

REVOLUTIONARY AERODYNAMICS

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TRADITIONAL AERODYNAMICS for Maximizing L/D

- Maintain **Laminar** Flow
- **Avoid** Boundary Layer **Separation**
- Maintain **Elliptical** Spanwise Lift Distribution

MOTIVATION

- Highest L/D is for Sailplanes (70 for AR of 33 with flaps, 48 for AR of 22 without flaps)
- L/D Restricted by Limits of Laminar Flow
- **Can we do better than Laminar Flow?**

AIRFOIL DESIGN APPROACHES FOR L/D MAXIMIZATION

Liebeck R.H. (J. of Aircraft, Oct 1973) Airfoil.

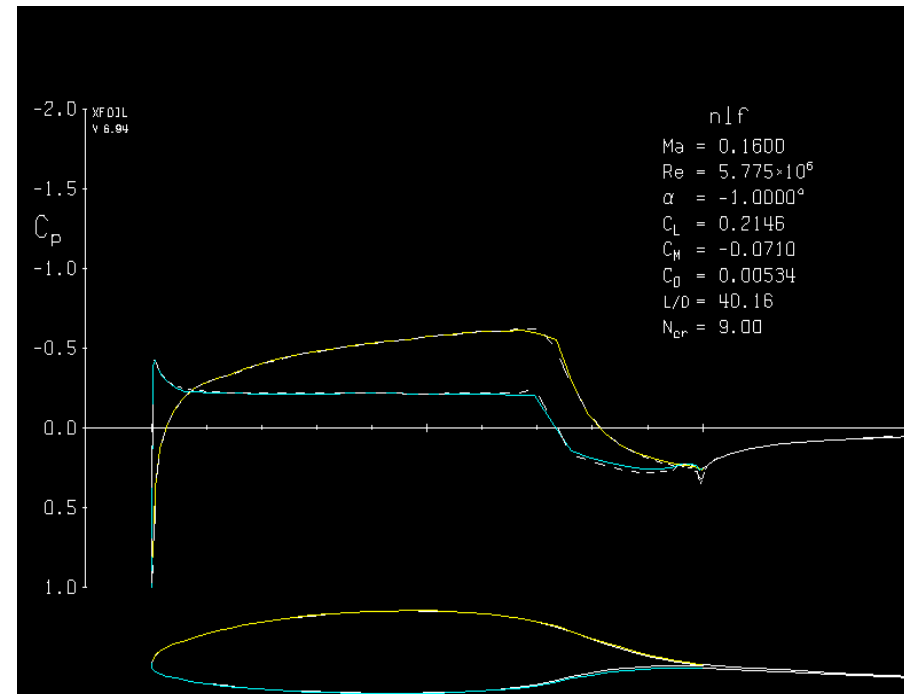
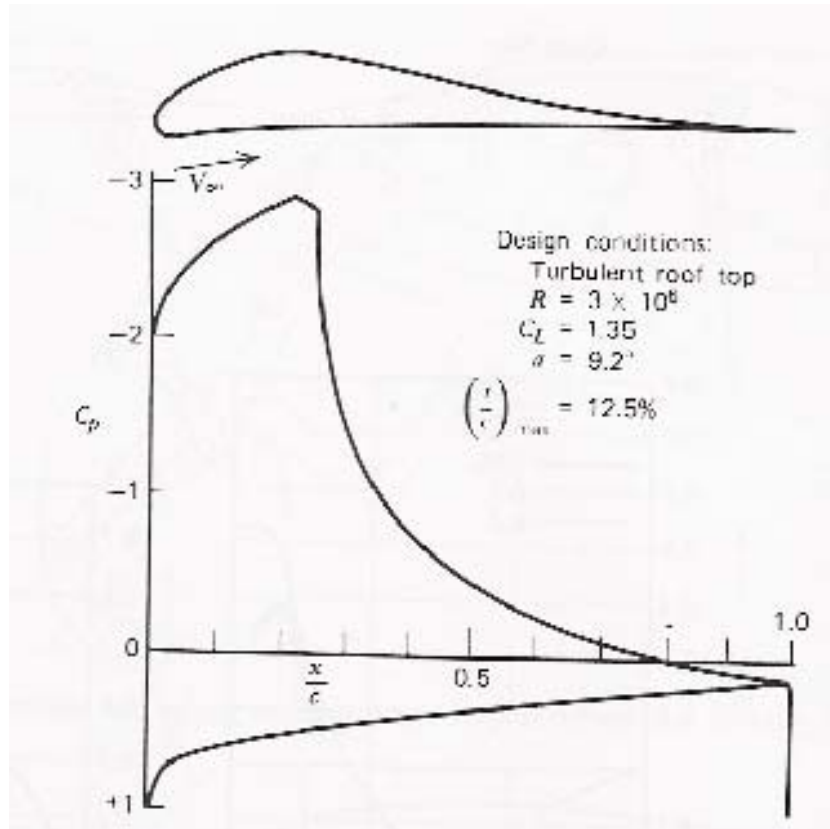
$C_d \sim 0.01$ for $1.6 > C_l > 0.6$

GT-3 testing simulation on XFOIL 6.94

Cp vs x Plot

NLF-0414-F airfoil

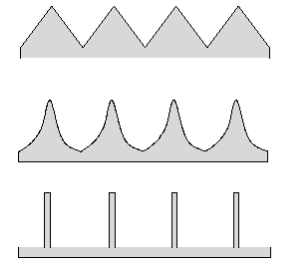
$Re_D = 5.775 \times 10^6$



Cp vs X plot - The blue line represents the pressure distribution on the lower surface and the yellow line represents the pressure distribution on the upper surface.

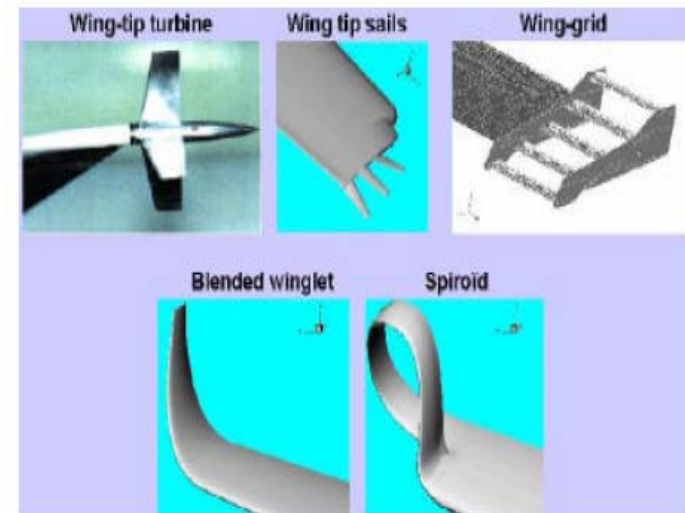
L/D Increase using Flow Control

- The turbulent skin friction drag reduction by the use of *Riblets* ($\delta CD/CD$ of about 1-2% flat-plate)
- The *hybrid laminar flow* technology ($\delta CD/CD$ of about 6 - 10% flat plate);
- The innovative *wing-tip devices* ($\delta CD/CD$ of about 5 - 8% flight);
- The *sub-layers vortex generators* and *MEMS* technology which can be used to control flow separation.
- **Deturbulator Flow Control** reduces parasitic & induced drag ($\delta CD/CD$ as much as 30% for **Total Aircraft**) *REVOLUTIONARY!*



Shapes of riblet films

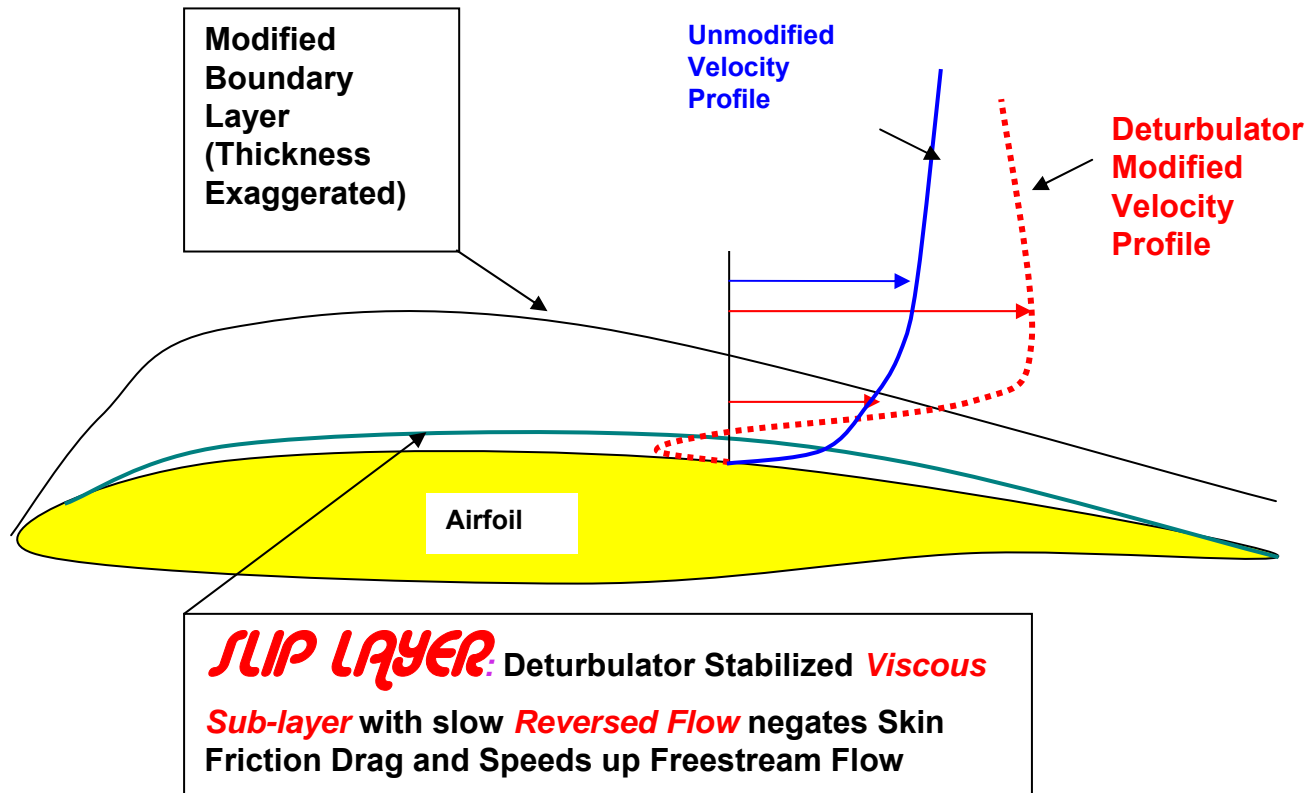
Source:<http://aerodyn.org/Drag/riblets>



