



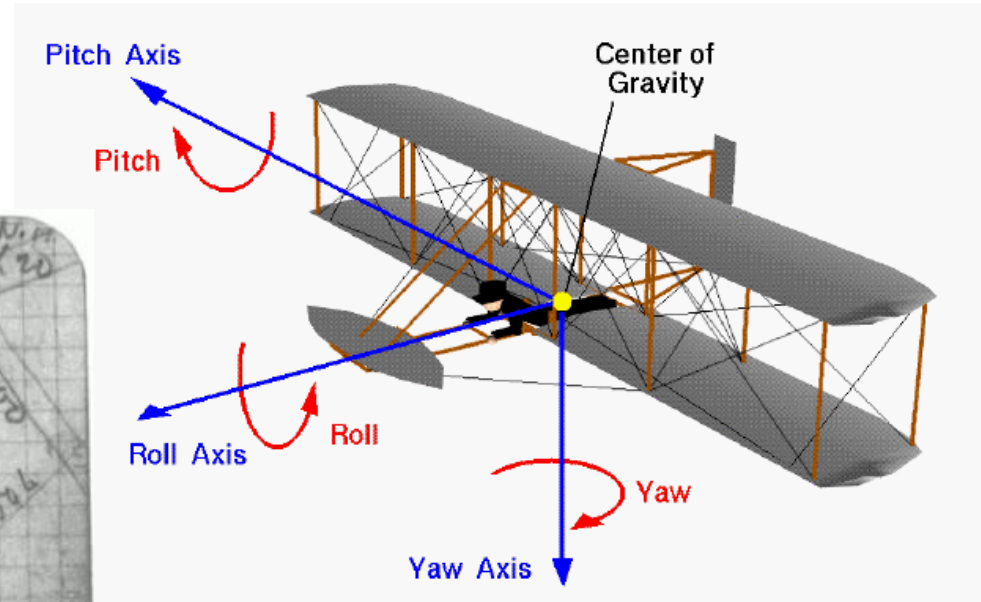
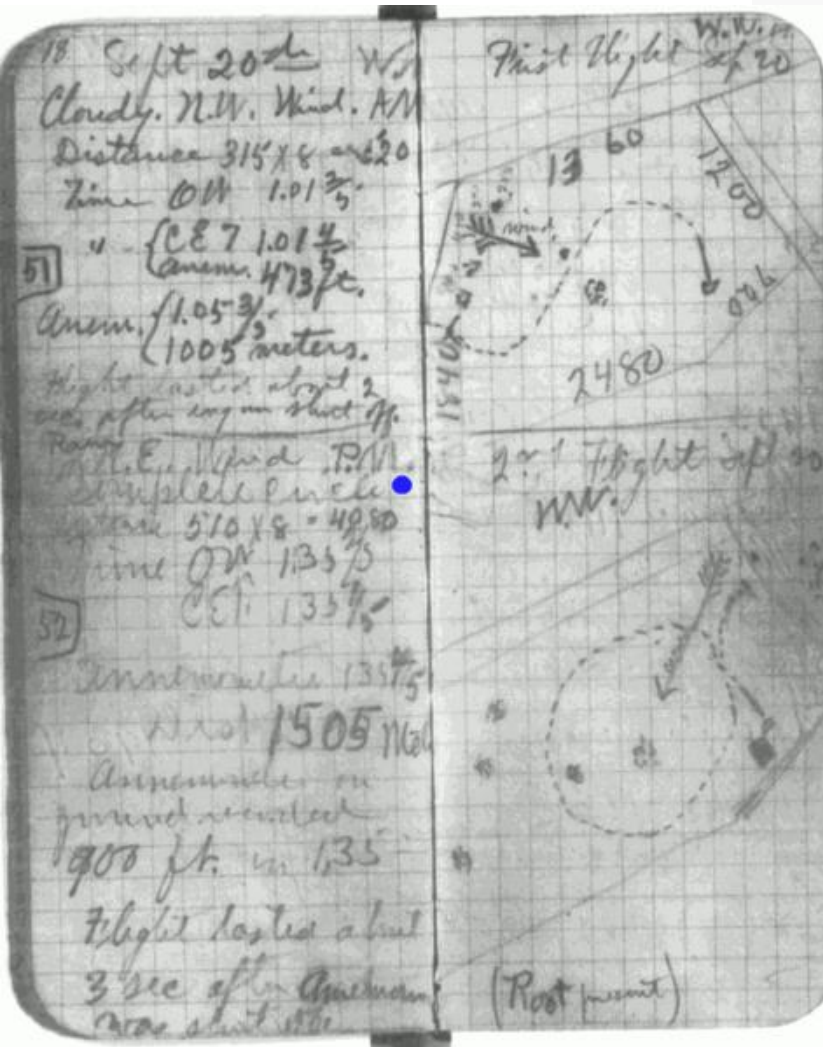
CAN ACTIVE FLOW CONTROL PROVIDE A PARADIGM SHIFT IN AIRPLANE DESIGN?

A COMMENTARY ON A FULL-SCALE VERTICAL TAIL MODEL TESTS AT NFAC

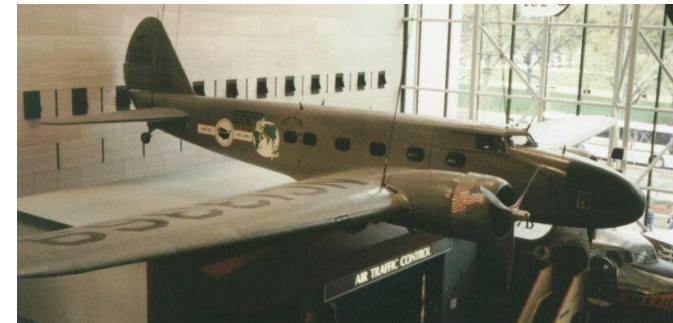
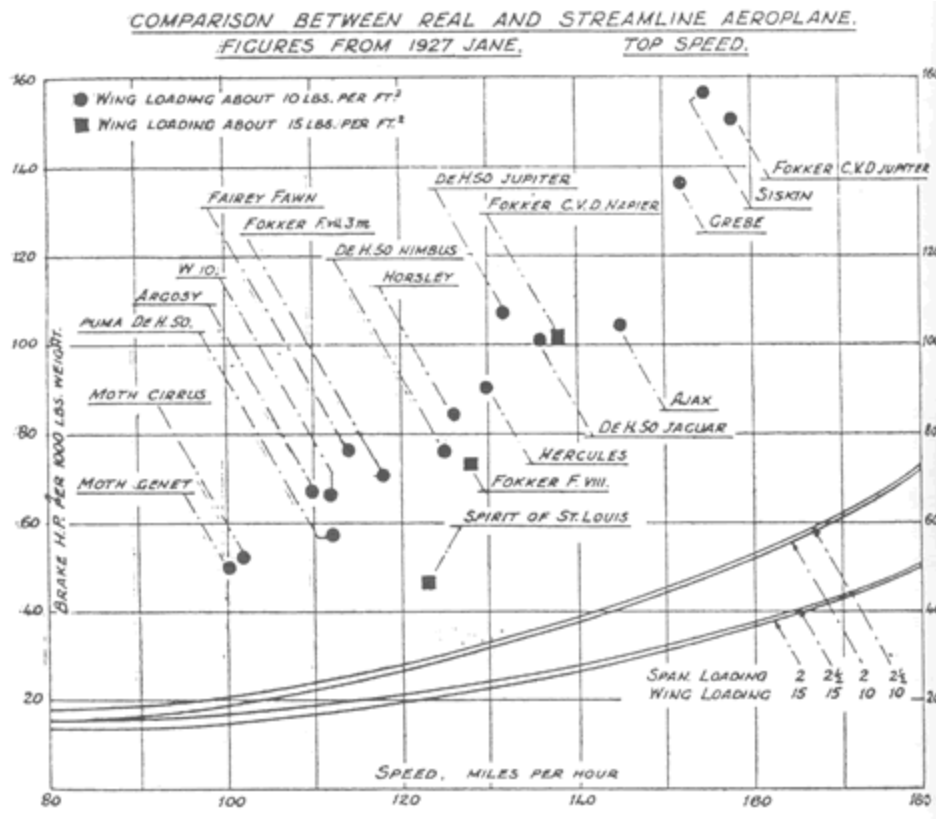
E. Graff, E. Whalen, J. Lin & I. Wygnanski

***WITH THANKS TO:
R. SEELE; E. PHILLIPS; L. TAUBERT; P. TEWES; R. WOSZIDLO;
AND THE MANY PARTICIPANTS FROM BOEING, NASA & AEDC WITHOUT WHOSE
EXPERTISE THIS PRESENTATION WOULD NOT HAVE BEEN POSSIBLE***

1



2



**'The streamline airplane' to the Royal Aeronautical Society
and that changed the conceptual design of
airplanes from the like of Handley Page 0/400 to
Boeing 247 and DC 1 that flew in 1933.**

3

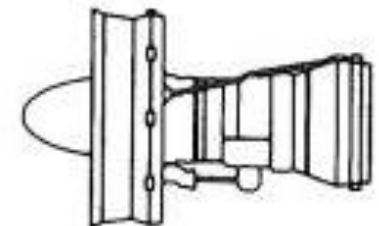
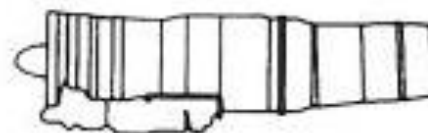
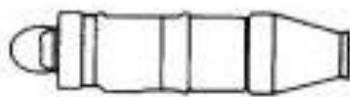


