Deturbulation

In a Nutshell

Jim Hendrix

The Deturbulator Project

www.deturbulator.org

Revised 5/6/2012

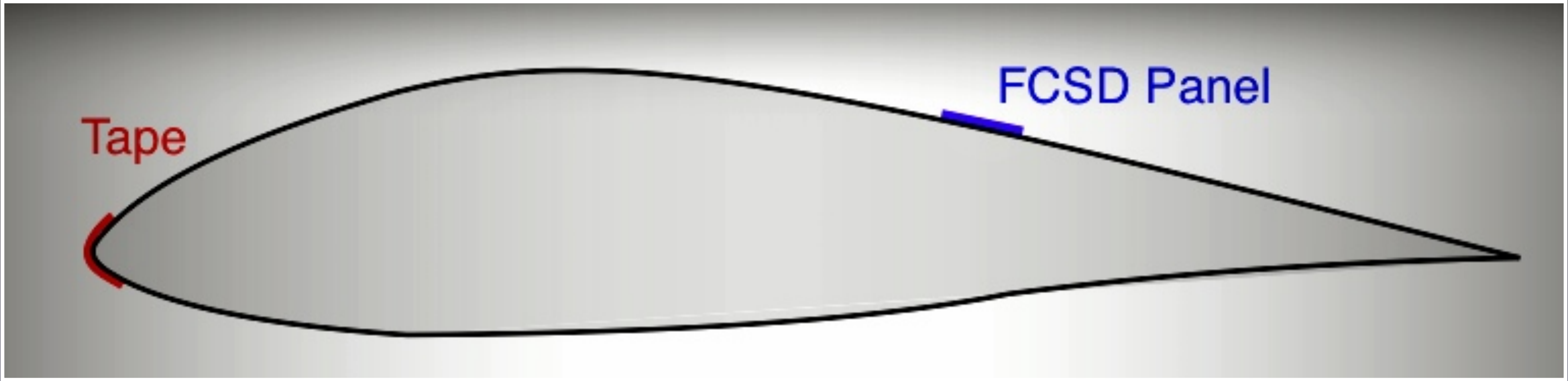
- **Overview**
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

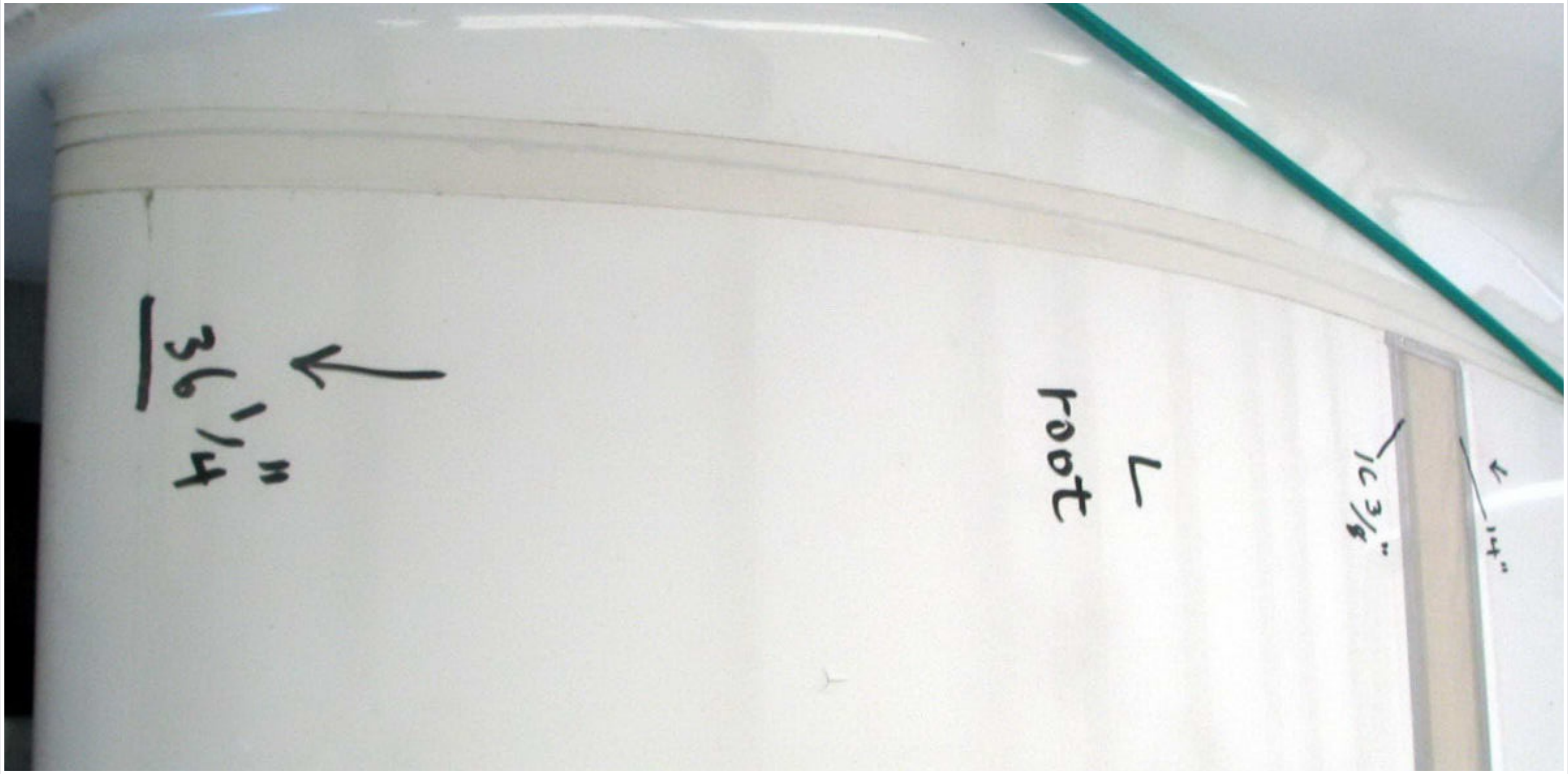
Overview: Deturbulator Components

In-flight measurements and other evidence indicate that boundary layers on some precision Wortmann airfoils flying at glider Reynolds numbers may be modified in new ways to achieve large performance improvements. Two components were used to achieve these results:

- A minute, spanwise, rear-facing step near the leading edge. These were achieved with .0025" thick glossy **tape** (carton sealing tape or similar).
- Thin, 2" wide, **flexible composite surface deturbulator** (**FCSD**) **panels**, oriented spanwise behind the reattachment point on the top surface. These consist of a very thin, flexible, dimensionally stable membrane lying over a textured substrate, trapping a thin layer of air beneath.

Overview: Full Configuration





Leading Edge Tape (.0025 inch thick) and FCSD Panel (at .6 chord)

Overview: Participants

Dr. Sumon K. Sinha (Oxford, Mississippi, Fluid Dynamics) invented the deturbulator concept.

Jim Hendrix (Oxford, Mississippi, Physics) built the test instrumentation and performed the flight tests and data reduction work. He continues to investigate deturbulator phenomena with help from volunteers around the world. His purpose is to amass enough evidence to justify serious investigation by professional aerodynamicists.

Overview: Participants

Jari Hyvärinen (Vintrosa, Sweden) is an aerodynamics consultant specializing in aeroelasticity. He is also developer of the LINFLOW commercial software package. Of the participants, Jari and daughter, Ann (aerodynamics student), are at the forefront of investigations into the phenomenon. They are modeling the modes of the FCSD panel, the behavior of the boundary flow behind the leading edge tape as well as overall wing aerodynamics. These simulations are being verified by in-flight pressure and sound measurements plus video evidence.

Overview: Participants

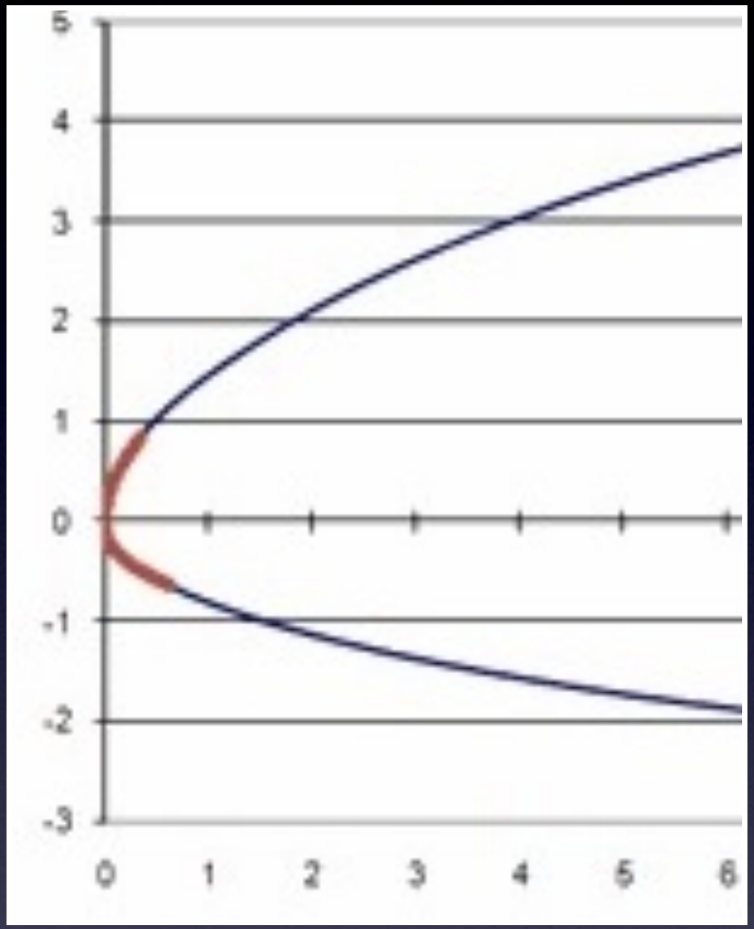
Aaron Kiley and Tom Shipp (Plymouth, Michigan) are assisting with performance measurements of the lower-surface, leading-edge tape mod. Mainly, they are investigating the effects of wing surface preparation on performance.

Aaron Kiley

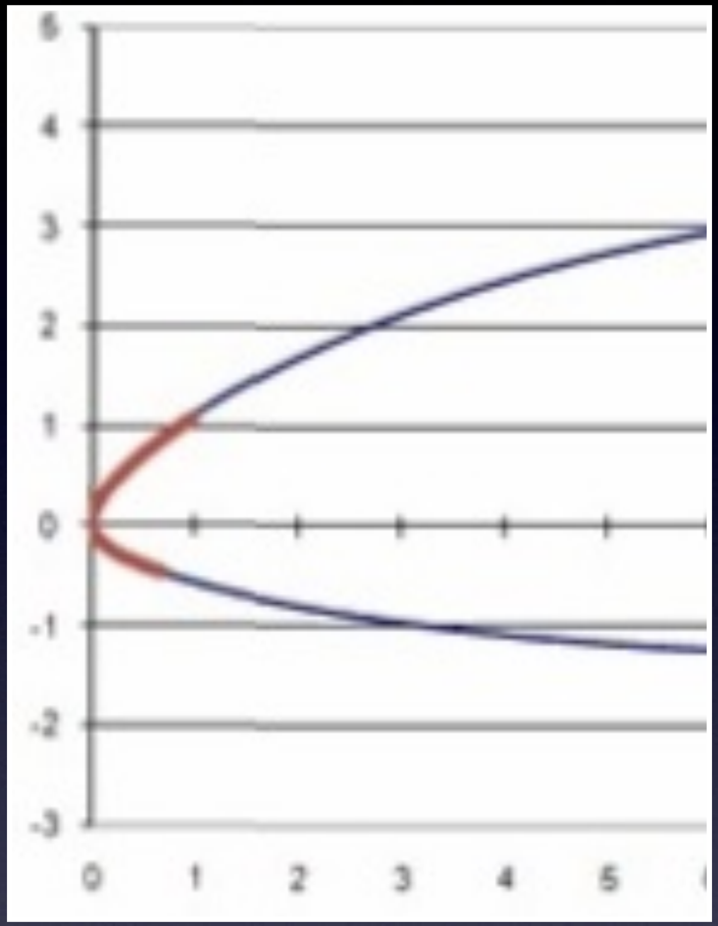
Tom Shipp

- Overview
- **Tapes**
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

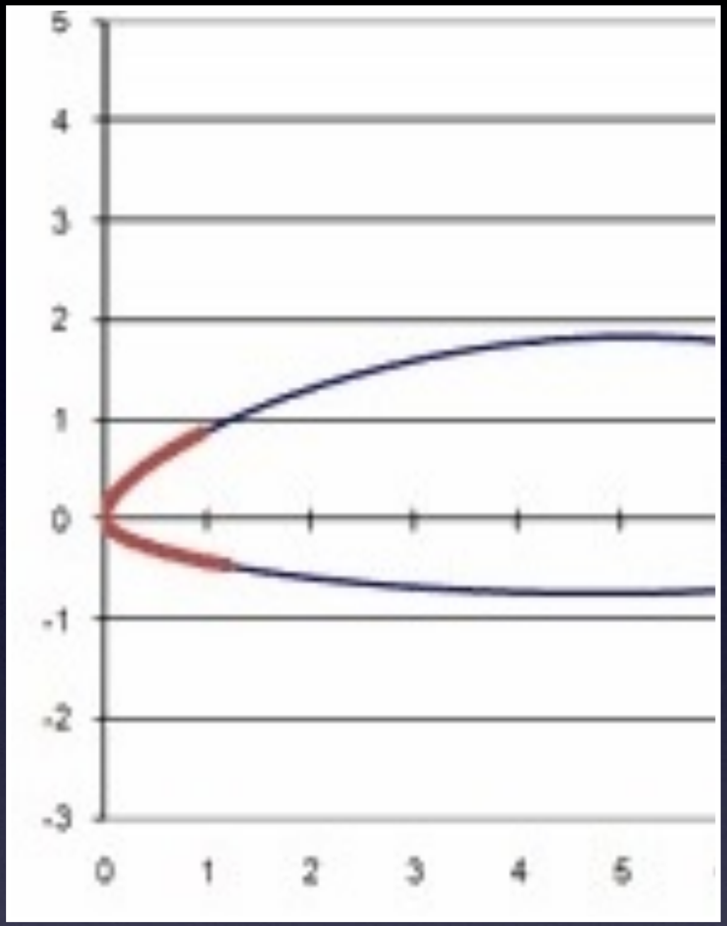
Tapes: Position



Wing Root



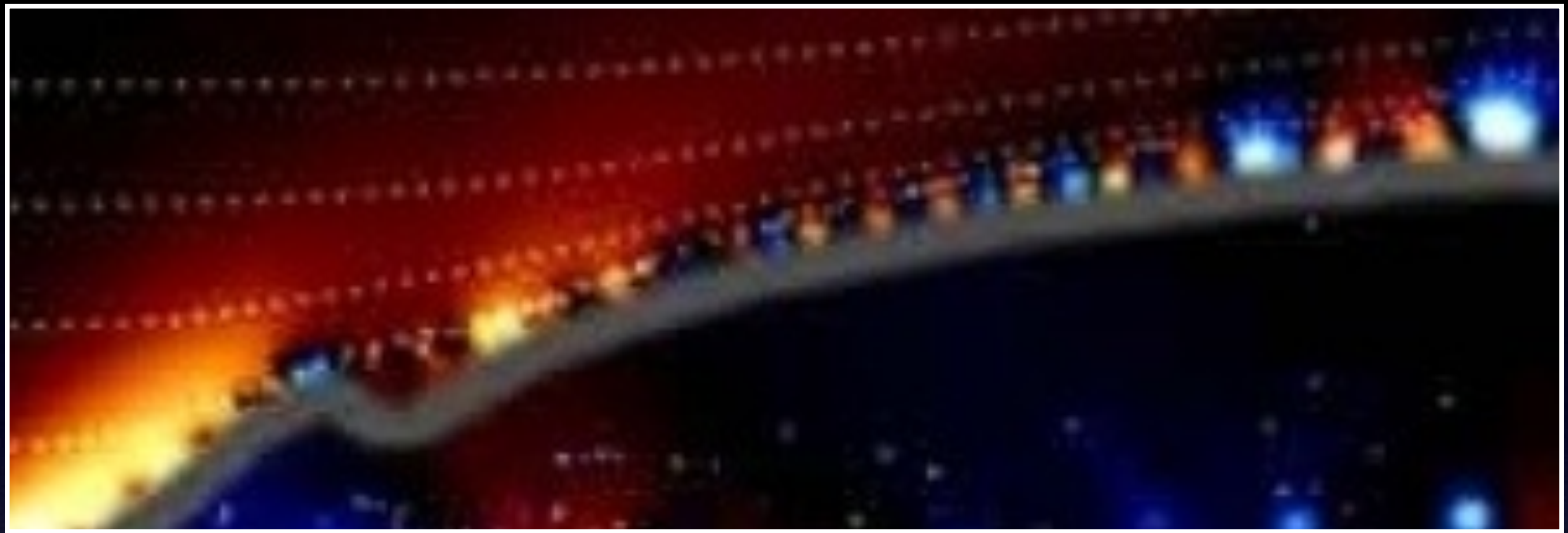
Inboard End of Aileron



Wing Tip

The tape thickness is .0025 inches (64 microns), less than the critical roughness Reynolds number for a rear-facing step, so the tape does not trip the flow.