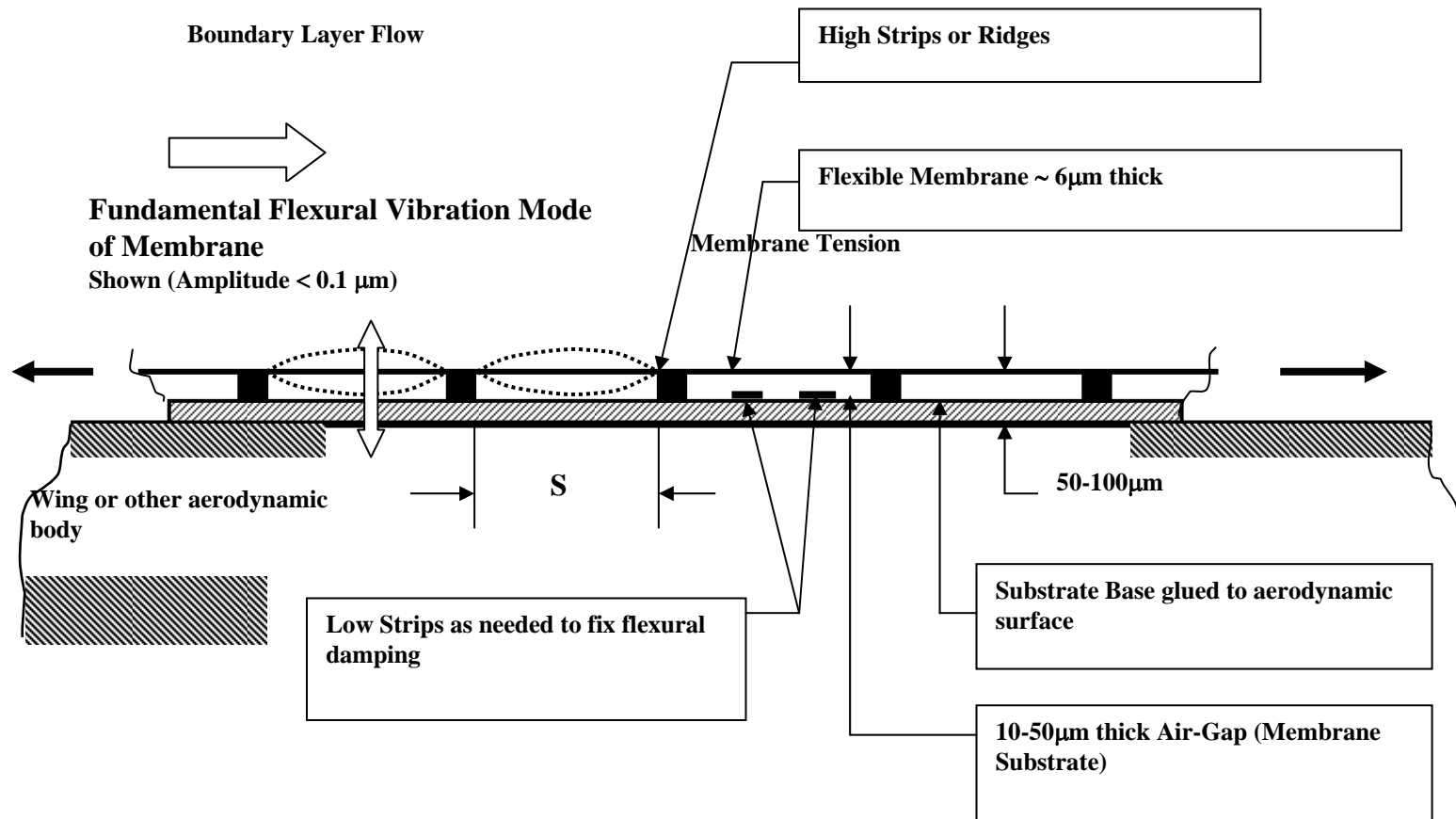
Wing-tip Devices

Source:J.Reneaux., "Overview on drag reduction technologies for civil transport aircrafts" European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS 2004.

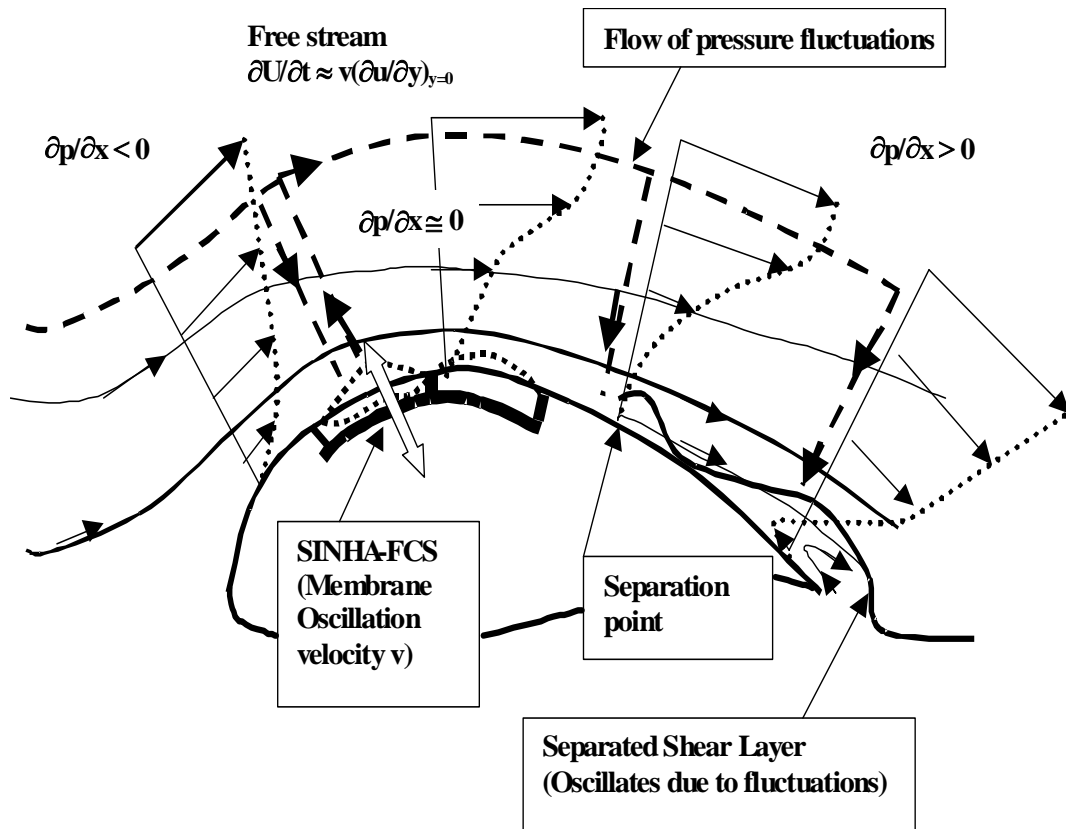
The Sinha-Deturbulator Approach



SINHA FLEXIBLE COMPOSITE SURFACE DETURBULATOR (FCSD)



FLOW-FCSD INTERACTION



BEST INTERACTION where
 $\partial p/\partial x = 0$

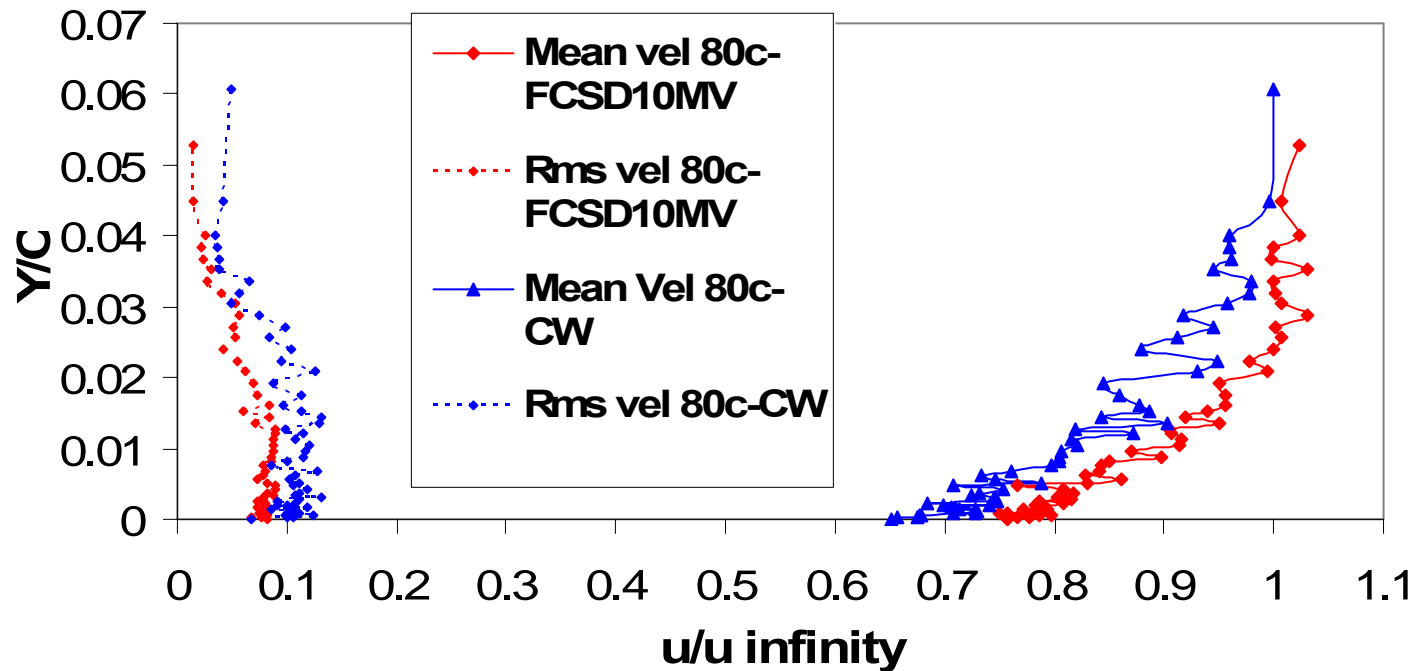
- FCSD passes oscillation without damping at the **Interaction Frequency**:

$$f = U/s$$

Attenuates other frequencies

- This **stabilizes the shear layer** and mitigates turbulent dissipation

Boundary Layer Velocity Profiles Showing Effect of Deturbulation

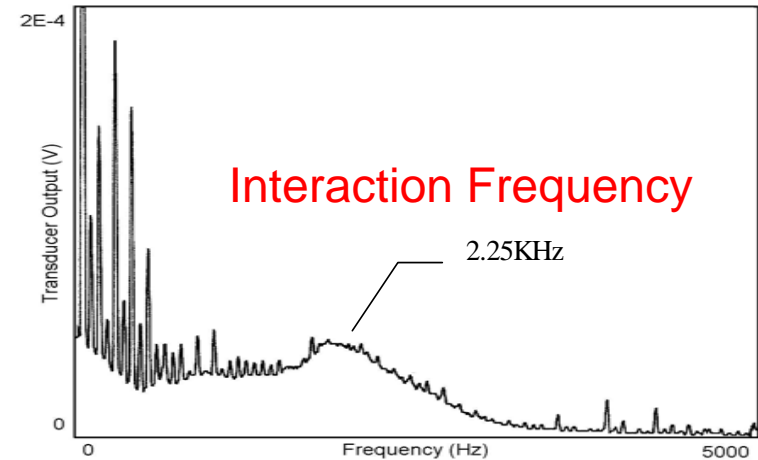


Development History

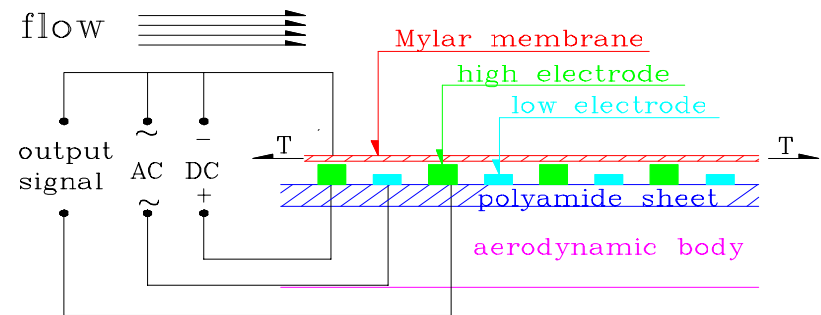
- Preliminary Drag Reduction Studies jointly with Global Aircraft 1999-2000 on GT-3 Aircraft based on Electrically actuated **Active Flexible Wall Transducer** (Invented in 1993, Sinha, 1999 Patent)
- Passive **Flexible Composite Surface Deturbulator** observed in 2001 (Pending Patents, Sinha 2003, 2004, 2005). *Subsequent 15-20% wing profile drag reduction on NLF-0414F on GT-3 (NASA Sponsored project with Advanced Technologies, 2004).*
- **Sailplane Drag Reduction** (2002-Present): **5-30% enhancement of total Lift/ Drag** over a wide range of airspeeds for the Standard Cirrus 15-m span Sailplane.