Turbojet

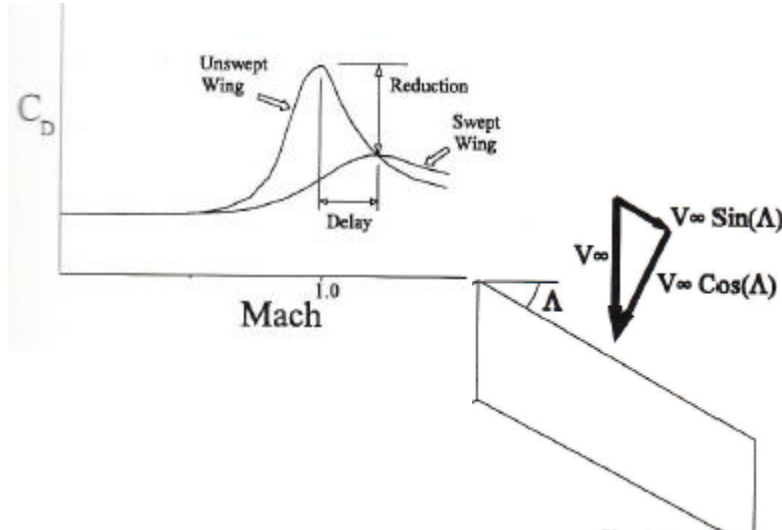
Turbojet

Low bypass
turbofan

High bypass
turbofan



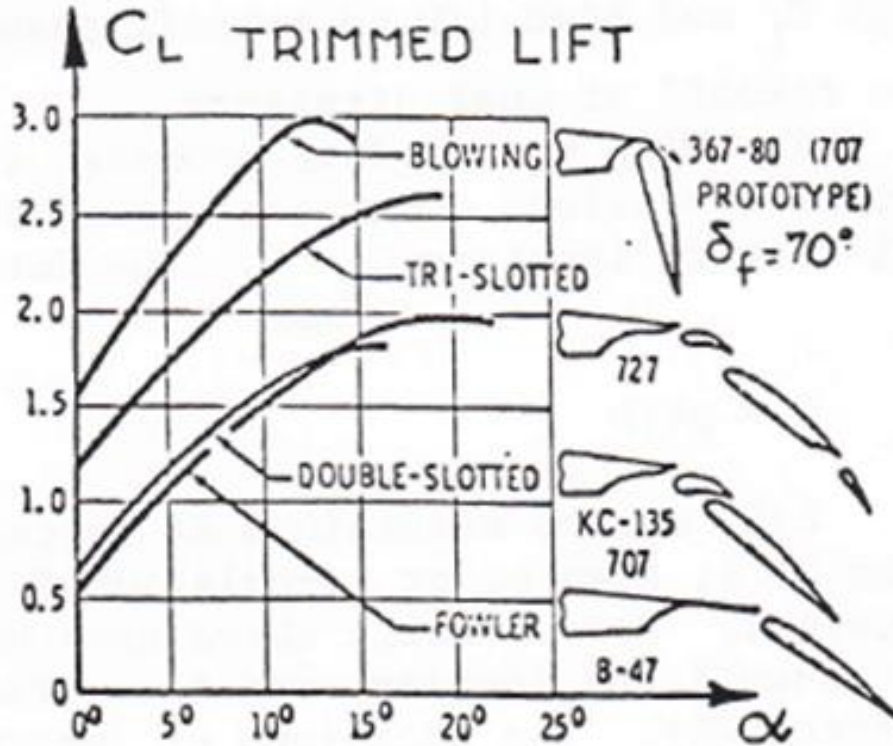
4



*Is there a possibility for a 5th paradigm shift
in commercial airplane design or is aeronautics
a mature science or a sunset technology?*

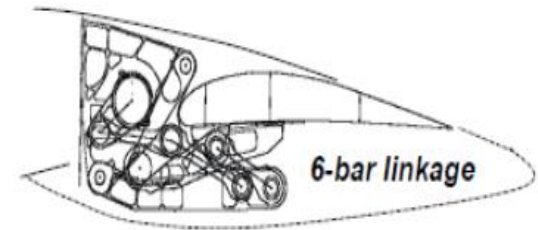


BACKGROUND



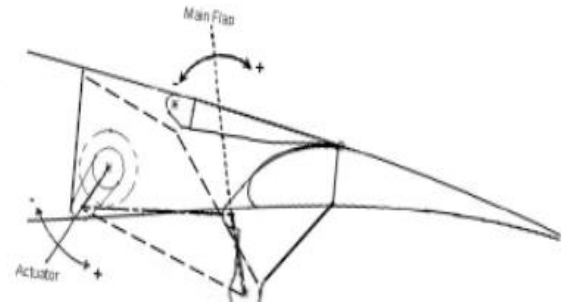
767

Double/single slotted with Fowler motion

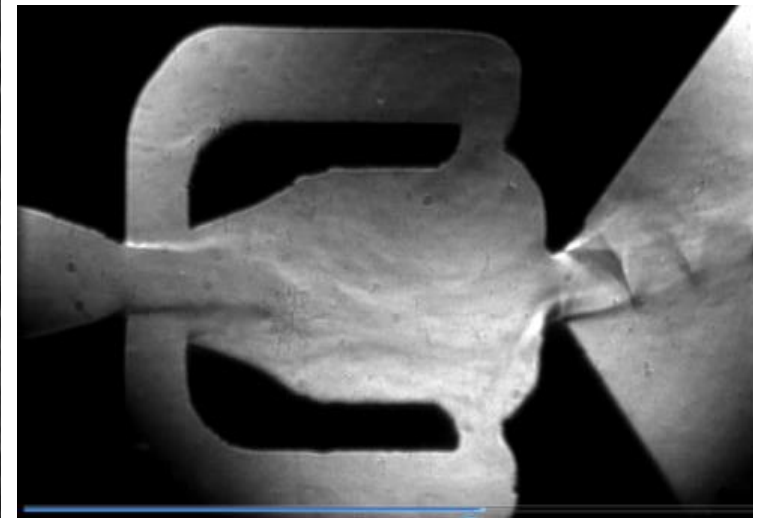
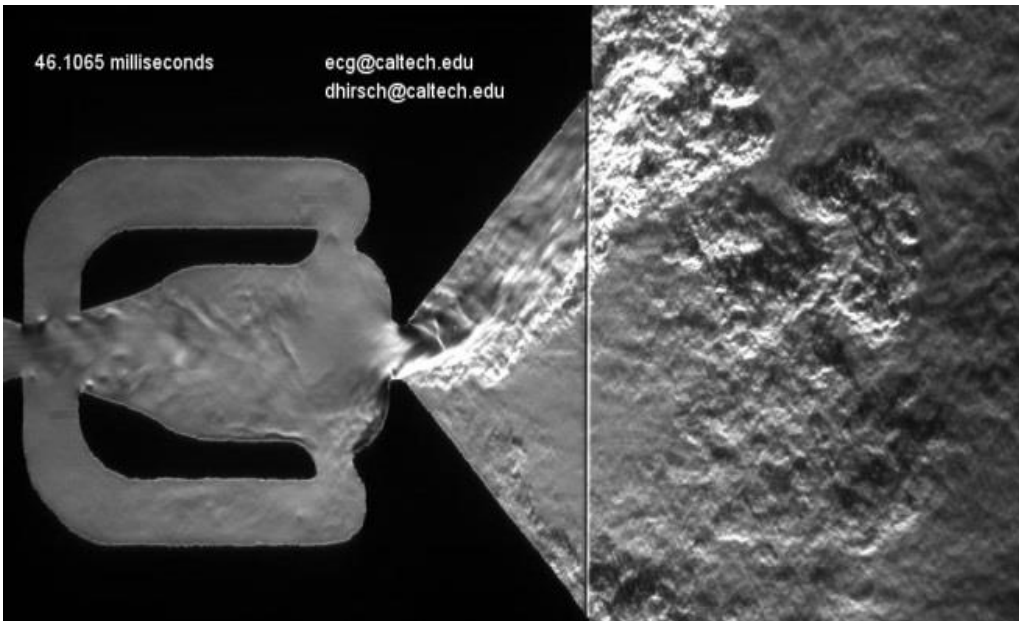
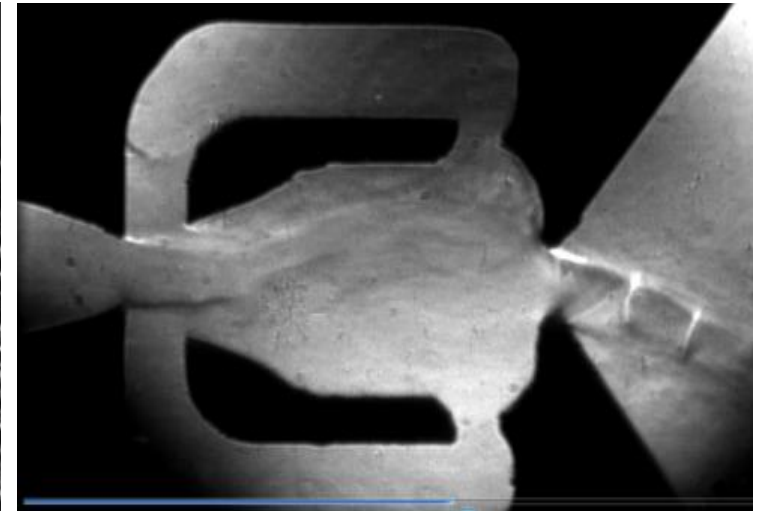
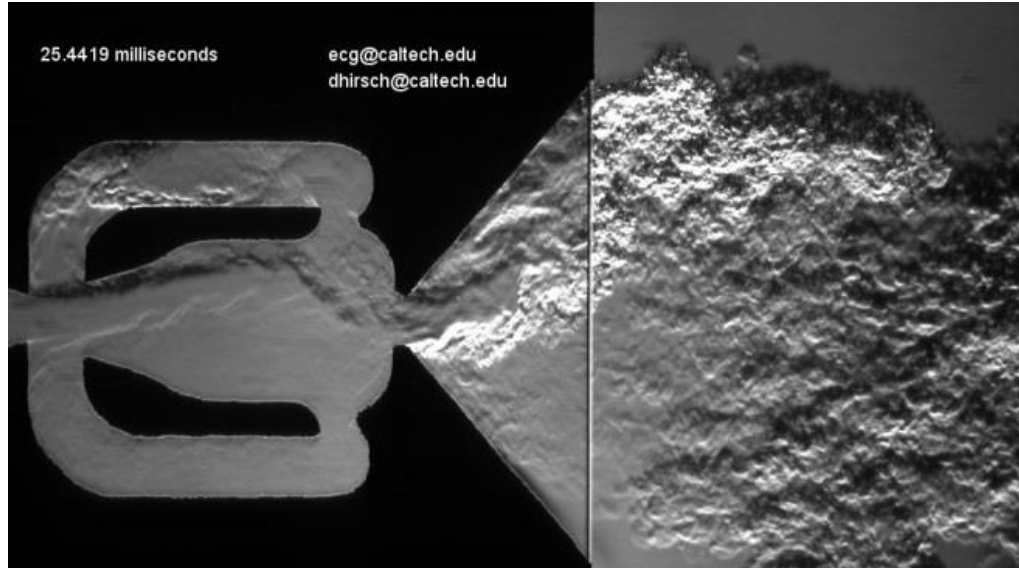