Tapes: Function

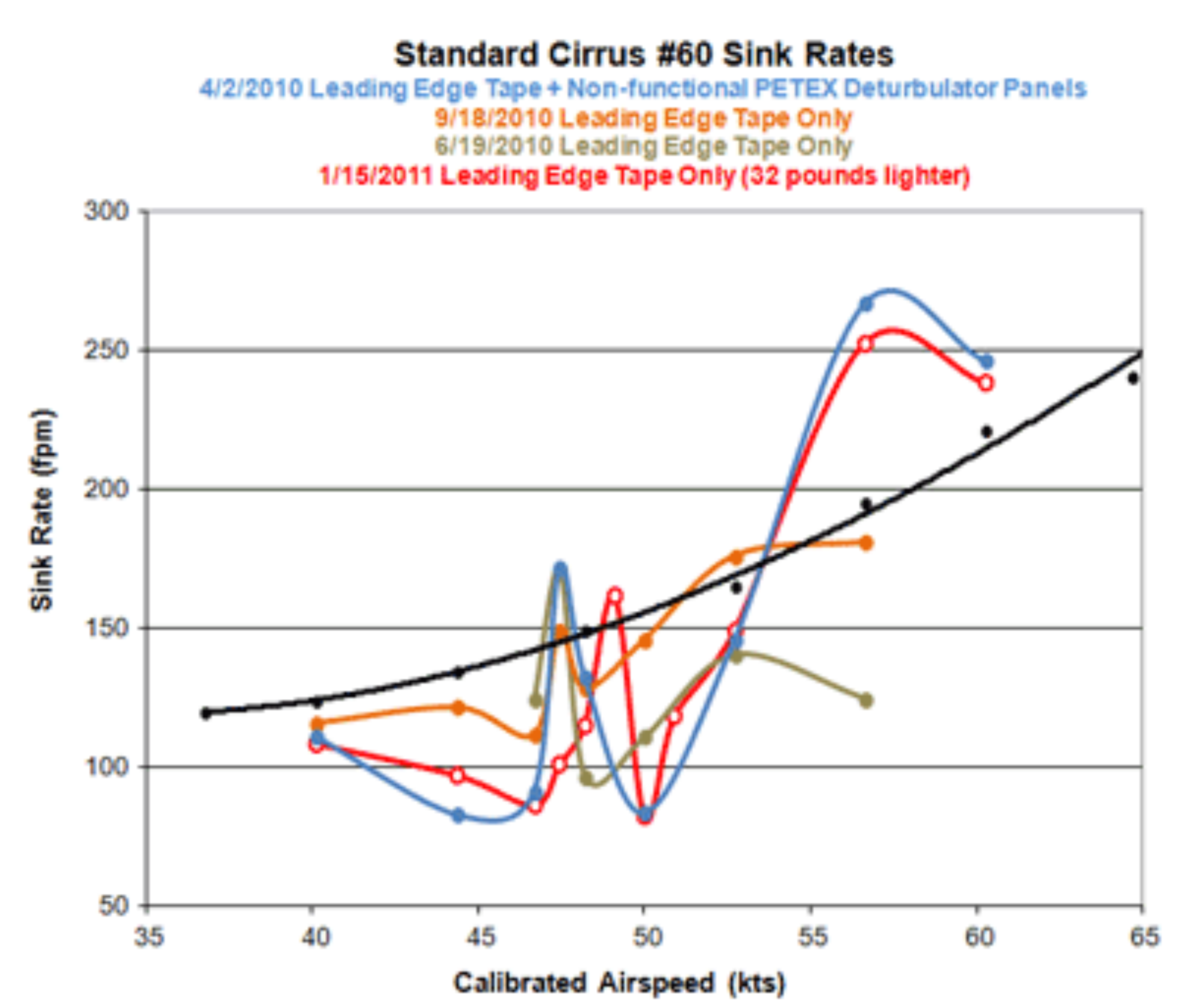


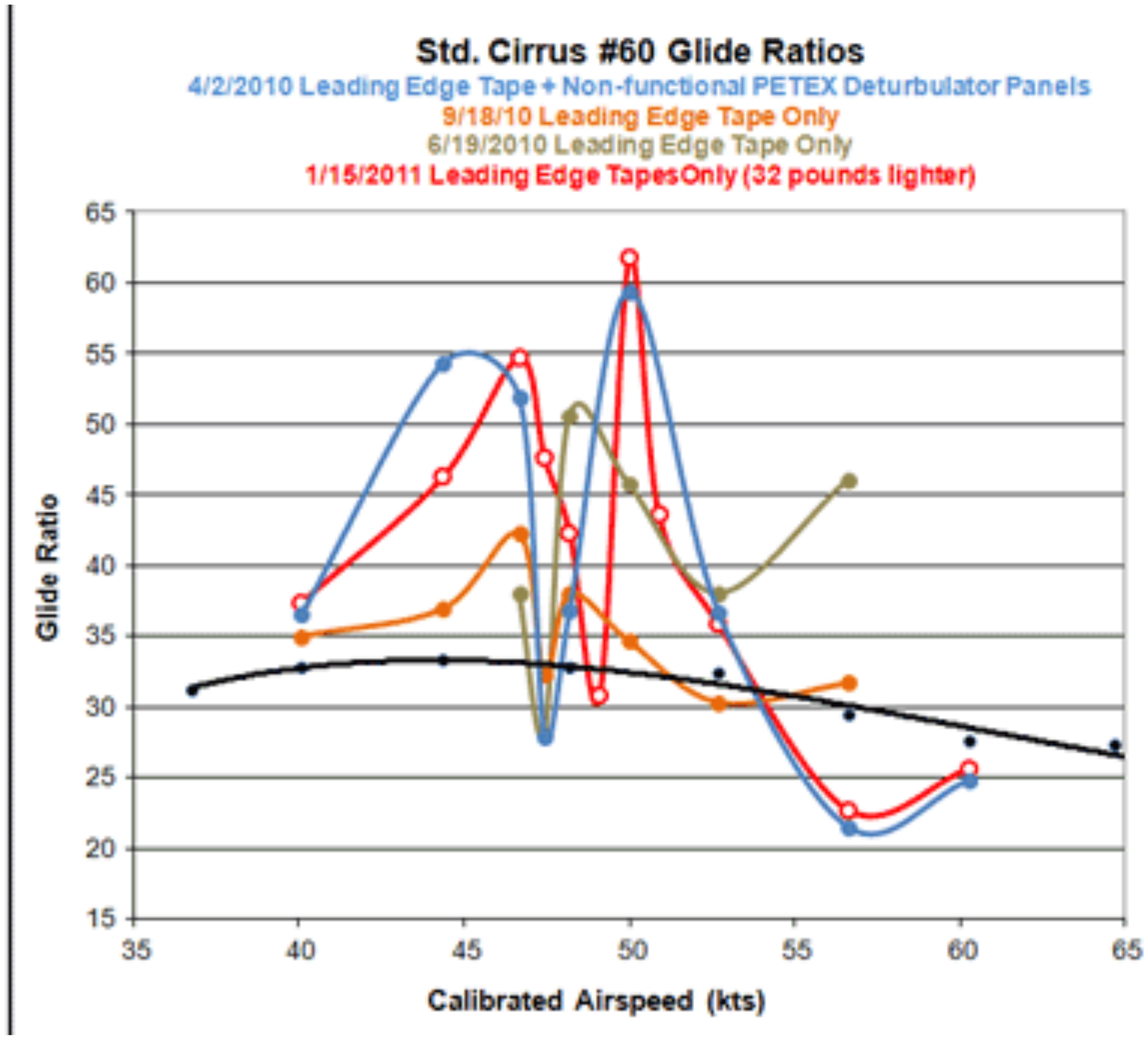
Demonstration of vortical flow behind a rear-facing step.
This is not a realistic simulation.

Current thinking is that the rear-facing step functions by triggering a thin bed of vortical flow over which the laminar, unsteady flow above is free to accelerate abnormally in the strong pressure gradient near the leading edge.

- Overview
- Tapes
  - **Notched Polars**
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes: Notched Polars





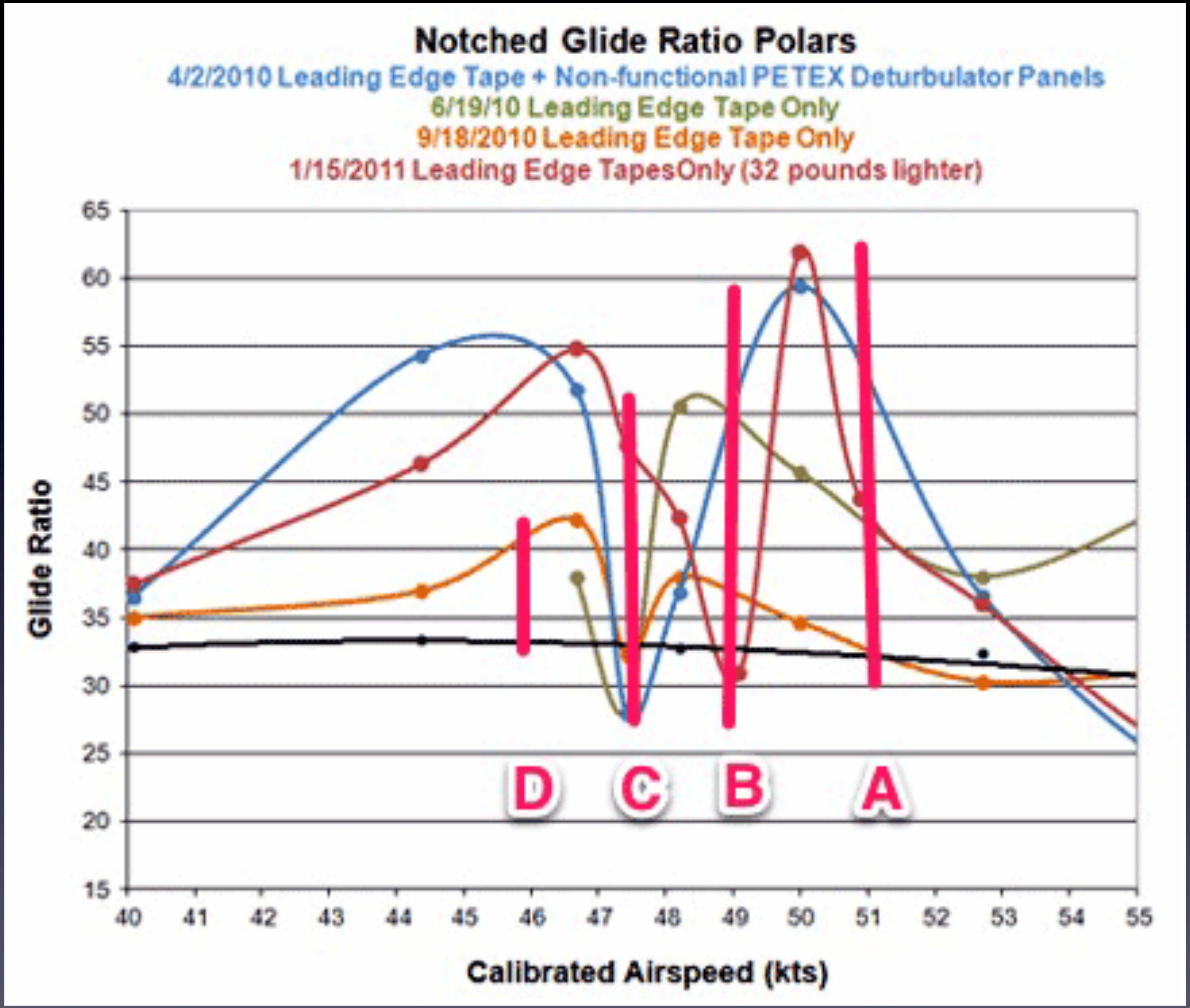
Four performance measurements with leading-edge tapes only.
Large amplitude swings and sharp structure are top-surface effects.
Notches are absolutely consistent.

One knot speed change gives 33:1 L/D change!
Something complicated is going on!

Black = Clean wing performance   Red = Notch 2 kts faster, glider 15% lighter

- Overview
- Tapes
  - Notched Polars
  - **Humidity Dependence**
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

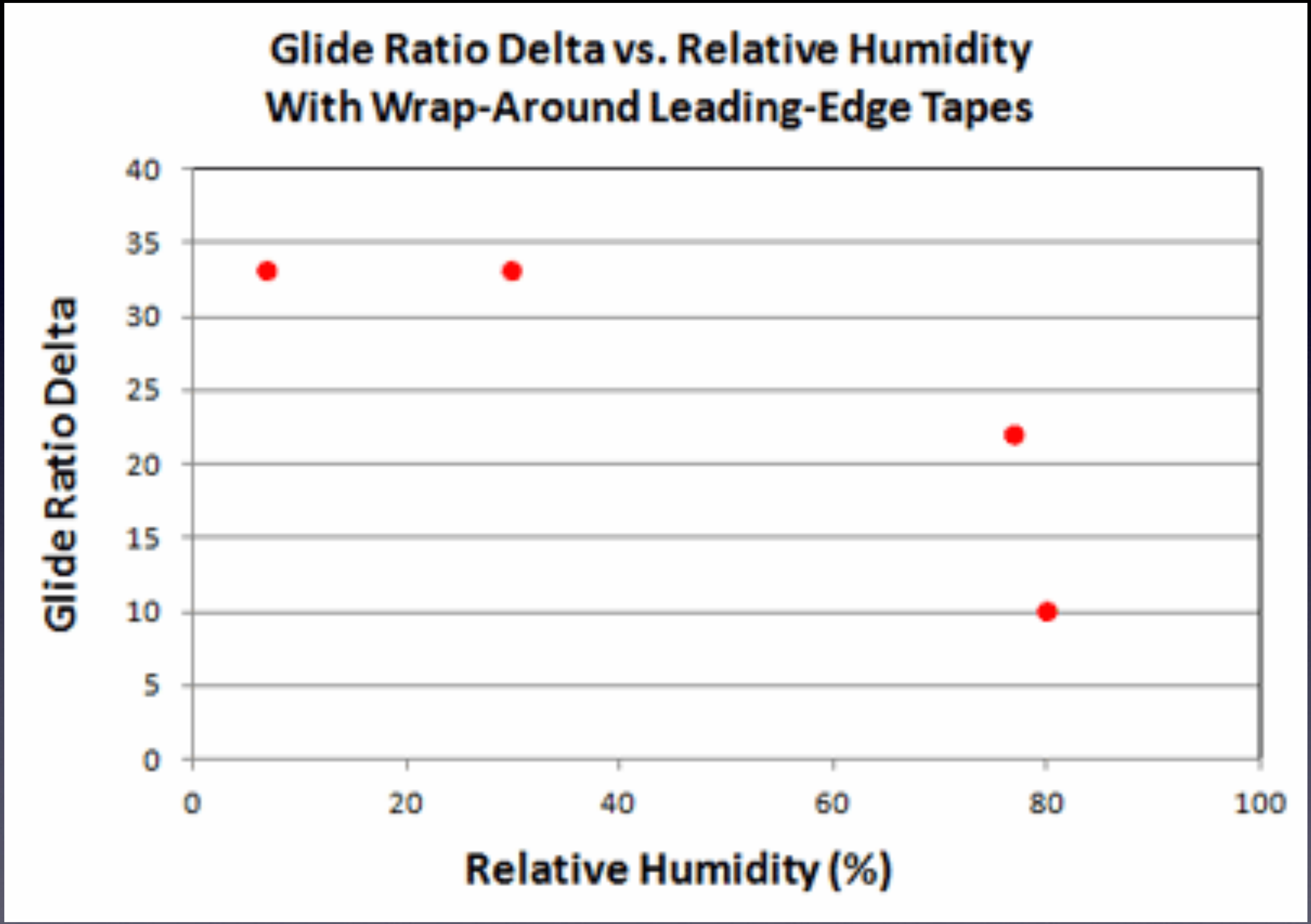
Tapes: Humidity Dependence



Same notched pattern. Different notch amplitude deltas. Why?

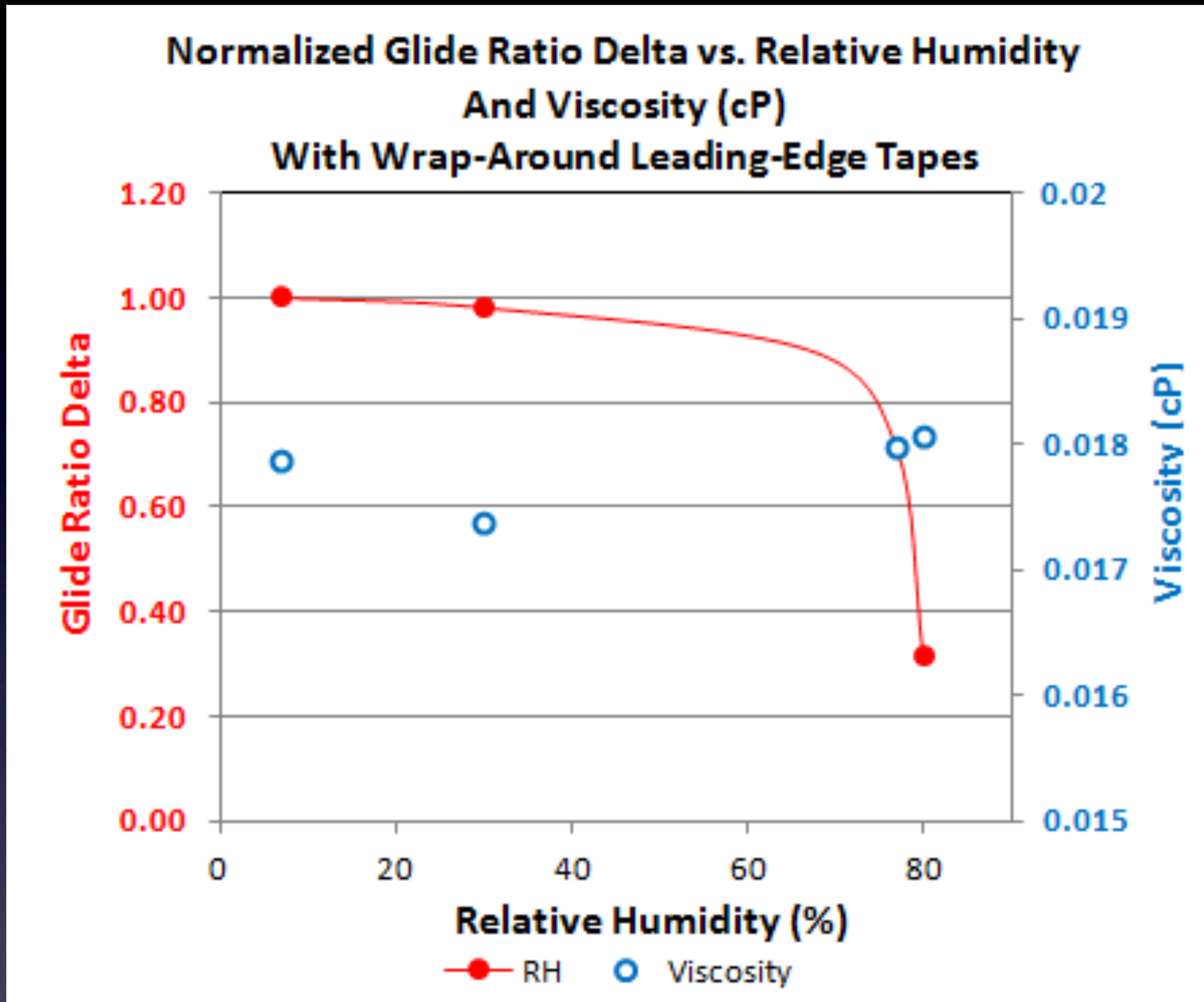
Black: Clean Wing

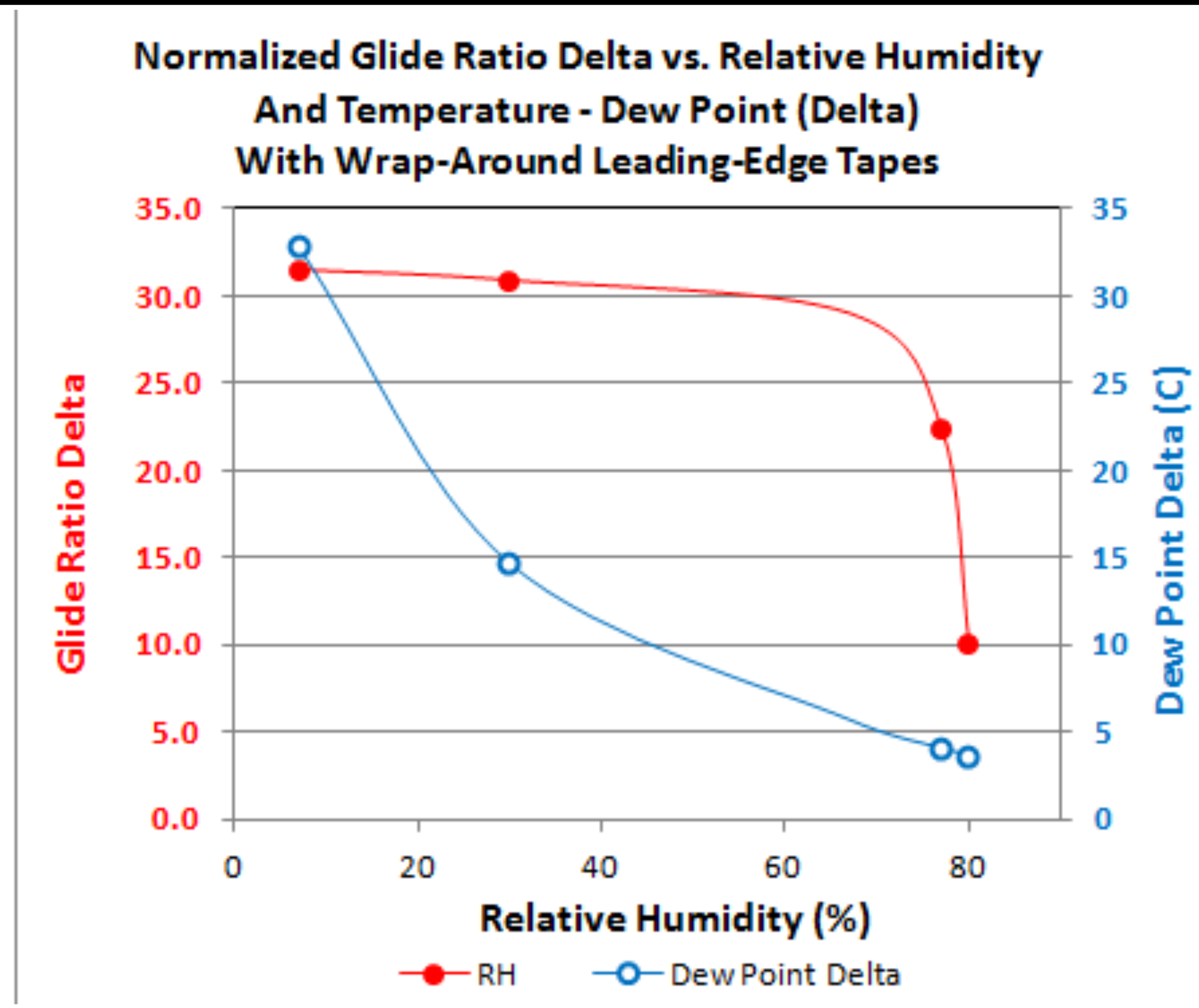
Tapes: Humidity Dependence



A clear dependence. Viscosity or surface effect?

Tapes: Humidity Dependence





Viscosity does not correlate. **(Temp - DewPoint) does correlate!**

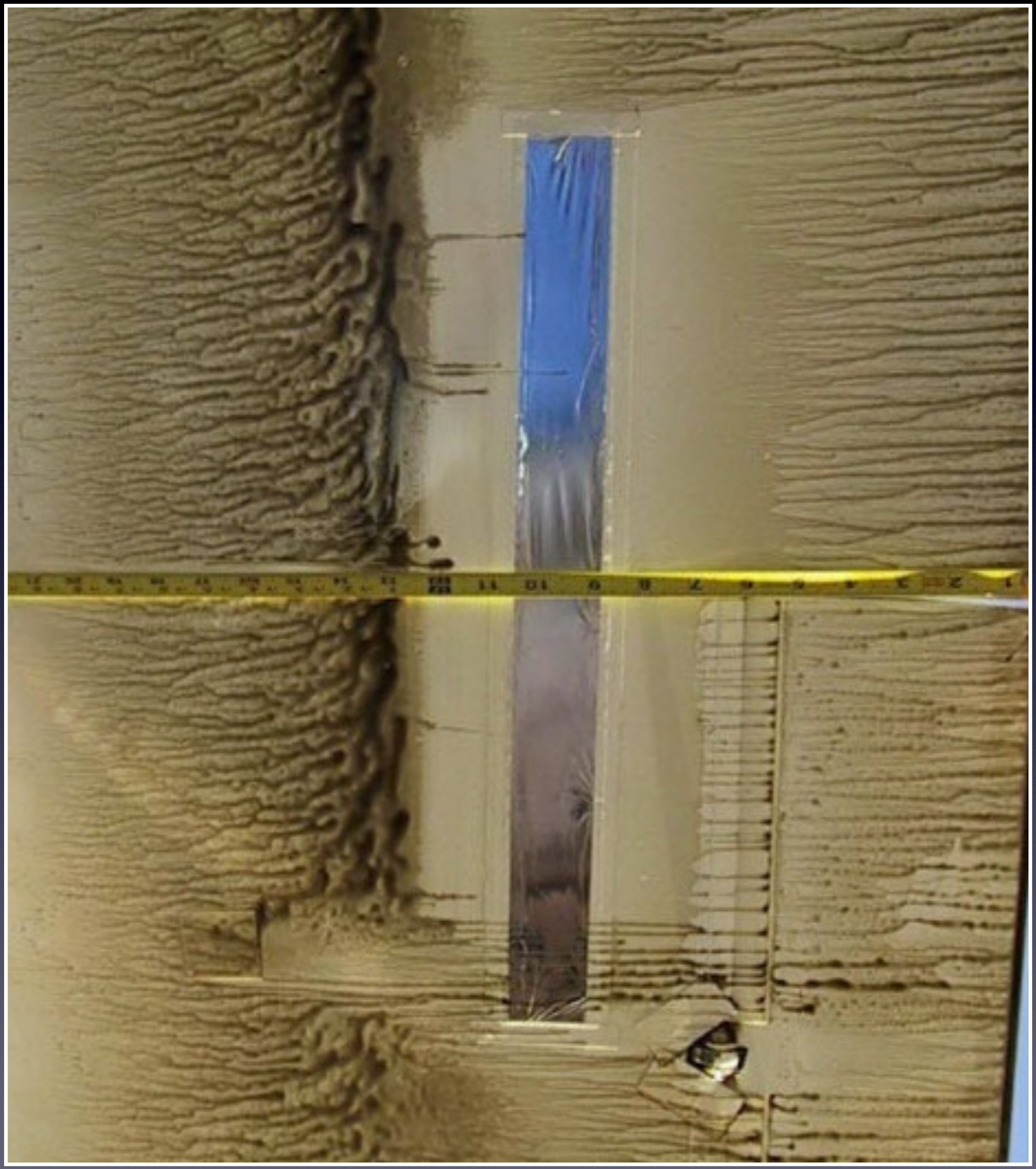
Performance enhancement diminishes when humidity nears saturation. Suggests a surface effect that destroys the no-slip condition that is necessary for .0025 inch vortical flow on the surface.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- **Tapes + Panels**
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels

- Flexible Composite Surface Deturbulator (FCSD) Panels.
- Thin, flexible membrane over textured substrate.
- Located behind reattachment point (stationary for Wortmann wing tested).
- Membrane energized by reattaching flow.
- Beneficial mode(s) modify frequency band of following attached turbulent flow.

