REVOLUTIONARY AERODYNAMICS

Sumon K. Sinha, Ph.D., P.E,

SINHATECH,

Oxford, Mississippi

www.sinhatech.com

SumonKSinha@aol.com

TRADITIONAL AERODYNAMICS for Maximizing L/D

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

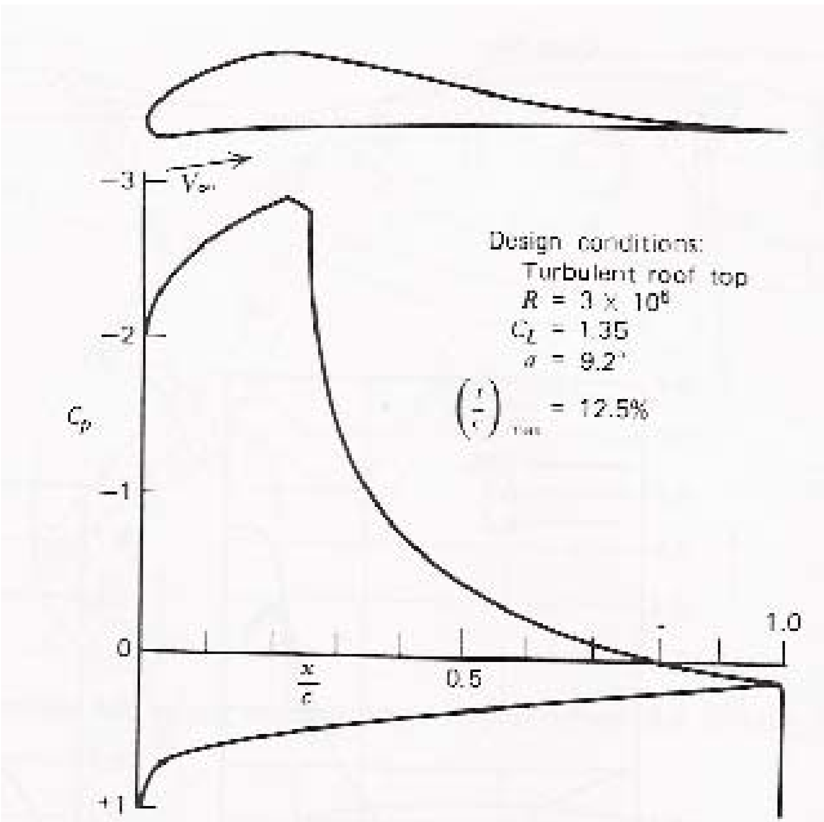
MOTIVATION

- 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.

Cd ~ 0.01 for 1.6 > Cl > 0.6

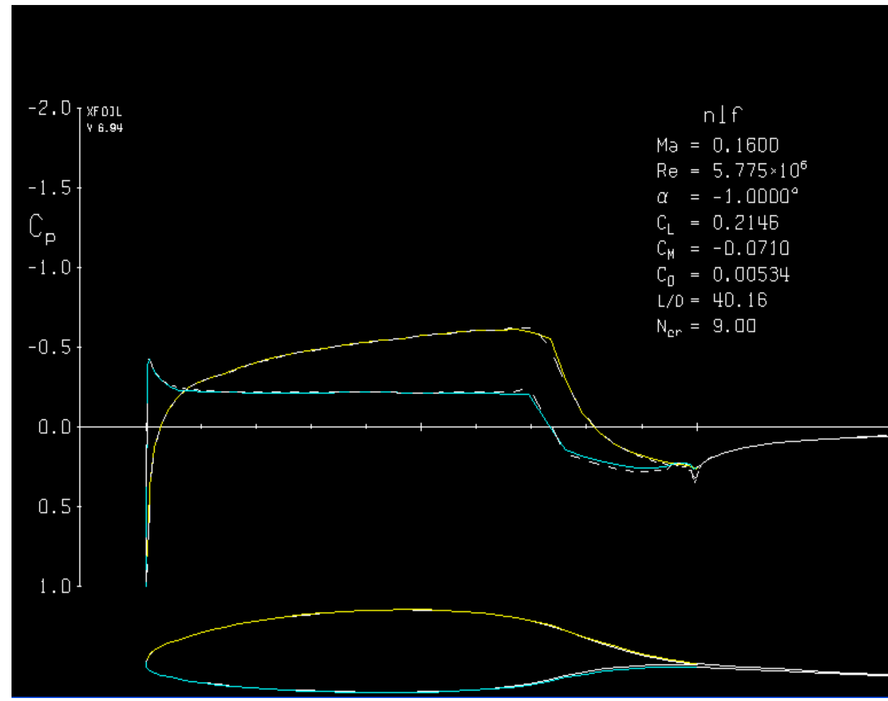


GT-3 testing simulation on XFOIL 6.94

Cp vs x Plot

NLF-0414-F airfoil

ReD = 5.775 * 10^6

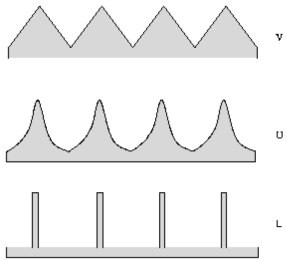


Cp vs X plot – The blue line represents the pressure distribution on the lower surface and the yellow line represents the pressure distribution on the upper surface.

L/D Increase using Flow Control

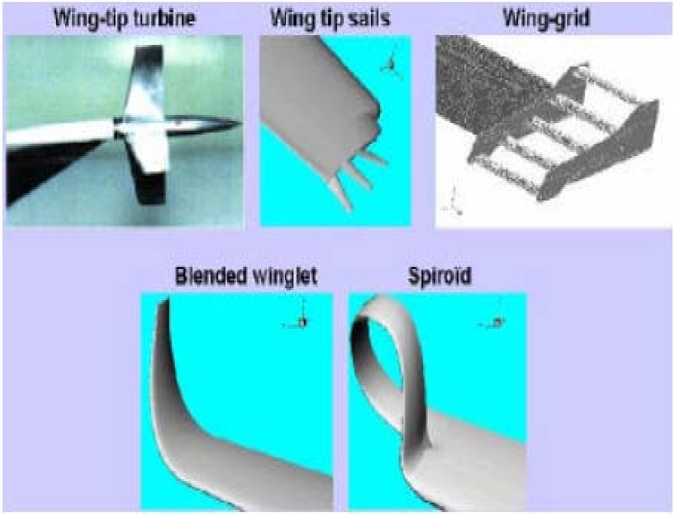
- **The turbulent skin friction drag reduction by the use of *Riblets* (δCD/CD of about 1-2% flat-plate)**
- **The *hybrid laminar flow* technology (δCD/CD of about 6 - 10% flat plate);**
- **The innovative *wing-tip devices* (δCD/CD of about 5 - 8% flight);**
- **The *sub-layers vortex generators and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

  (δCD/CD as much as 30% for Total Aircraft) *REVOLUTIONARY!*



Shapes of riblet films

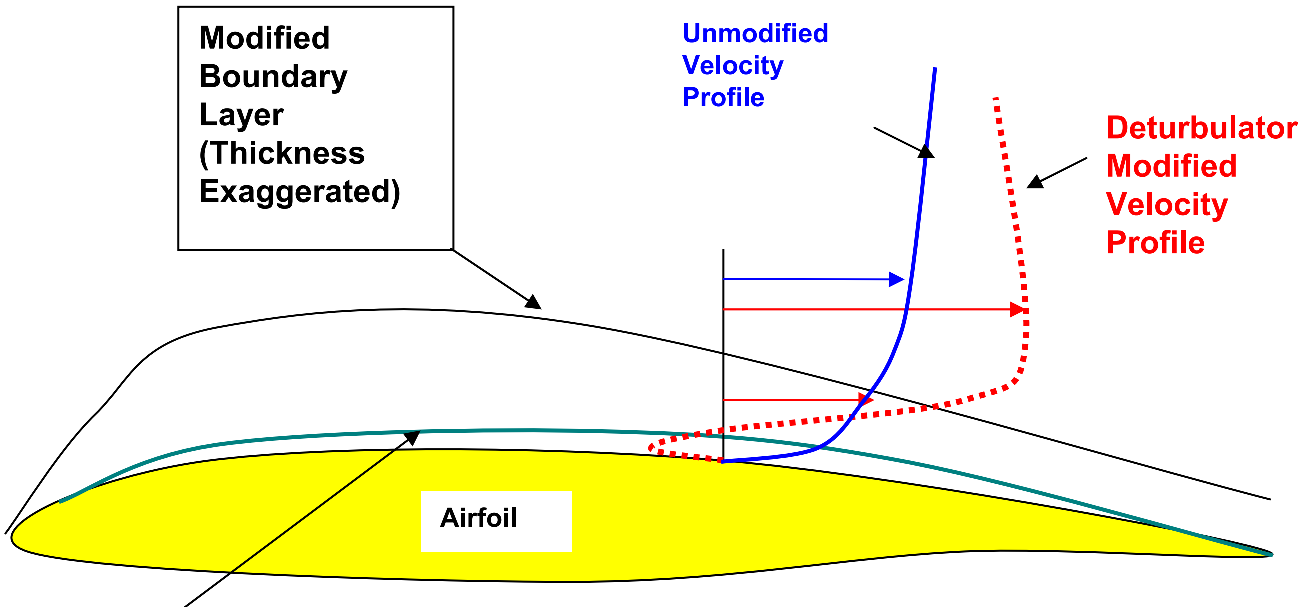
Source:http://aerodyn.org/Drag/riblets



Wing-tip Devices

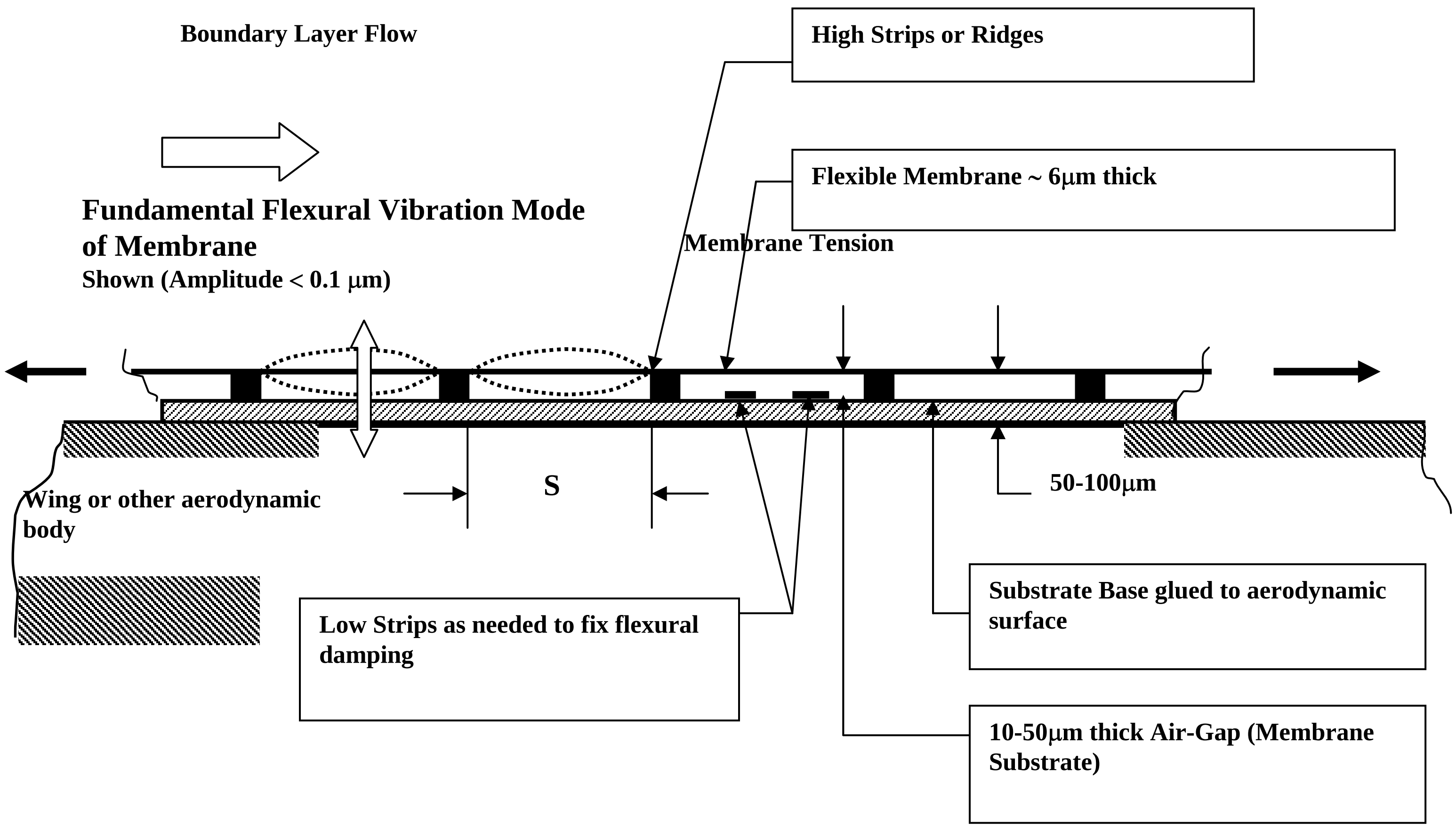
Source:J.Reneaux., “Overview on drag reduction technologies for civil transport aircrafts” European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS 2004.