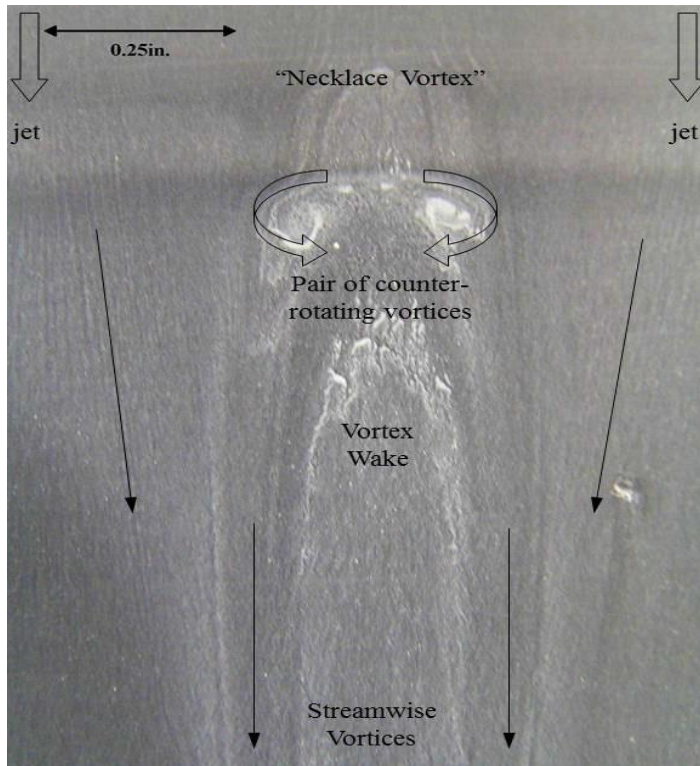
787

Single/single slotted

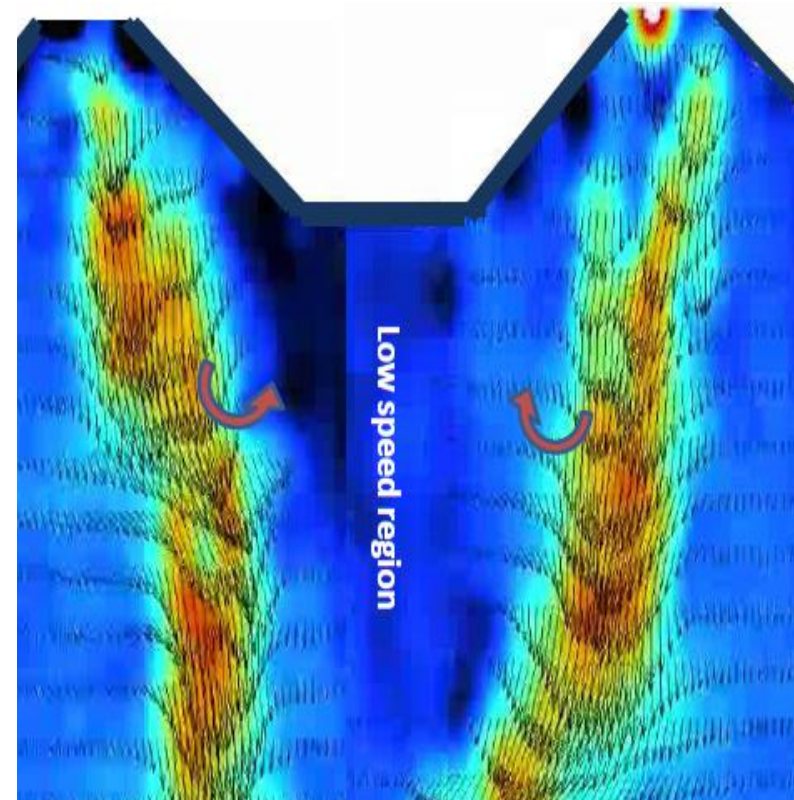


AFC Technology: Sweeping Jet Actuators

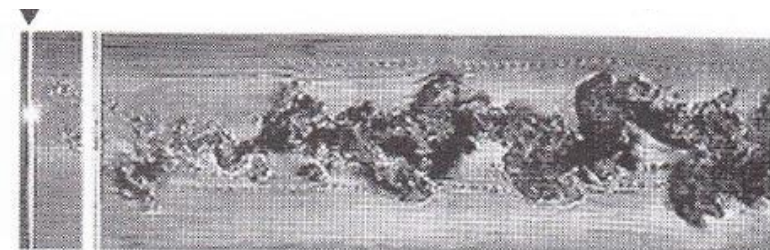
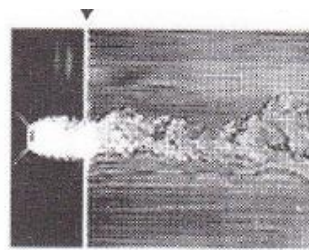
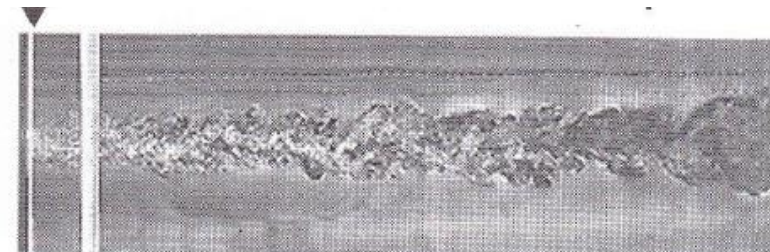
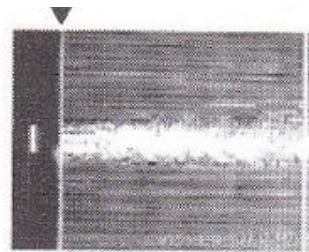
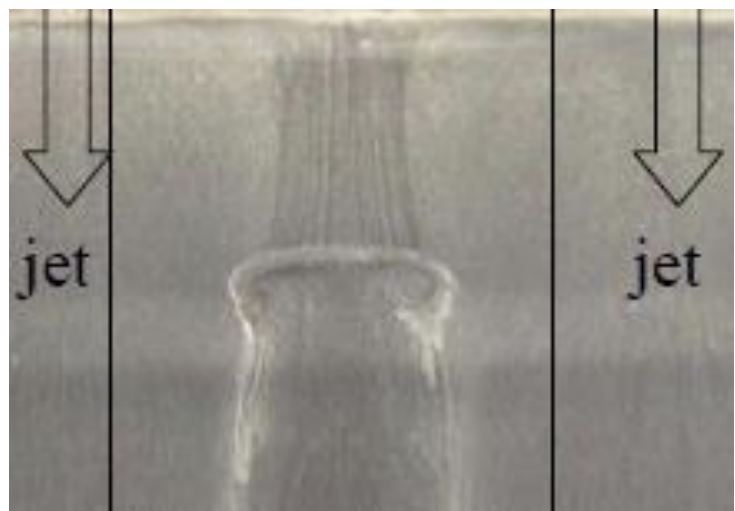
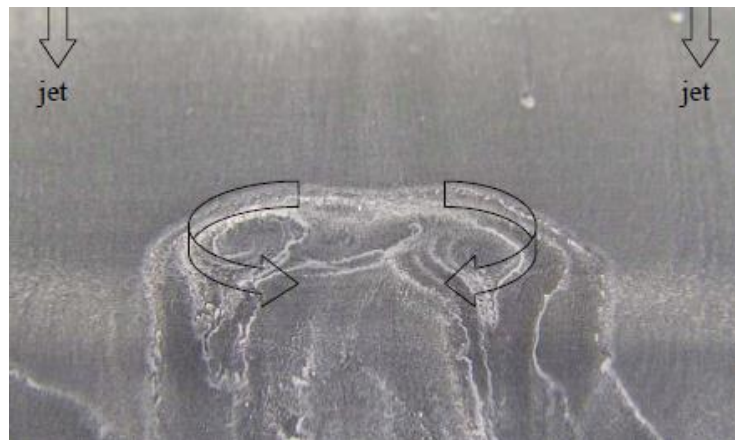