Tapes + Panels: Lower-Surface Panel Oil-Flow Pattern



- Early deturbulator panel on pressure side of wing behind reattachment point.
- Pushes reattachment forward and delays the onset of turbulence.
- Aileron seal behind trips flow, also small tape patch ahead of FCSD.
- FCSD panel does something that a normal strip of tape will not do.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - **Johnson Flight Tests**
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels: Johnson Flight Tests

- Internationally recognized authority on glider performance evaluation by the sink-rate measurement method.
- Published flight test evaluations for virtually every glider produced since 1960.
- Evaluations cited in books on glider design.
- Known for absolute objectivity.
- Performed deturbulator flight tests in December 2006.

Tapes + Panels: Johnson Flight Tests

Average of Six Flights

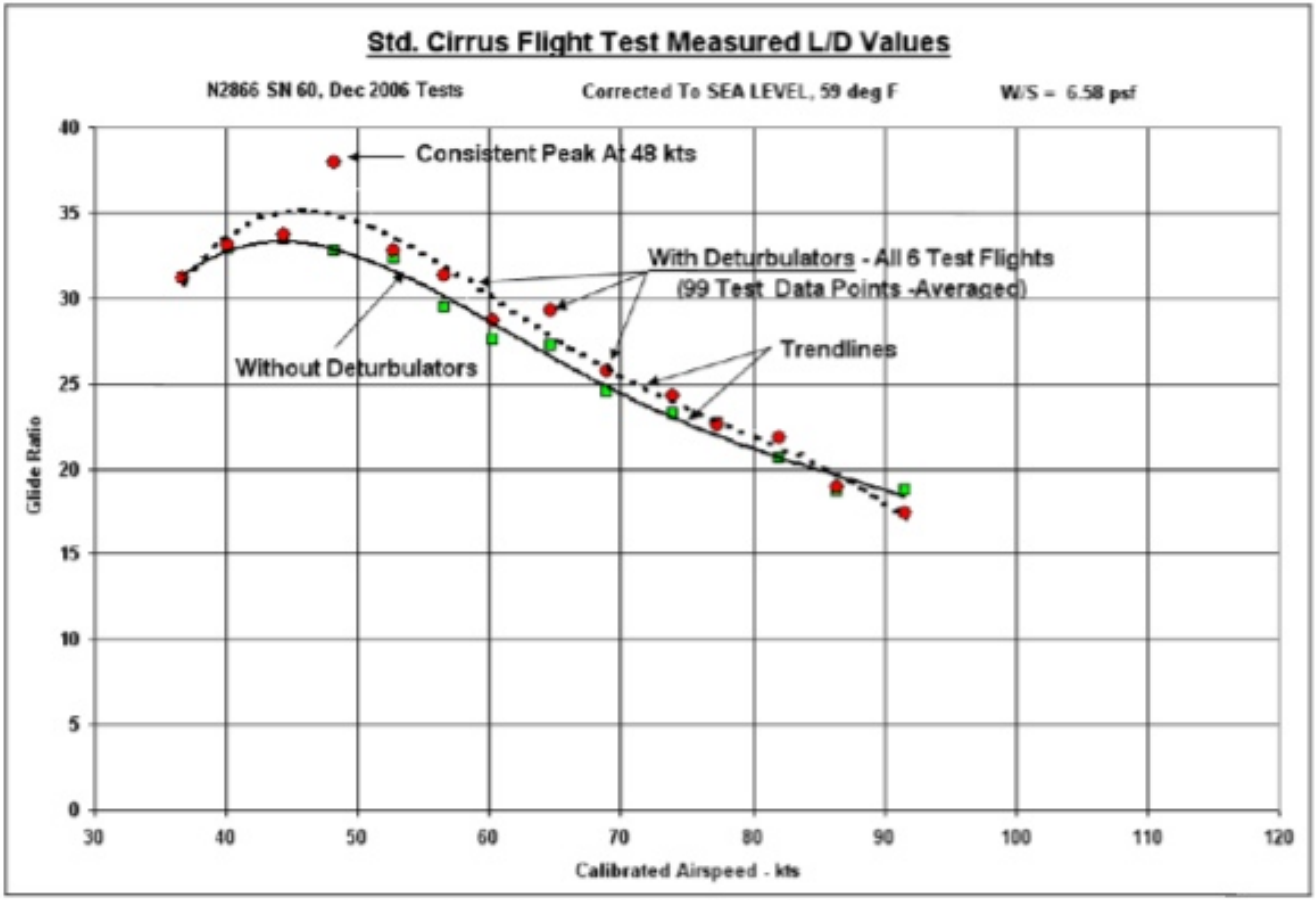


Figure 5. Average L/D Ratios

15% Improvement at 48 kts Calibrated Airspeed (50 KIAS)

Johnson Flight Tests

Flight-to-flight deviations were <u>4 to 5 times larger than normal</u>. So Johnson discarded the three flights with the greatest deviations.

Tapes + Panels: Johnson Flight Tests

Average of Three Flights

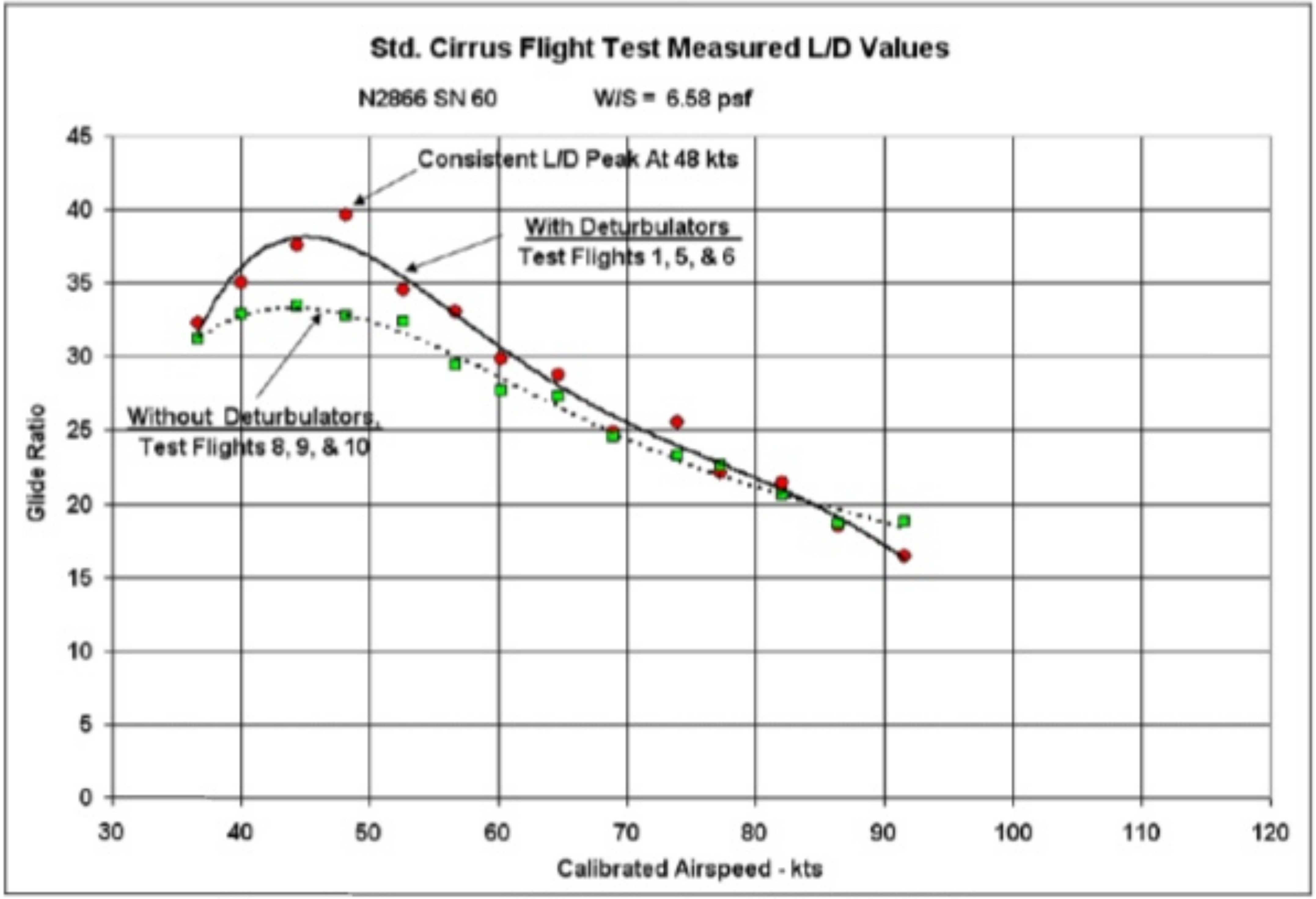


Figure 7. Average L/D Ratios for Flights 1, 5 & 6

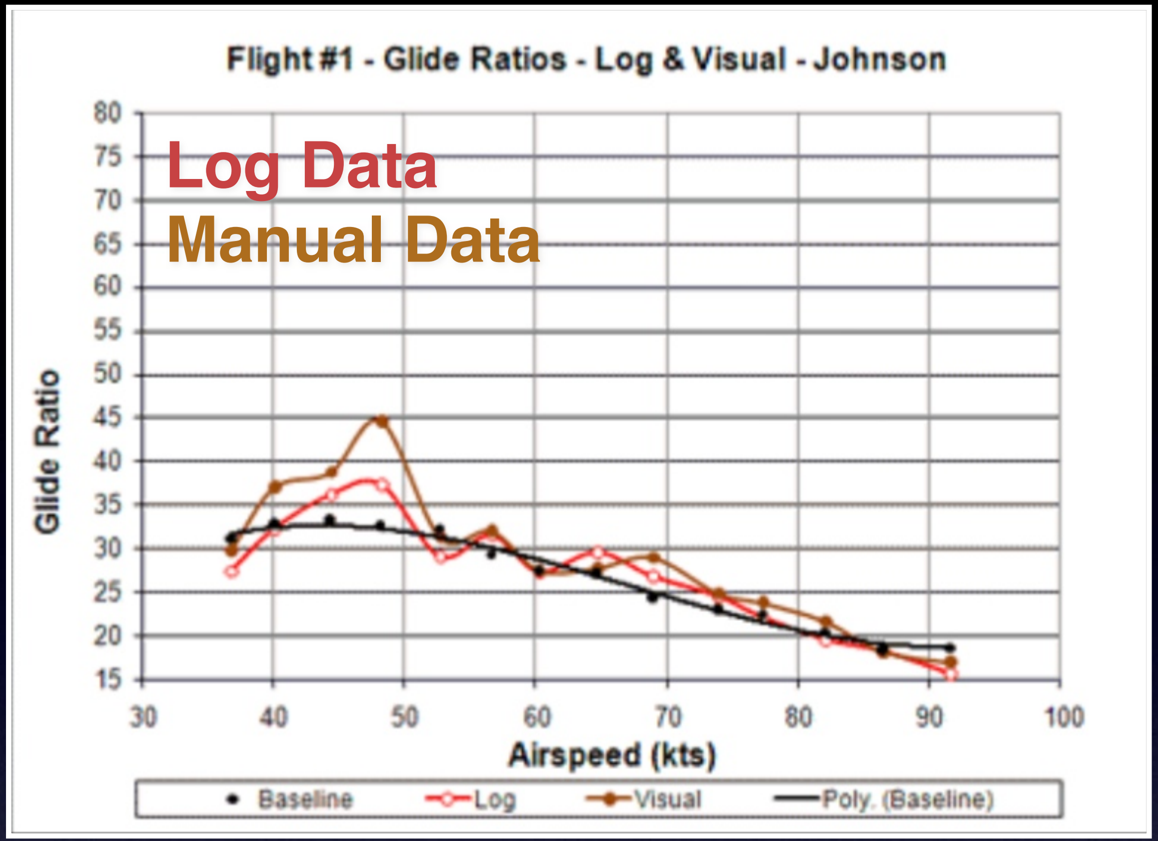
18% Improvement at 48 kts Calibrated Airspeed (50 KIAS)

Tapes + Panels: Johnson Flight Tests
Observation

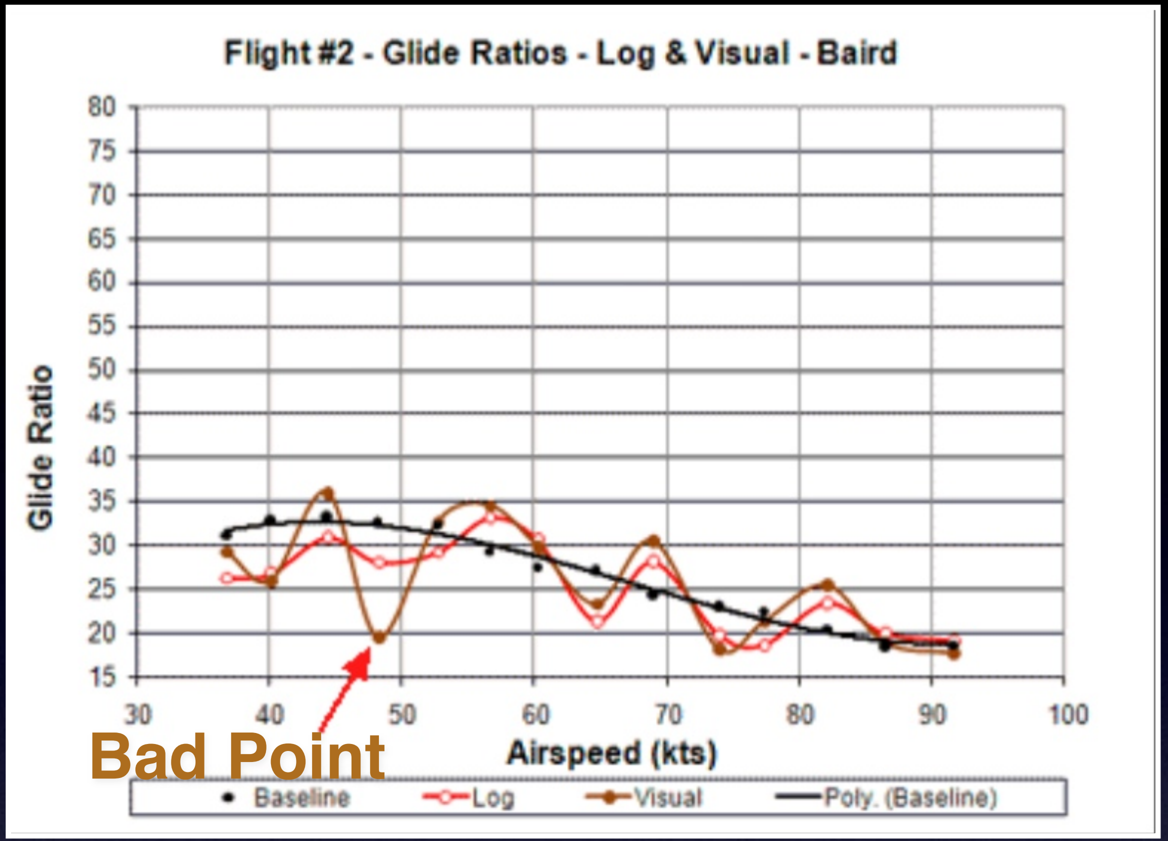
Deturbulator effects are large, but are not consistently repeatable, so averaging measurements obscures the full potential of deturbulation methods. Nevertheless, averaging data sets produced impressive results.

Individual flight tests must be studied!

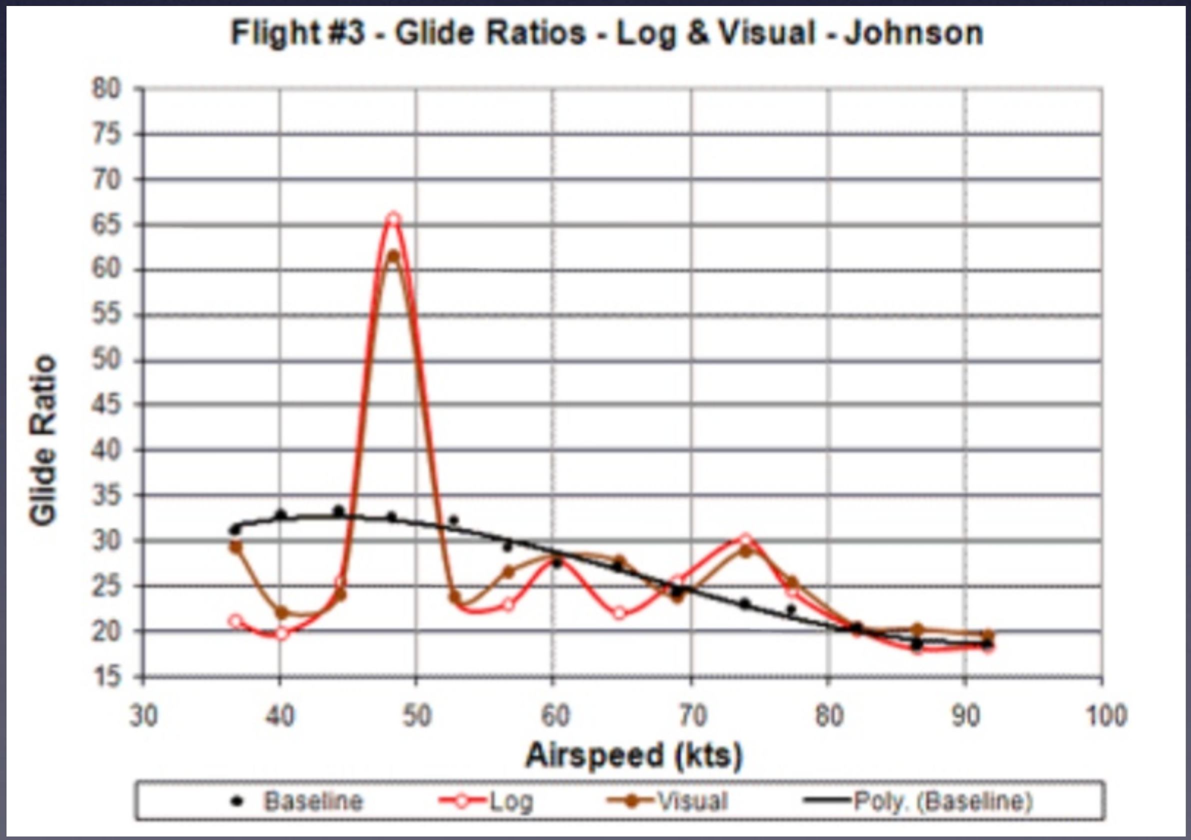
Tapes + Panels: Johnson Flight Tests: Day 1