The Sinha-Deturbulator Approach

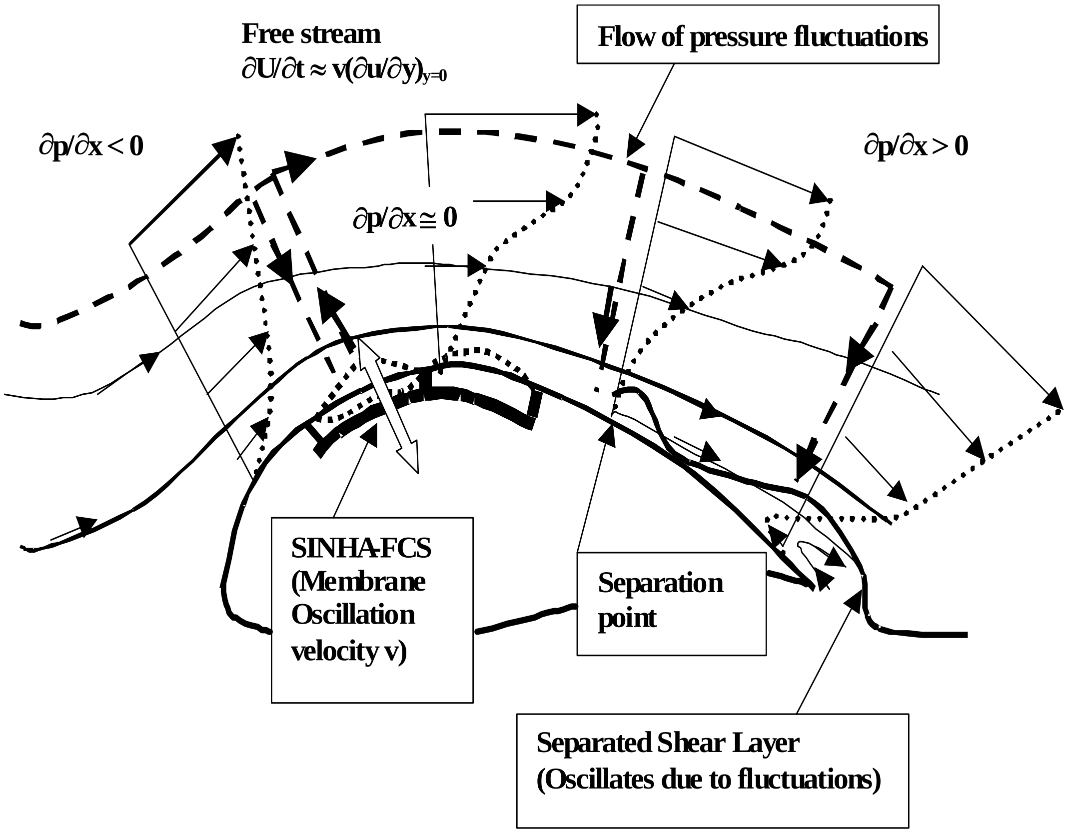


SLIP LAYER: Deturbulator Stabilized *Viscous Sub-layer* with slow *Reversed Flow* negates Skin Friction Drag and Speeds up Freestream Flow

SINHA FLEXIBLE COMPOSITE SURFACE DETURBULATOR (FCSD)



FLOW-FCSD INTERACTION



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

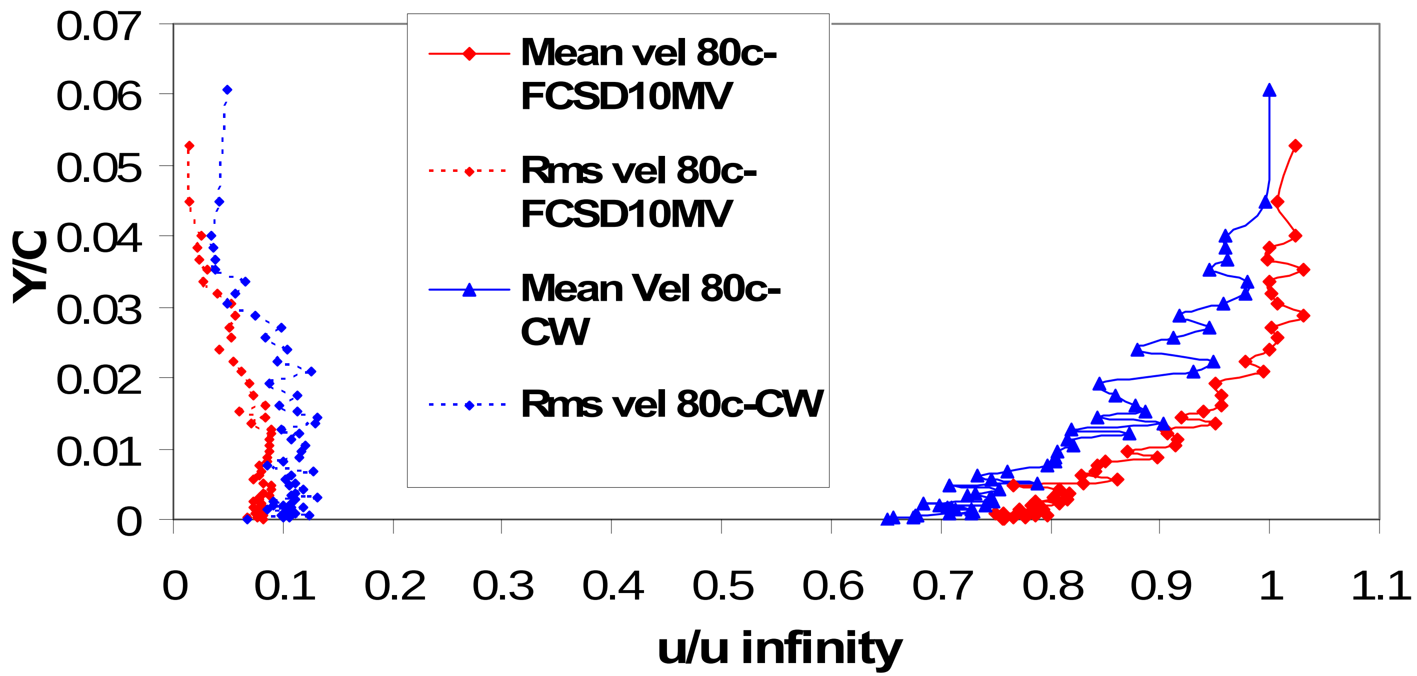
- FCSD passes oscillation without damping at the *Interaction Frequency*:

$$f = U/s$$

Attenuates other frequencies

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

Boundary Layer Velocity Profiles Showing Effect of Deturbulation

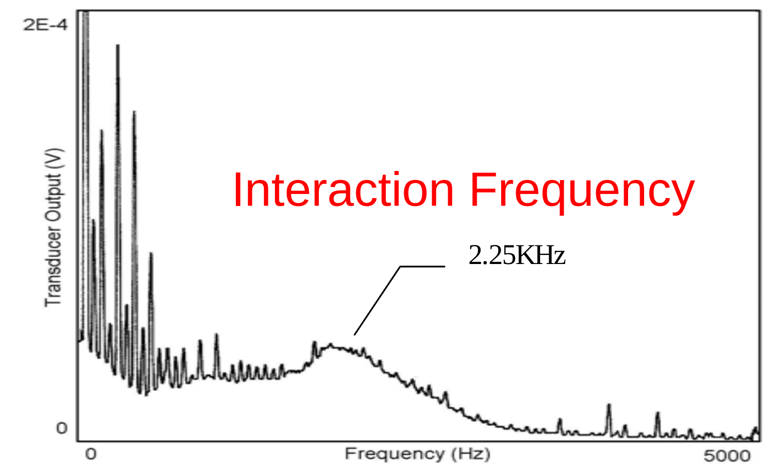


Development History

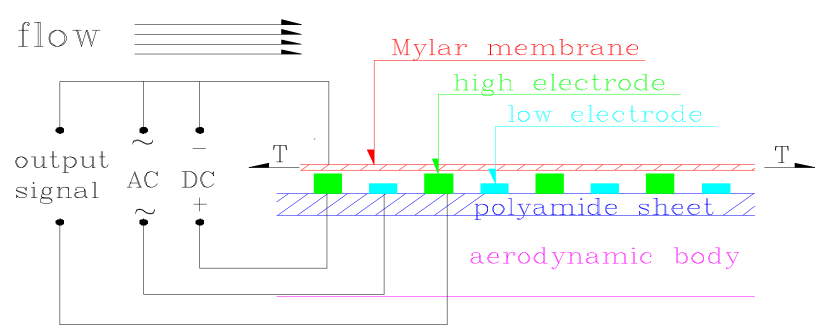
- Preliminary Drag Reduction Studies jointly with Global Aircraft 1999-2000 on GT-3 Aircraft based on Electrically actuated **A**ctive **F**lexible **W**all Transducer (Invented in 1993, Sinha, 1999 Patent)
- Passive **Flexible Composite Surface Deturbulator** observed in 2001 (Pending Patents, Sinha 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)

