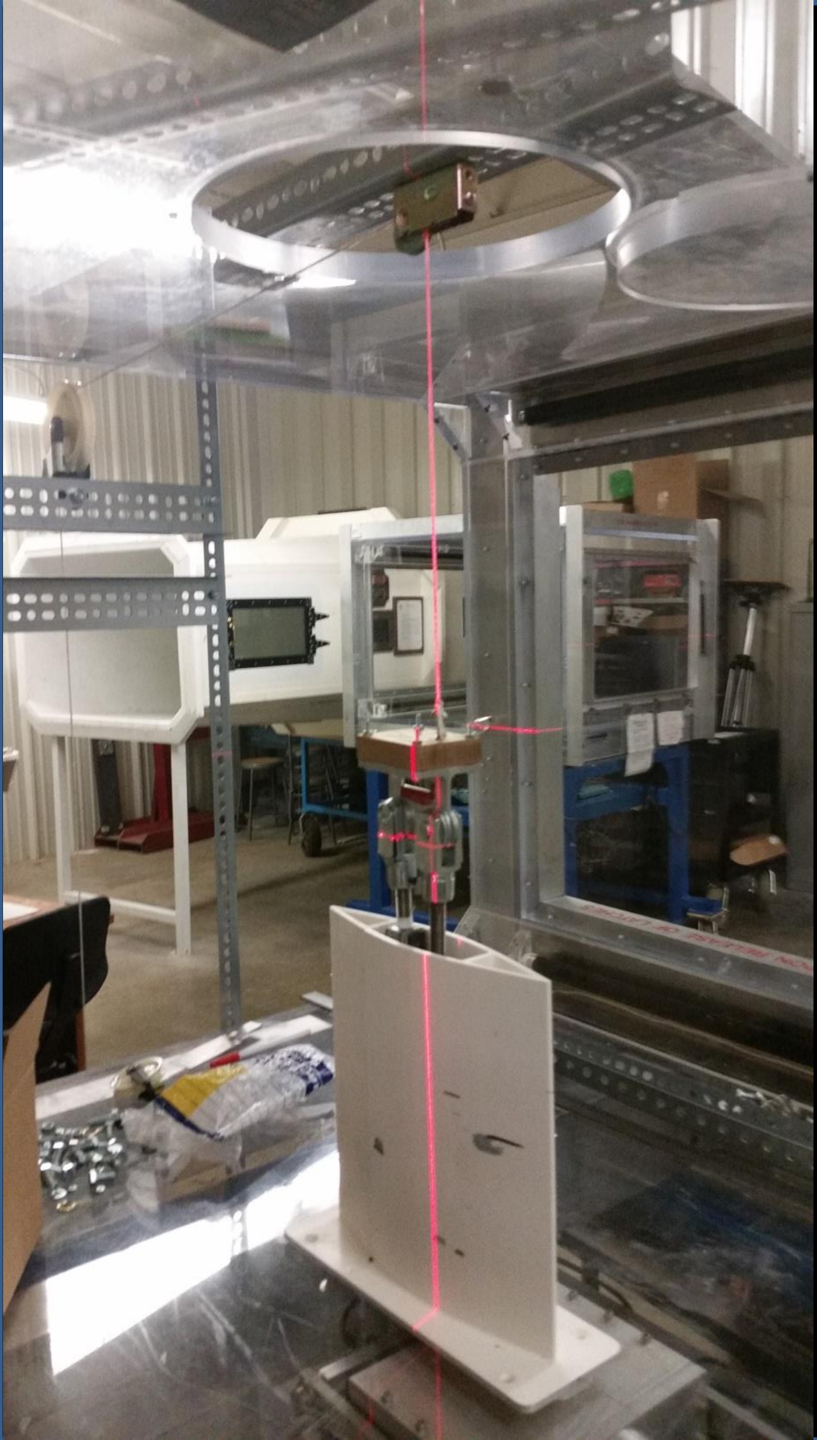
with test article attachment

and AOA control


First
Installation
Test

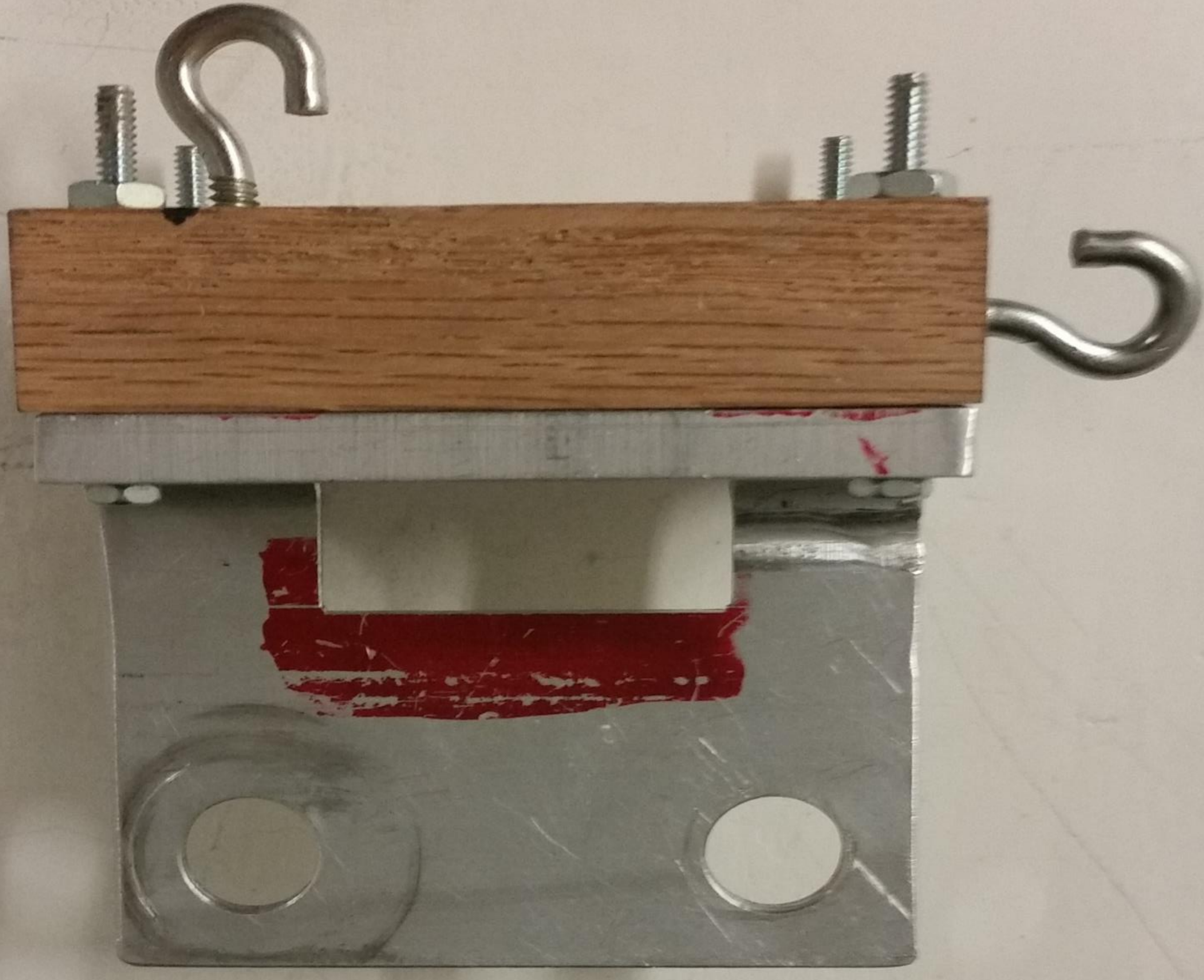


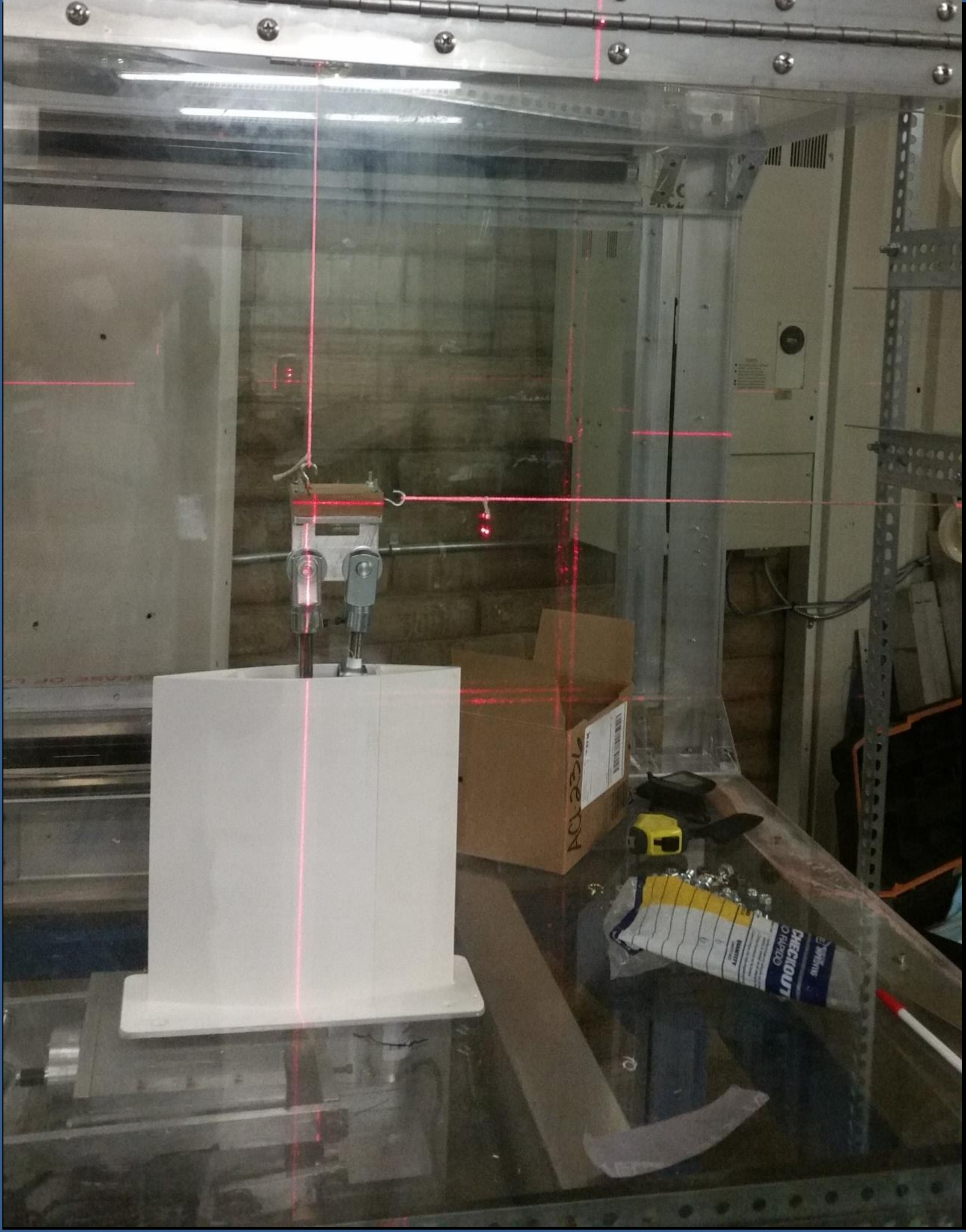

3-D Printed flow shield and wind splitter - $295