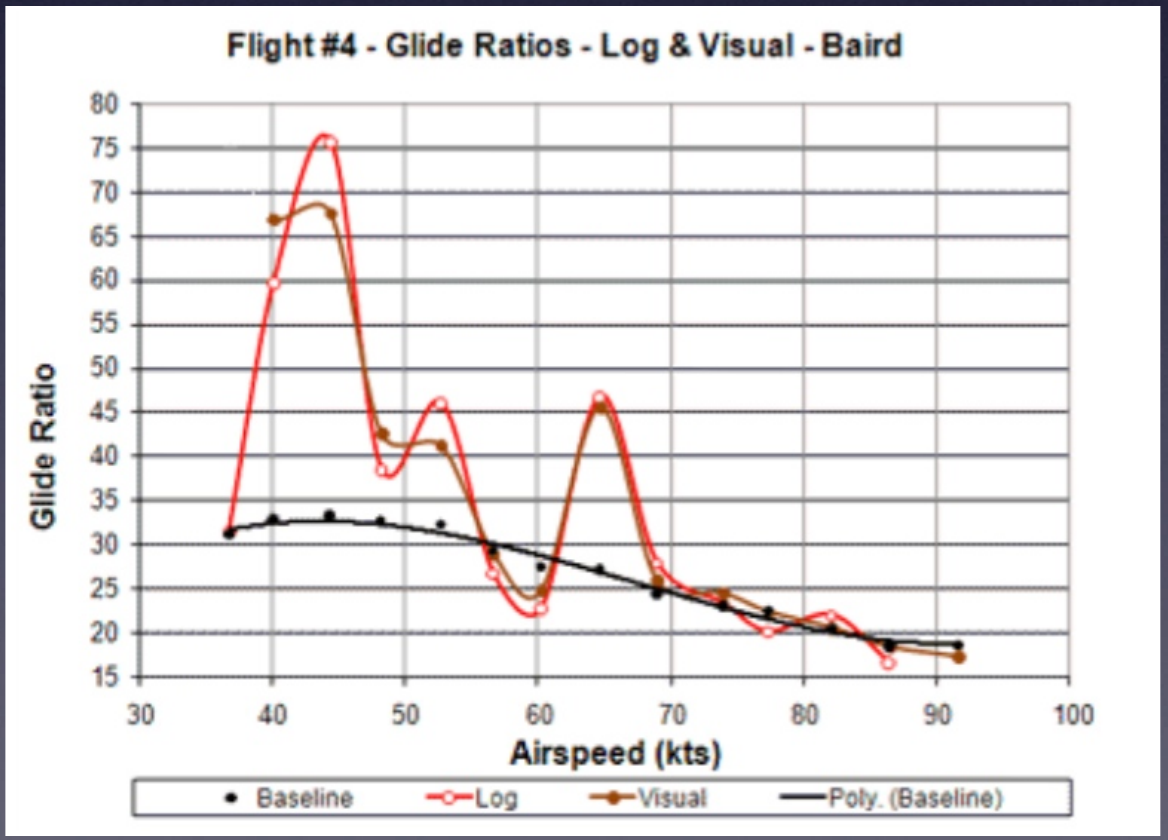
Flight 1



Flight 2



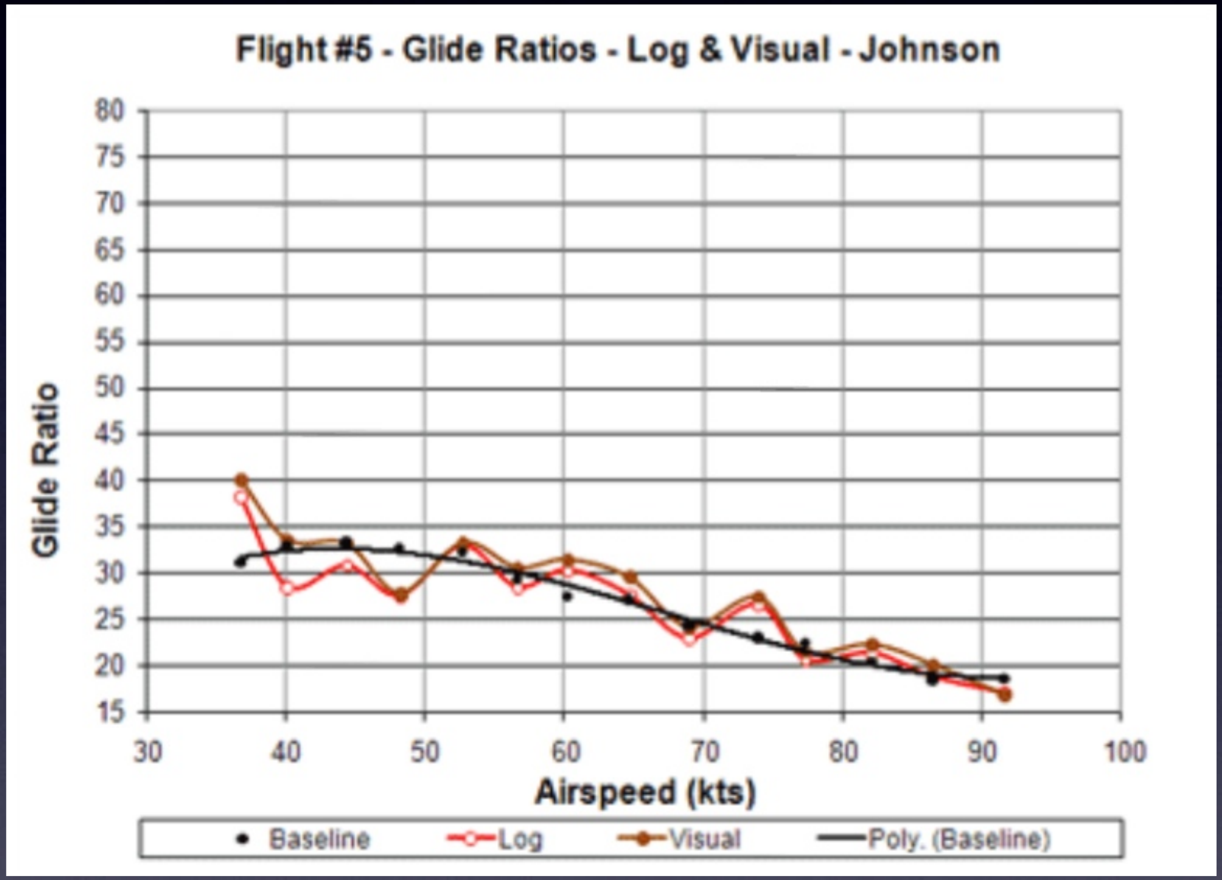
Flight 3



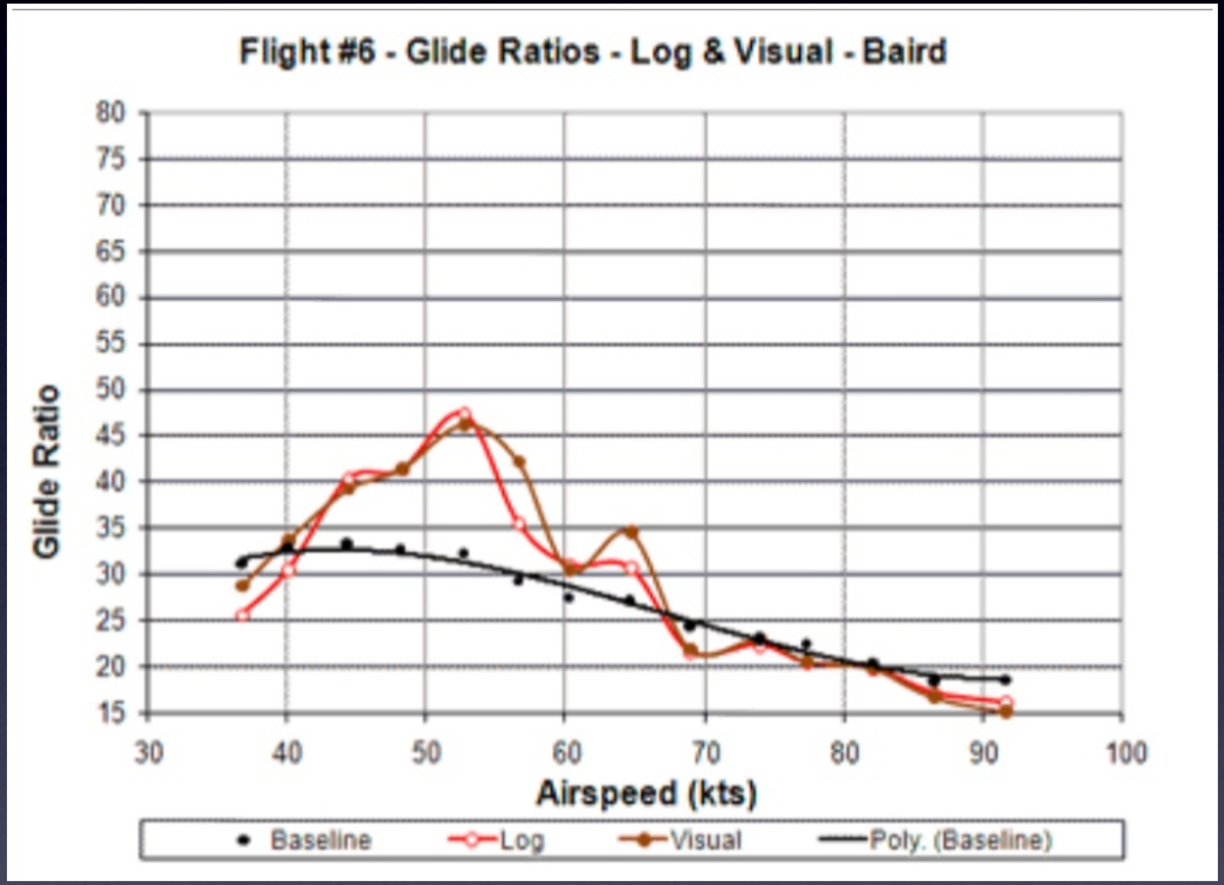
Flight 4

Compare

Tapes + Panels: Johnson Flight Tests: Day 2

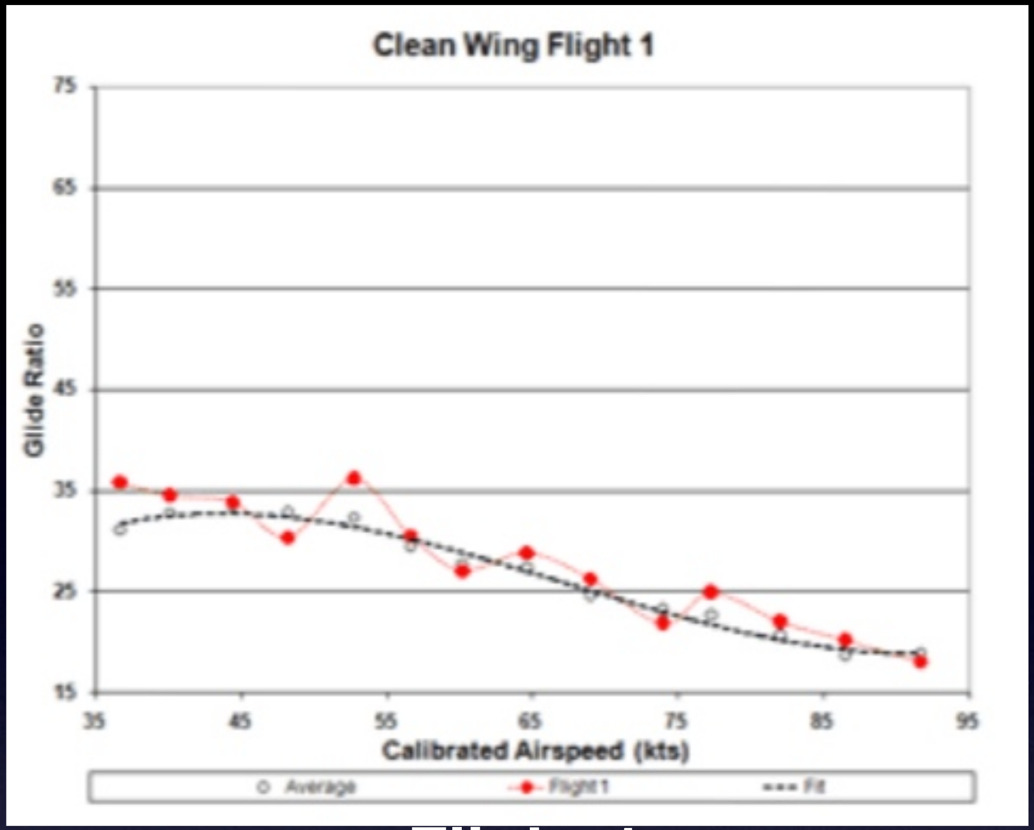


Flight 5

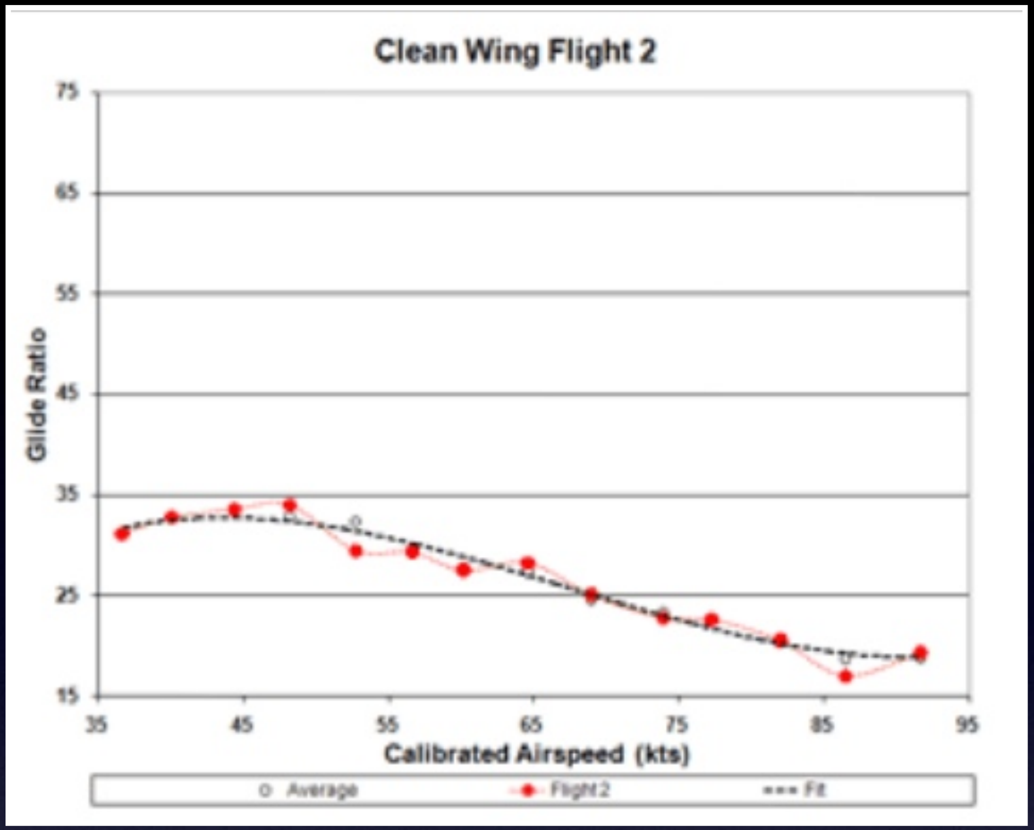


Flight 6

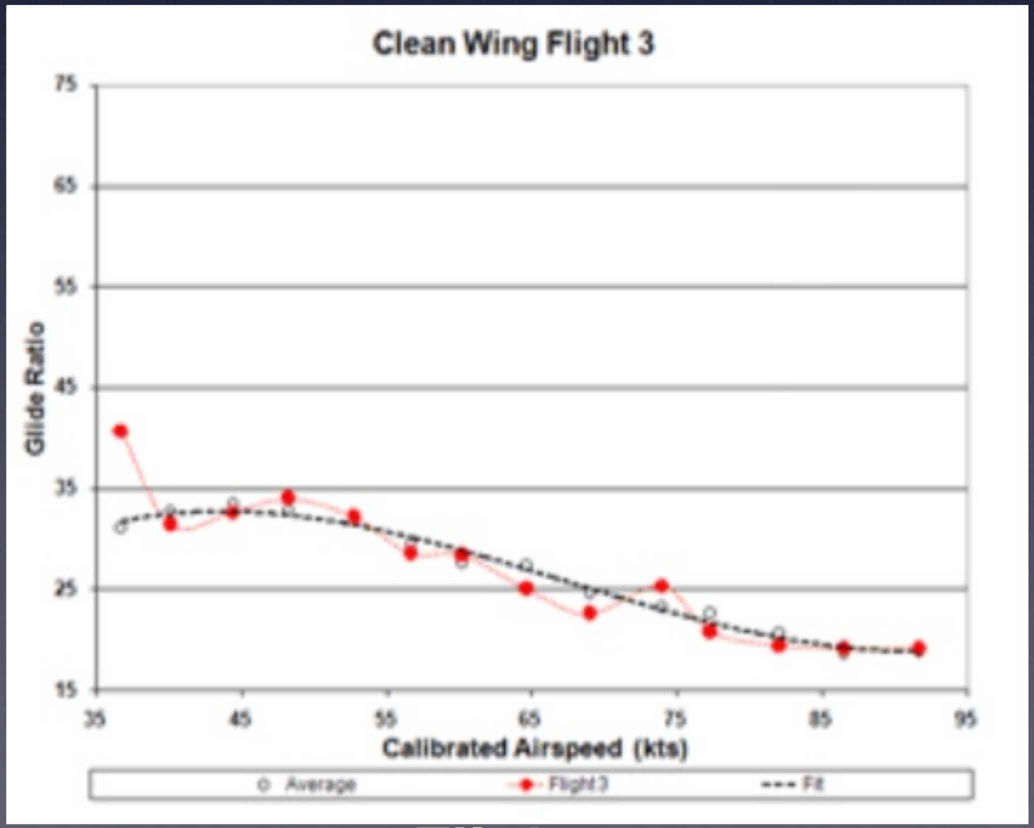
Tapes + Panels: Johnson Flight Tests: Clean Wing Flights



Flight 1



Flight 2



Flight 3

No huge deviations!

Compare

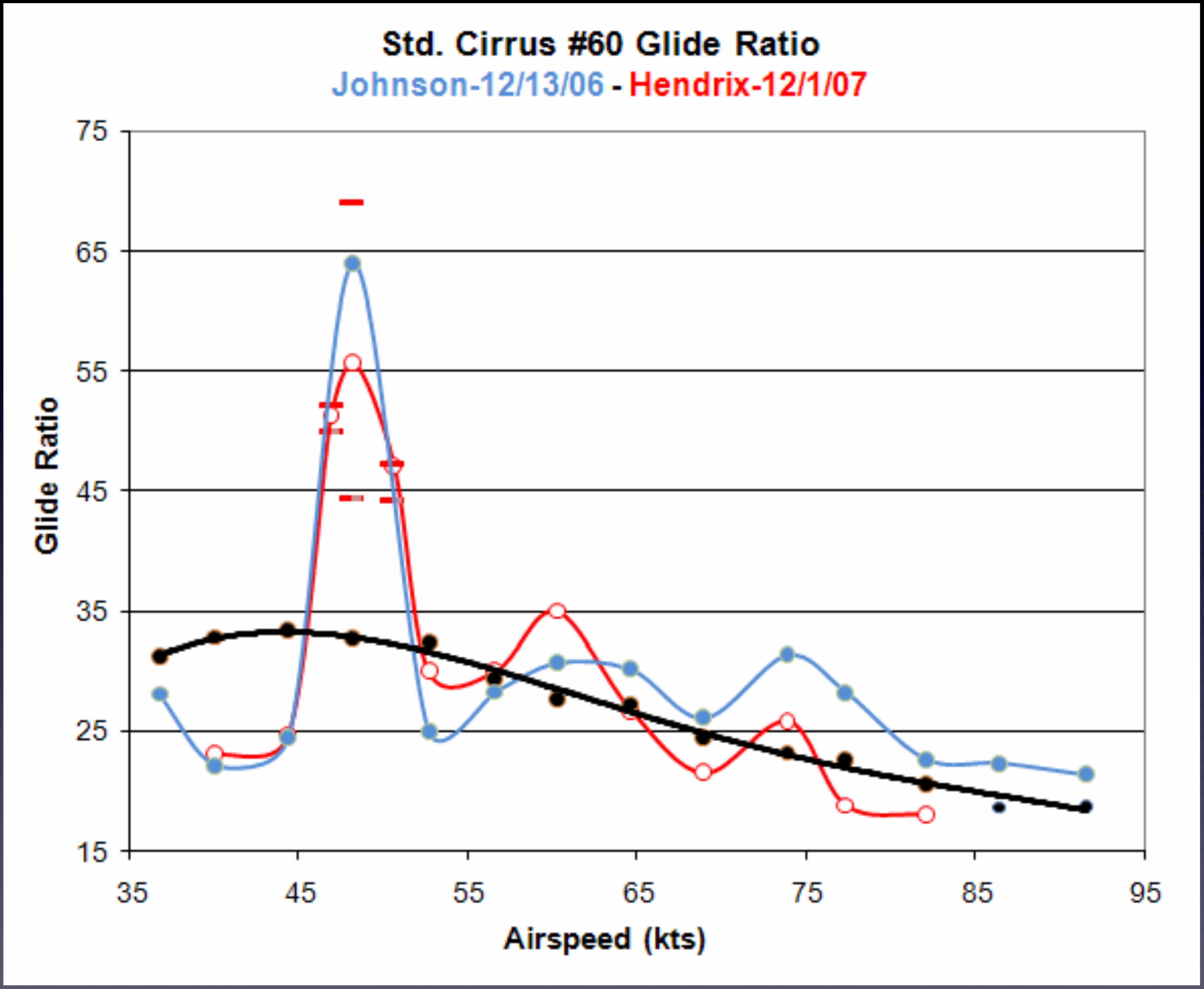
Tapes + Panels: Johnson Flight Tests
Concluding Remark

"*The new Sinha Deturbulator could be the first really significant drag-reducing aerodynamic invention since the development of the now-common laminar-flow airfoils that were developed some 65 years ago. Its small size and lightweight make it easy to apply on a sailplane wing.*"

Richard H. Johnson, A FLIGHT TEST EVALUATION OF THE SINHA WING PERFORMANCE ENHANCING DETURBULATORS, 1/2/07

- Overview
- Tapes
    - Notched Polars
    - Humidity Dependence
- Tapes + Panels
    - Johnson Flight Tests
    - **Peaked Polars**
    - Performance Transitions
    - Drag Probe Measurements
    - Parallel Flying
    - Nose Dipping Events
    - Hyvärinen Project
    - Oil-Flow Patterns
- Lower Surface Tapes
    - Performance Measurements
    - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels: Peaked Polars