Rene Woszidlo 2011



Rob Fong 2014

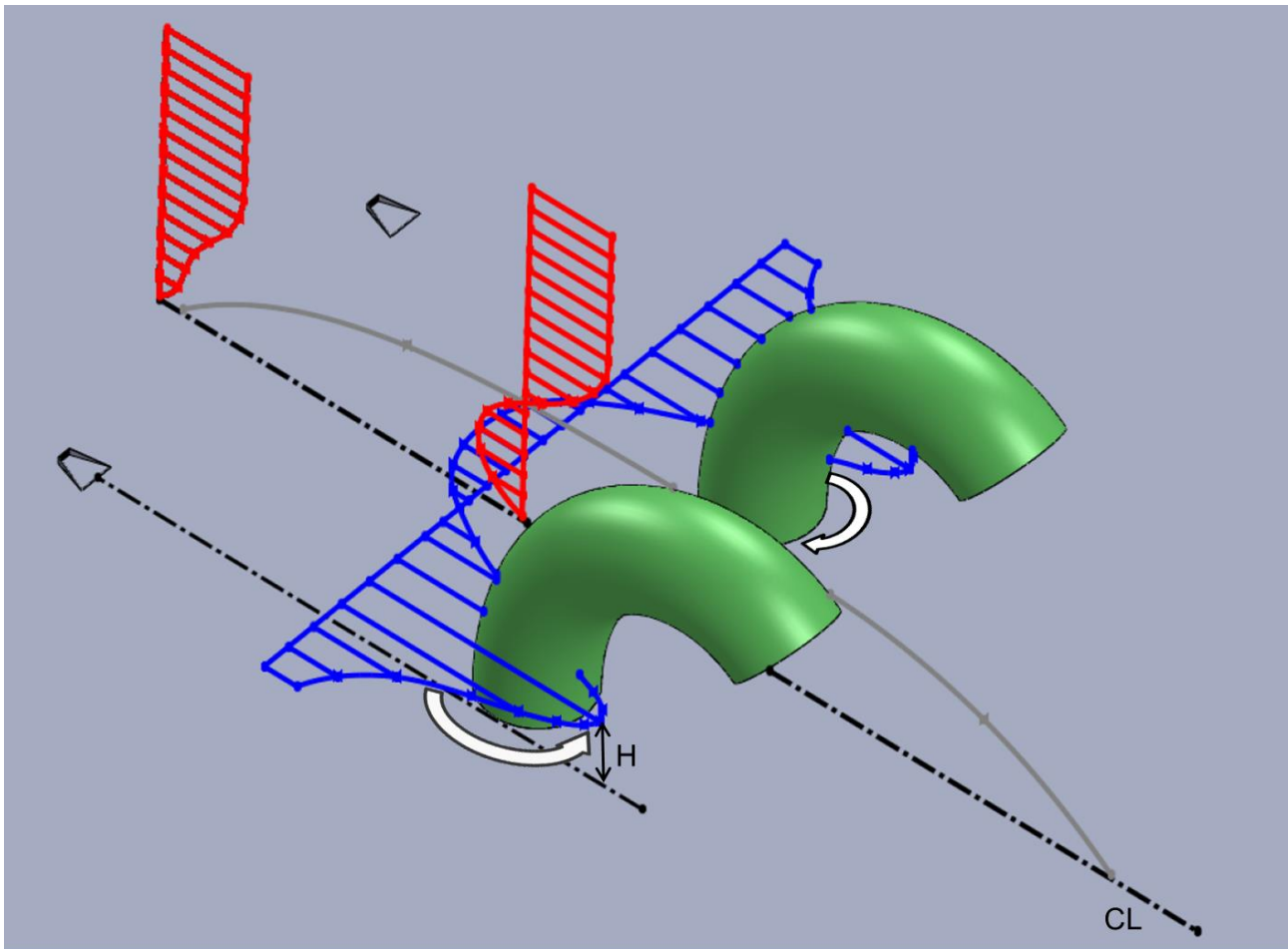


0 x/θ 40

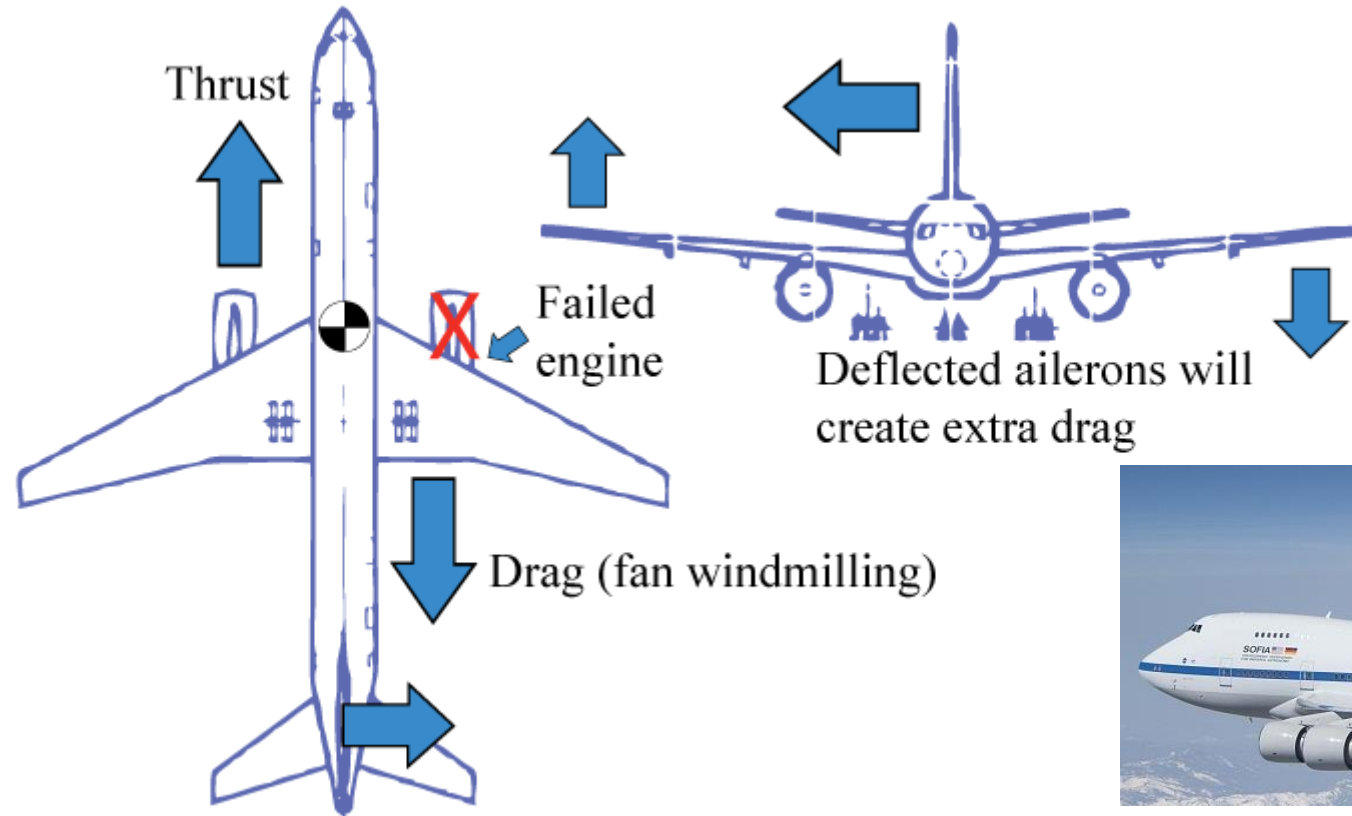
85

x/θ

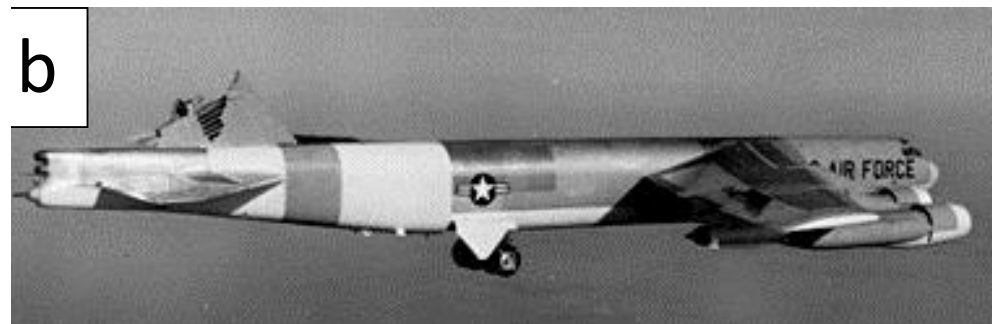
185



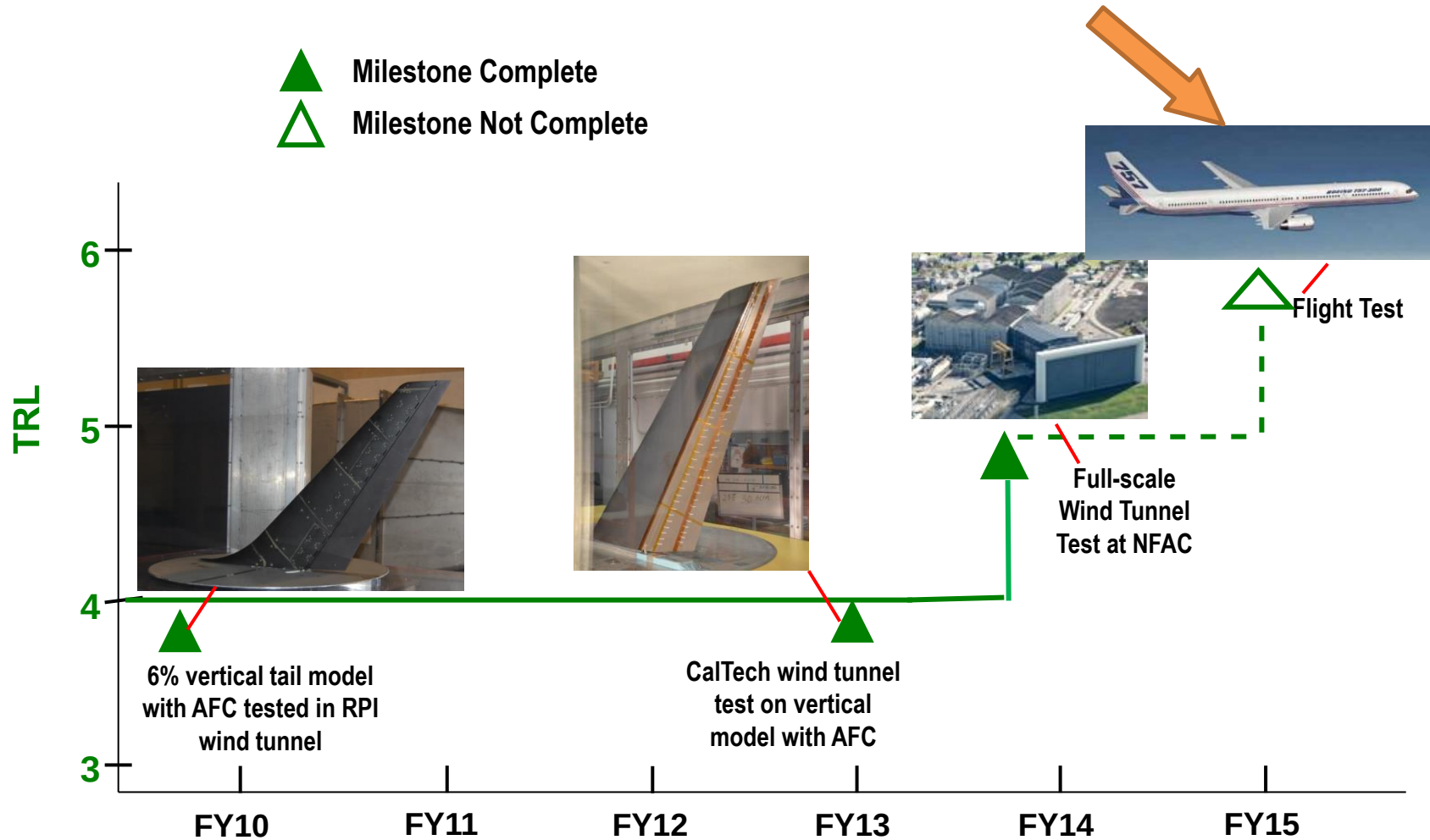
Motivation: Vertical Tail Size Reduction