Previous Research On Active Flexible Wall (AFW Transducer)

- **FCSD concept evolved out of an earlier electrically powered AFW (Sinha, 1999).**
- **Mylar stretched across the high and low electrode.**
- **Air gap between Mylar and electrode provide the mechanical damping.**
- **DC bias applied across membrane**
- **Flow-membrane interaction produces an AC signal**
- **AC signal decomposed into fundamental flow-membrane frequencies**
- **Membrane actuated at those aforementioned frequencies**



Spectrum of AFW sensed signals on a cylinder showing the 2.25 kHz interaction

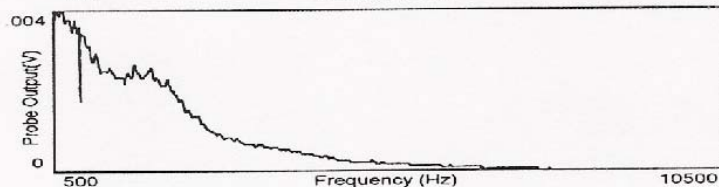
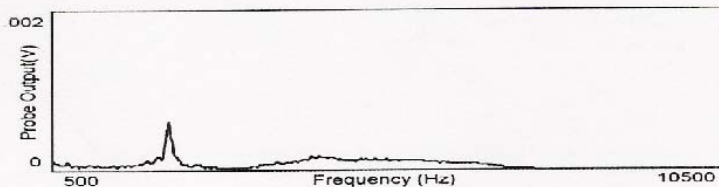
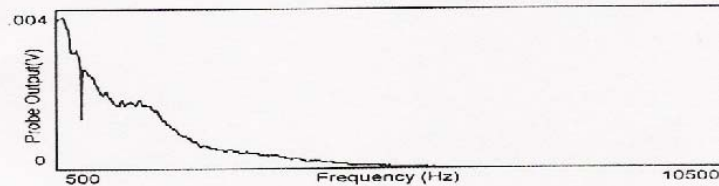
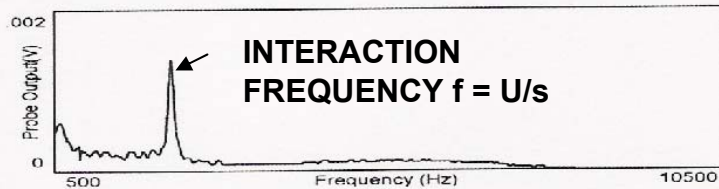
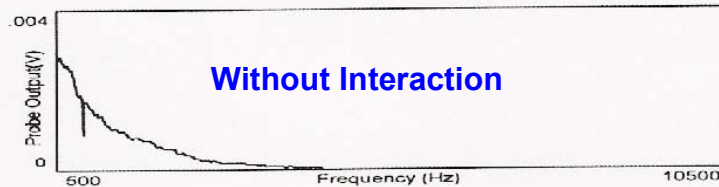
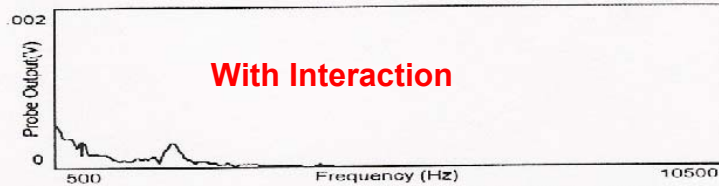
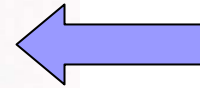


Schematic of the Active Flexible Wall (AFW) Transducer

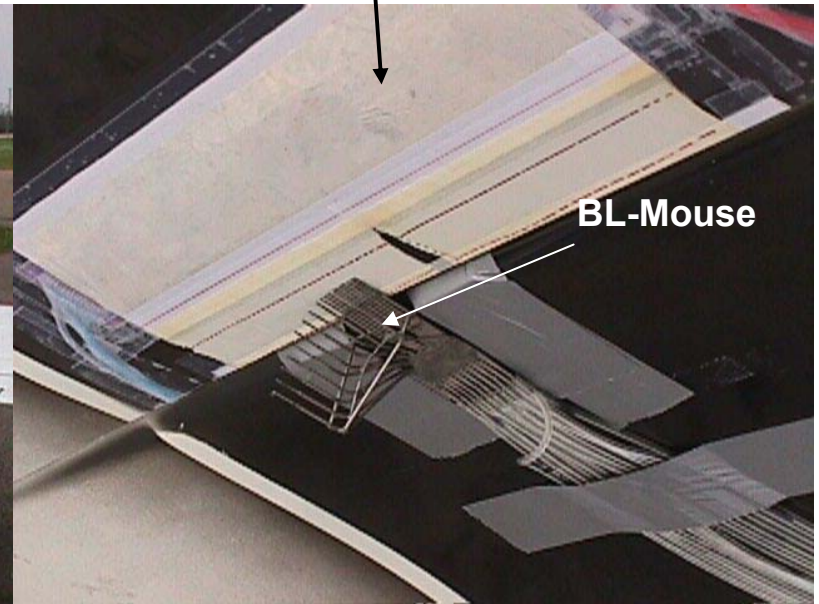
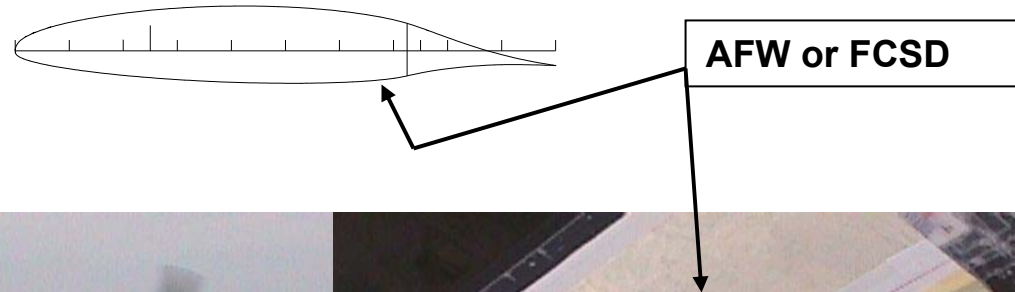
MODIFICATION OF TURBULENCE BY FLEXIBLE SURFACE

SPECTRA OF STREAMWISE VELOCITY FLUCTUATIONS

With (top) and **Without (bottom)** Flexible-Surface Interaction for Separated Flow over a Cylinder in Crossflow for $Re = 150,000$, $M = 0.05$ at $\theta = 90^\circ$ from stagnation (From: Sinha and Wang, 1999, AIAA Paper 99-0923)