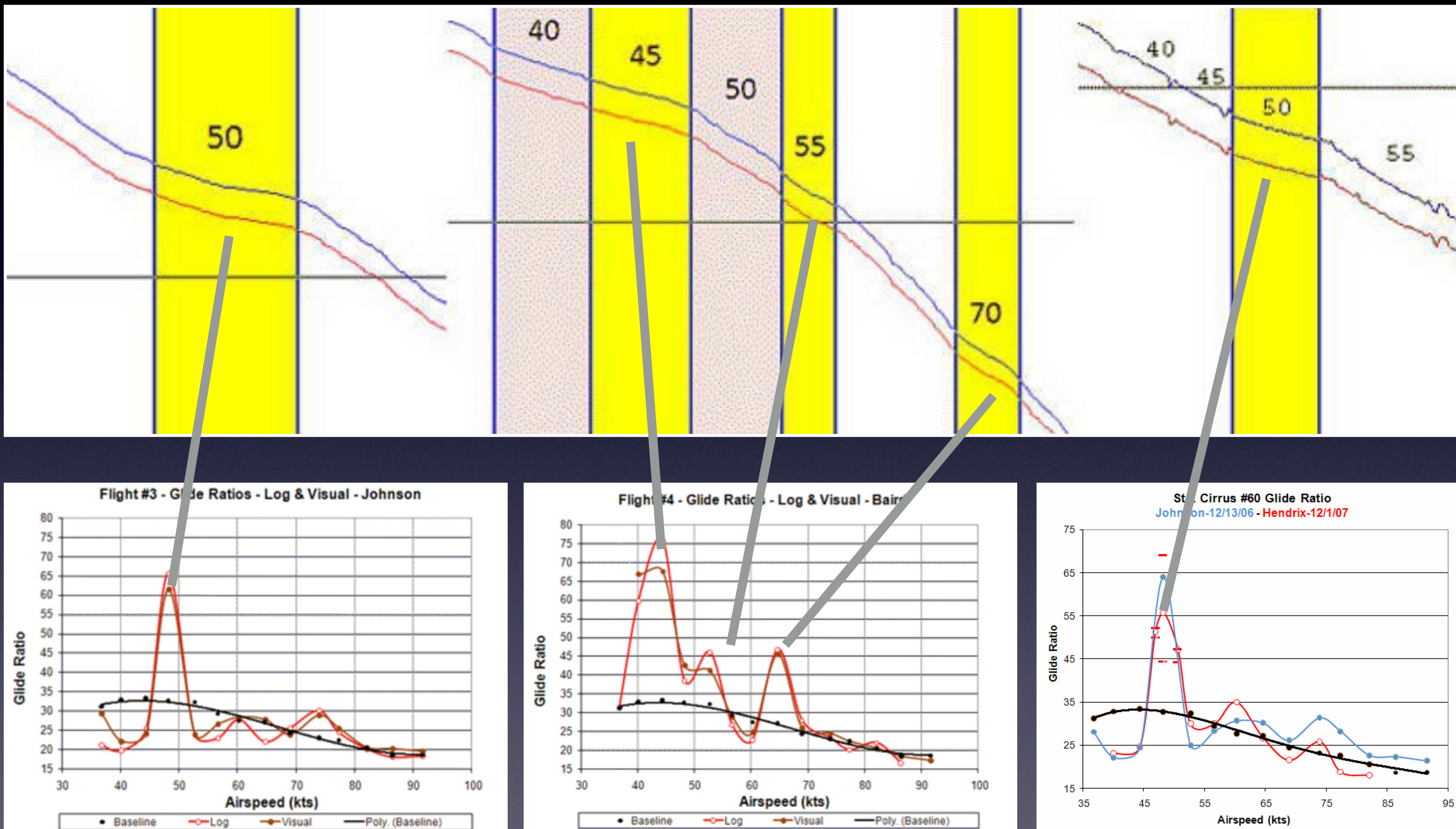
Johnson's third flight was repeated by Hendrix one year later.

Johnson's third measurement was real.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - **Performance Transitions**
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels: Performance Transitions

Altitude vs. Time



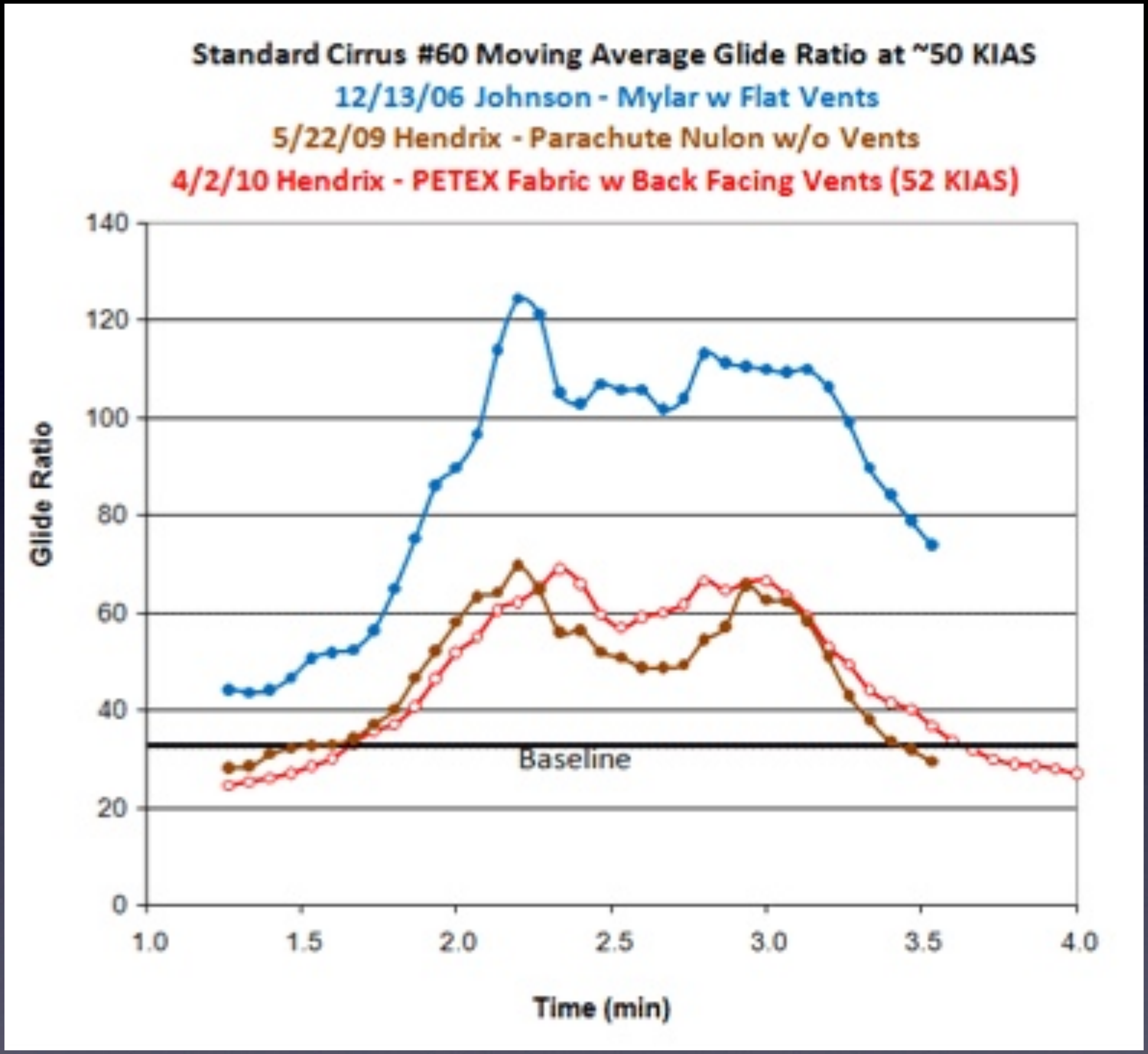
Johnson 12/13/06 #3 **Johnson 12/13/06 #4** **Hendrix 12/1/2007**

Tapes + Panels: Performance Transitions
Altitude vs. Time

5 occurrences, **10** transitions. Performance transitions occur at speed changes. Too coincidental to attribute good measurements to convection (rising air).

Also, performance improves while holding airspeed constant. Notice consistent scollop shaped altitude profiles at the 5 performance speeds.

Tapes + Panels: Performance Transitions
Repeating Mesa Shaped Transitions



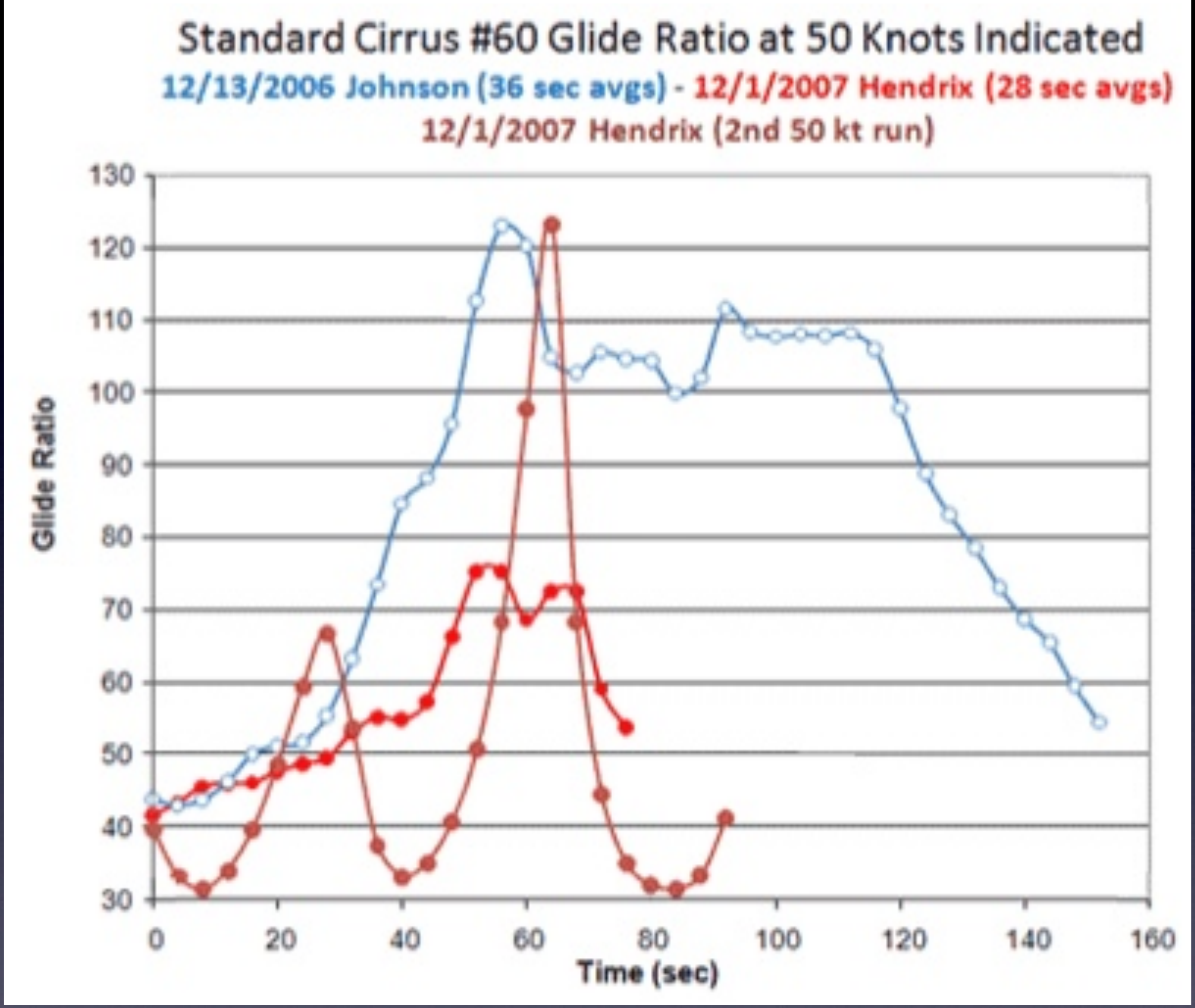
36 second averages at 4 second intervals

Airspeed constant at ~50 KIAS.

Maximum duration consistent at 2 min.

Repeating pattern at constant speed implies wing aerodynamics change with corresponding pitch attitude changes that gain, hold then lose critical aerodynamic condition over same time scale.

Tapes + Panels: Performance Transitions



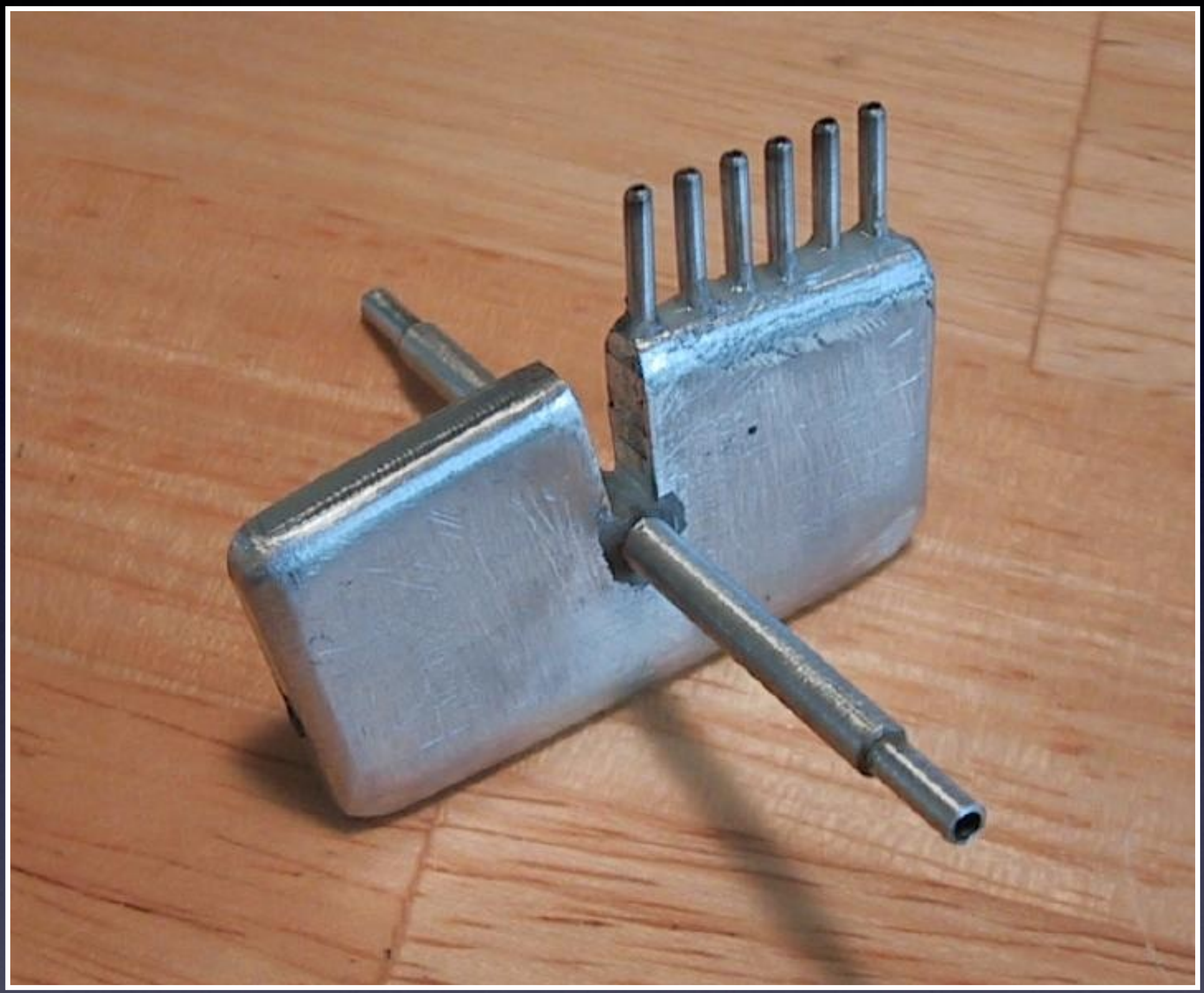
36 second averages at 4 second intervals

Curious, oscillating transition is thought to be from approaching 50 KIAS with excessive pitch momentum. Peaks match steady transition pattern. Valleys match baseline. Period increases with performance swing.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - **Drag Probe Measurements**
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

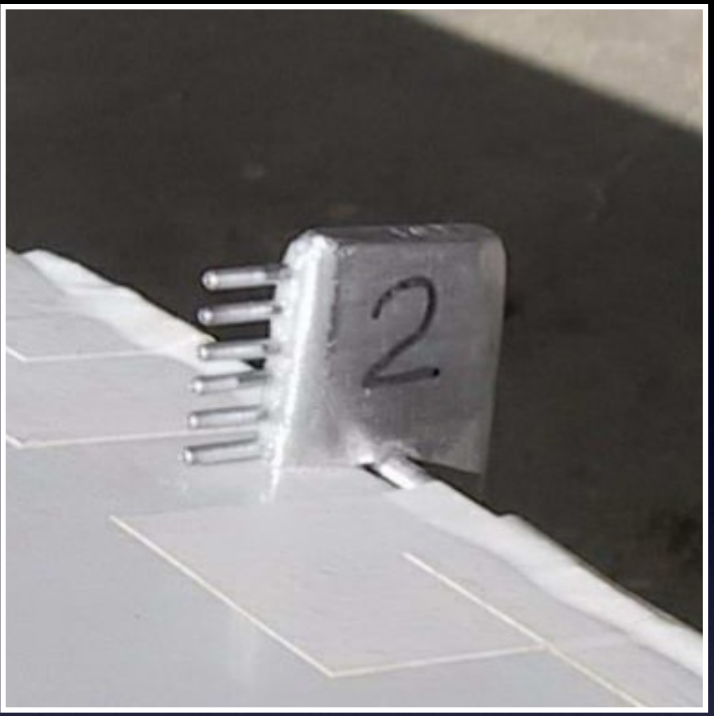
Tapes + Panels: Drag Probe Measurements

Johnson style drag probe.
Taped over unused side.



Second generation probe.