C A L I B R A T I O N

Calibration Rig -- Load Attachment Armature



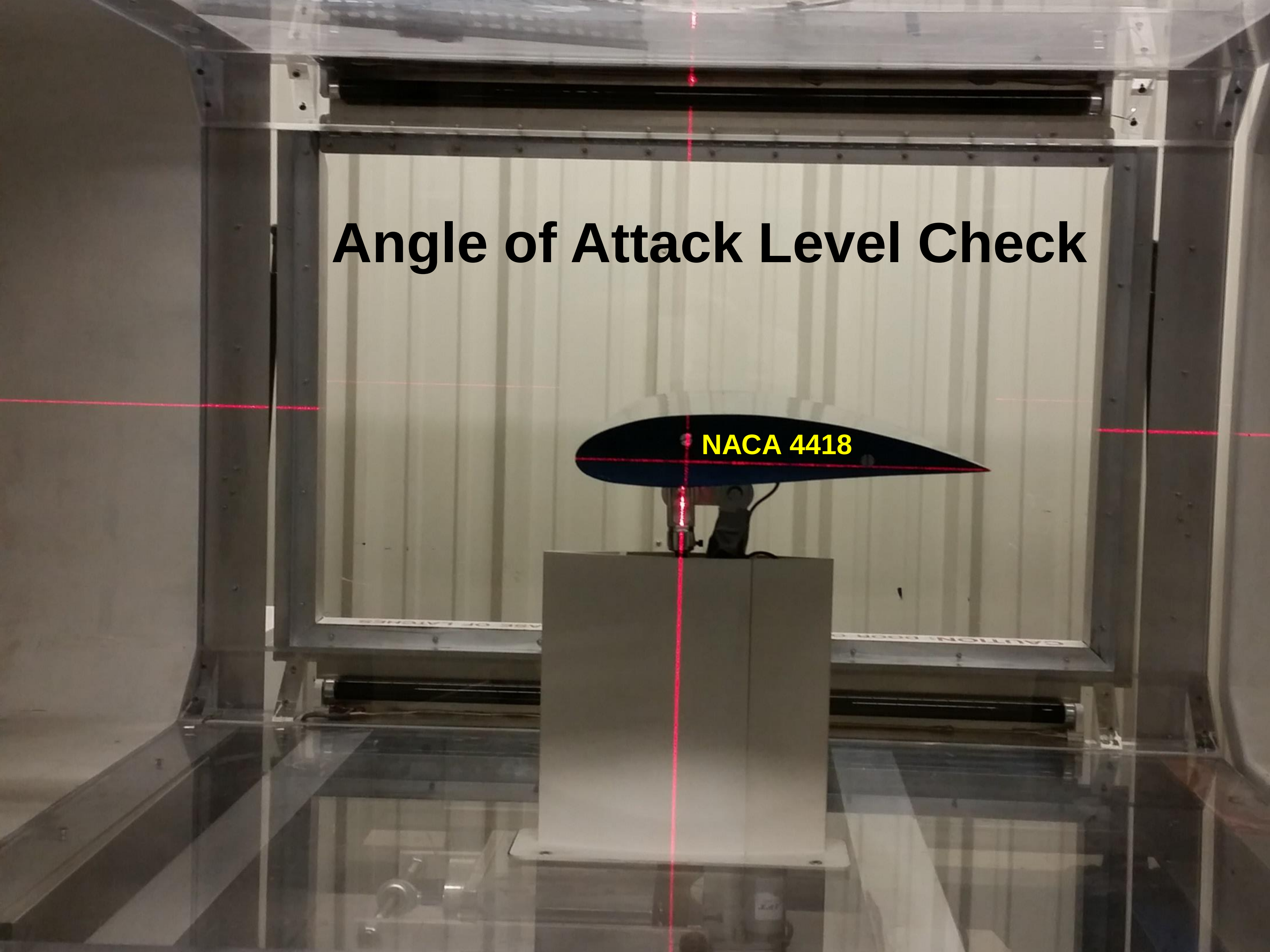


Wallboard LASER level - $100

Used for:

- **measurement checks**
- **centering and alignment**
- **calibration setup**
- **AOA calibration**
- **Many other applications**

Angle of Attack Level Check



Lessons Learned

- Design for maintenance
- Design for accessability
- If it really has to move freely – use ball or roller bearings
- Pre-load steel support has spring action that introduces/amplifies harmonic vibration
- We are considering a captured lift sensor


Thank
You !

Postscript: Redesign of lift channel after discovery of vibration induced problems with initial design.