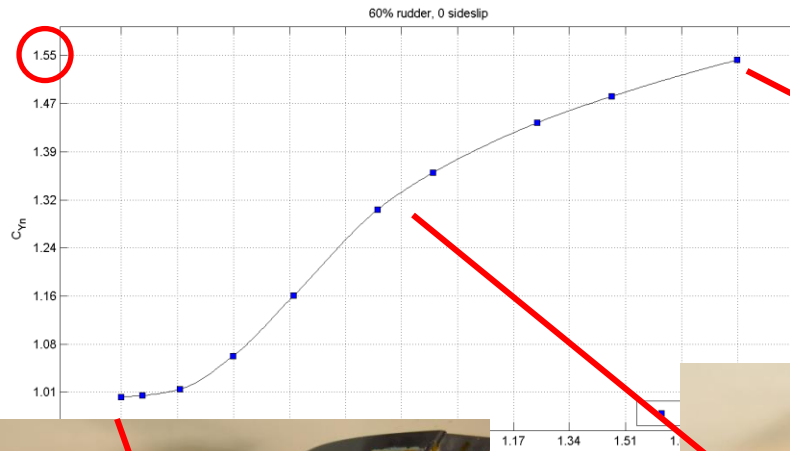
NASA SOFIA Aircraft



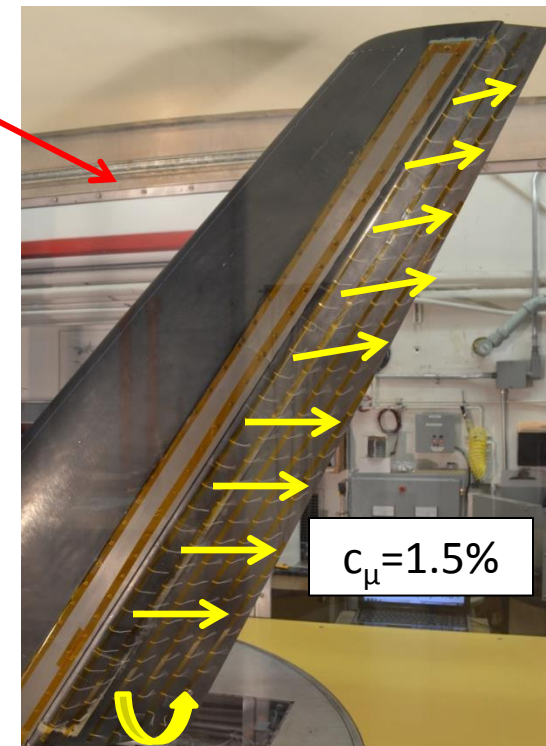
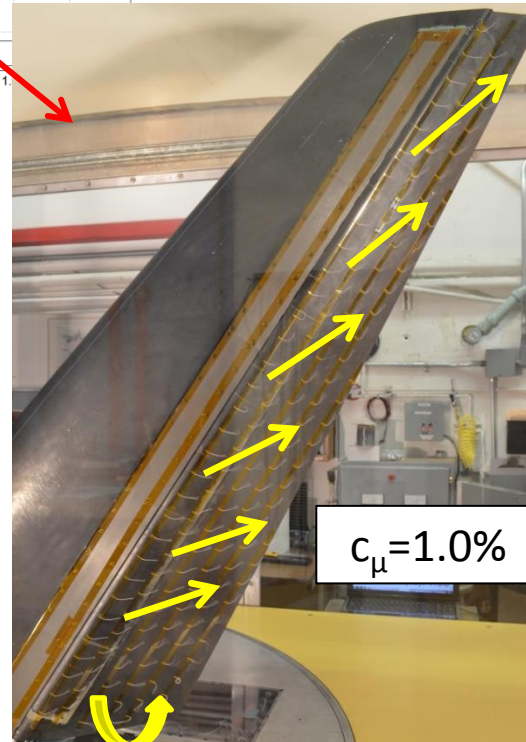
- System study indicated a $\sim 0.4\%$ in fuel saving for AFC-enhanced vertical tail



General Effect of AFC

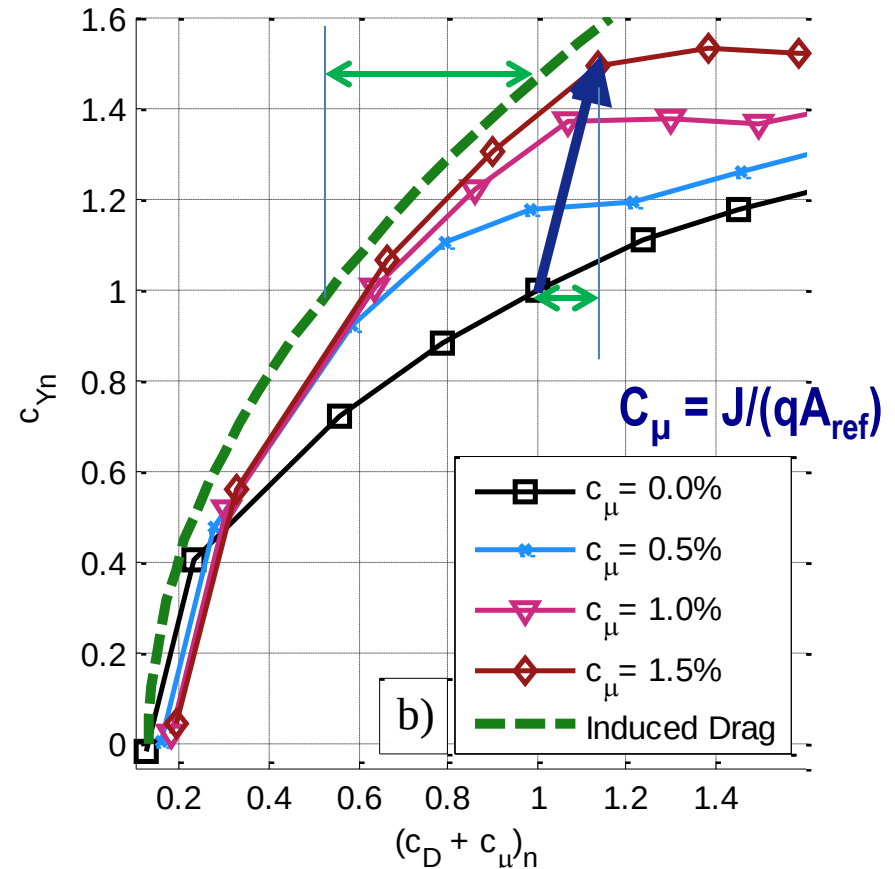
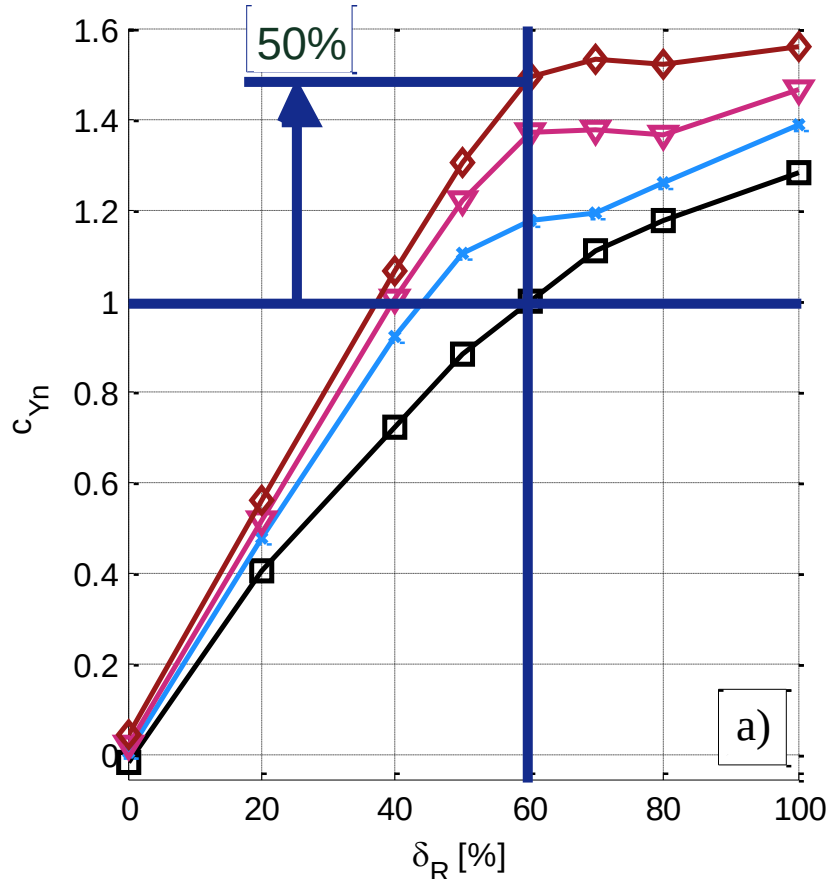