Tapes + Panels: Drag Probe Measurements

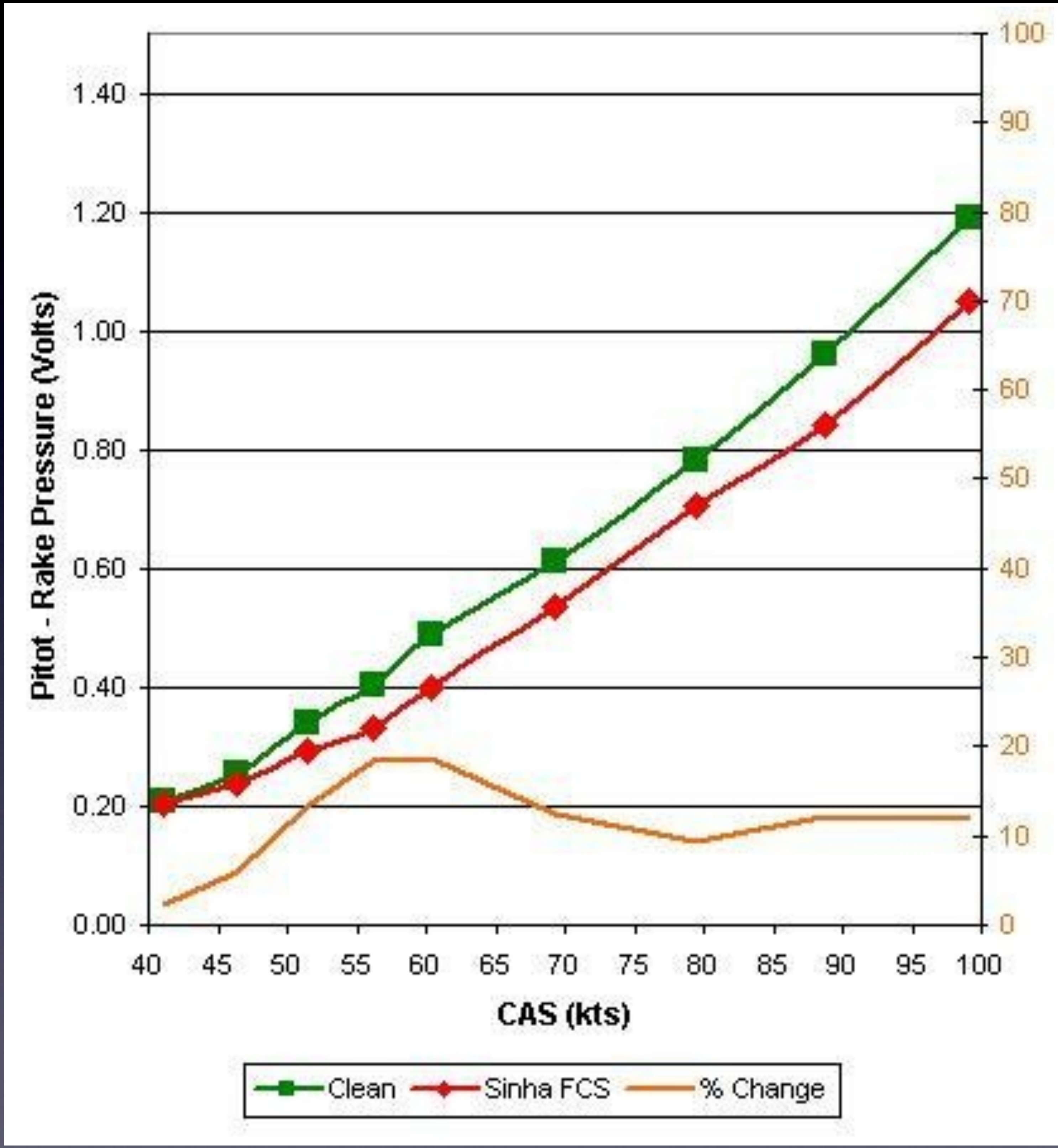


Probe Mounted

Honeywell DC002NDR4
differential pressure sensor

Two sensors with digital displays

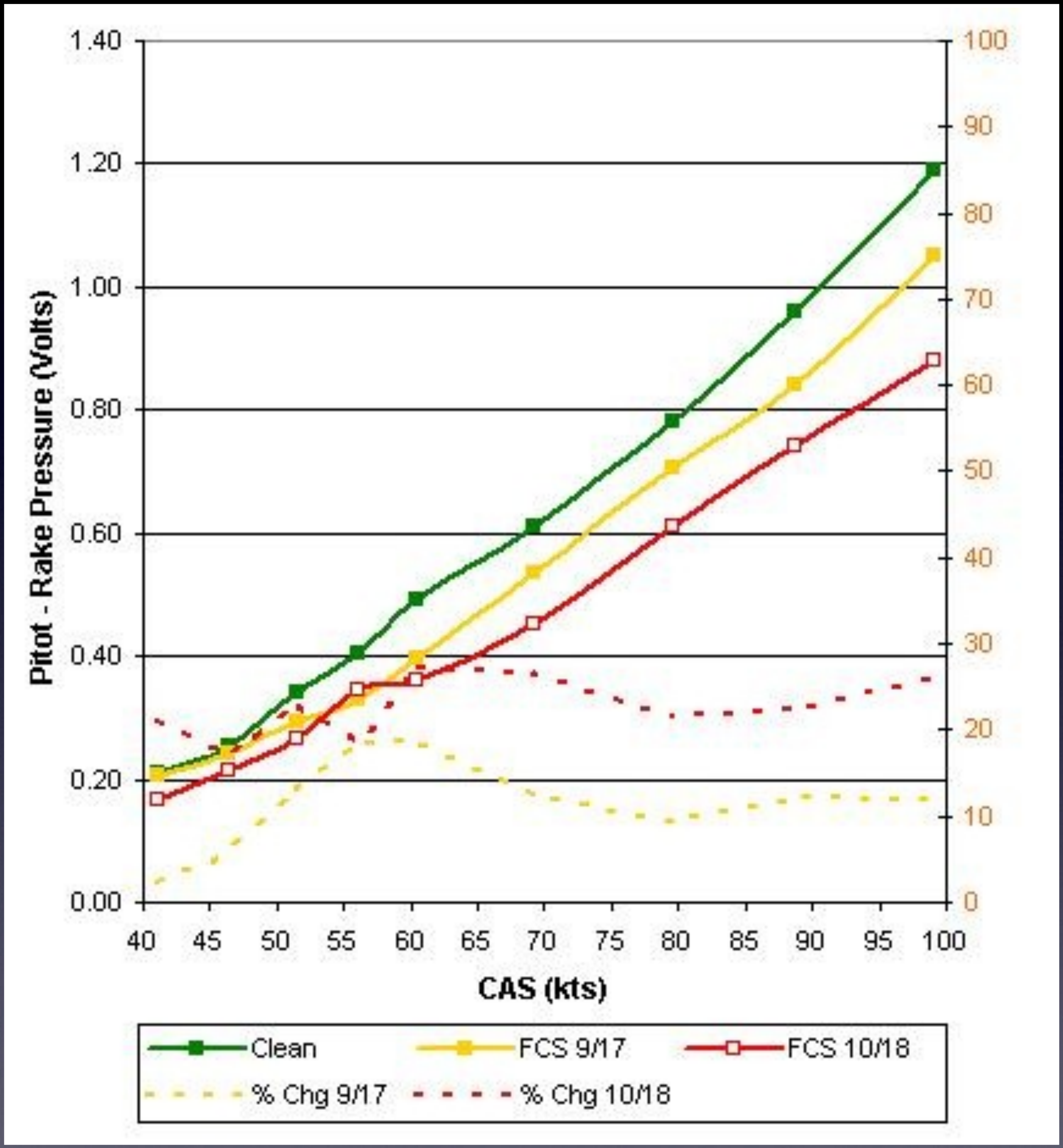
Tapes + Panels: Drag Probe Measurements: 9/17/2003



Lower surface at 52" span station

(Pitot - Average Wake) pressure in sensor voltage units

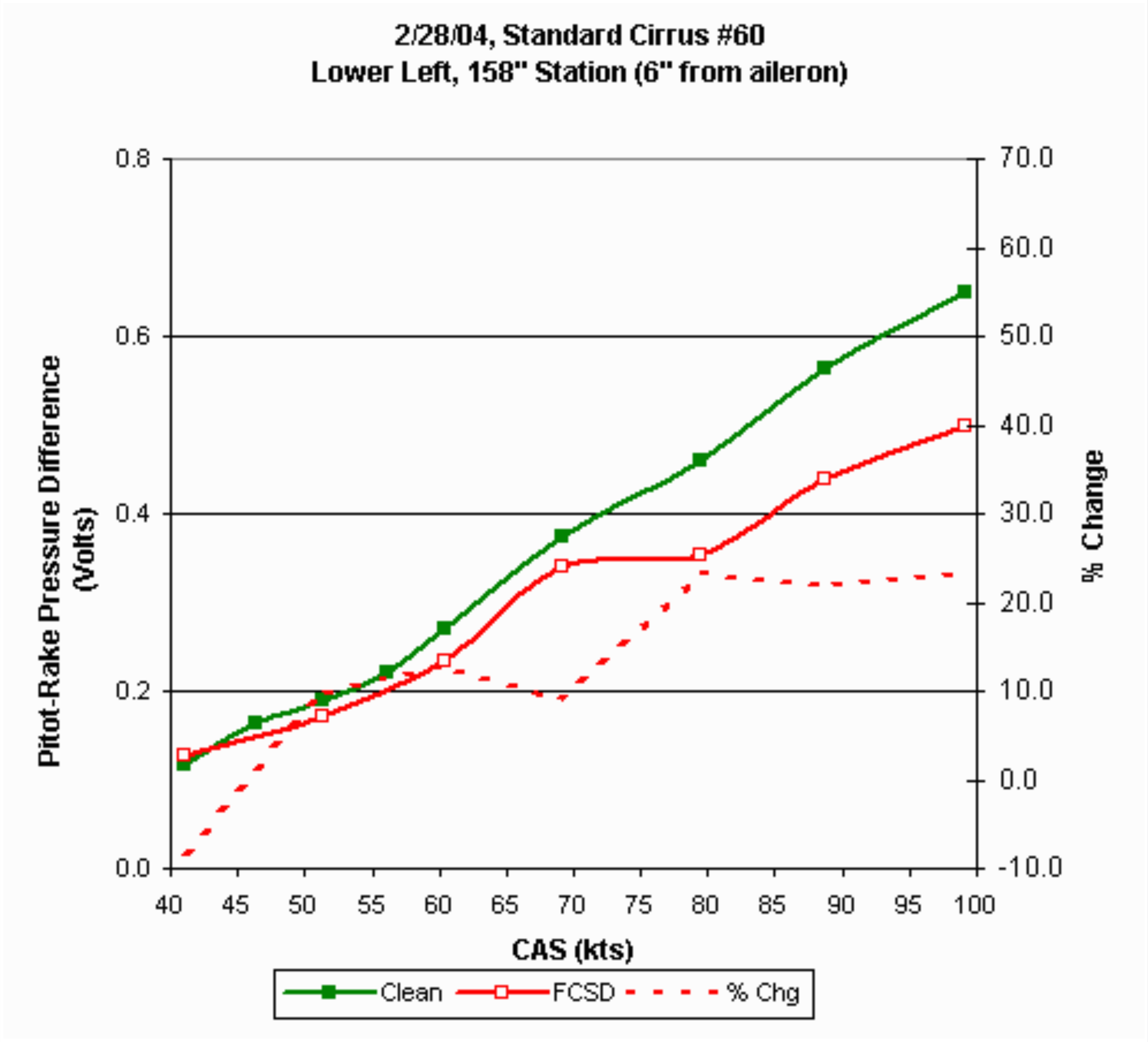
Tapes + Panels: Drag Probe Measurements: 10/18/2003



Lower surface at 52" span station

After adding a second, narrow FCSD panel behind original one.

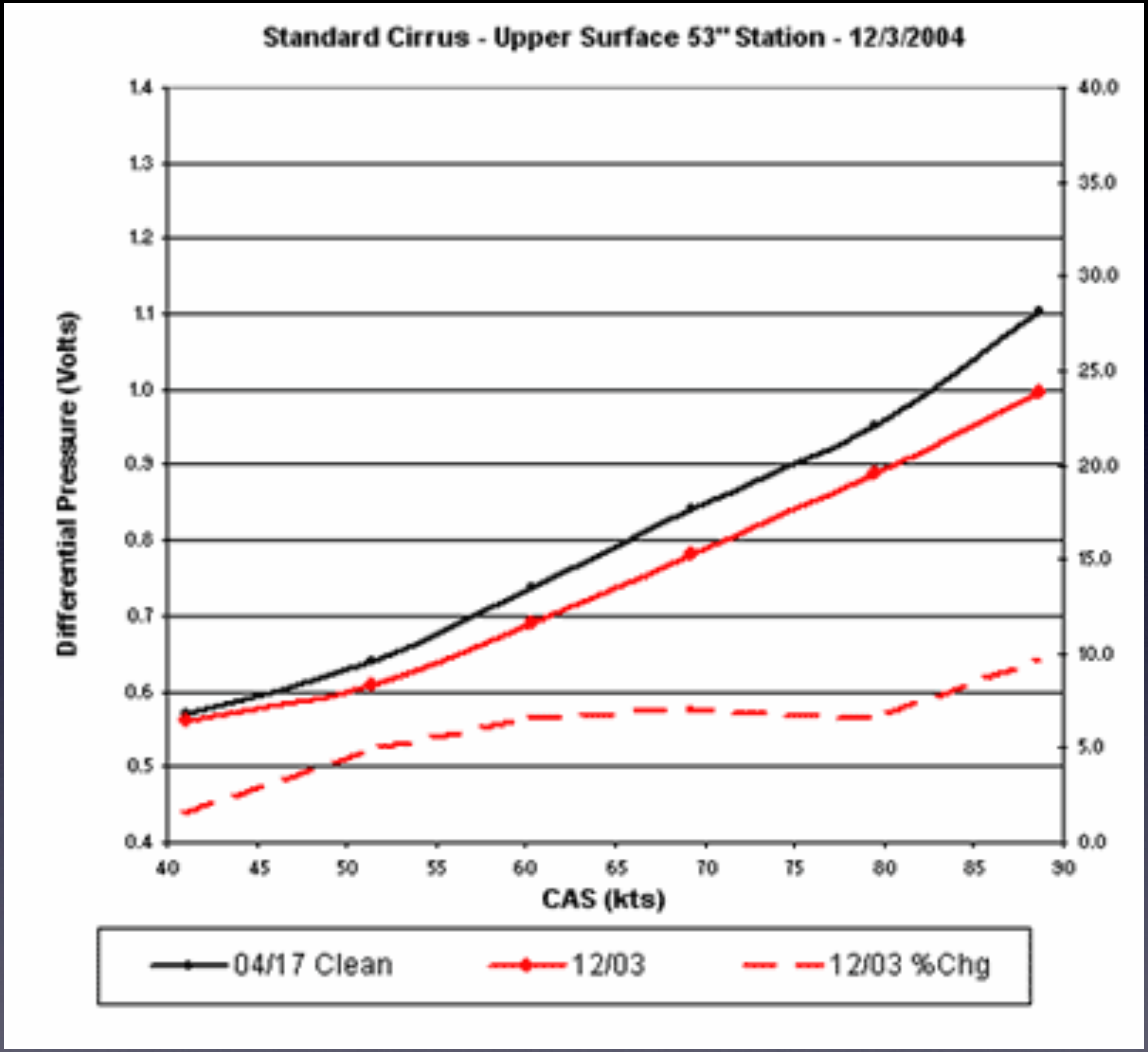
Tapes + Panels: Drag Probe Measurements: 2/28/2004



Lower surface at 158" span station

(Pitot - Average Wake) pressure in sensor voltage units.

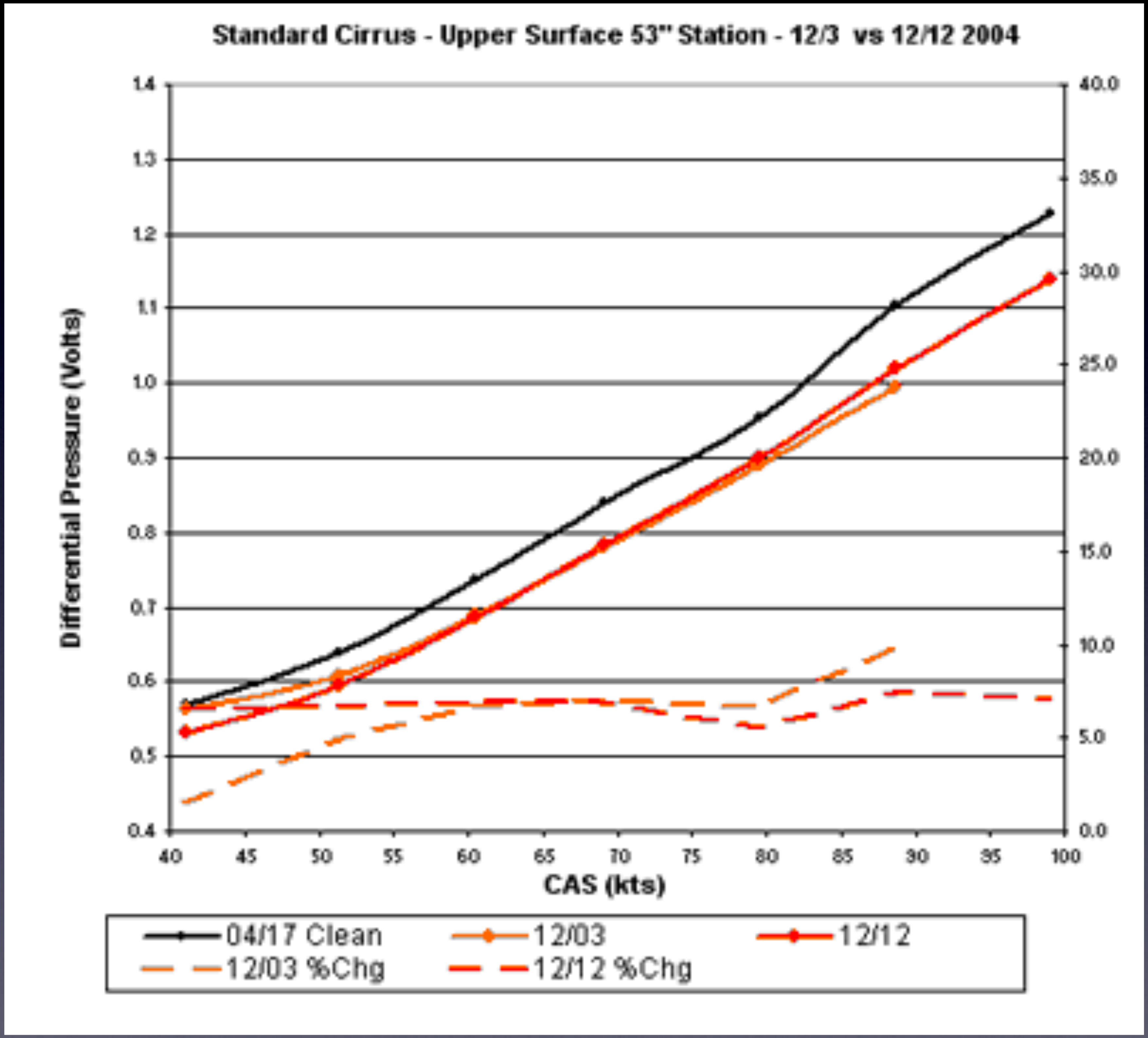
Tapes + Panels: Drag Probe Measurements: 12/3/2004



Upper surface at 53" span station

(Pitot - Average Wake) pressure in sensor voltage units.

Tapes + Panels: Drag Probe Measurements: 12/12/2004



Upper surface at 53" span station

And again nine days later.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - **Parallel Flying**
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels: Parallel Flying: Versus Diana 1

Standard Cirrus

L/D @ 49 kts = 33.5 (Johnson)
All up weight = **728 lbs**
Circa 1970

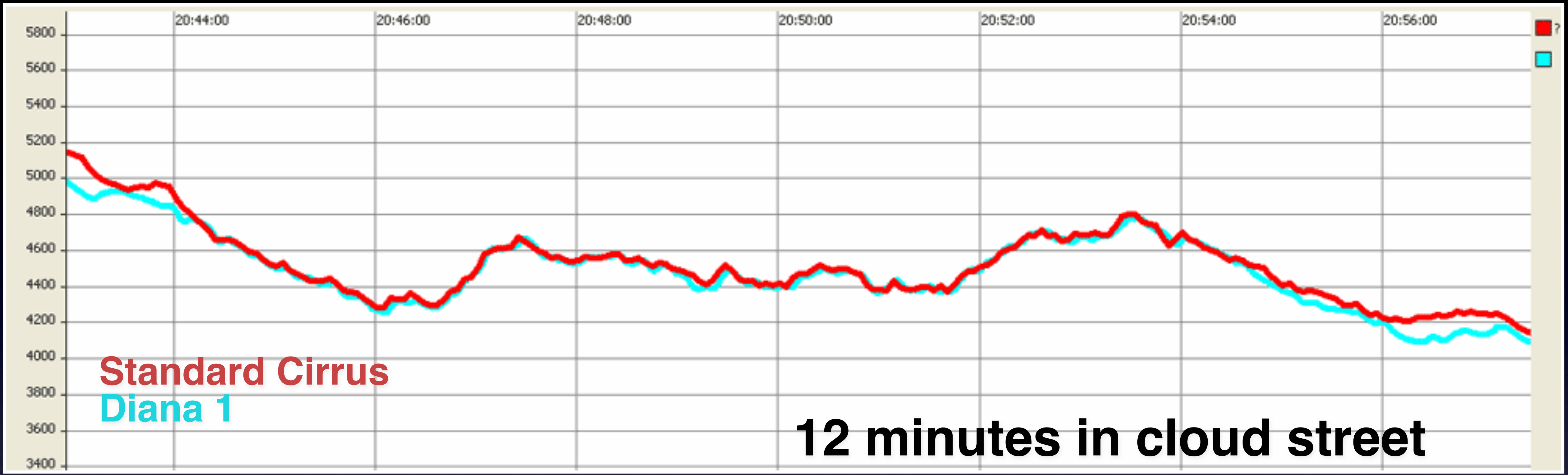
Diana 1

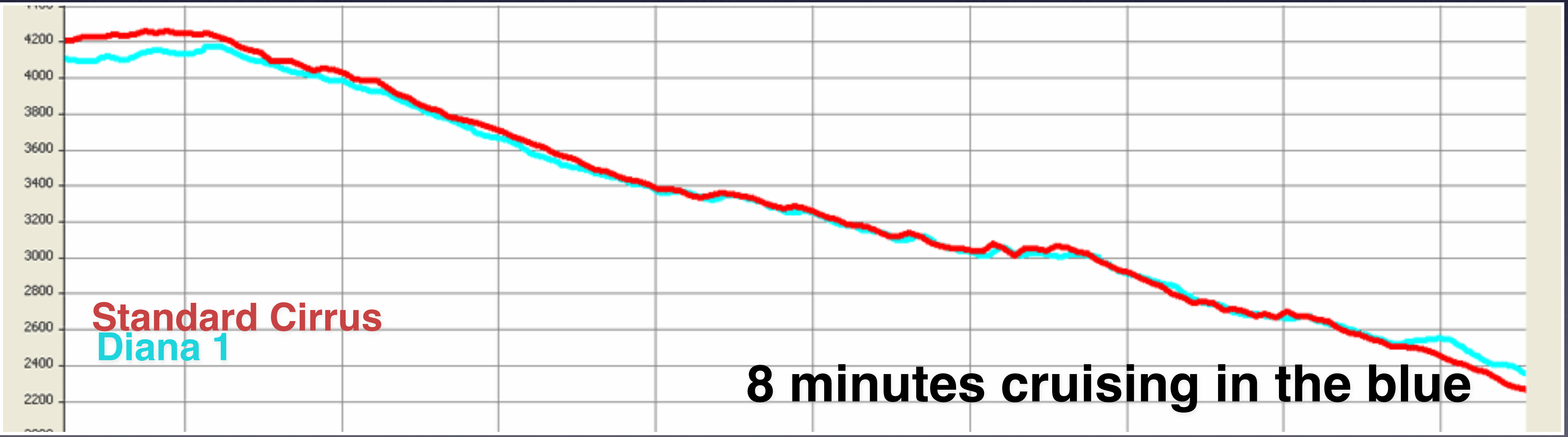
L/D @ 49 kts = 40:1 (Johnson)
All up weight = **660 lbs** (est.)
Circa 2003