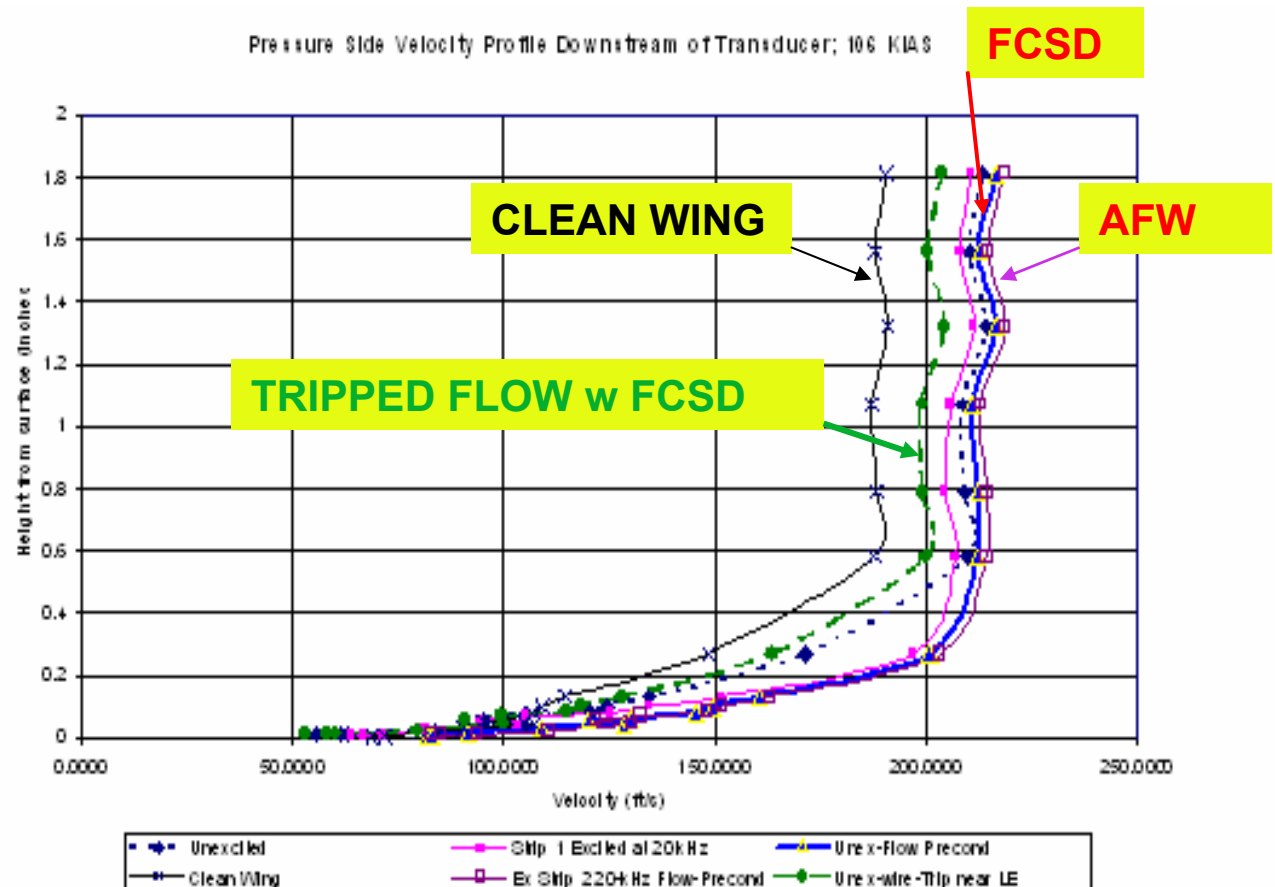


TESTS ON NLF 0414F WING



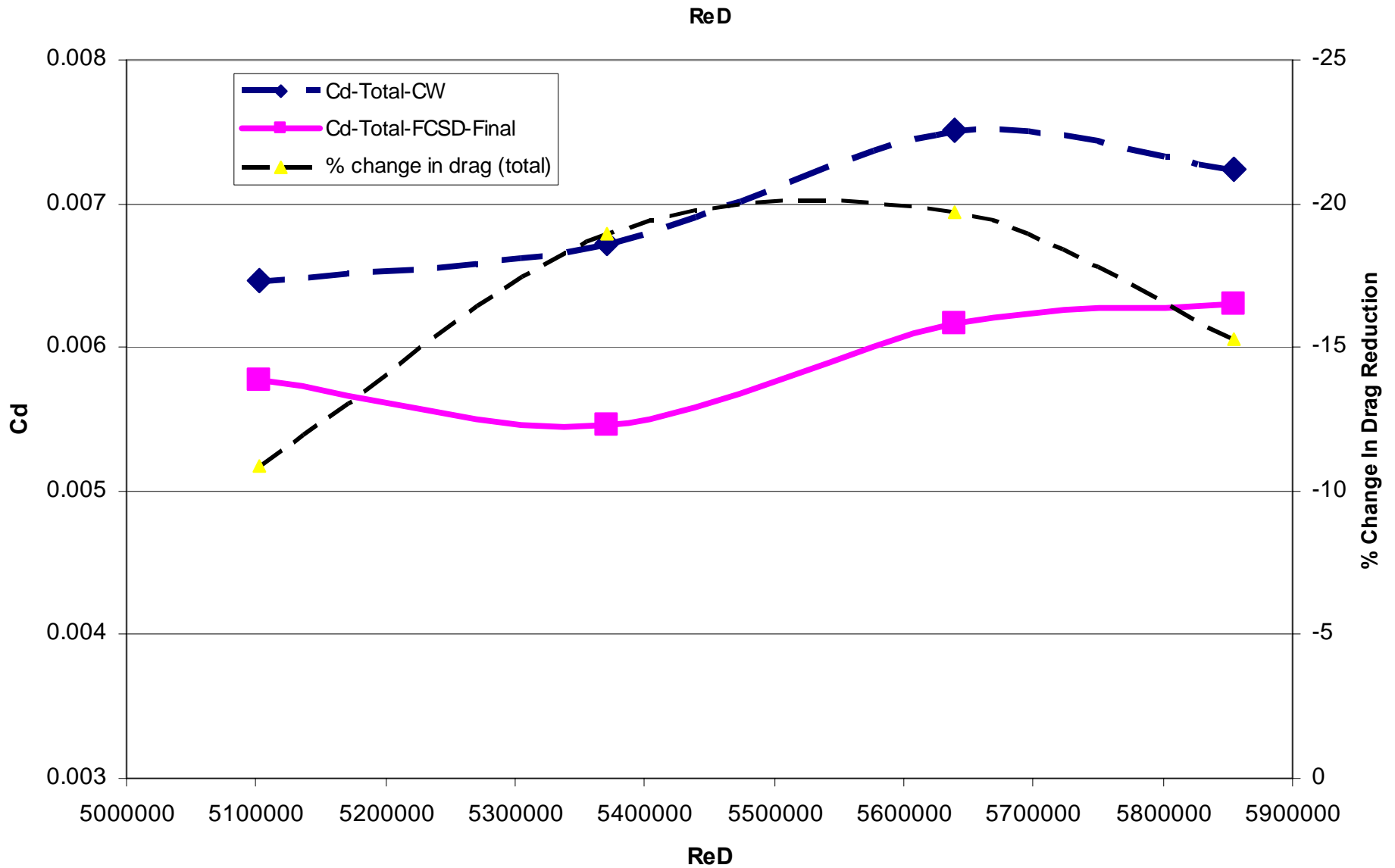
Transition from AFW to FCSD

- Unexcited AFW produced a boundary layer profile very similar to the excited AFW.
- Difference in percentage drag reduction is minimal.
- FCSD Simplifies the manufacturing and installation procedure.
- More pragmatic on retrofitting existing aircrafts



GT-3 WING BOTTOM VEL PROFILES @ 0.8C

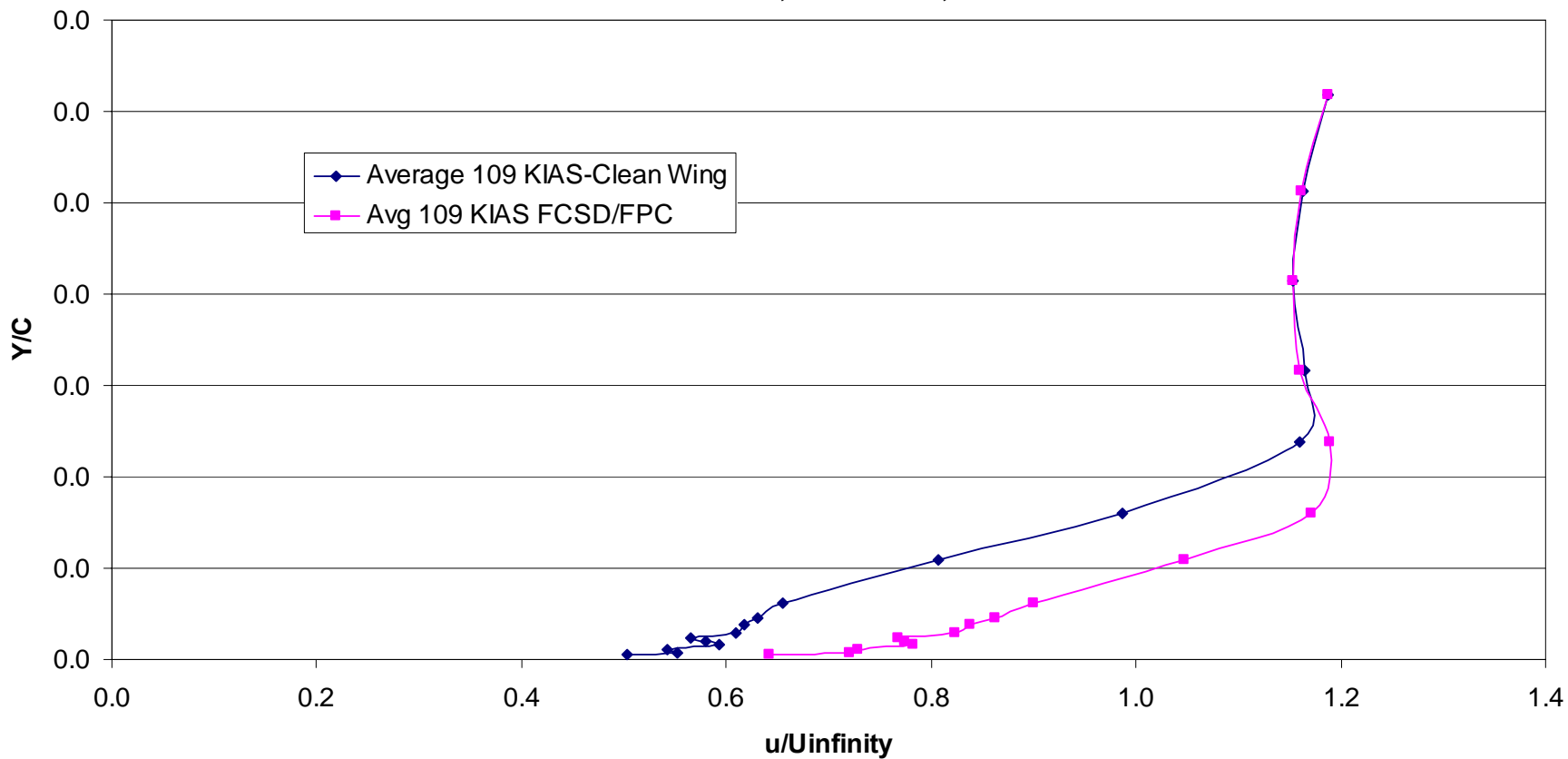
Comparision of coefficient of Total drag Vs ReD-GT-3- Clean Wing and FCSD Final



Boundary Layer Measurement

BL Probe 0.90c, Upper Surface, , WS115, Global GT-3

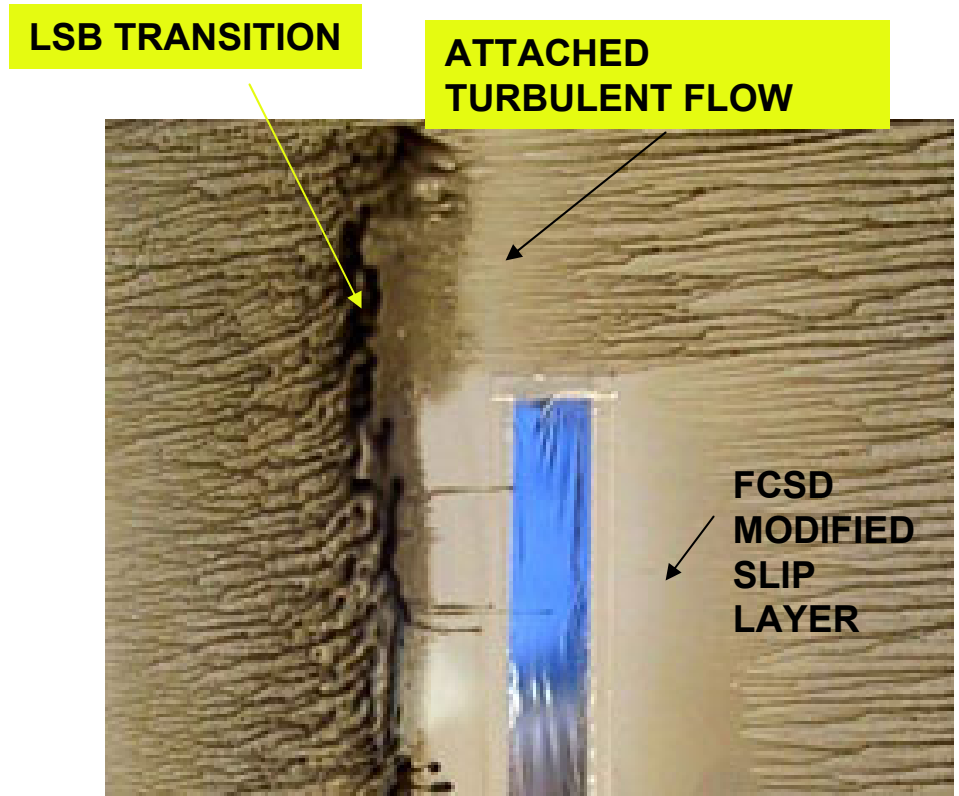
109 KIAS, Palt 2000 ft, 88 F



DETURBULATOR CLOSE UP & SURFACE OIL FLOW PATTERNS



CLOSE UP OF FCSD



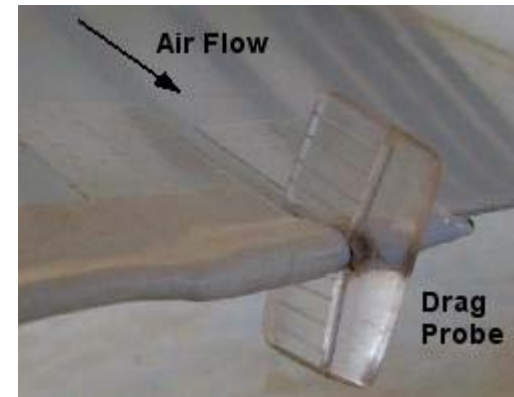
TESTS ON STANDARD CIRRUS SAILPLANE TO IMPROVE L/D