Nearly 55% increase in side force over baseline at 1.8% C_μ



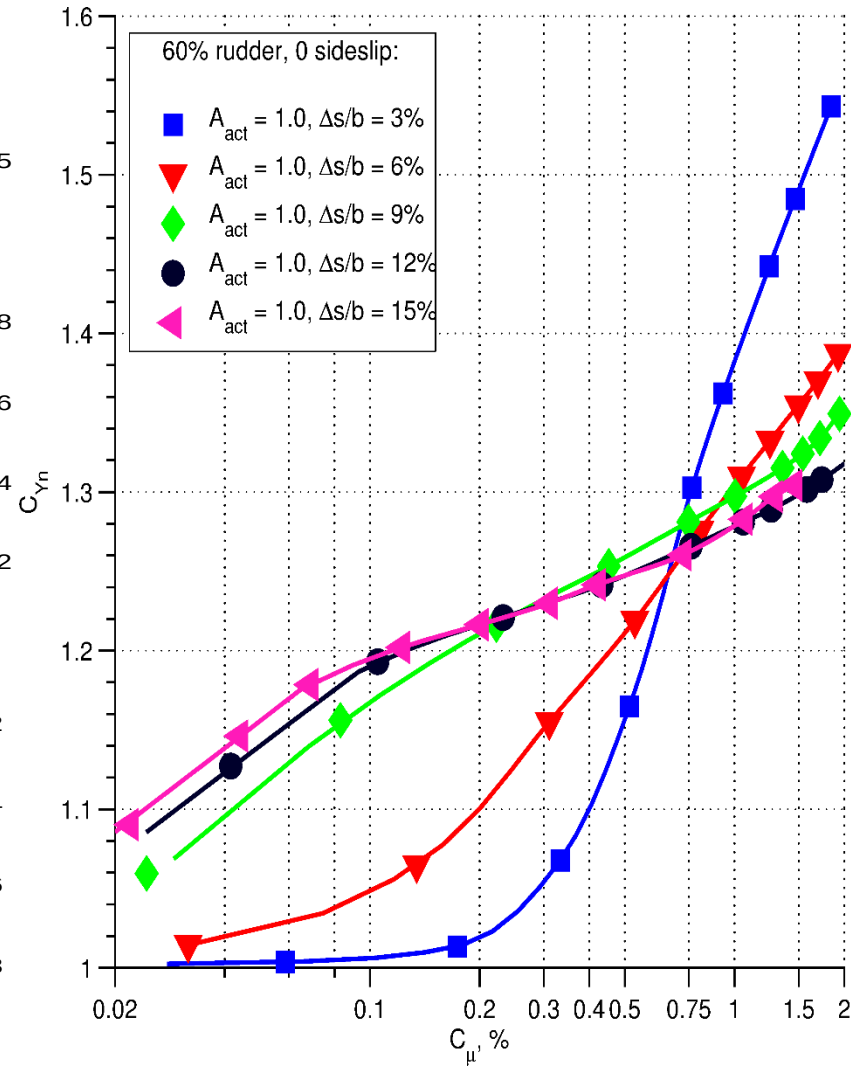
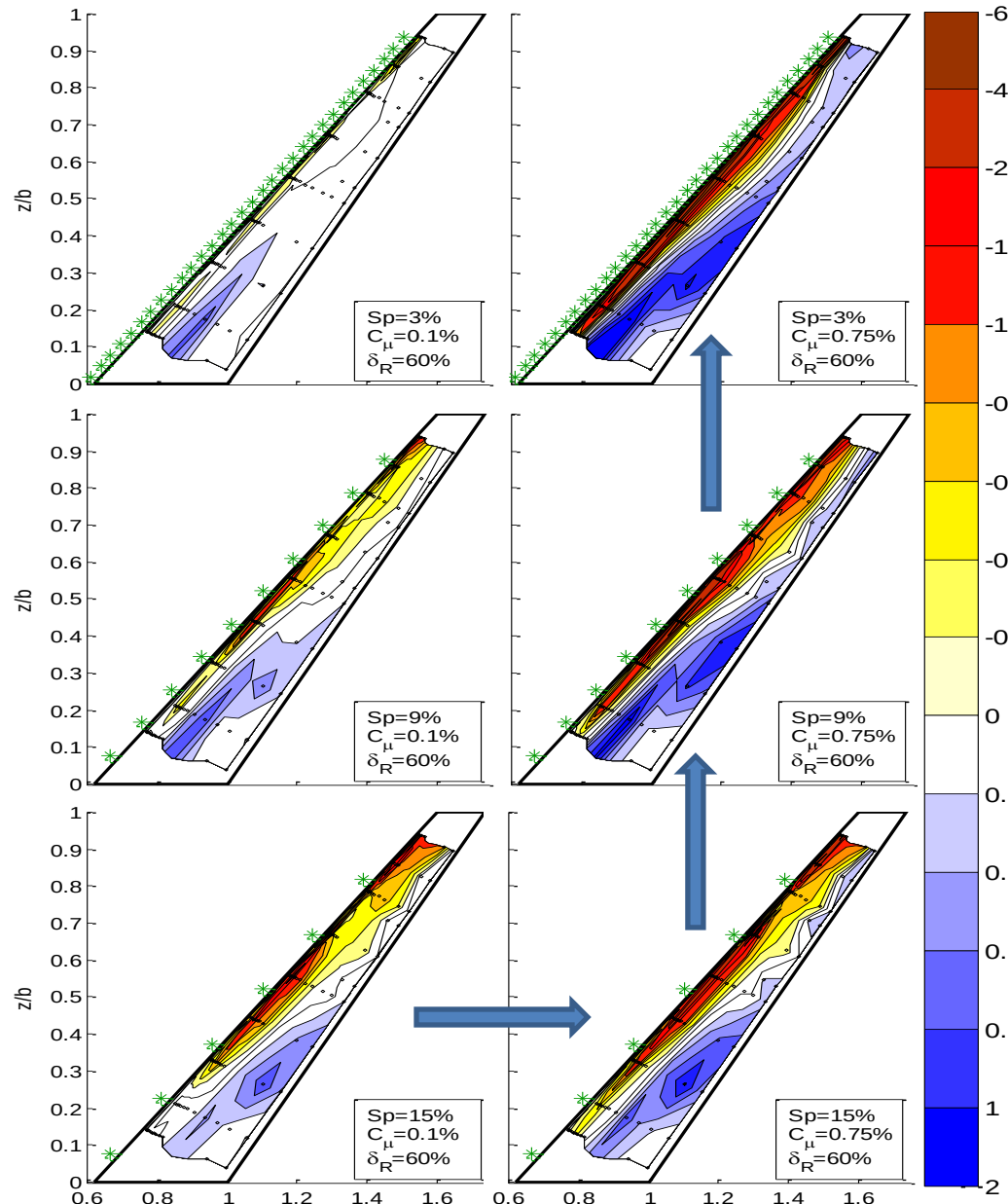
Effects of Momentum Coefficient on Side Force and Drag

$\beta = 0^\circ$, $U_\infty = 40$ m/s, $Sp = 3\%$ (dimensionless spacing between adjacent actuators), $A_{Act} = 1$ nozzle

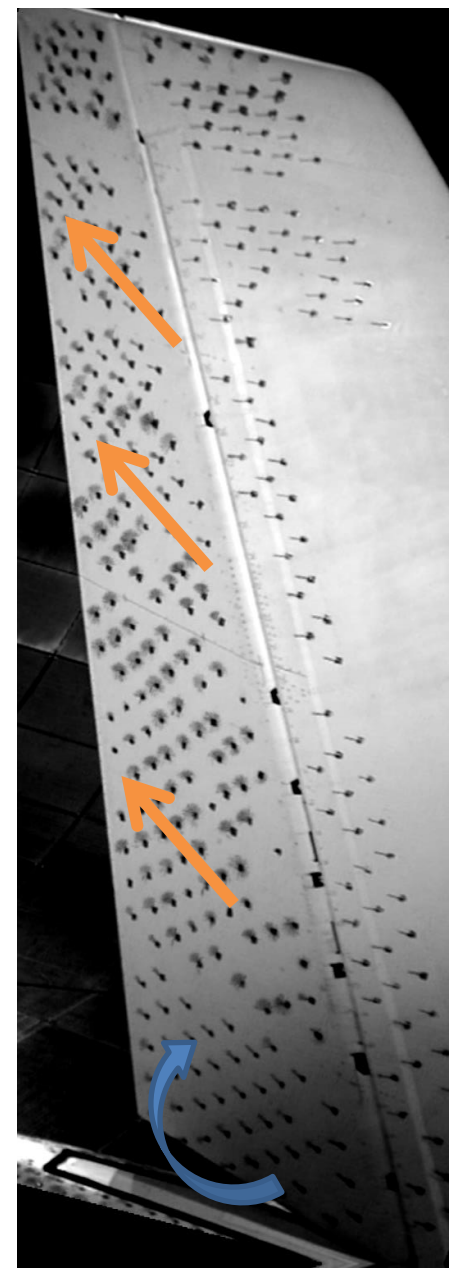
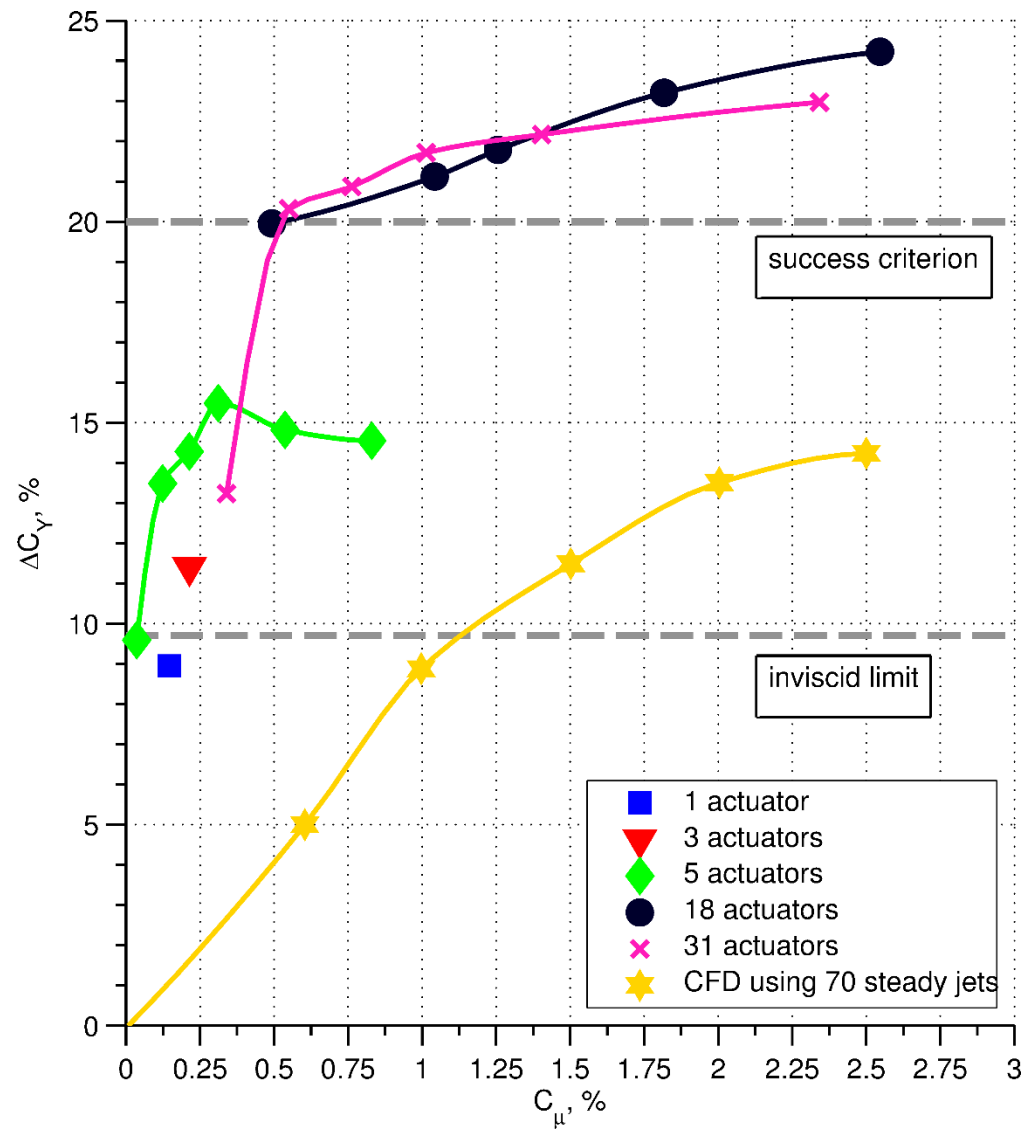