Deturbulated Standard Cirrus matched Diana 1

- 20 minutes minutes cruising @ 48-54 kts
- 3000 ft gain in thermal

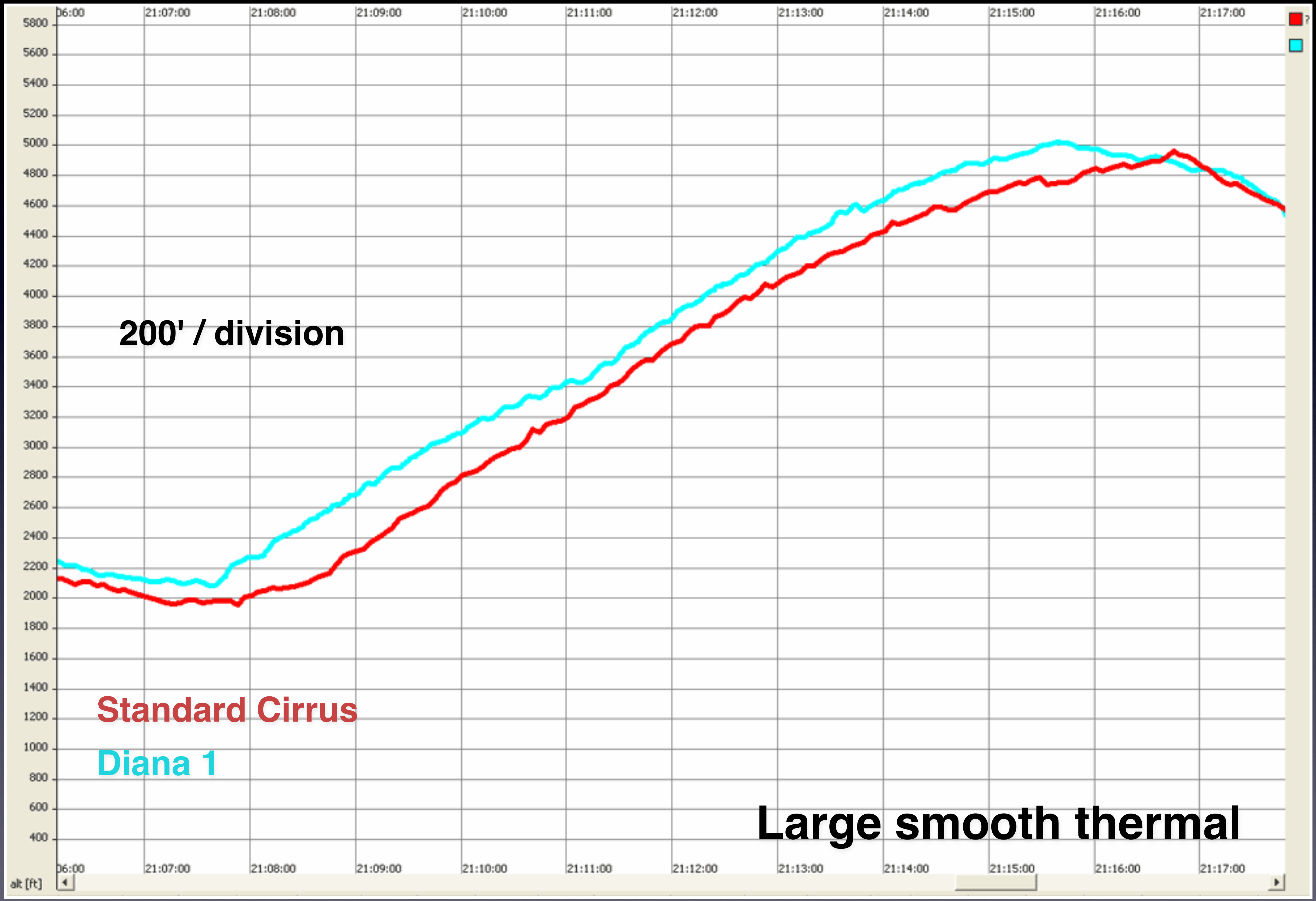
Tapes + Panels: Parallel Flying: Versus Diana 1





20 Minutes @ ~52 kts

Tapes + Panels: Parallel Flying: Versus Diana 1



Tapes + Panels: Parallel Flying: Versus ASW 28

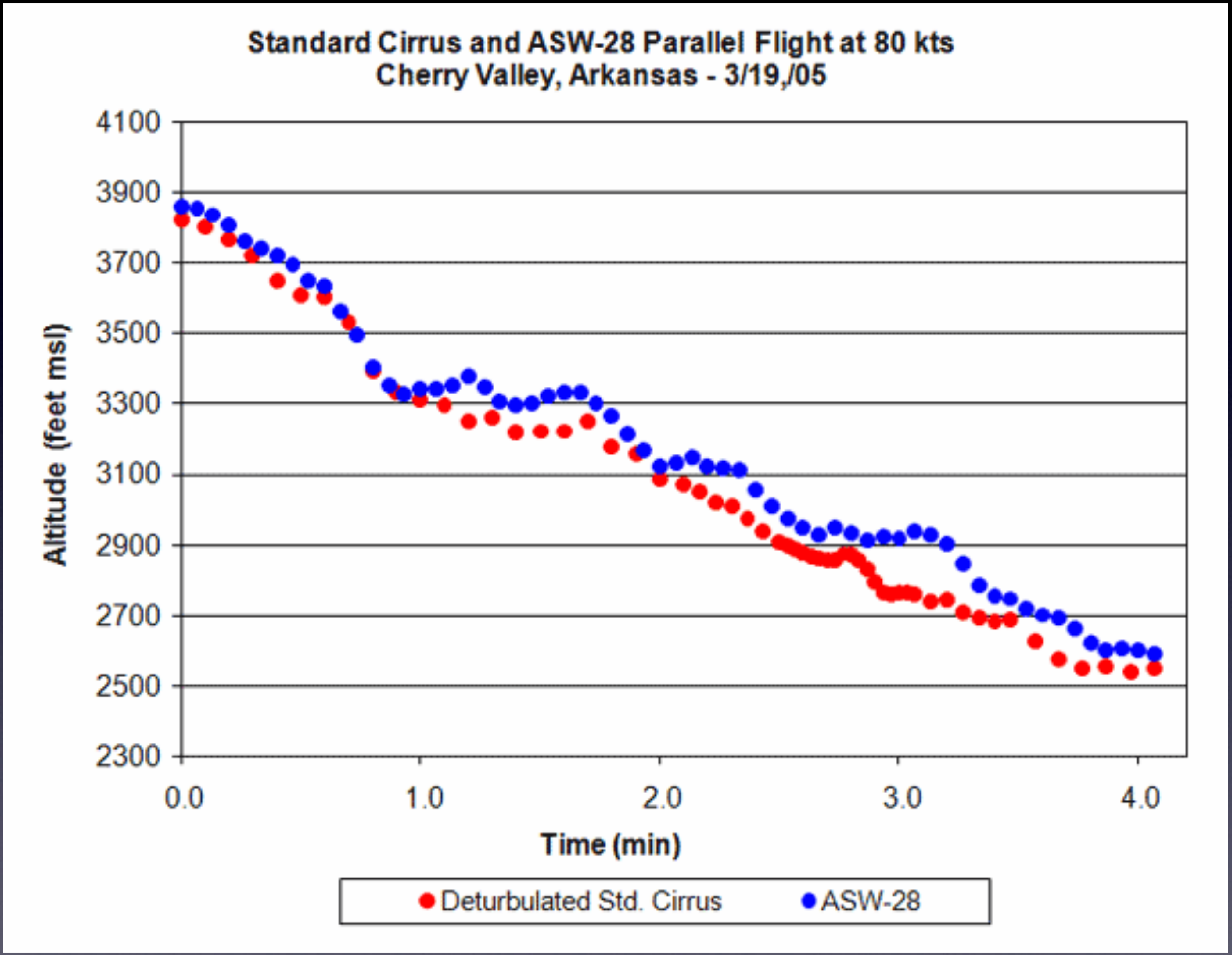
ASW 28

45:1
Circa 2000

Standard Cirrus

33.5:1 (Johnson)
Circa 1970

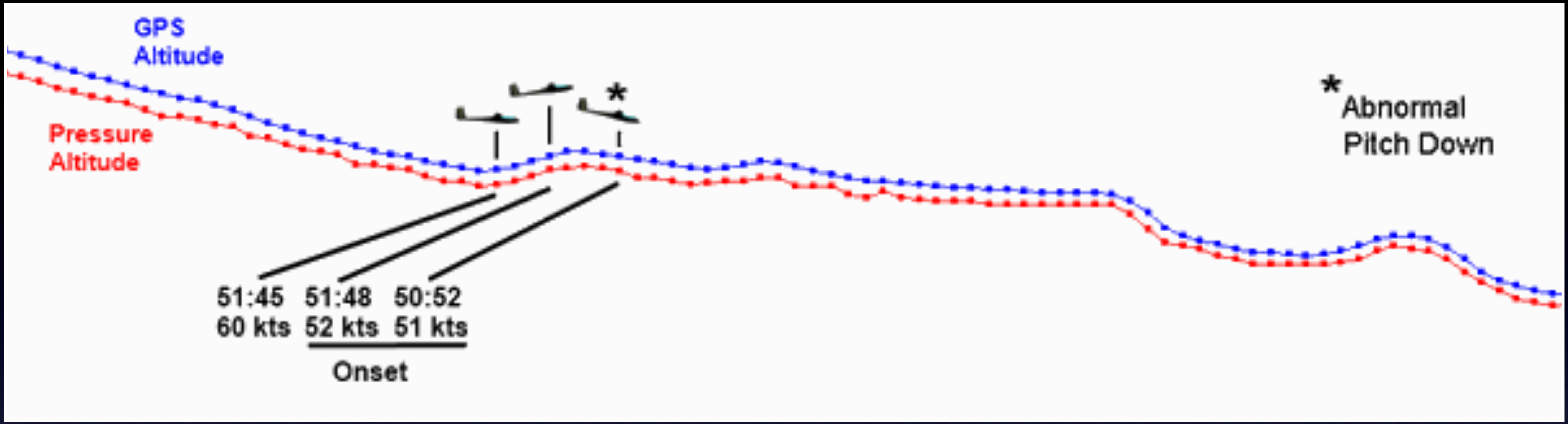
Tapes + Panels: Parallel Flying: Versus ASW 28



4 minutes @ 80 kts

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - **Nose Dipping Events**
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels: Nose Dipping Events



On several occasions the nose dropped dramatically upon reaching 52 kts.

Nose rises while slowing from 60 to 52 kts, then, drops dramatically upon reaching 52 kts, as the sink rate goes down!

http://www.youtube.com/watch?v=vk-FV9zM2vQ

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - **Hyvärinen Project**
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels: Hyvärinen Project

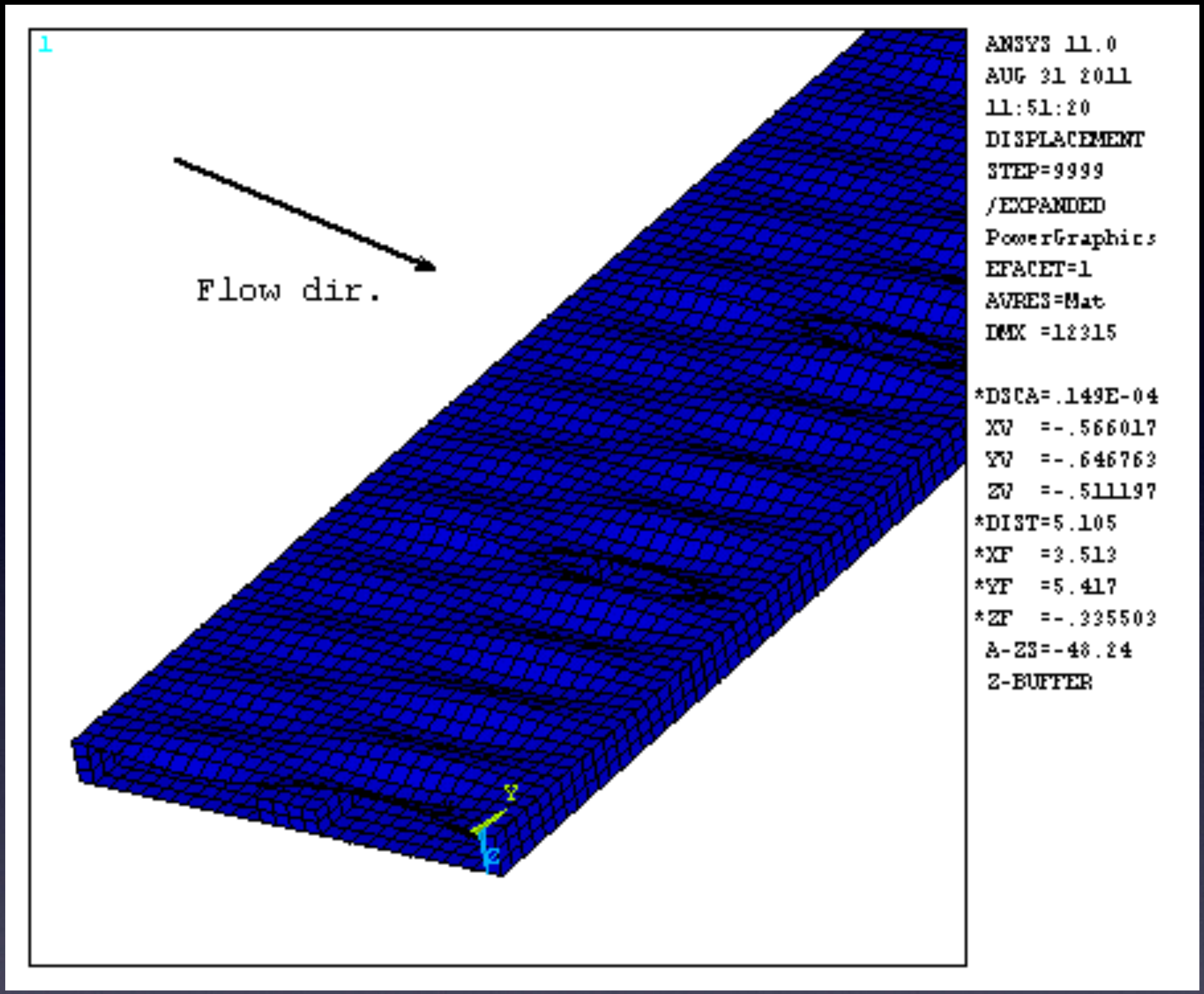
- Jari Hyvärinen is author of LINFLOW software for simulating aeroelastic behaviors.
- LINFLOW is suitable for simulating deturbulator panel modes.
- Daughter, Ann, is working on her undergraduate degree in aerodynamics. She performs test flights.

Preliminary Investigations of Aeroelastic Panel Vibration with respect to Performance Boost of Airplane Wings, 2011

Jari

Ann

Tapes + Panels: Hyvärinen Project: **Panel Simulation**

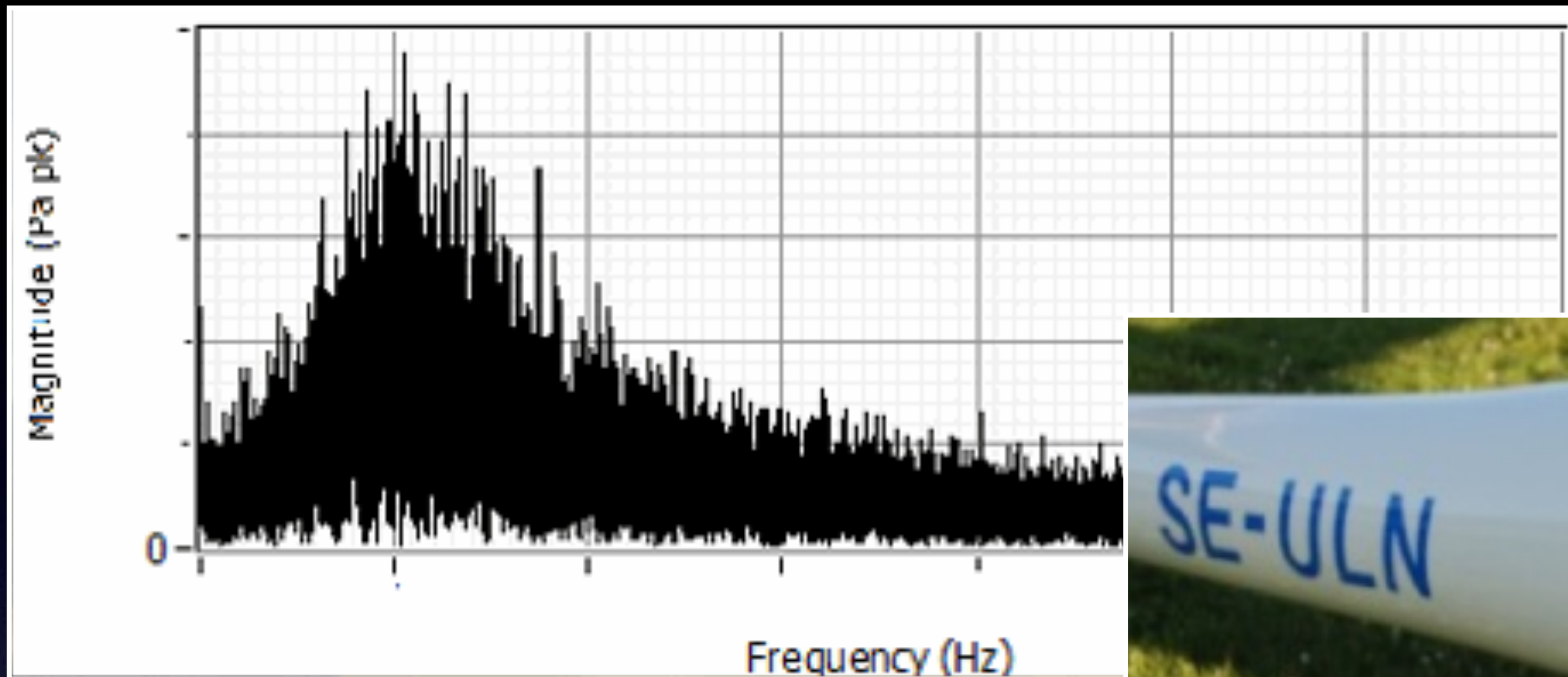


LINFLOW Simulation

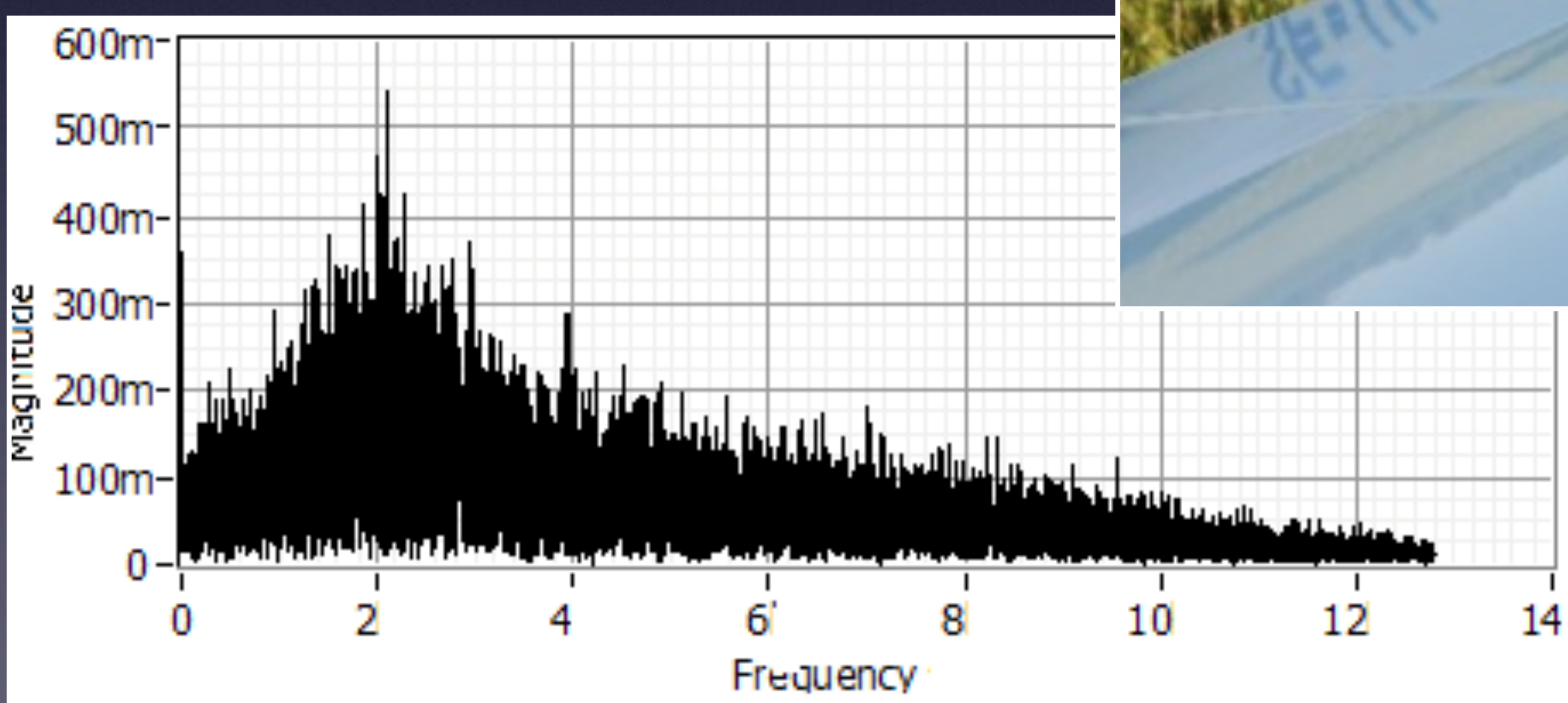
Photographic Corroboration

Mode appears at 52 knots indicated airspeed,
the principle performance speed in Hendrix test flights,
the speed at which nose dipping occurs!