Gross Weight: 728 lbs

Best L/D: 36 @ 52-kts

Wing Loading: 6.8 lb/ft² Aspect Ratio: 22.5



STANDARD CIRRUS LOWER SURFACE DRAG REDUCTION

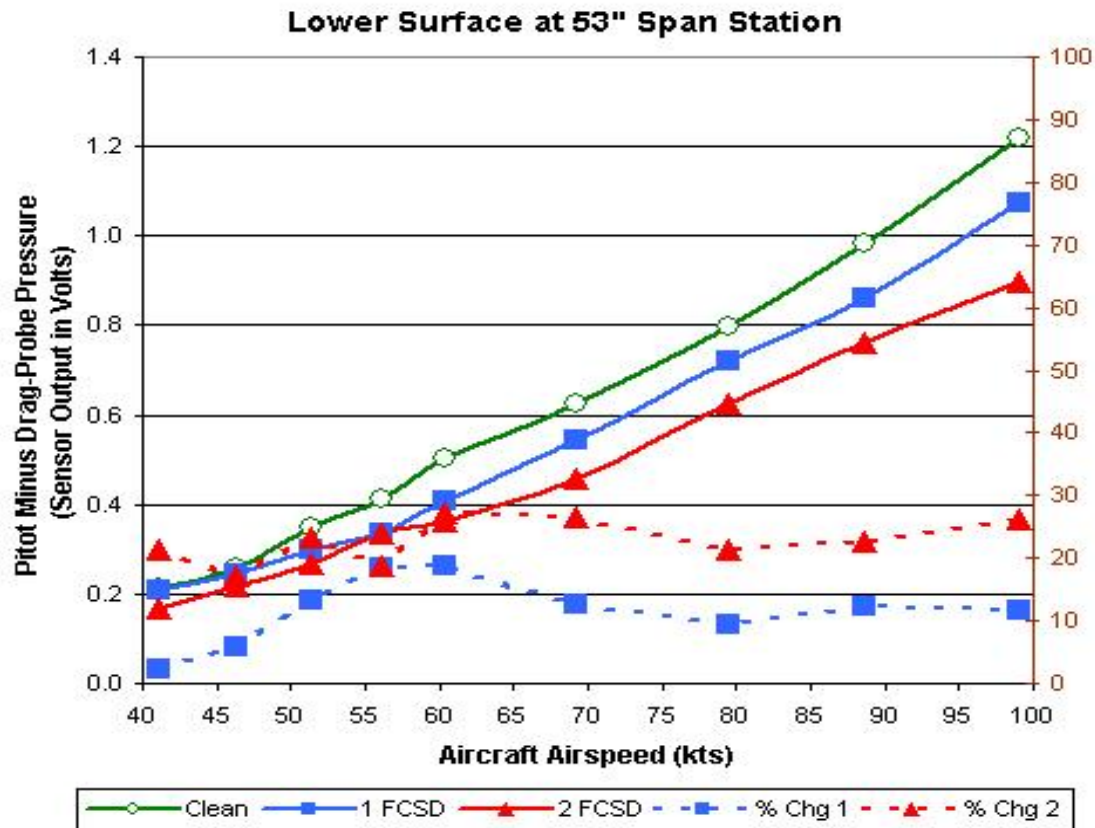


Fig. 7. Drag-probe pressure sensor output (proportional to upstream stagnation pressure minus wake stagnation pressure). A reduction in output indicates drag reduction resulting from FCSD applications (1FCSD and 2FCSD) on wing bottom at the given location. % change (reduction) scale is on the right