- Coefficients are normalized by values at $\delta_R = 60\%$ & $\beta = 0^\circ$
- 50% increase in lift for $C_\mu = 1.5\%$ with minimal increase in drag

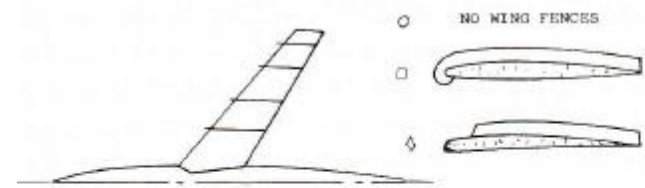
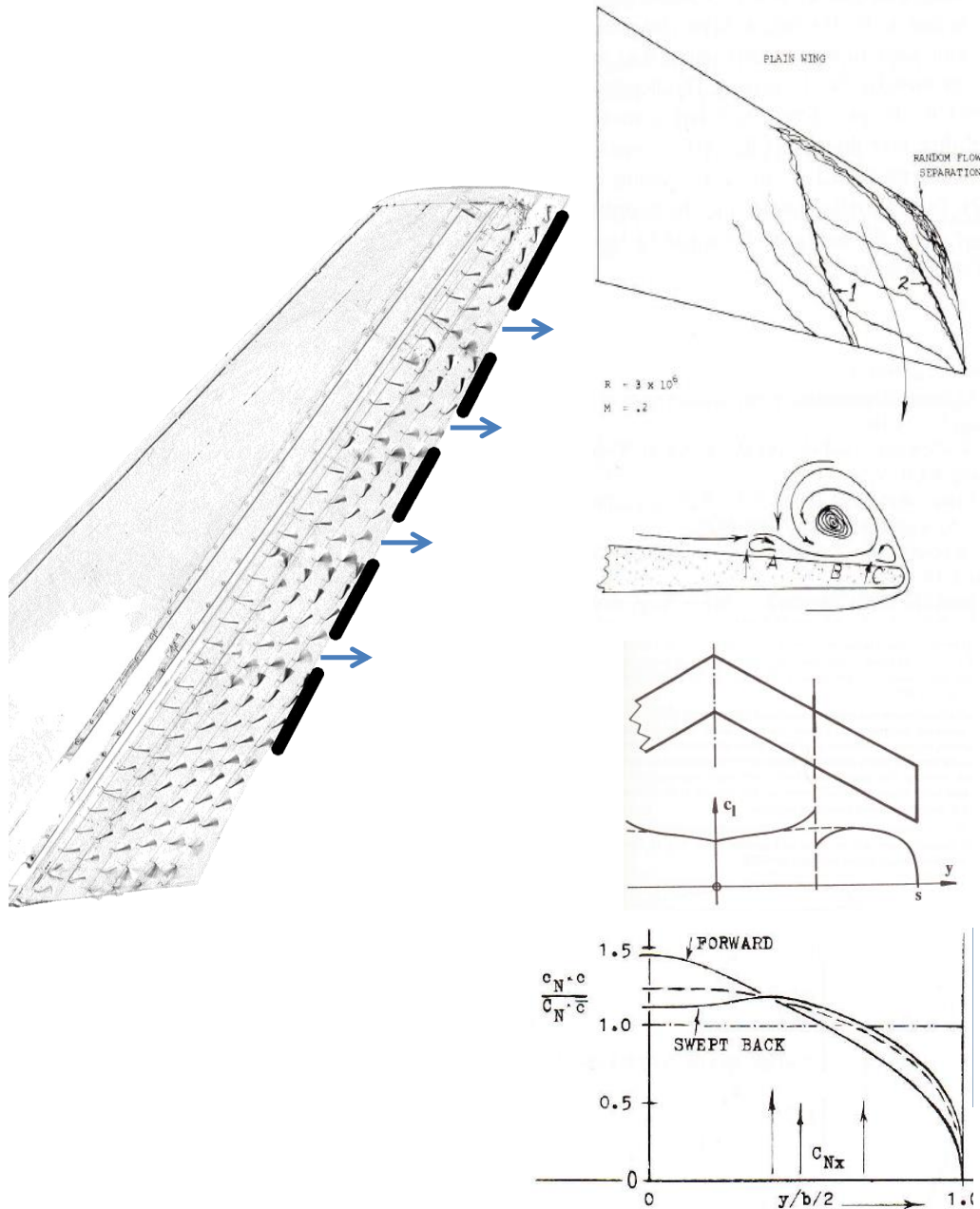
Pressure Contours on the Rudder taken at $Sp=3; 9; 15\%$