Tapes + Panels: Hyvärinen Project: Spectra at Reattachment



Clean Wing



Taped Leading Edge

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - **Oil-Flow Patterns**
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Tapes + Panels: Oil-Flow Patterns

Normal Top Surface Pattern with Separation Bubble

Tapes + Panels: Oil-Flow Patterns

Deturbulated pattern.

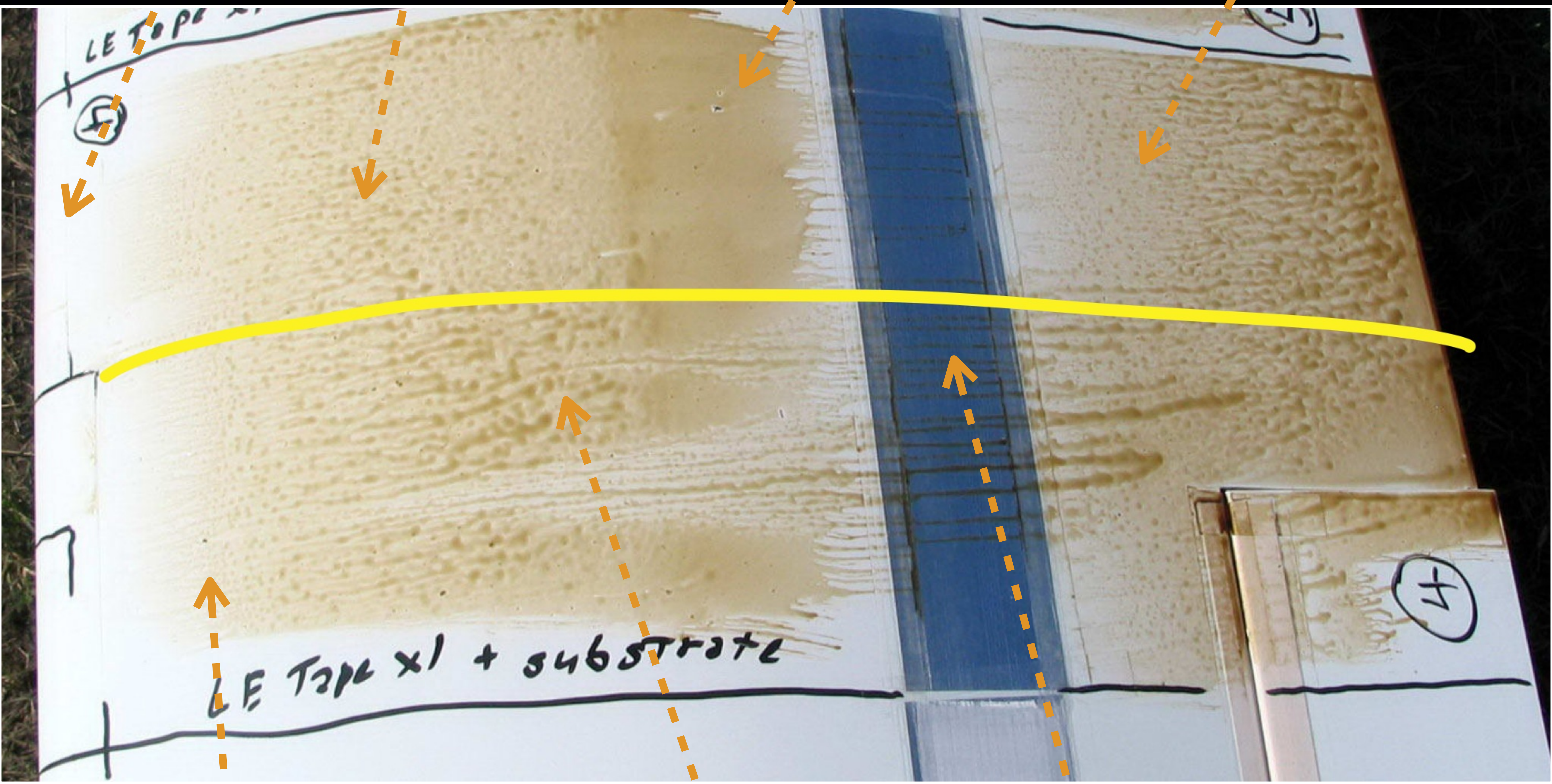
Tapes + Panels: Oil-Flow Patterns:
Effect of shifting tape edge .8 inches

Forward edge

Forward flow detachment

Debris spec in dead air

Higher flow velocity



Debris spec starts turbulence wedge.

Aft flow detachment

Non-functional FCSD panel (substrate only).

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- **Lower Surface Tapes**
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- Conclusion

Lower Surface Tapes: Applying the Tape

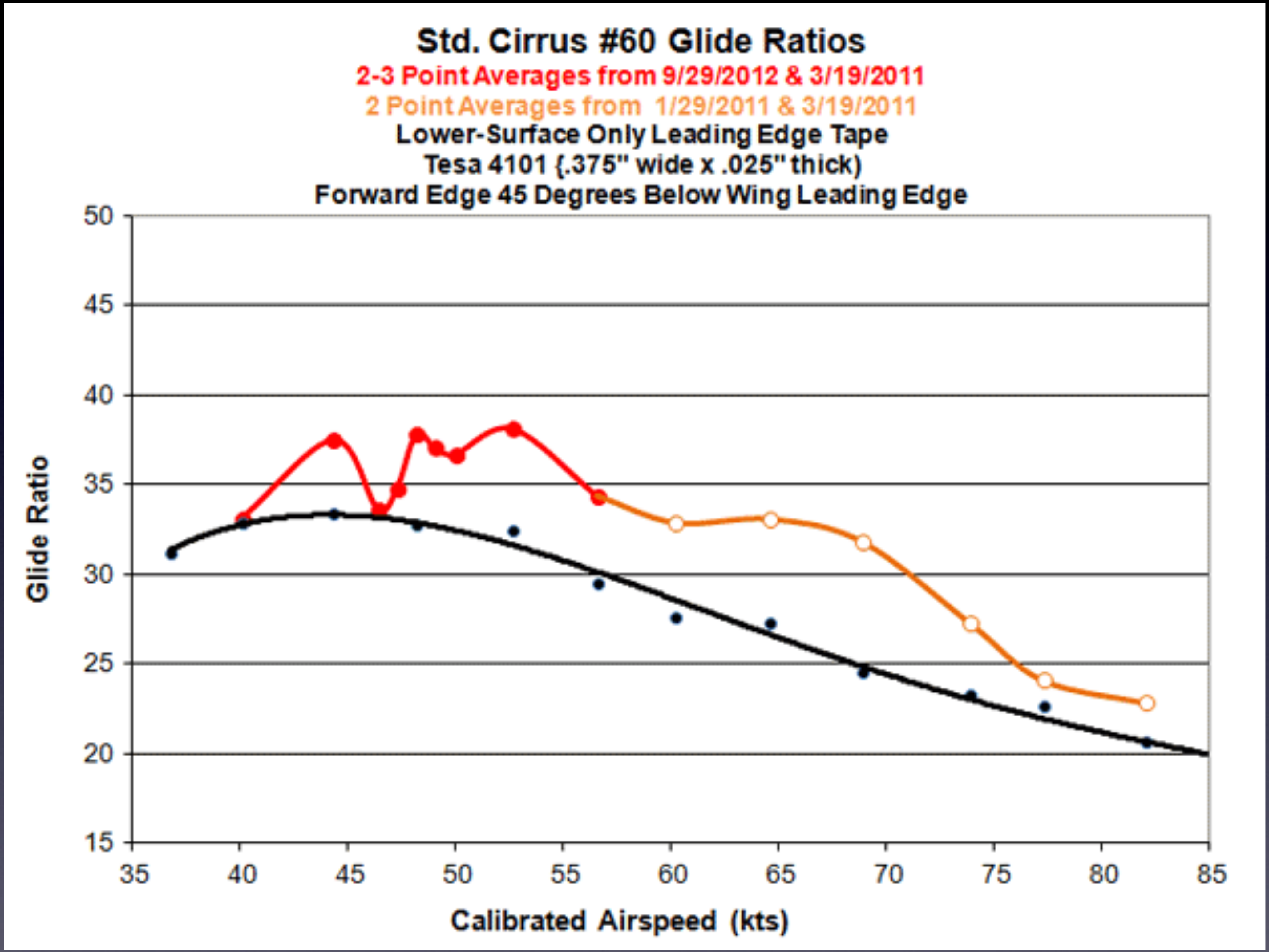
12 mm wide, .0025" thick leading-edge tape on lower surface.

Lower Surface Tapes: Oil-Flow Pattern

Normally, a single airspeed is tested, but this photo was taken after flying 33 minutes at 45 to 70 knots. The region of smooth oil in the box shows detached flow over a range of airspeeds on the lower surface.

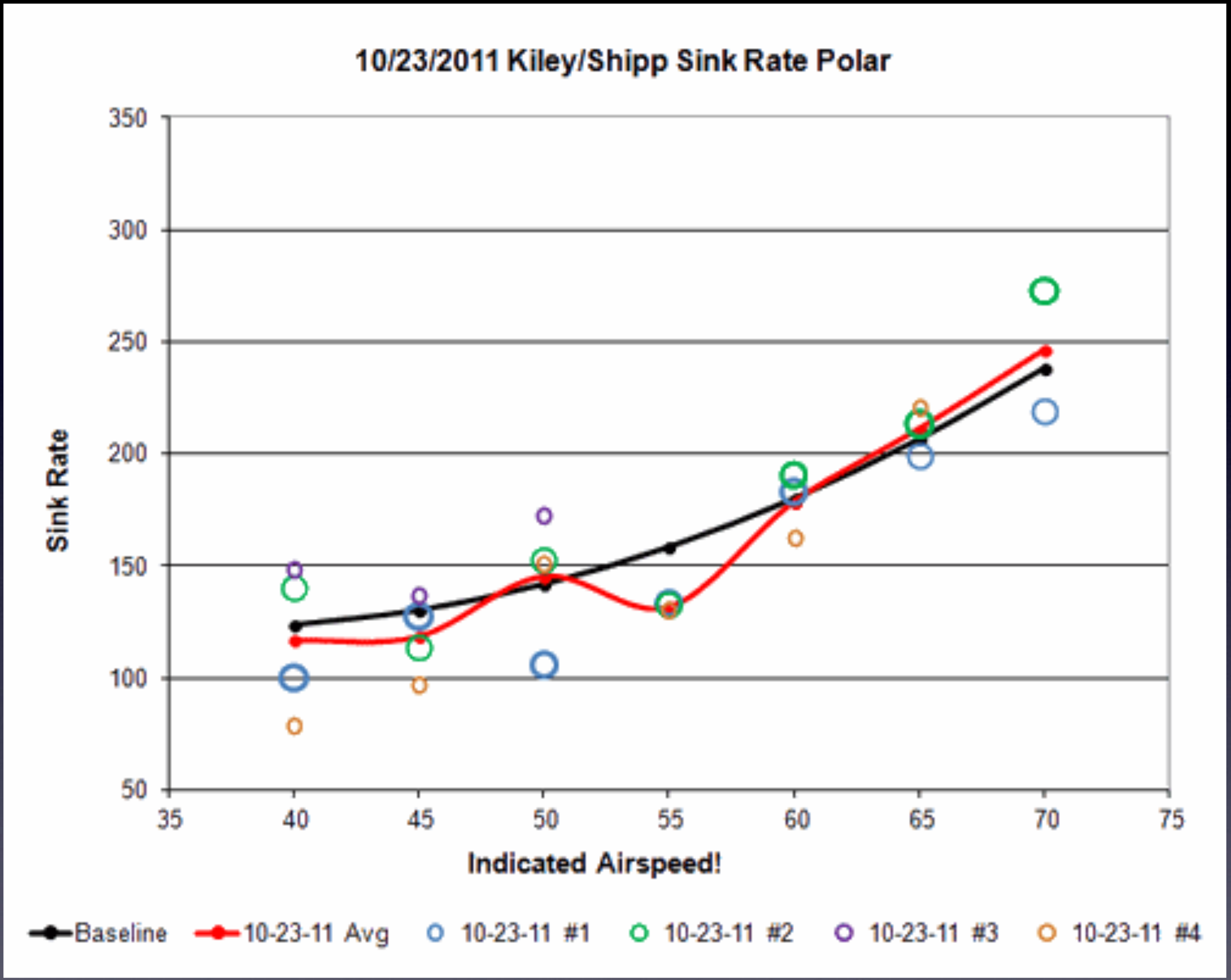
- Overview
- Tapes
    - Notched Polars
    - Humidity Dependence
- Tapes + Panels
    - Johnson Flight Tests
    - Peaked Polars
    - Performance Transitions
    - Drag Probe Measurements
    - Parallel Flying
    - Nose Dipping Events
    - Hyvärinen Project
    - Oil-Flow Patterns
- Lower Surface Tapes
    - **Performance Measurements**
    - Anecdotal Accounts
- Failures
- Review
- Conclusion

Lower Surface Tapes: Performance Measurements



Shows a performance notch resembling the top surface effect.
Minor differences in skin friction may affect results.

Lower Surface Tapes: Performance Measurements



Independent measurements on Aaron Kiley and Tom Shipp's Standard Cirrus.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - **Anecdotal Accounts**
- Failures
- Review
- Conclusion

Lower Surface Tapes: Anecdotal Accounts:
Erik Braun, Salto V1

(6/2011): Since I installed the leading edge tape I did several cross country flights often together with other gliders. ... Combining the leading edge tape and winglets ... **seems to give a big performance boost** to the **Salto** (**13.6m**). I flew ... against a **LS-1c** and **ASW-15** on flights of **200 to 300 km**. In **climb** there was **no difference** and **to my surprise almost none in cruising**. Wing loading was slightly higher on the Salto because of the small wing, so **it did very well in fast cruising especially compared to the ASW-15**.

Lower Surface Tapes: Anecdotal Accounts:
Jim Hendrix, Standard Cirrus

(8/28/2011): Flew vs. **PIK-20D** thermalling and cruising better. Flying at 75 kts, I overtook the PIK flying 60 kts, constantly gaining altitude over the PIK from a mile back.

Lower Surface Tapes: Anecdotal Accounts:
Jim Hendrix, Standard Cirrus

(9/11/2011): On the 2nd day of a **local contest**, I cruised **74 nm in dead air** with sparse thermals, **76% more than other competitors**. (Don't ask why!) Two other gliders landed out, but I came home cruising at **110 kts the last 12 nm**. The last **37 nm** was flown into a **14 kt headwind**, during which I tested various airspeeds for best differential altitude (height above/below computed glide slope) performance. As in past years with full deturbulator configurations, my **best performance, cruising into the headwind was at 42-45 kts!** A normal polar should have performed best around 60 kts! This implies a low speed performance hump.

Lower Surface Tapes: Anecdotal Accounts:
Jari Hyvärinen, Standard Cirrus

(7/27/2011): I am attending a regional soaring **competition** this week. We have completed 3 days so far. The first day ended in an **outlanding** in tricky weather conditions. Yesterday, I **won the day** and today I was **second**. I am flying with the **lower side tape** on the wings. I have done **2 final glides of 30-40 km** length and used my IPAQ as calculator. This is the same system that I have used during the past 10 years. **Both final glides have ended in a 300 to 400 m overshoot. So, something has dramatically changed in the glider!!!**

A **Discus 2** pilot, that I did not see **following me**, told me that he **did not gain on me during fairly long glides at 110-120 kph** (60-65 kts). After a few climbs **he lost track of me**, I left a thermal he entered and I **got home before him**.

Lower Surface Tapes: Anecdotal Accounts:

Jari Hyvärinen, Standard Cirrus

I have over the years learned that I get L/D of about 26 if the average speed on the final glide is 120 kph, which is a typical mid-Sweden summer average with 1.5 m/s average thermal strength. So, **my impression from my last 3 cross country flights still is that I need to increase speed with about 15-20 kph to have the same glide path that I had with the clean wings**.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- **Failures**
- Review
- Conclusion

Failures

Delft Wind Tunnel Test of Tape + Panel - 2009

- Upper-surface tested, depends critically on airspeed and wing loading.
- Precise match of wing loading/airspeed condition may not have been achieved.
- Chordwise scaling.

Failures

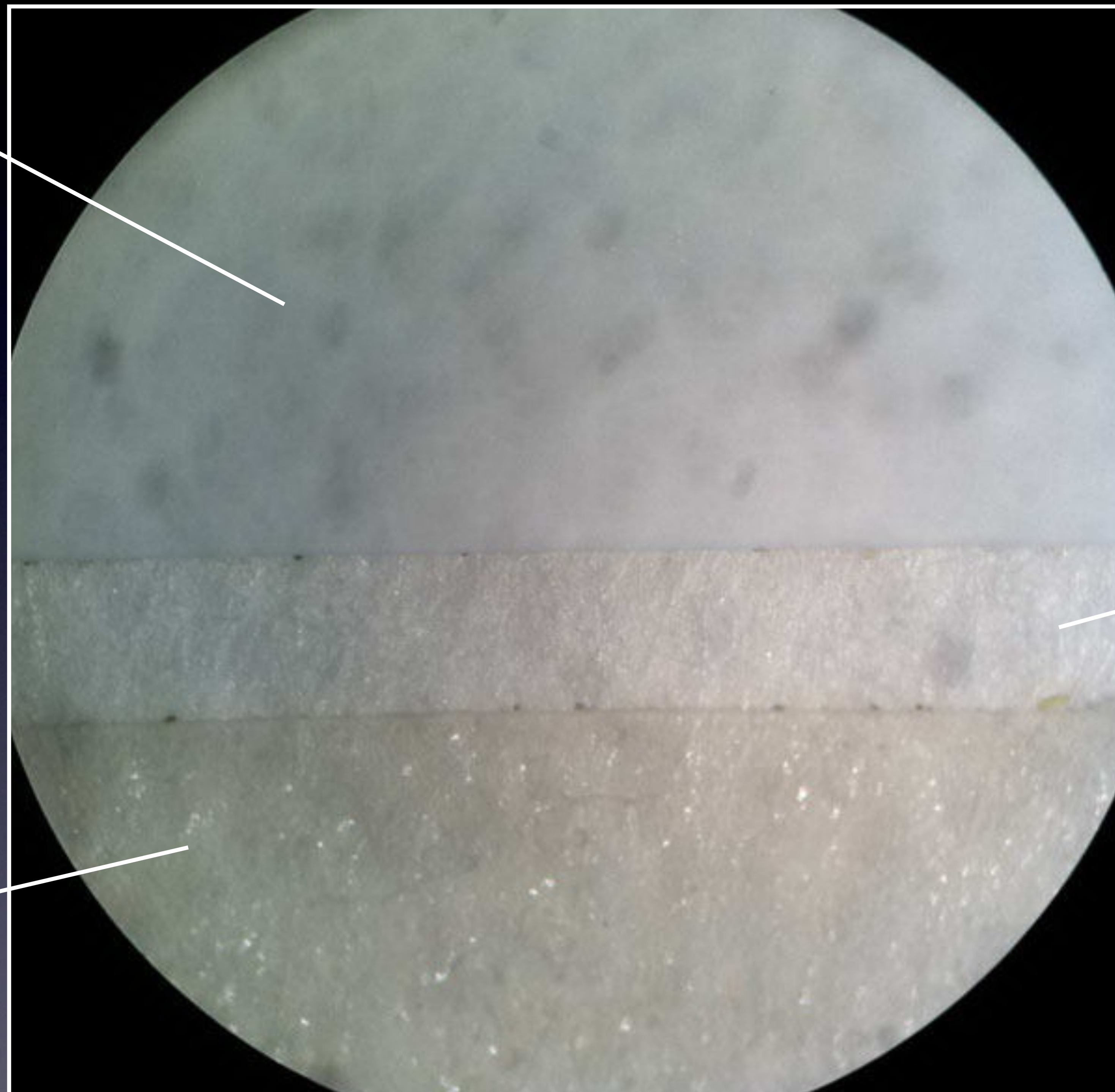
Akaflieg In-Flight Tests of Tapes Only - 2010

- Textured surface (clear Tesa 4104) tape used (next slide).

Failures

Akaflieg In-Flight Tests of Tapes Only - 2010

White Tape



Clear over White

Clear Tape

Tesa 4104 tape. White works. Clear appears not to work.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- **Review**
- Conclusion

Review: Evidence

- Johnson flight tests.
- Notched and peaked polars repeat: (LE tape only).
- Peaked-polar performance at 50 KIAS repeatedly transitions through the "butte" shaped pattern with same time scale.
- Humidity dependence.
- Altitude vs. time profiles show onset and loss of performance coincide with speed changes. So, convection does not explain measurements.
- Numerous drag probe measurements.
- Parallel flying vs. higher performance gliders.
- Nose dip + performance boost at 52 KIAS. Matches Hyvärinen's simulation and video evidence.
- Oil-Flow Patterns.
- Hyvärinen simulations, pressure and acoustical measurements.
- Anecdotal accounts.

- Overview
- Tapes
  - Notched Polars
  - Humidity Dependence
- Tapes + Panels
  - Johnson Flight Tests
  - Peaked Polars
  - Performance Transitions
  - Drag Probe Measurements
  - Parallel Flying
  - Nose Dipping Events
  - Hyvärinen Project
  - Oil-Flow Patterns
- Lower Surface Tapes
  - Performance Measurements
  - Anecdotal Accounts
- Failures
- Review
- **Conclusion**

Conclusion

Sufficient evidence exists to warrant formal investigations. Questions that need to be answered include:

- What are the physics behind deturbulation phenomena?
- Why is the effect so strongly dependent on airspeed.
- How is deturbulation limited by Reynolds number?
- How may airfoil designs and deturbulation methods be optimized for maximum performance and airspeed?
- What other applications may benefit from deturbulation methods?