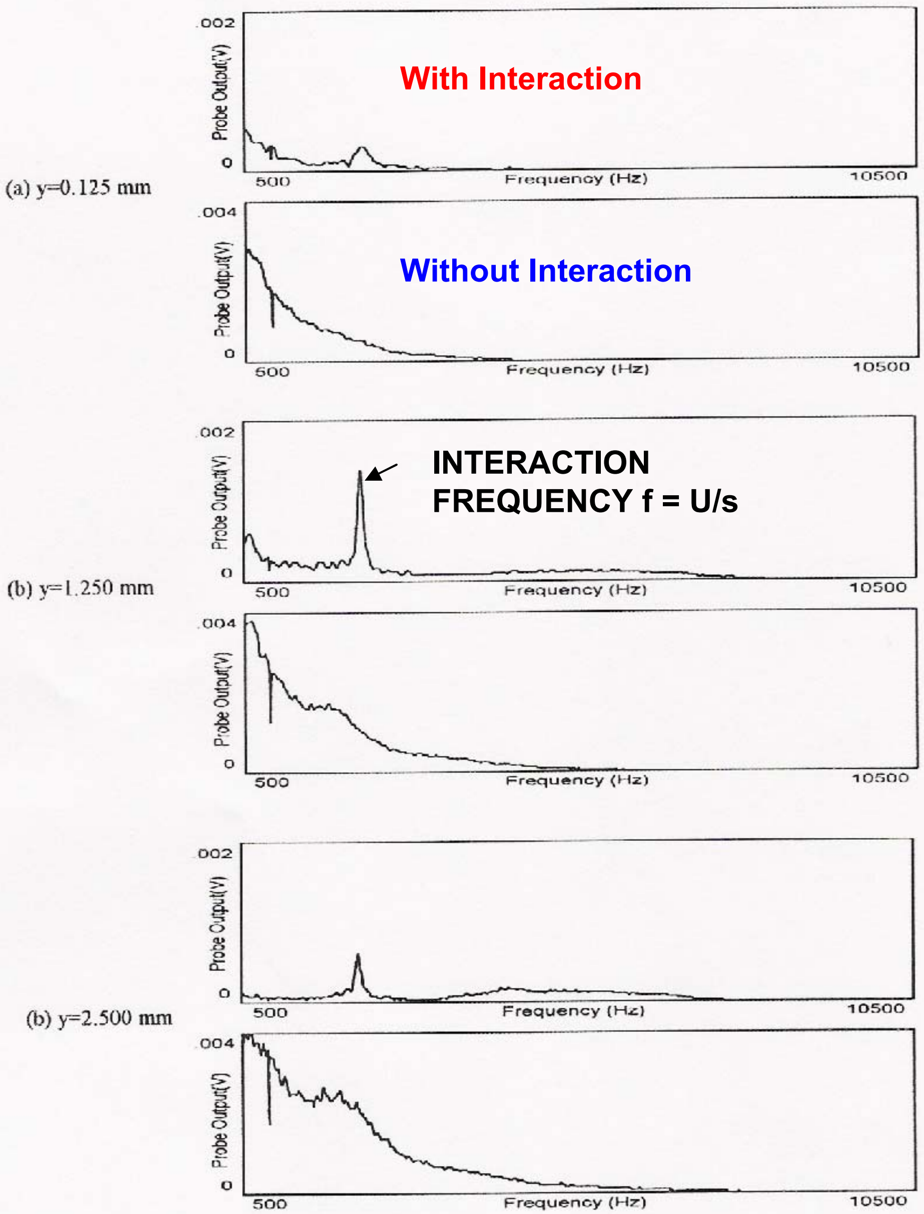
- FCSD concept evolved out of an earlier electrically powered AFW (Sinha, 1999).
- Mylar stretched across the high and low electrode.
- Air gap between Mylar and electrode provide the mechanical damping.
- DC bias applied across membrane
- Flow-membrane interaction produces an AC signal
- AC signal decomposed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

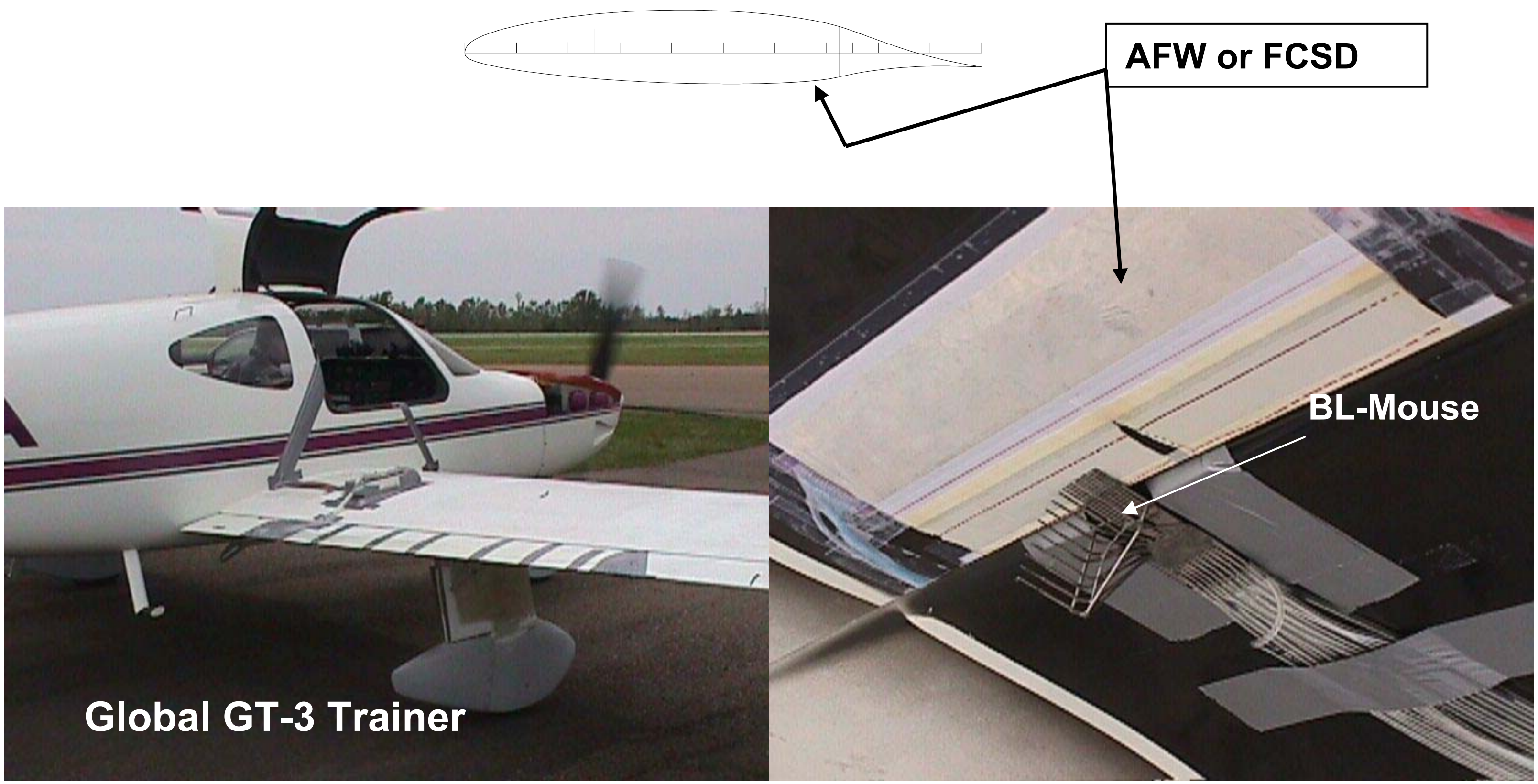


MODIFICATION OF TURBULENCE BY FLEXIBLE SURFACE

SPECTRA OF STREAMWISE VELOCITY FLUCTUATIONS

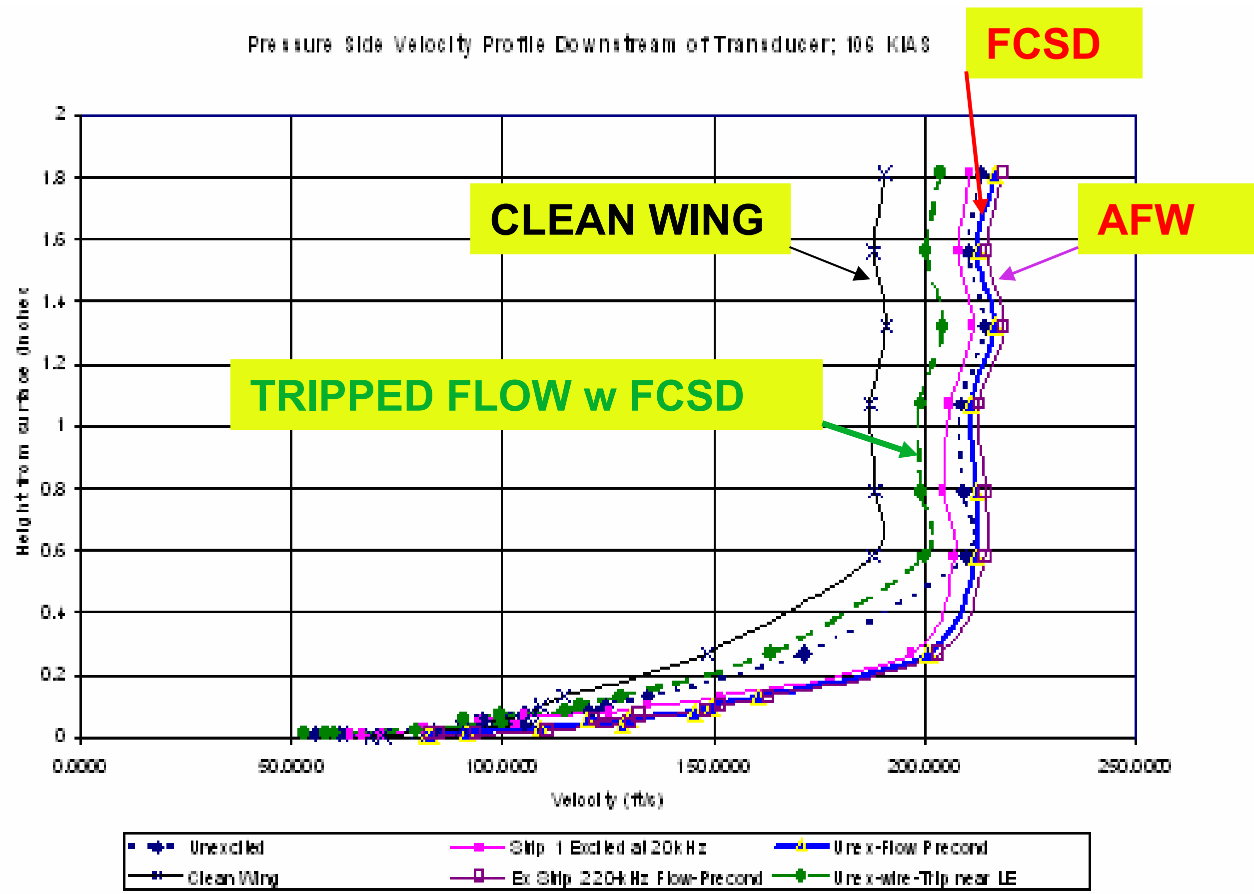
With (top) and Without (bottom) Flexible-Surface Interaction for Separated Flow over a Cylinder in Crossflow for Re = 150,000, M = 0.05 at θ = 90º from stagnation (From: Sinha and Wang, 1999, AIAA Paper 99-0923)