Sinhatech Low-Speed Wind-Tunnel

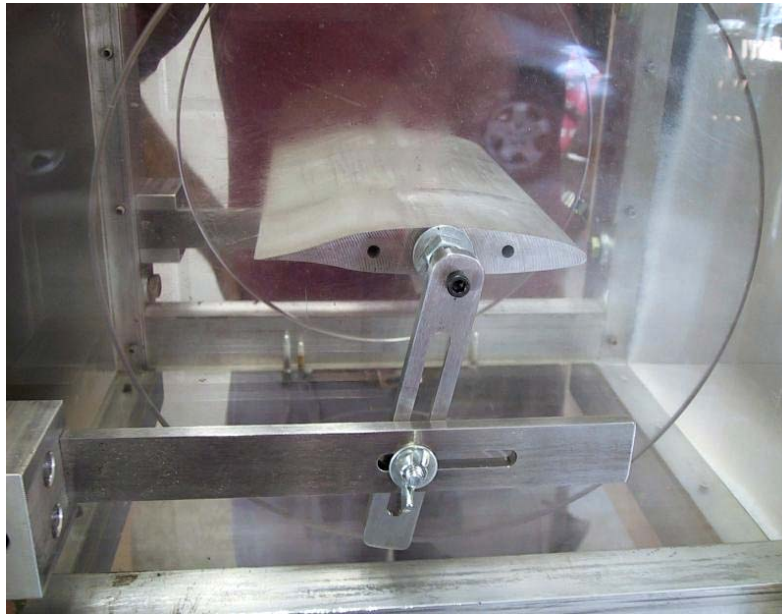


Sinhatech Slow-Speed Wind-Tunnel



Experimental set-up showing the pressure transducers and manometer

Airfoils Tested in the Wind-Tunnel

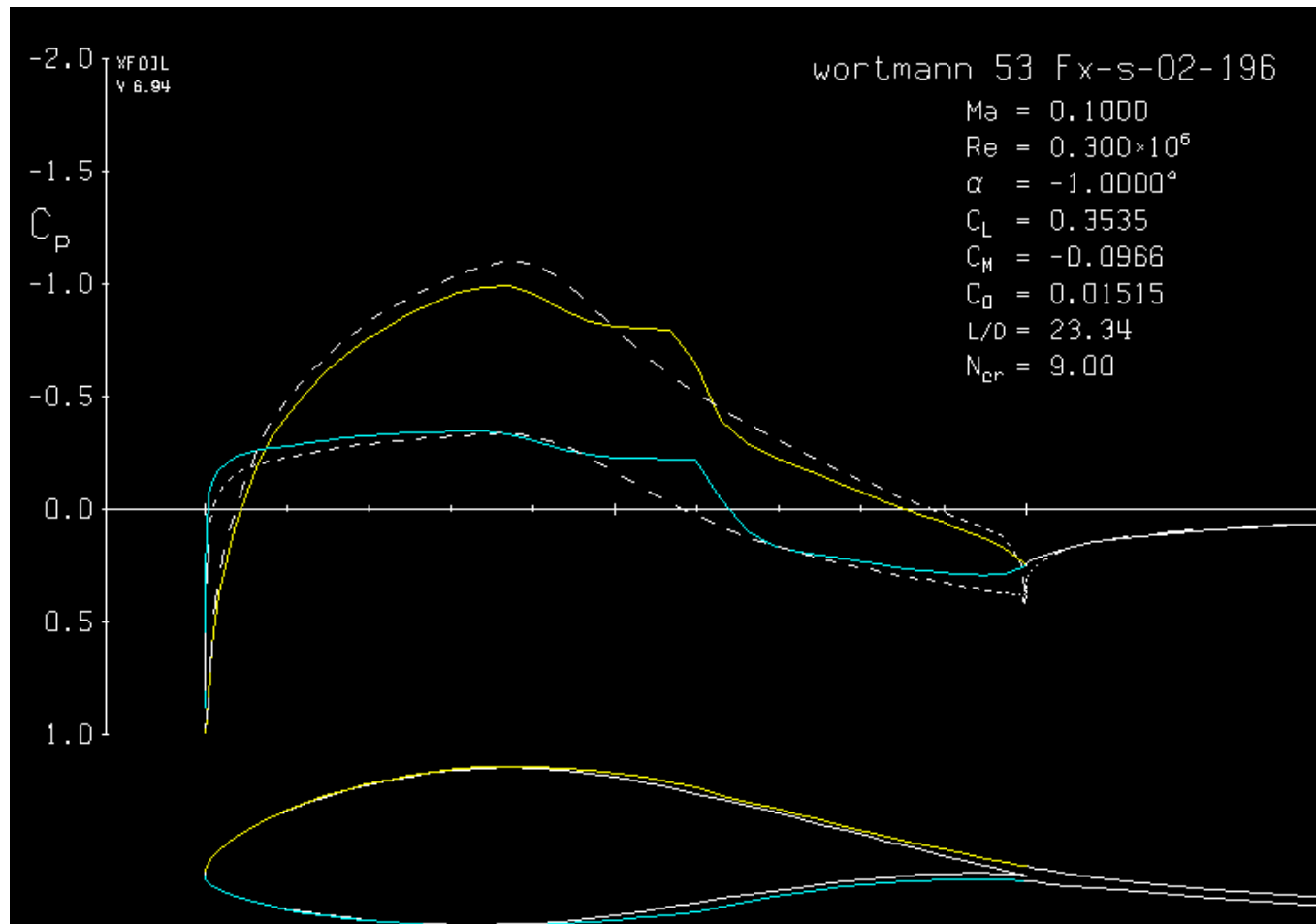


Close up of tunnel test section showing NLF-0414F airfoil being tested

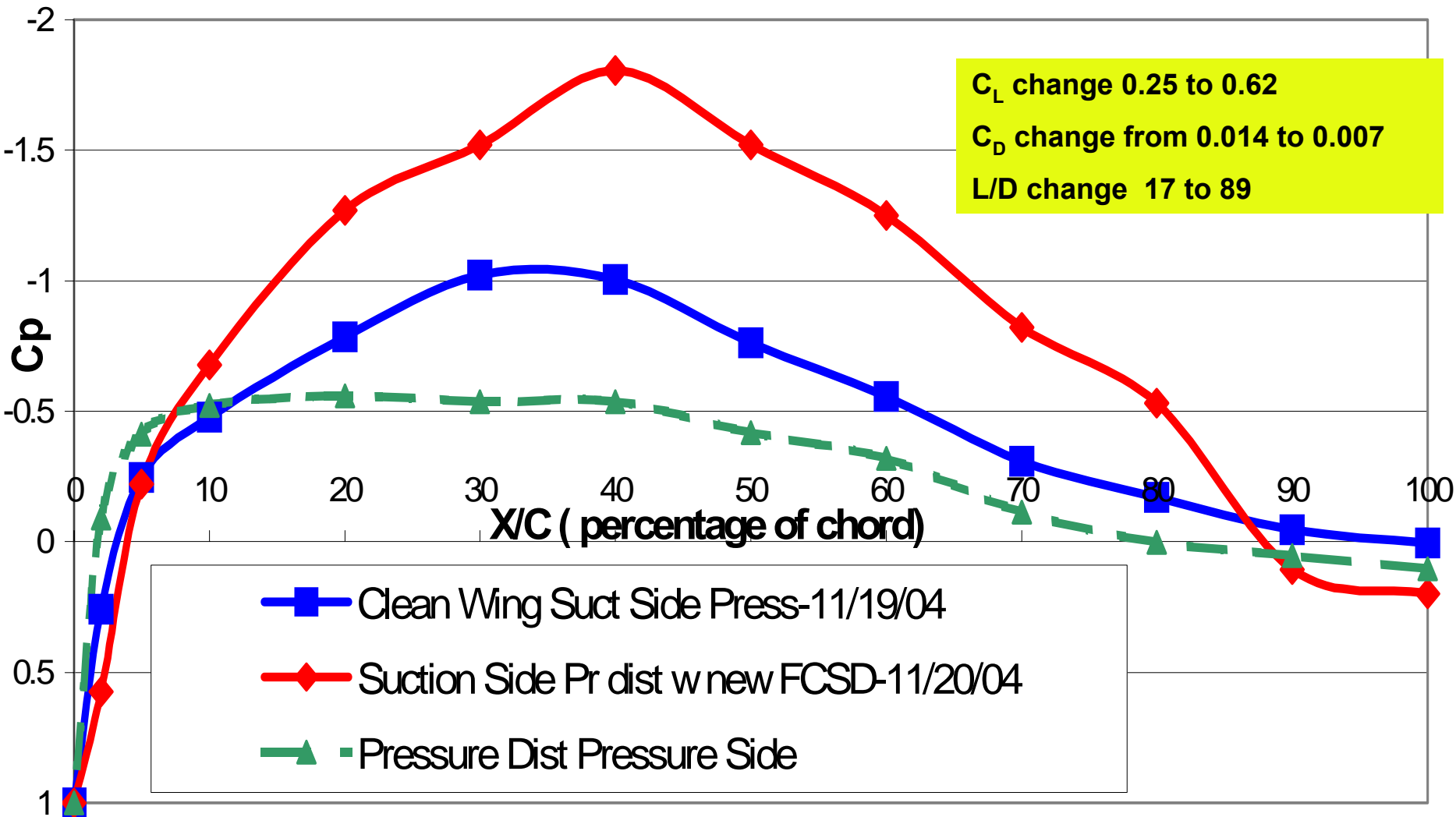


Stereo-lithography used to develop the Wortmann FX-S-02-196 Airfoil

XFOIL SIMULATION OF STANDARD CIRRUS 53"-SPAN WORTMANN AIRFOIL

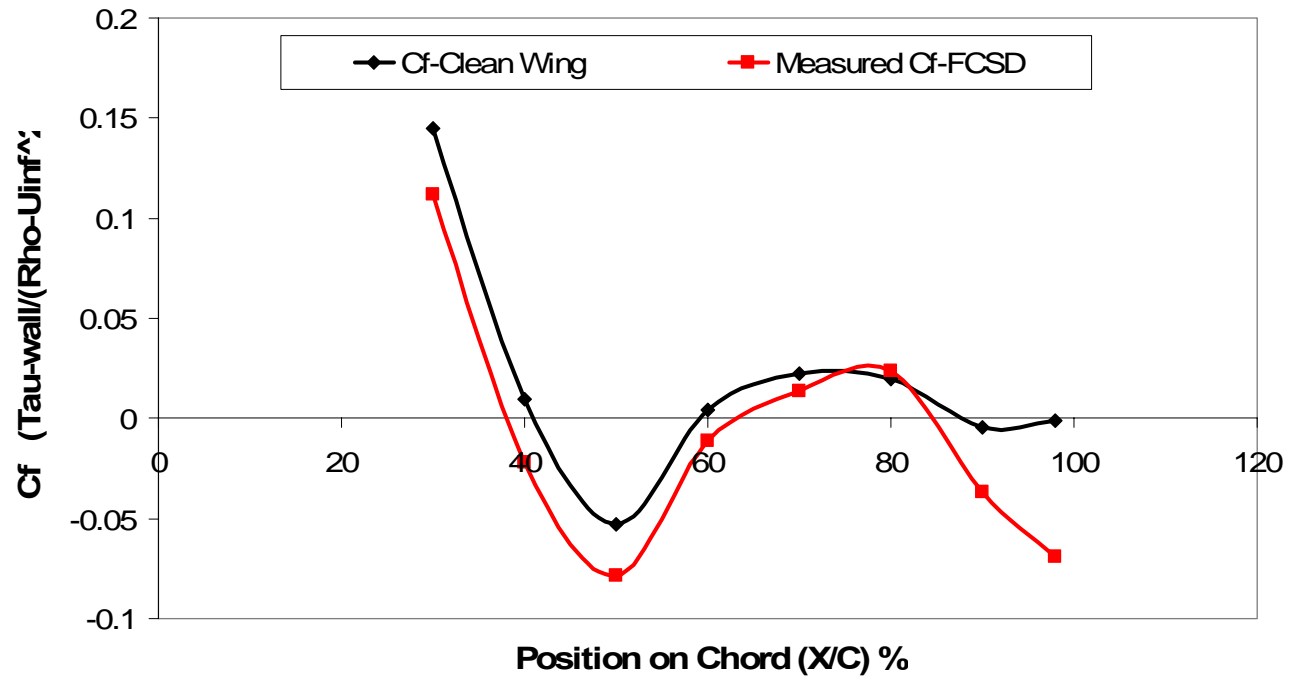


Pressure distribution on 2nd. Wind-Tunnel model of 53-Inch Span Section of Standard Cirrus Wing (New FCSD installion on Suction Side Only)-11/20/04

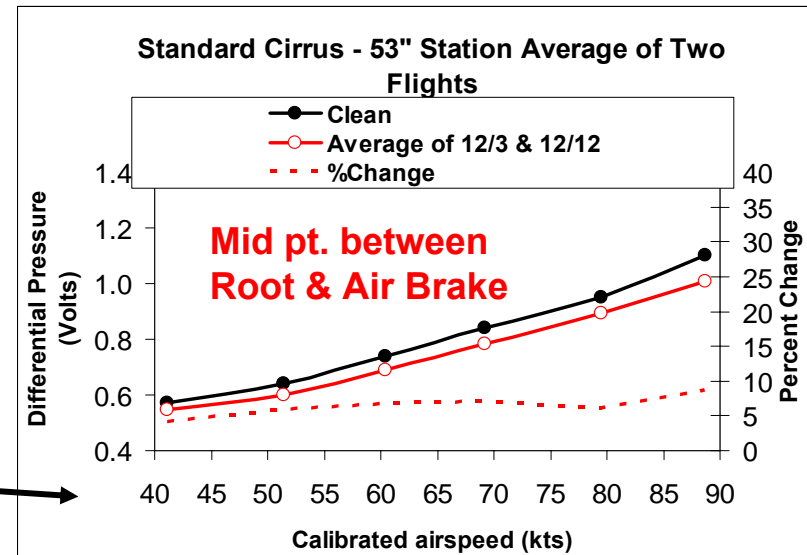
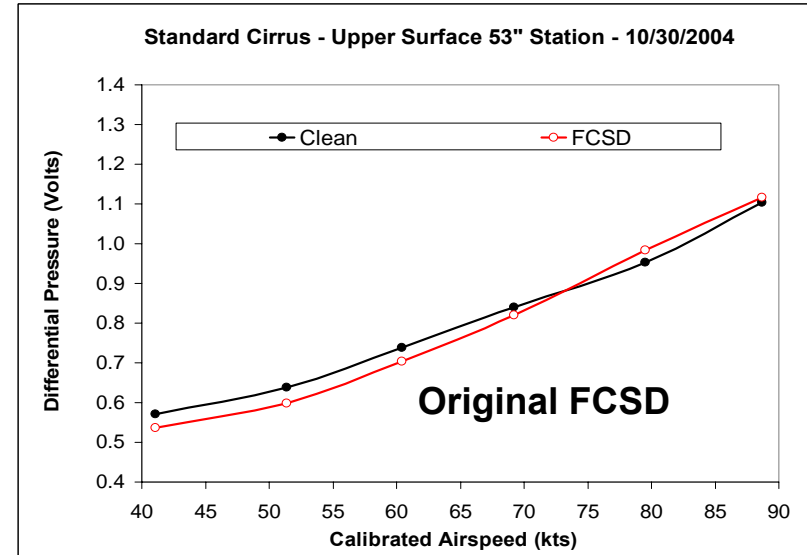
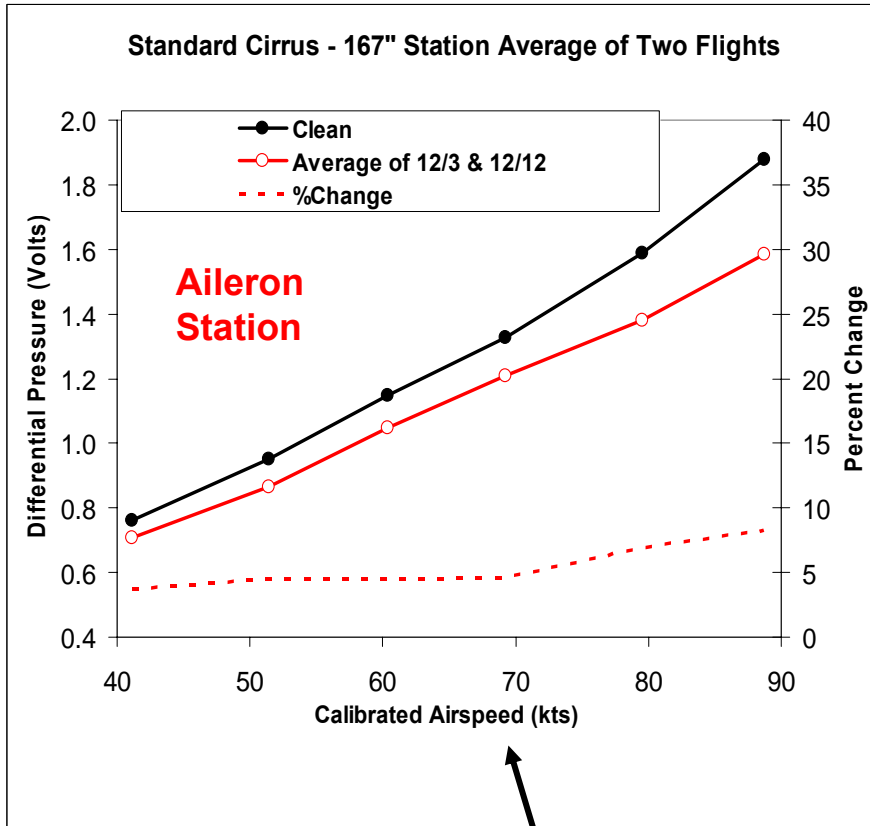


SKIN FRICTION REDUCTION

Suction Surface C_f Distribution Wortmann 53 inch Std Cirrus Airfoil (Re 300,000 in Sinhatech Wind Tunnel)