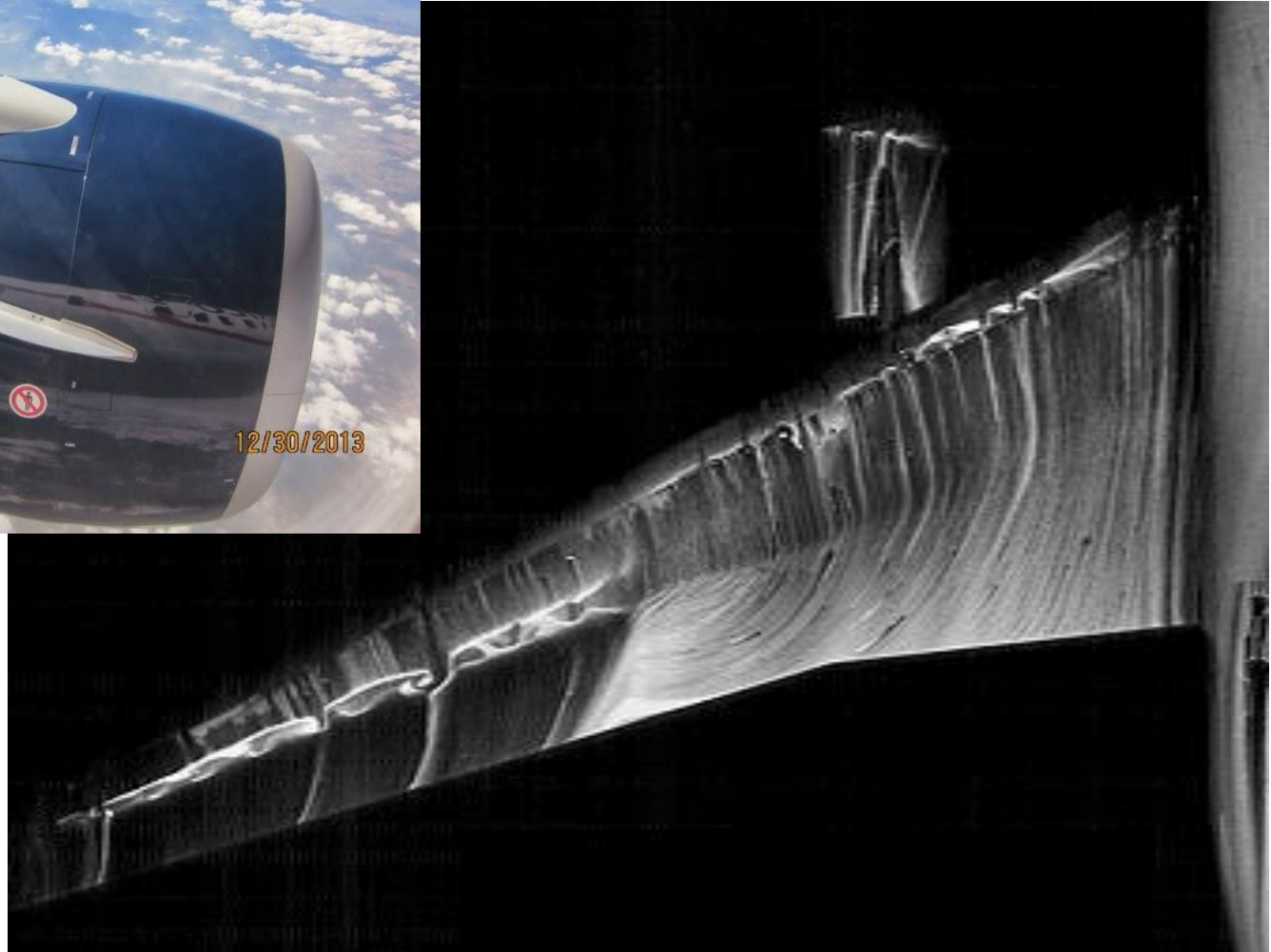


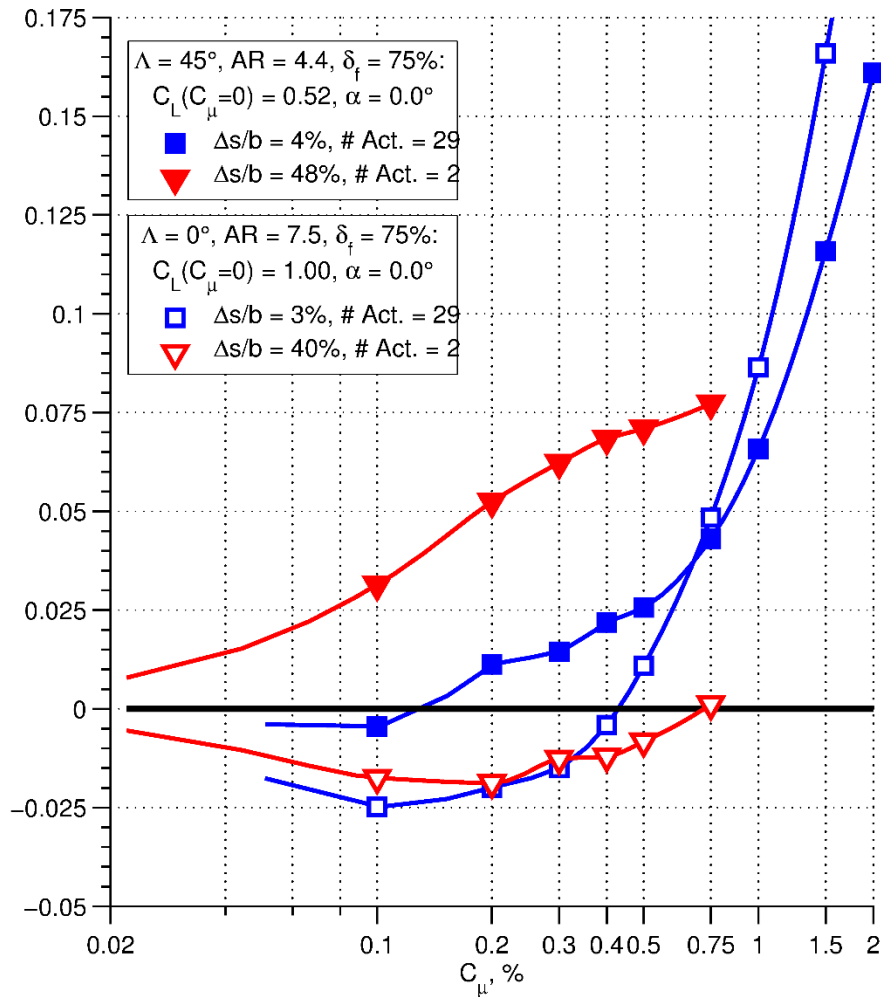
Comparing normalized results with commercial CFD $\delta=60\%$



Boundary layer fences on sweptback wings



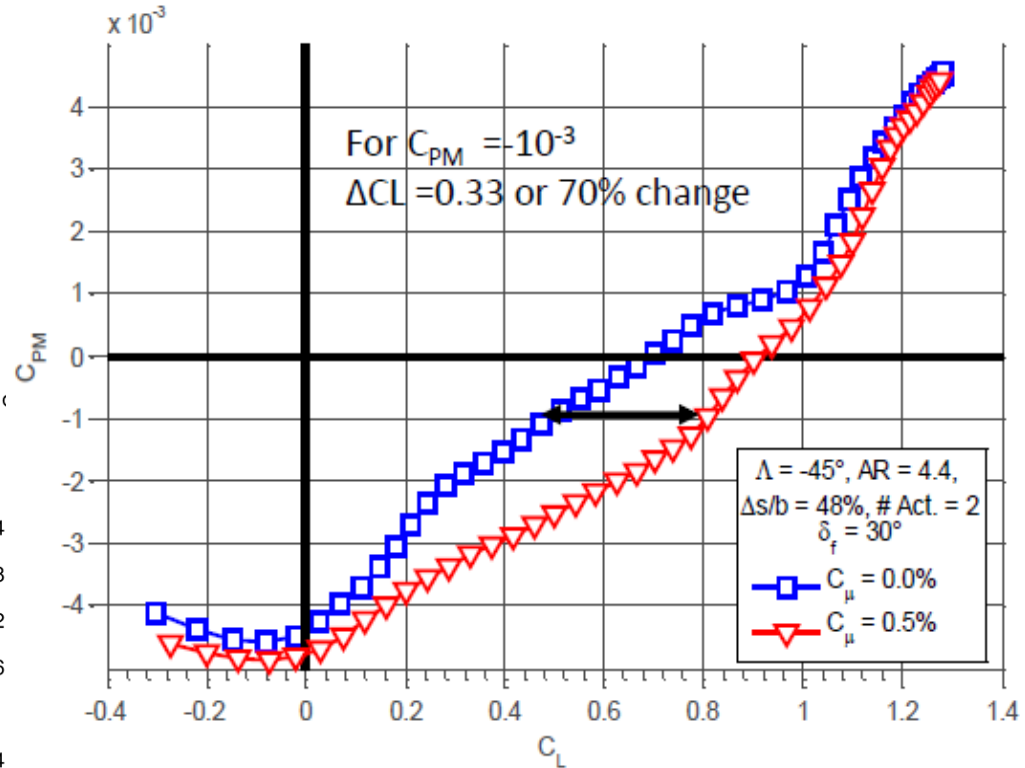
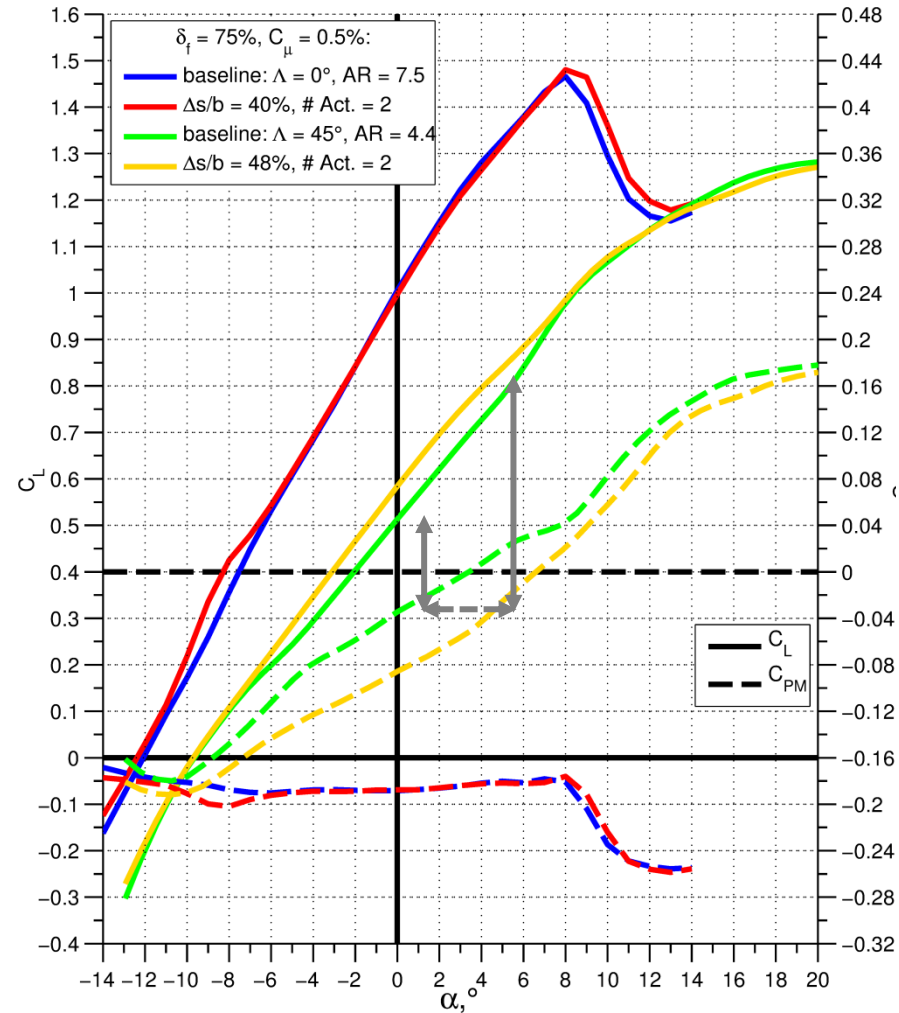




$\Lambda = 45^\circ,$
 $AR = 4.4$

$\Lambda = 0^\circ,$
 $AR = 7.5$

Results: Effects of Λ on AFC



Conclusions



- ***A 50% increase in C_L is possible on a tapered finite & swept back wing equipped with a simple flap at acceptable levels of input***
- ***Benefits realized at $C_{\mu} \approx 0.1\%$ are due to reorientation of the flow on swept back finite wings.***
- ***Reattachment of the flow over a highly deflected flap requires a $C_{\mu} \approx 1\%$ when sweeping jet actuators are used.***
- ***One has to take care of two boundary layers over a swept back wing: First eliminate or reduce the spanwise flow and only later (in terms of incidence, flap deflection and C_{μ}) take care of the boundary layer that develops along the chord.***
- ***Boundary Layer independence principle that does apply to Reynolds averaged turbulent boundary layer equations provides guidance for controlling such flows***
- ***Spacing, location & size of the actuators determine the effectiveness of the system.***
- ***Jet velocities should be at least 3 times larger than the free stream & preferably subsonic. Jet pairs are more effective as they may create regions of absolute instability.***
- ***There is a need to improve CFD capabilities for unsteady AFC applications.***

Questions?