TESTS ON NLF 0414F WING

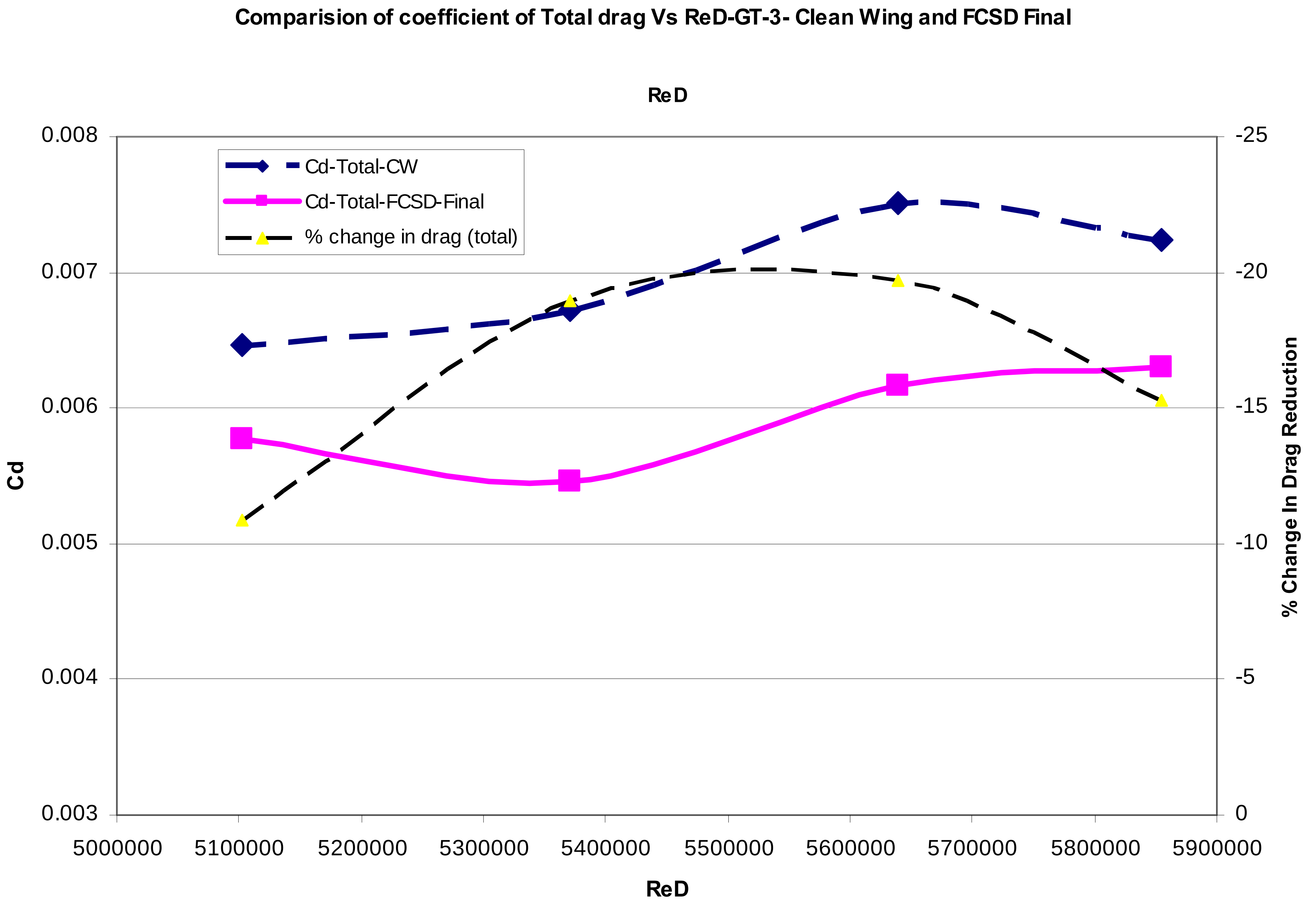


Transition from AFW to FCSD

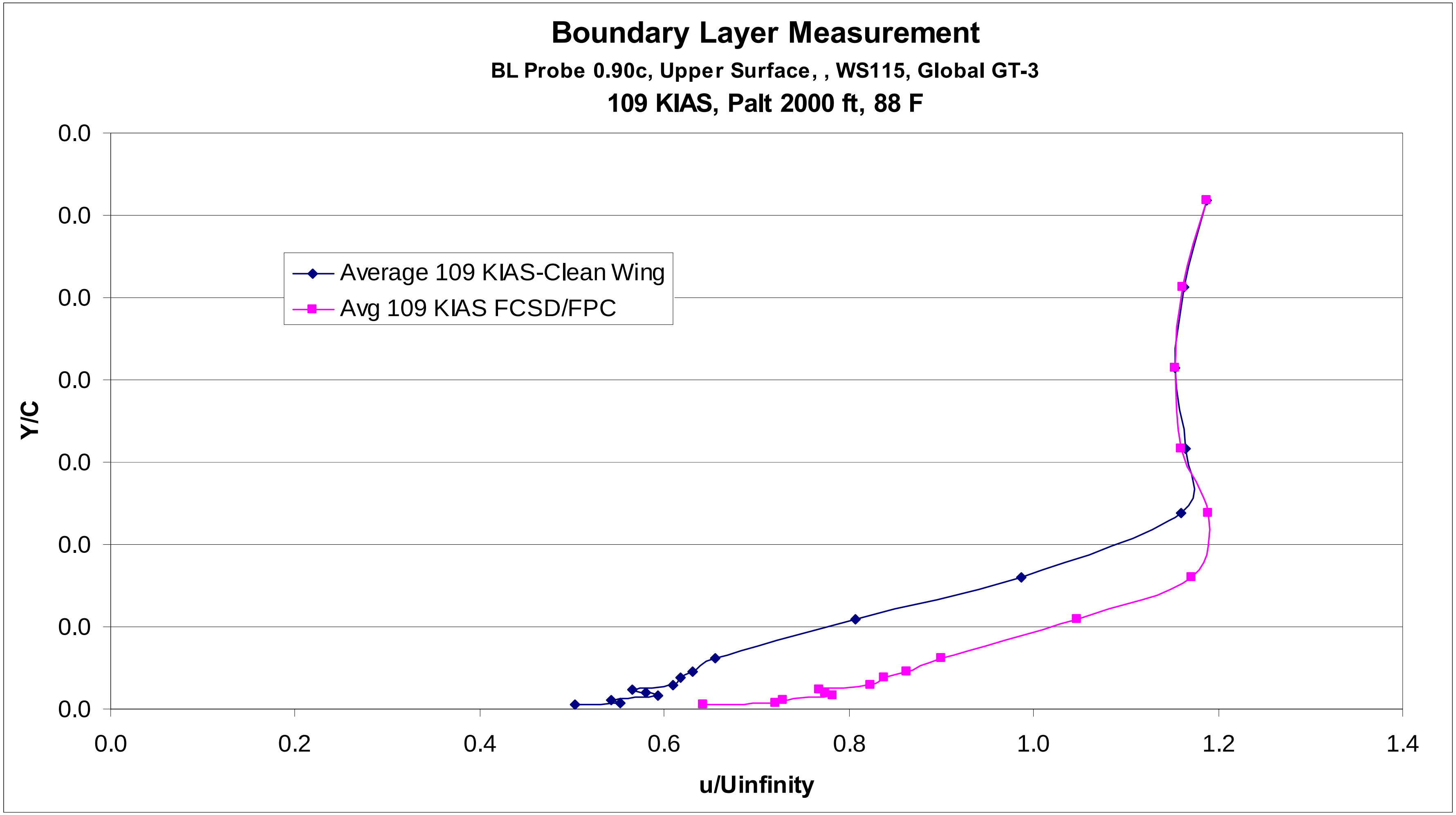
- Unexcited AFW produced a boundary layer profile very similar to the excited AFW.
- Difference in percentage drag reduction is minimal.
- FCSD Simplifies the manufacturing and installation procedure.
- More pragmatic on retrofitting existing aircrafts



GT-3 WING BOTTOM VEL PROFILES @ 0.8C



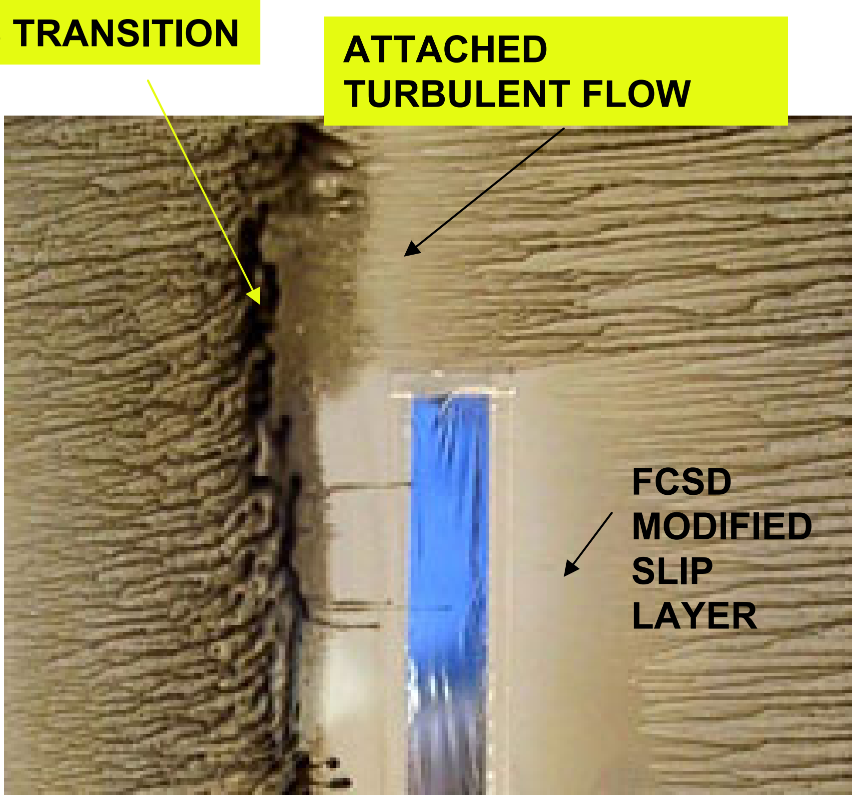
Comparision of coefficient of Total drag Vs ReD-GT-3- Clean Wing and FCSD Final
ReD
Cd-Total-CW
Cd-Total-FCSD-Final
% change in drag (total)
0.008
0.007
0.006
0.005
0.004
0.003
Cd
-25
-20
-15
-10
-5
0
% Change In Drag Reduction
5000000
5100000
5200000
5300000
5400000
5500000
5600000
5700000
5800000
5900000
ReD



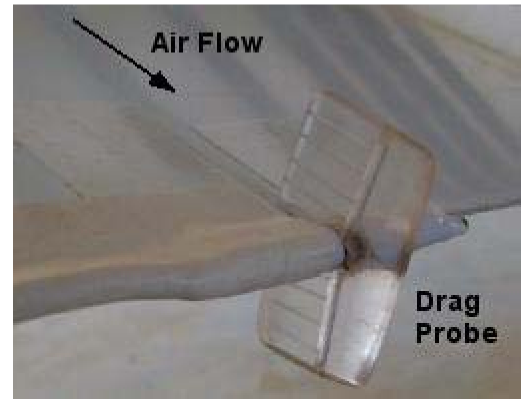
Boundary Layer Measurement
BL Probe 0.90c, Upper Surface, , WS115, Global GT-3
109 KIAS, Palt 2000 ft, 88 F
Y/C
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
u/Uinfinity
Average 109 KIAS-Clean Wing
Avg 109 KIAS FCSD/FPC