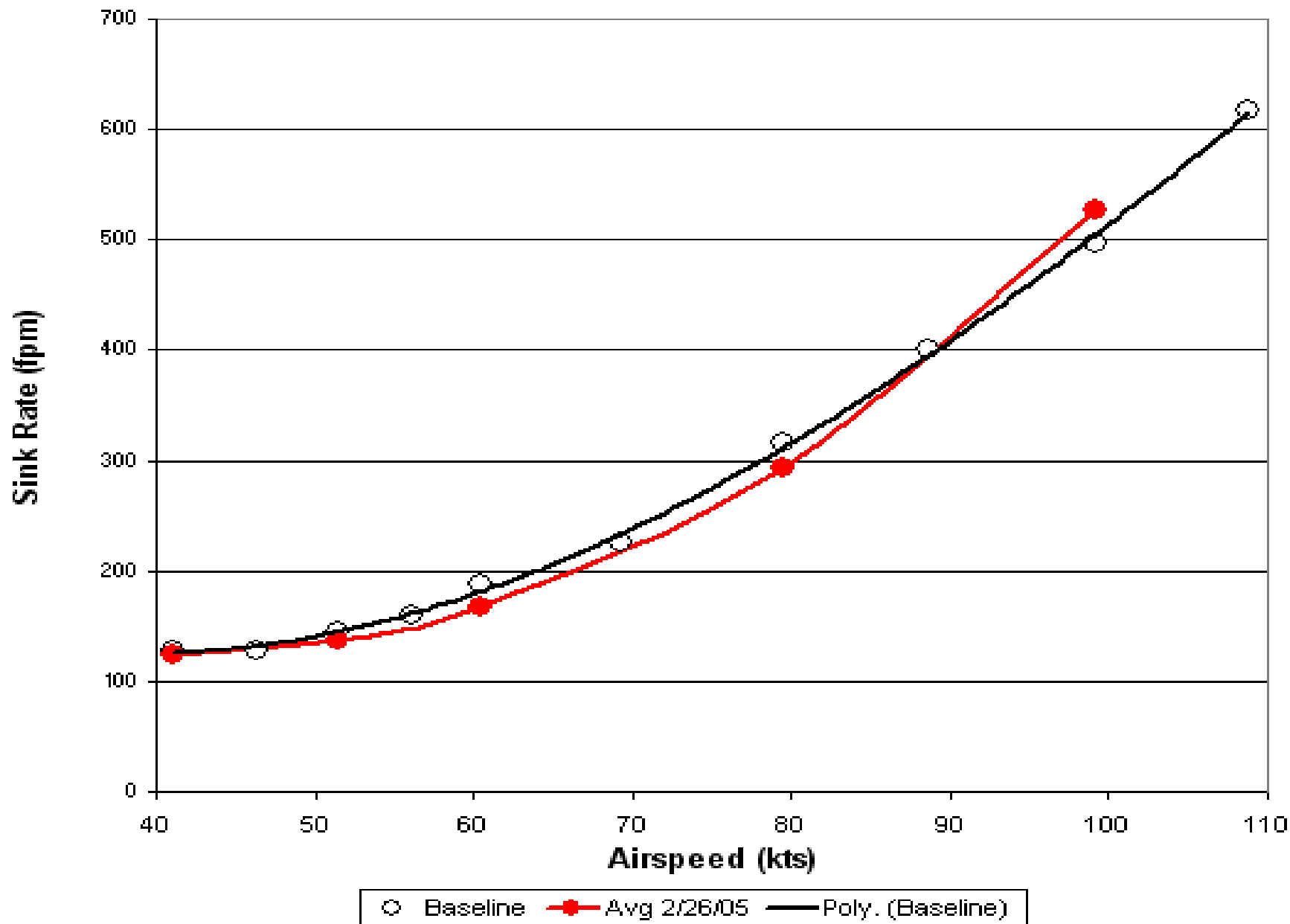


Drag Reduction on a Standard Cirrus Sailplane (Wing Top)



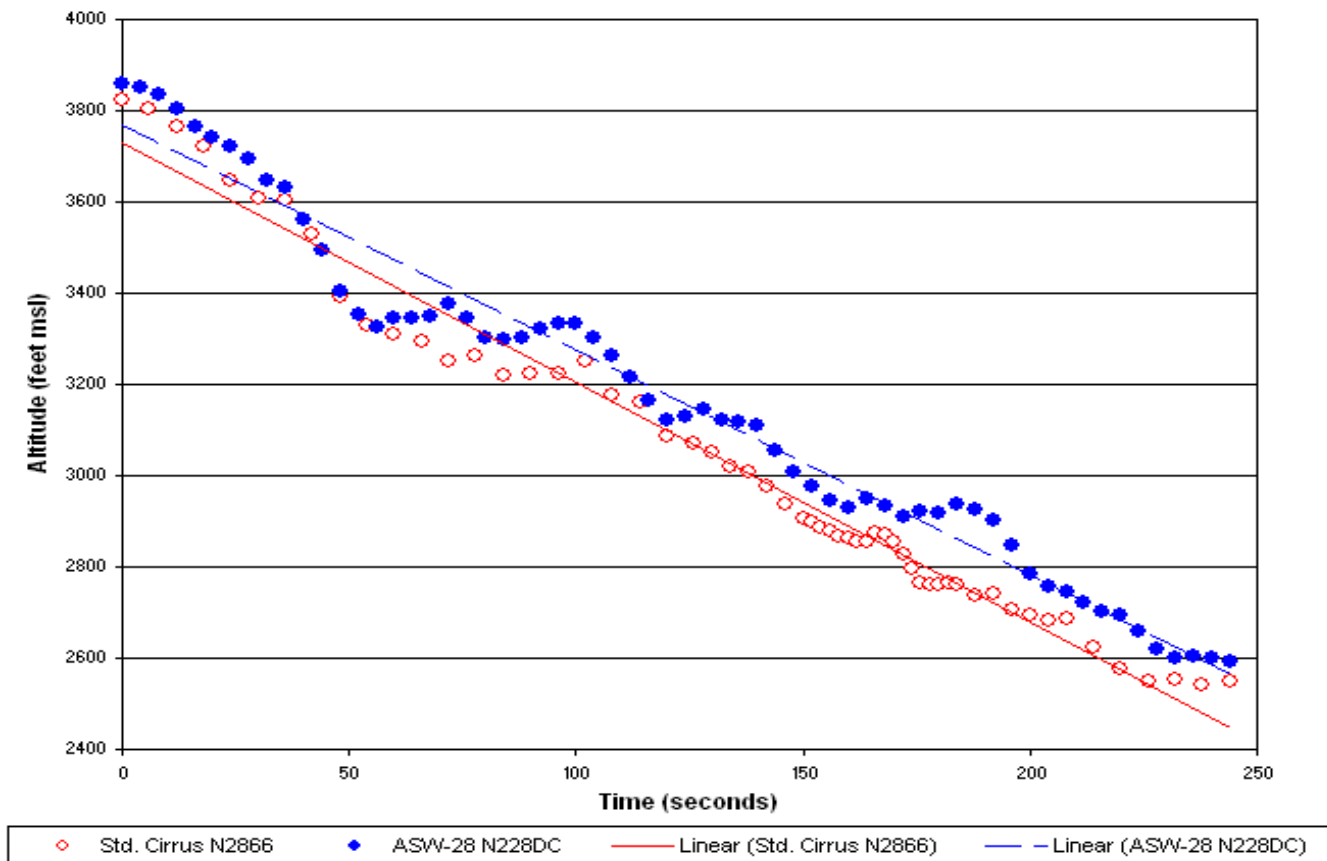
Modified FCSD

Std. Cirrus #60 2/26/05 Averaged vs Baseline
(2nd test: top inboard 14' of each wing fully deturbulated)

