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
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.
Diagram of typical wind tunnel.
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
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.


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

Airflow

LIFT

DRAG

~16”

~5.75”

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

Mc=$700
Balance Support Structure

6061 Multipurpose Aluminum Alloy Bar Stock 1/2” thick

Balance Support Plate

Floor of Wind Tunnel

Airflow

Test article
Metal Stock - ~$200 (Ebay!) + Precision machining - $1200 = Precision Machined Parts - $1400
First Time Basic Structure Assembly
Placement of Drag Sensor
Drag Sensor and Balance
Friction Reducing Titanium carbonitride (TiCN) Coated 18-8stainless steel Shoulder Bolts
Main Balance Body

½” 6066 Aluminum Bar

Balance Support Structure

Bronze Thrust Bearings

½” TiCn Coated Shoulder Bolts

Balance Force Arms – 3/8” 6066 Aluminum
Installation of Lift Sensor

Lift Sensor Support

Pivot Points – Free to move

Drag force to Sensor

Balance Support Plate

Lift Sensor

Pre-load Weight
Lift Sensor
Attached to balance
Cradle
Test Article Attachment Post

Lift

Drag

Test article

½ inch threaded steel rod

1.5 inch diameter brass rod – 9 lb

Airflow

Lift Force

Floor of Wind Tunnel

Drag force to Sensor

Drag Sensor

Balance Support Plate

Lift Sensor

Pre-load Weight
Test Article Attachment Post

Test article

Lift

Drag

Clevis

Test article attachment

Floor of Wind Tunnel

Balance Support Plate

Drag force to Sensor

Drag Sensor

Lift Sensor

Airflow
Angle of Attack Control

Test article

Clevis

Swivel

Test article attachment

Airflow

Angle of attack control

AOA Linear Actuator

Floor of Wind Tunnel

Balance Support Plate

Drag force to Sensor

Drag Sensor

Lift Sensor
Balance
with test article attachment
and AOA control
3-D Printed flow shield and wind splitter - $295
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

NACA 4418
Lessons Learned

• Design for maintenance

• Design for accessibility

• 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!
Airflow

Angle of attack control

AOA Actuator

Test article

Attachment

Drag force to Sensor

Drag Sensor

Lift Sensor

Balance Support Plate

Floor of Wind Tunnel

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