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/ft^2 Aspect Ratio: 22.5

STANDARD CIRRUS LOWER SURFACE DRAG REDUCTION

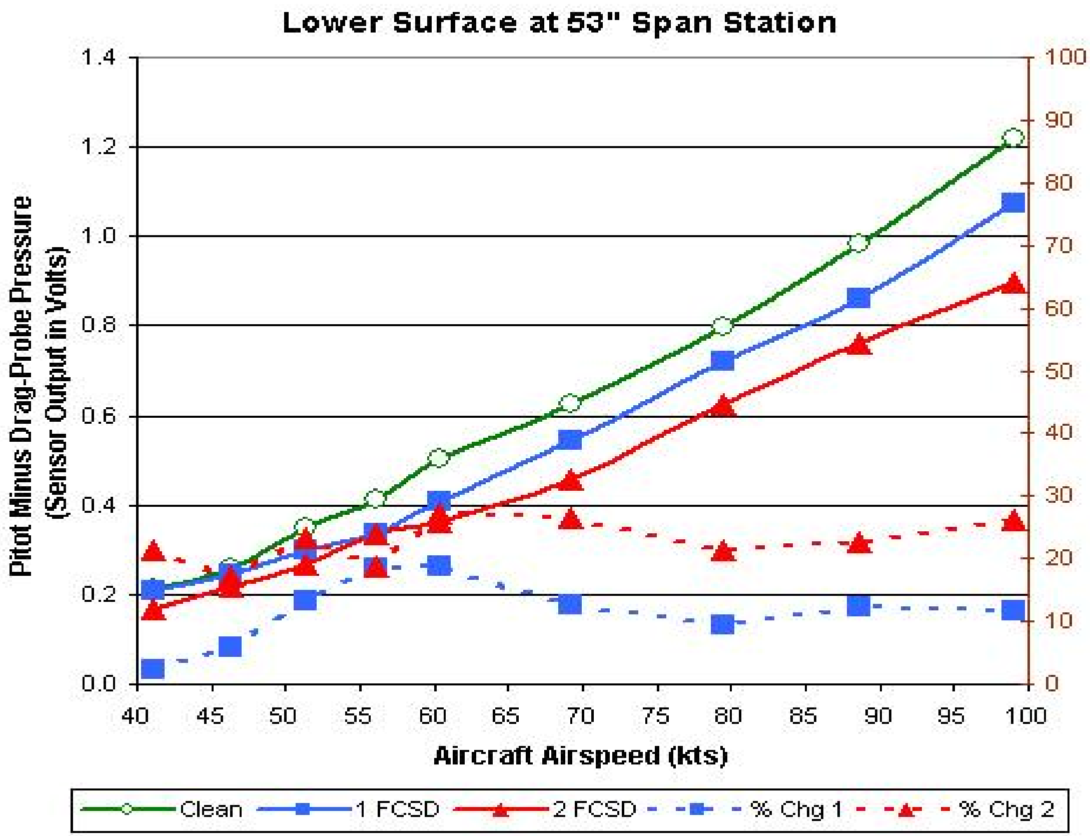
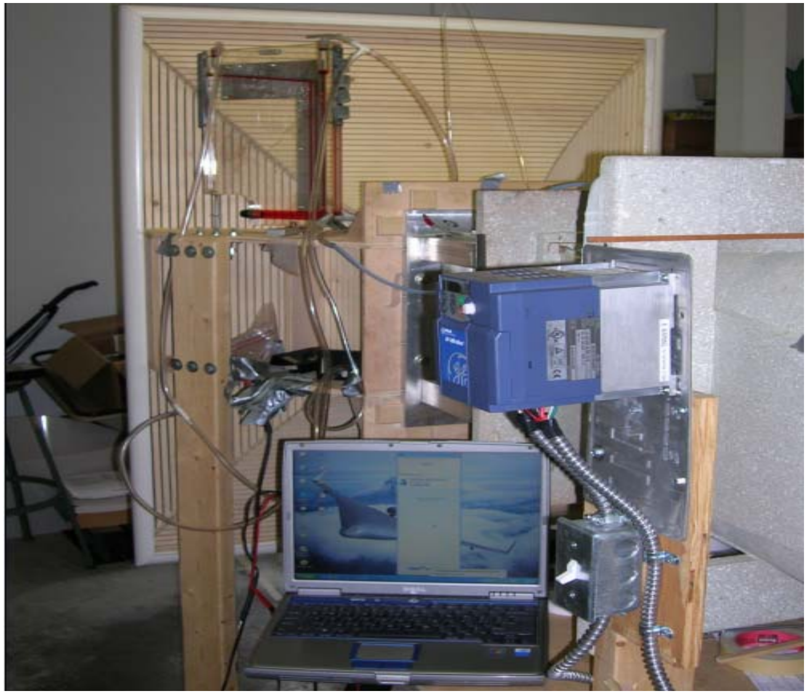


Fig. 7. Drag-probe pressure sensor output (proportional to upstream stagnation pressure minus wake stagnation pressure). A reduction in output indicates drag reduction resulting from FCSD applications (1FCSD and 2FCSD) on wing bottom at the given location. % change (reduction) scale is on the right