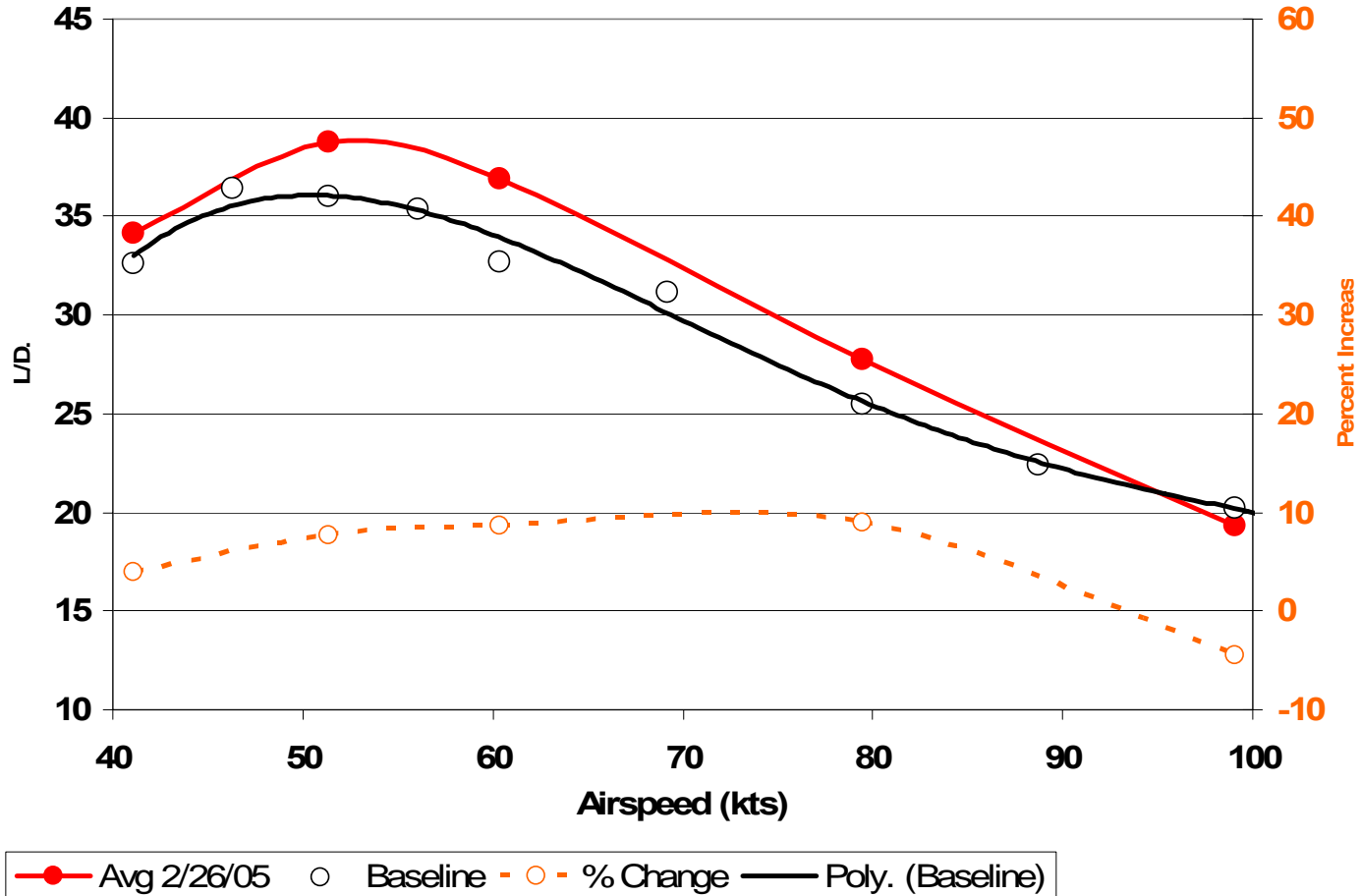


PARALLEL FLIGHT WITH ASW-28 SAILPLANE HAVING 18% LOWER SINK RATE COMPARED TO UNTREATED STANDARD CIRRUS

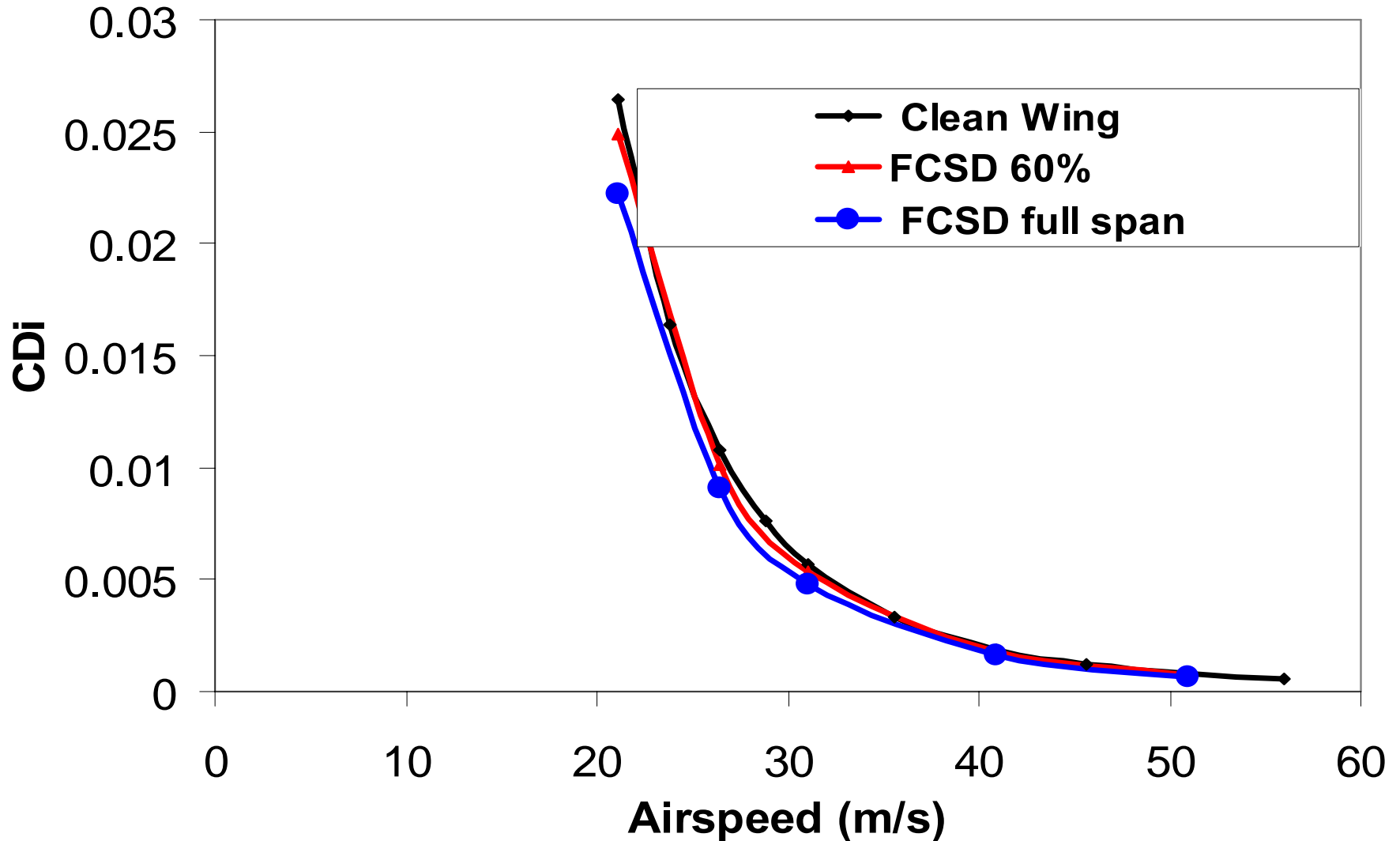
Standard Cirrus and ASW-28 Parallel Flight at 80 kts
Cherry Valley, Arkansas - March 19, 2005



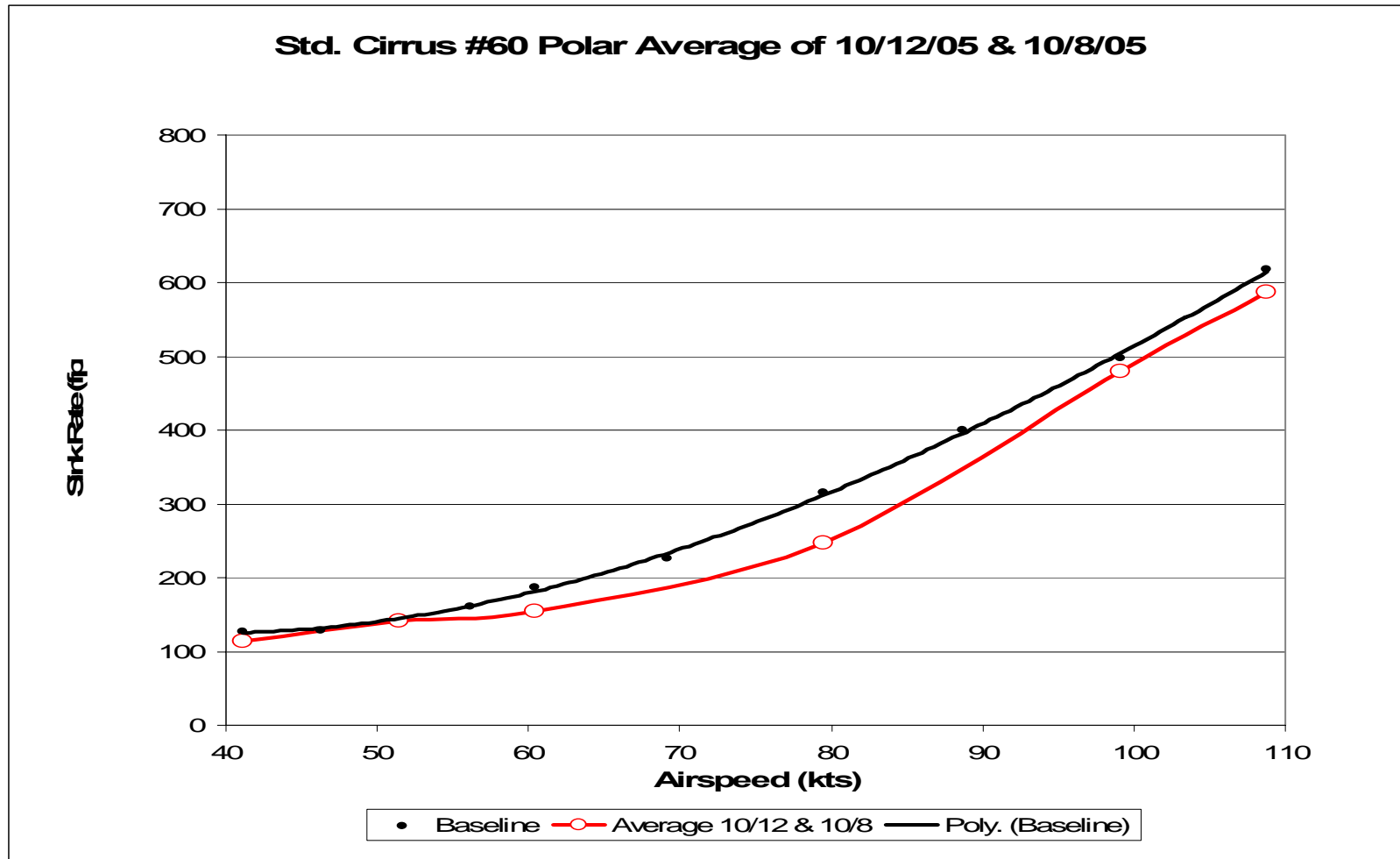
Std. Cirrus #60 2/26/05 L/D Averaged vs Baseline
(2nd test: top Inboard 14' of each wing fully deturbulated)



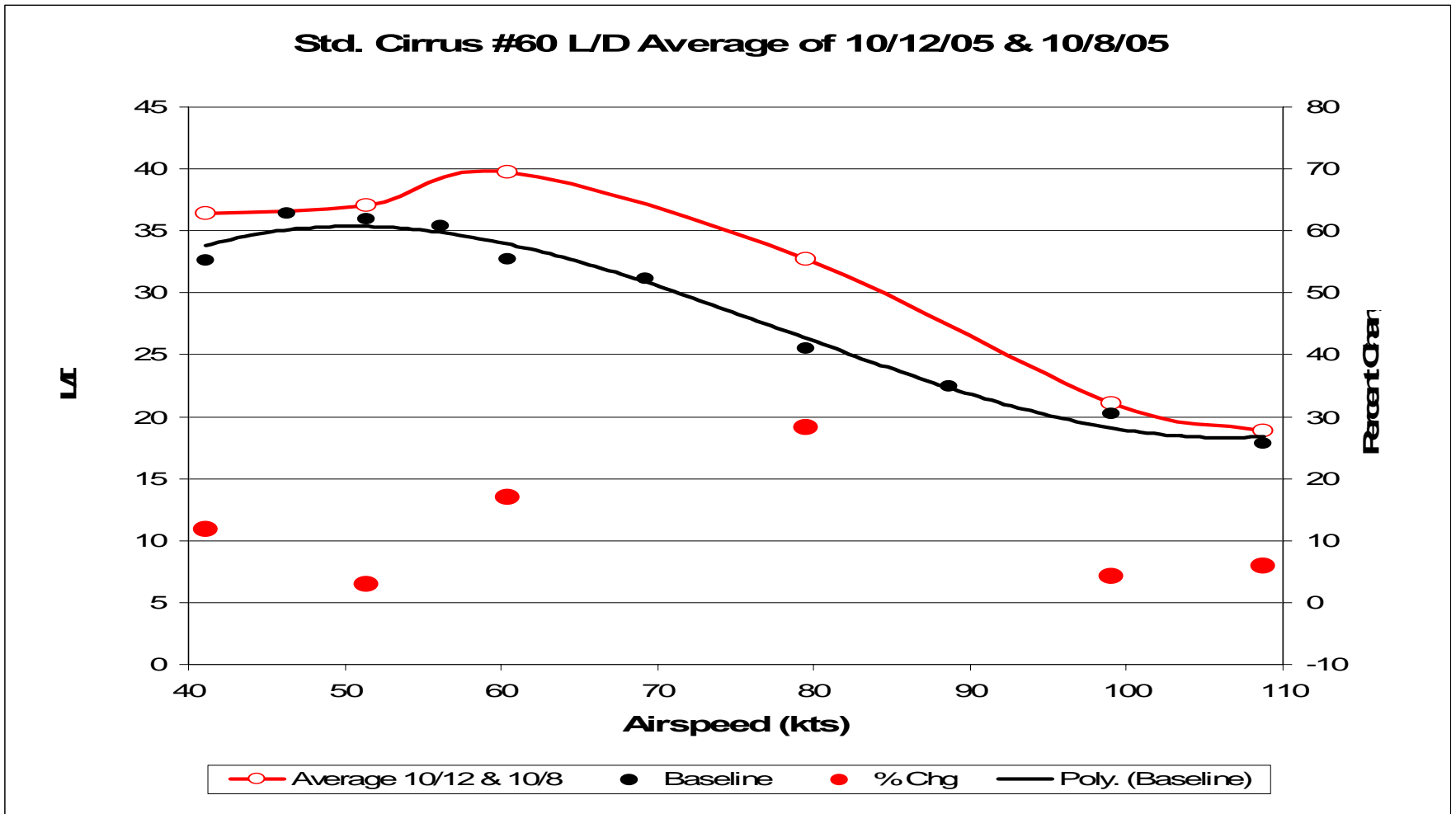
Induced Drag Vs Airspeed on a Standard Cirrus sailplane - CW and FCSD - 03/01/05



Sink Rates with Modified Full Span FCSD Treatment



L/D Improvement with Modified Full Span FCSD Treatment



SUMMARY OF REVOLUTIONARY FCSD AERODYNAMICS

- FCSD Reduces Turbulence Creates “Slip Layer”
- Reduces Skin Friction Increases Lift
- Reduces Induced and Parasitic Drag Across Speed Range.
- Increased Best Sailplane L/D by 7-11%
- Max Sailplane L/D increase 30%
- Max Section L/D increase (Low-Re) ~ 400%

OTHER **Important** ISSUES

- **Consistency**
- **Robustness**
- Integration with Wing at the Design stage



ACKNOWLEDGEMENTS

- National Science Foundation
- NASA
- Oxford Aero Equipment
- Global Aircraft
- Mr. Robert Williams
- Mr. Sundeep Ravande



QUESTIONS ?