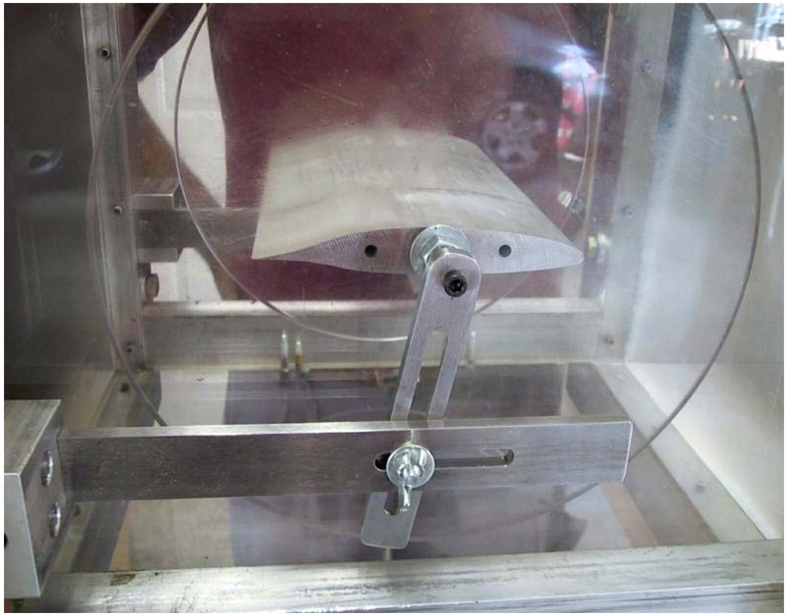
Sinhatech Low-Speed Wind-Tunnel

Sinhatech Slow-Speed Wind-Tunnel



Experimental set-up showing the pressure transducers and manometer

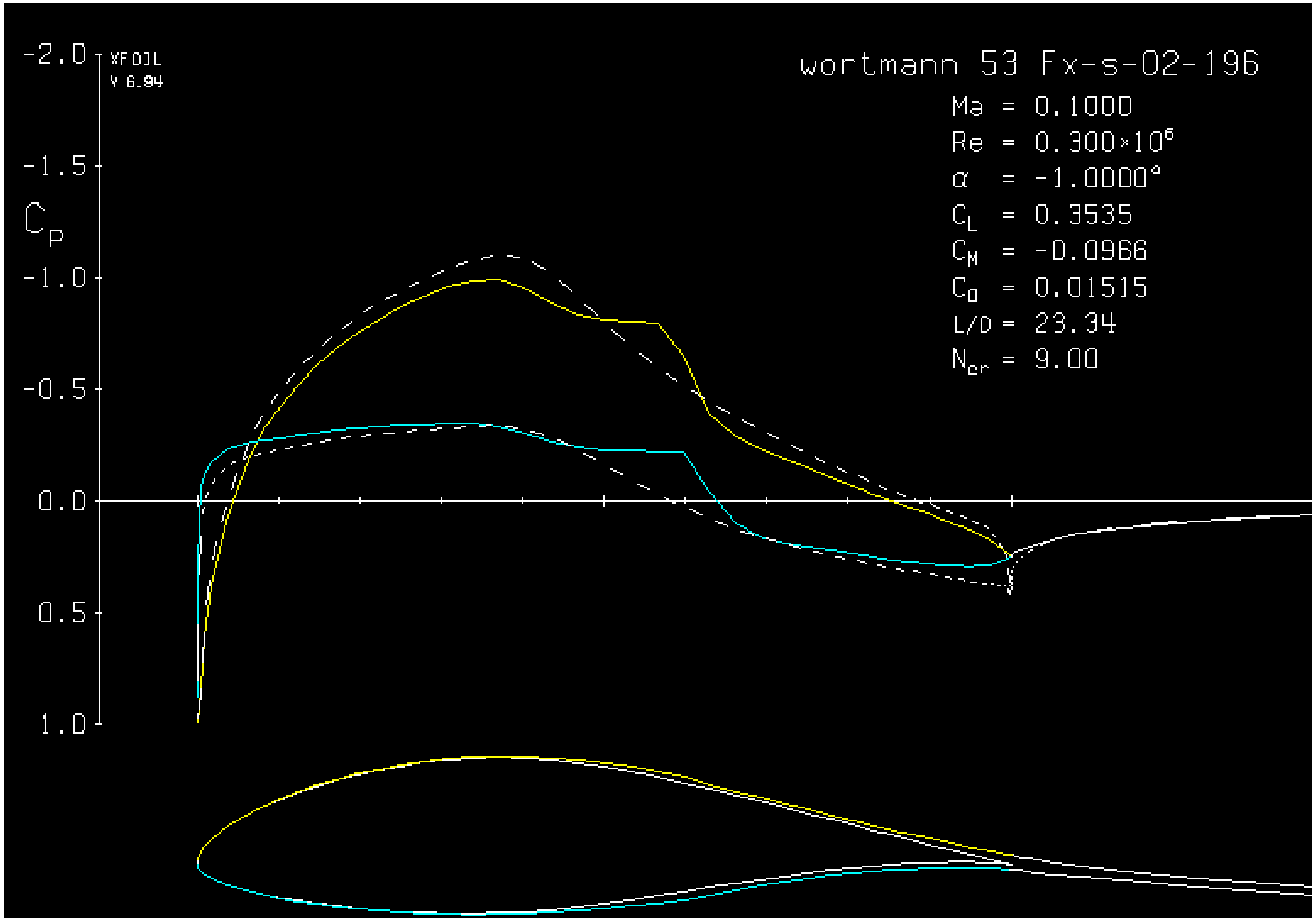
Airfoils Tested in the Wind-Tunnel



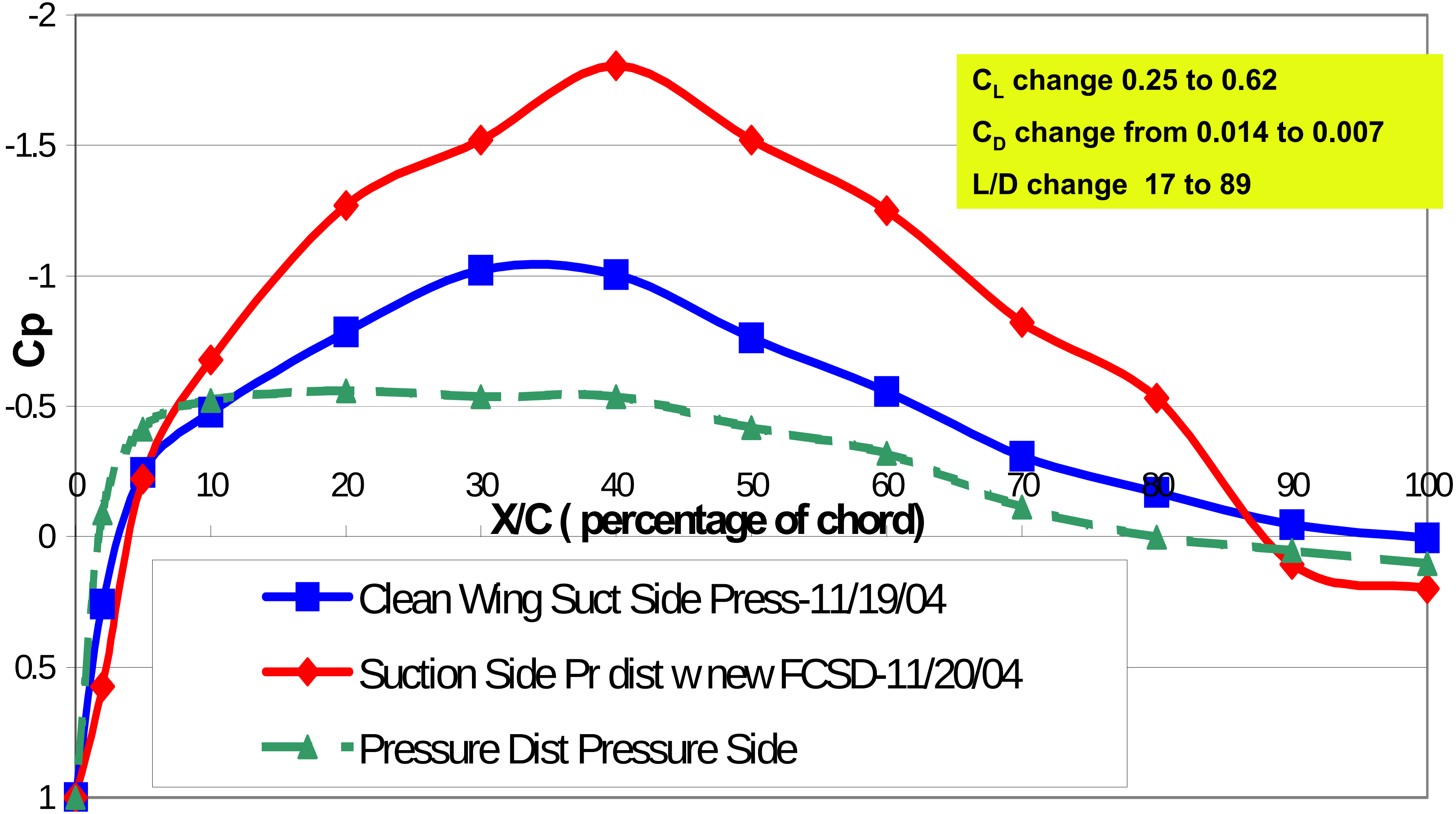
Close up of tunnel test section showing NLF-0414F airfoil being tested

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

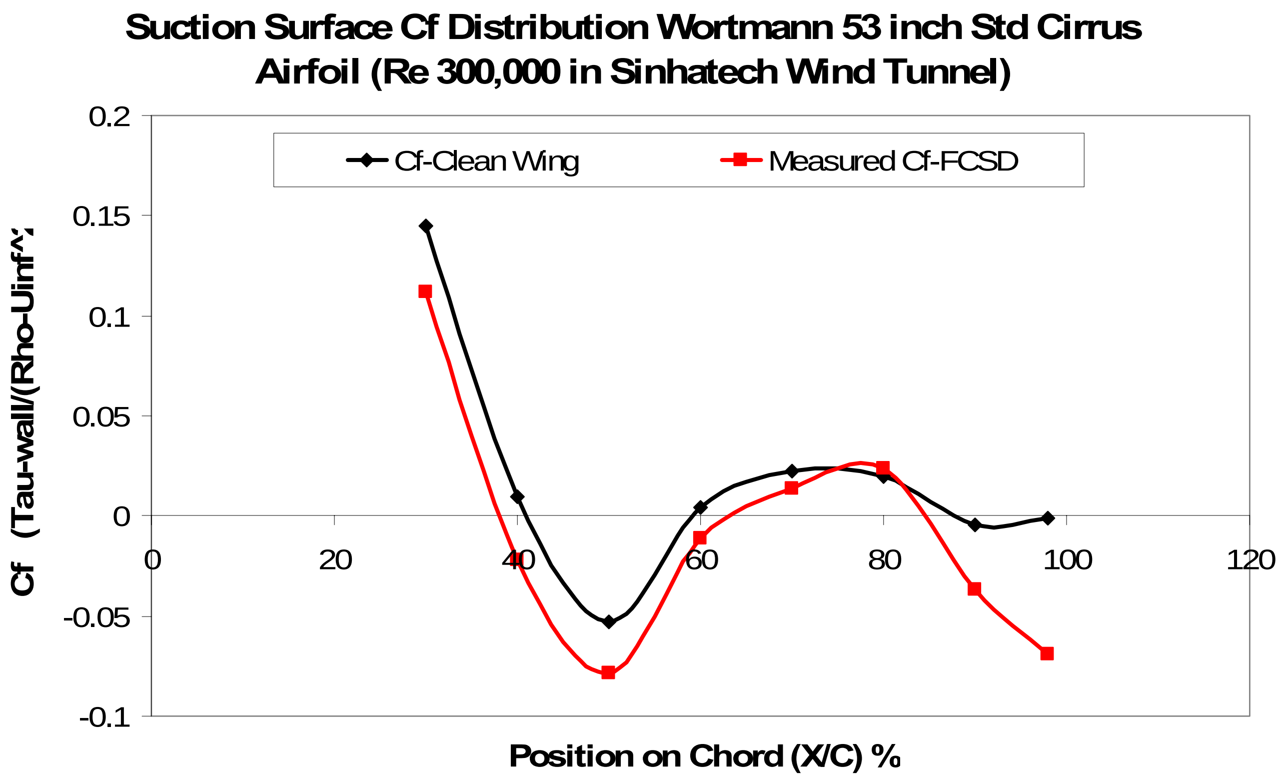
XFOIL SIMULATION OF STANDARD CIRRUS 53"-SPAN WORTMANN AIRFOIL



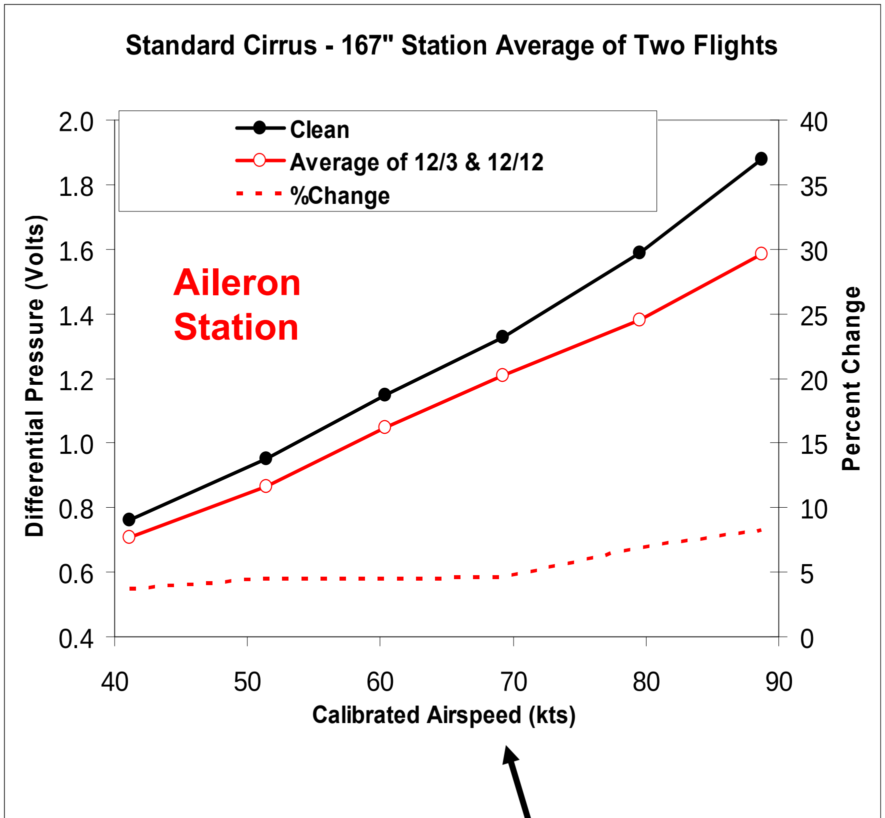
Pressure distribution on 2nd. Wind-Tunnel model of 53-Inch Span Section of Standard Cirrus Wing (New FCSD installion on Suction Side Only)-11/20/04

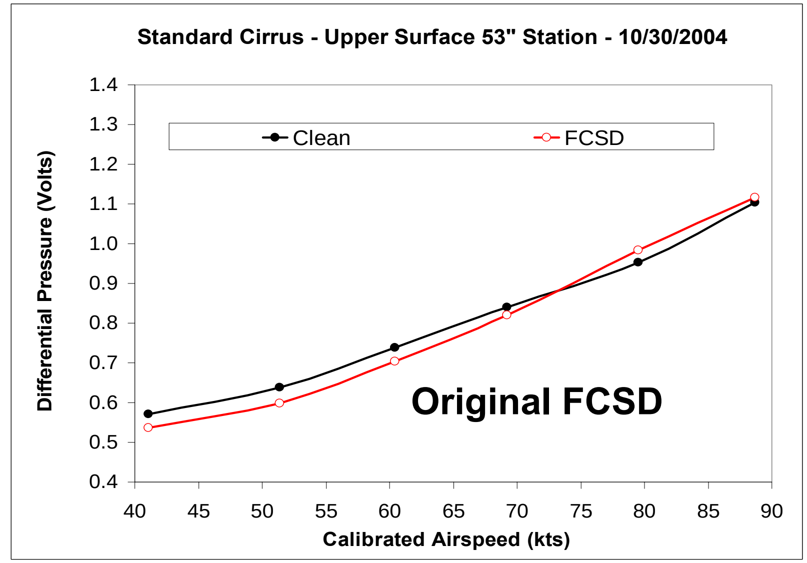


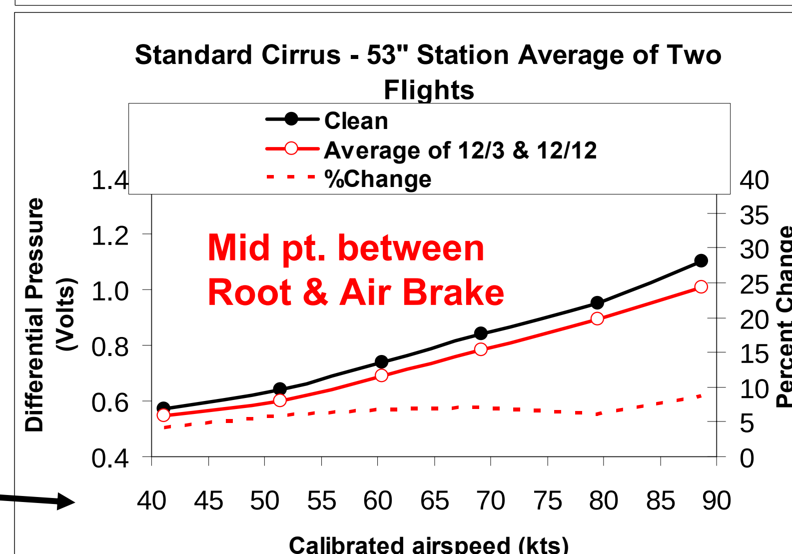
SKIN FRICTION REDUCTION



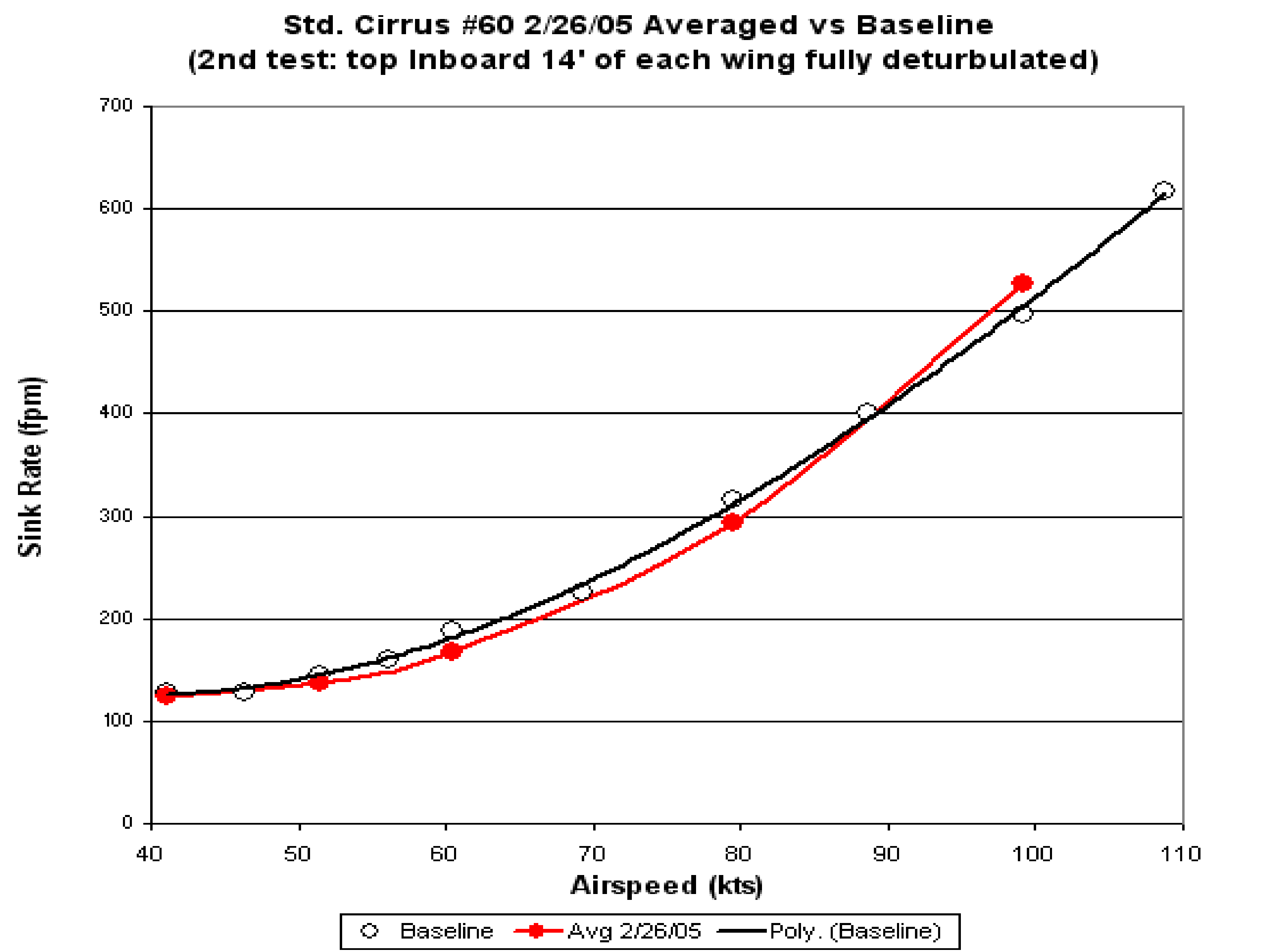
Drag Reduction on a Standard Cirrus Sailplane (Wing Top)



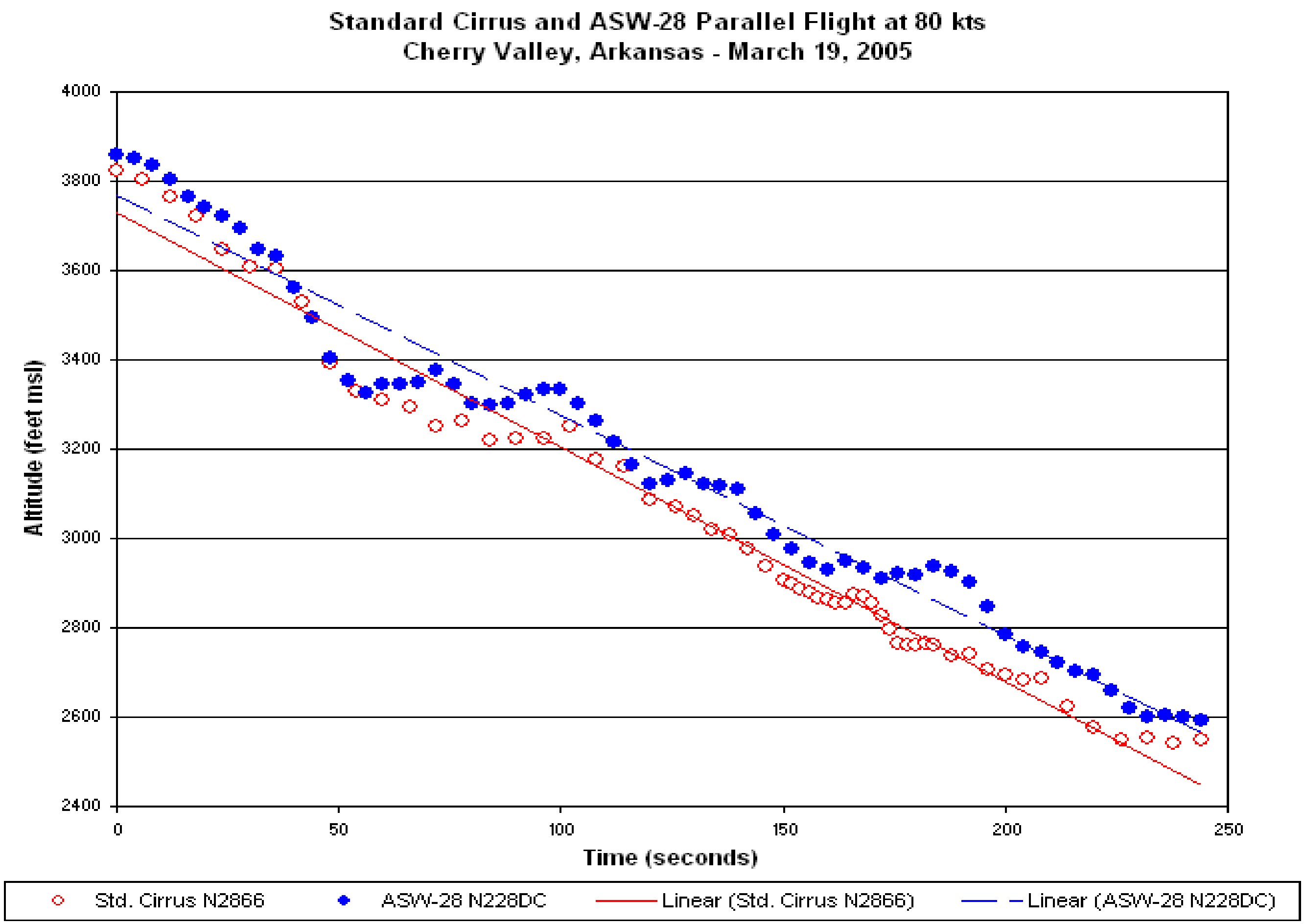


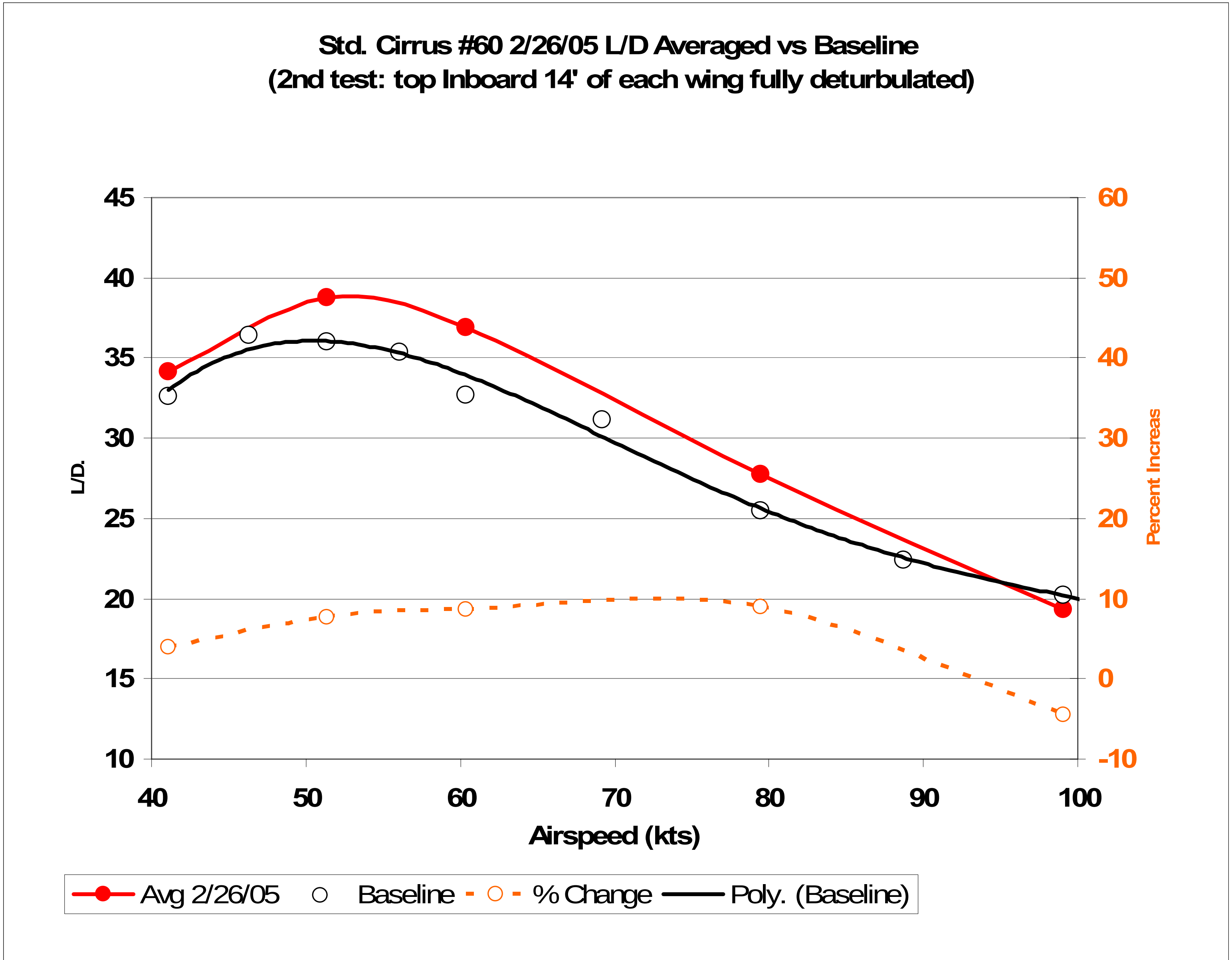


Modified FCSD

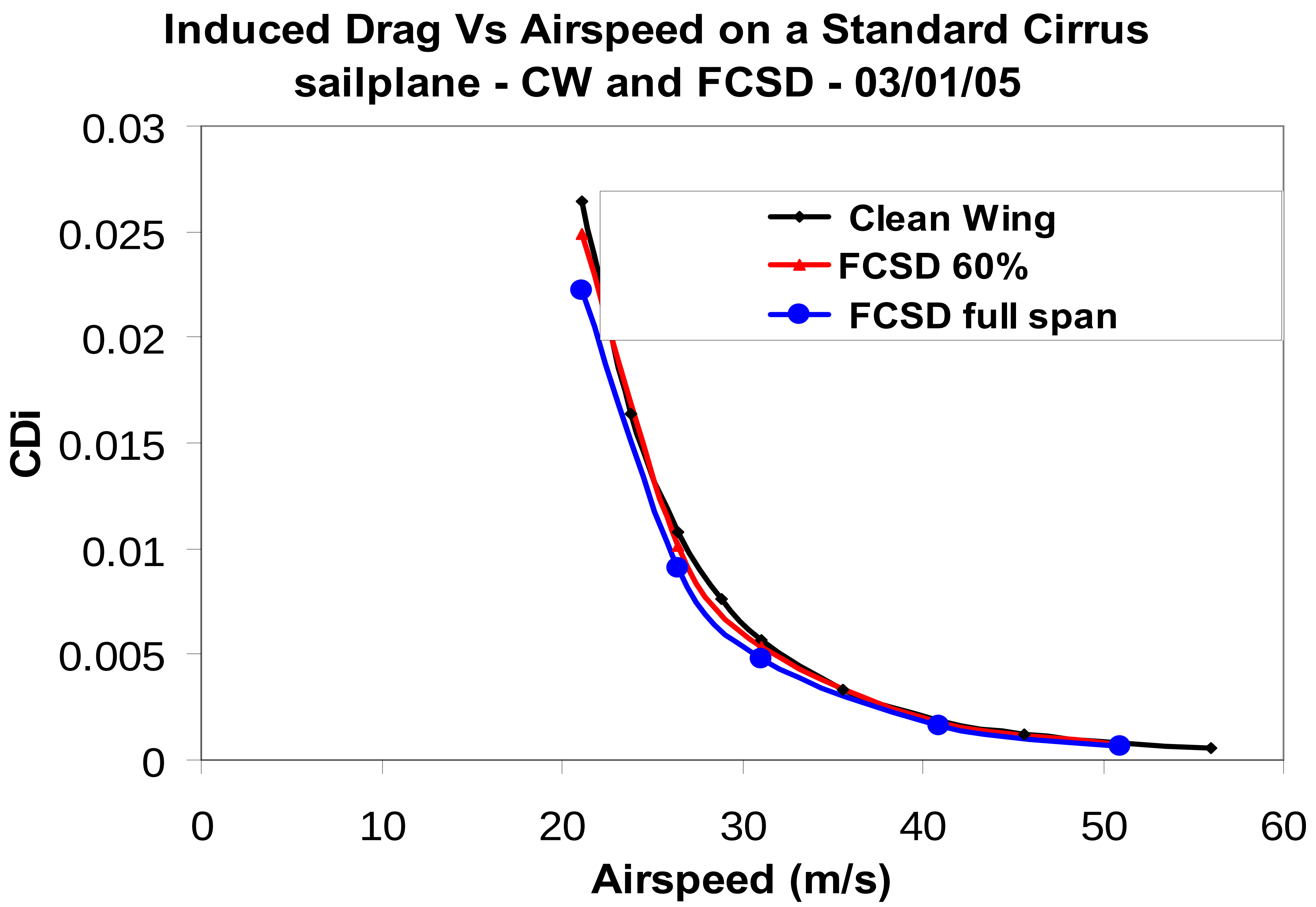

Std. Cirrus #60 2/26/05 Averaged vs Baseline
(2nd test: top Inboard 14' of each wing fully deturbulated)
Sink Rate (fpm)
700
600
500
400
300
200
100
0
40
50
60
70
80
90
100
110
Airspeed (kts)
Baseline
Avg 2/26/05
Poly. (Baseline)

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

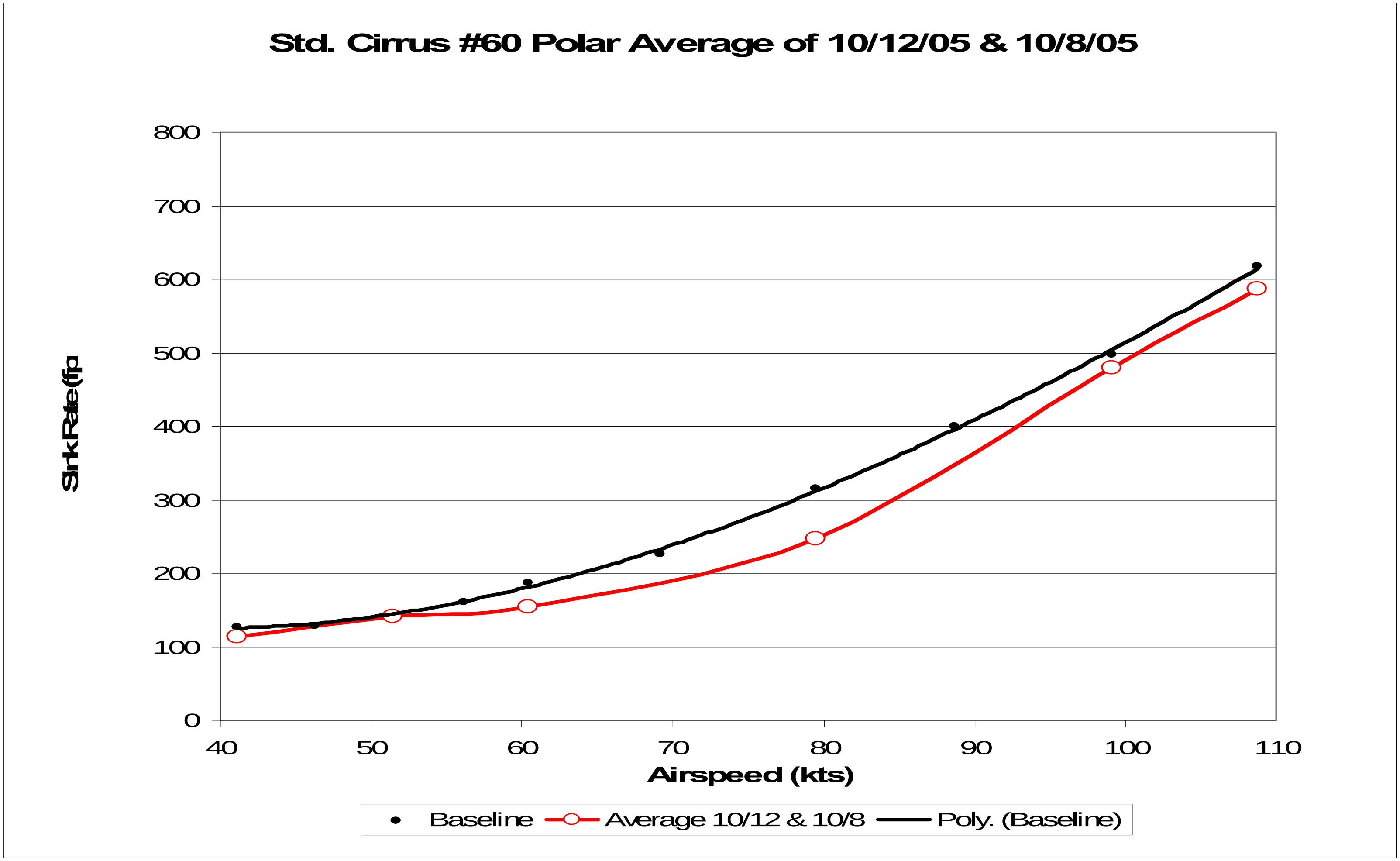




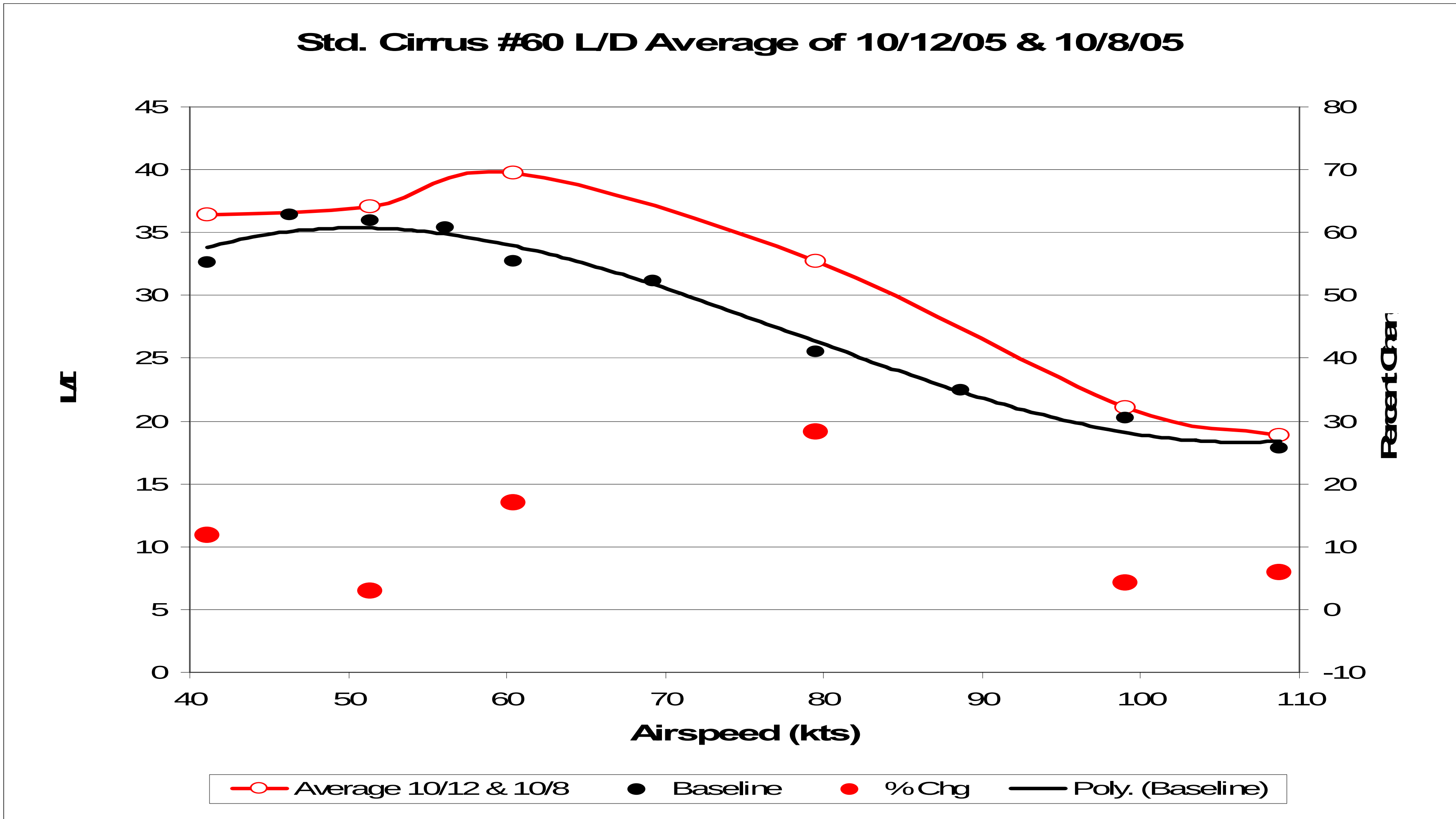
Std. Cirrus #60 2/26/05 L/D Averaged vs Baseline
(2nd test: top Inboard 14' of each wing fully deturbulated)
L/D.
45
40
35
30
25
20
15
10
Percent Increas
60
50
40
30
20
10
0
-10
40
50
60
70
80
90
100
Airspeed (kts)
Avg 2/26/05
Baseline
% Change
Poly. (Baseline)


Induced Drag Vs Airspeed on a Standard Cirrus sailplane - CW and FCSD - 03/01/05
0.03
0.025
0.02
0.015
0.01
0.005
0
CDi
0
10
20
30
40
50
60
Airspeed (m/s)
Clean Wing
FCSD 60%
FCSD full span

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

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QUESTIONS ?