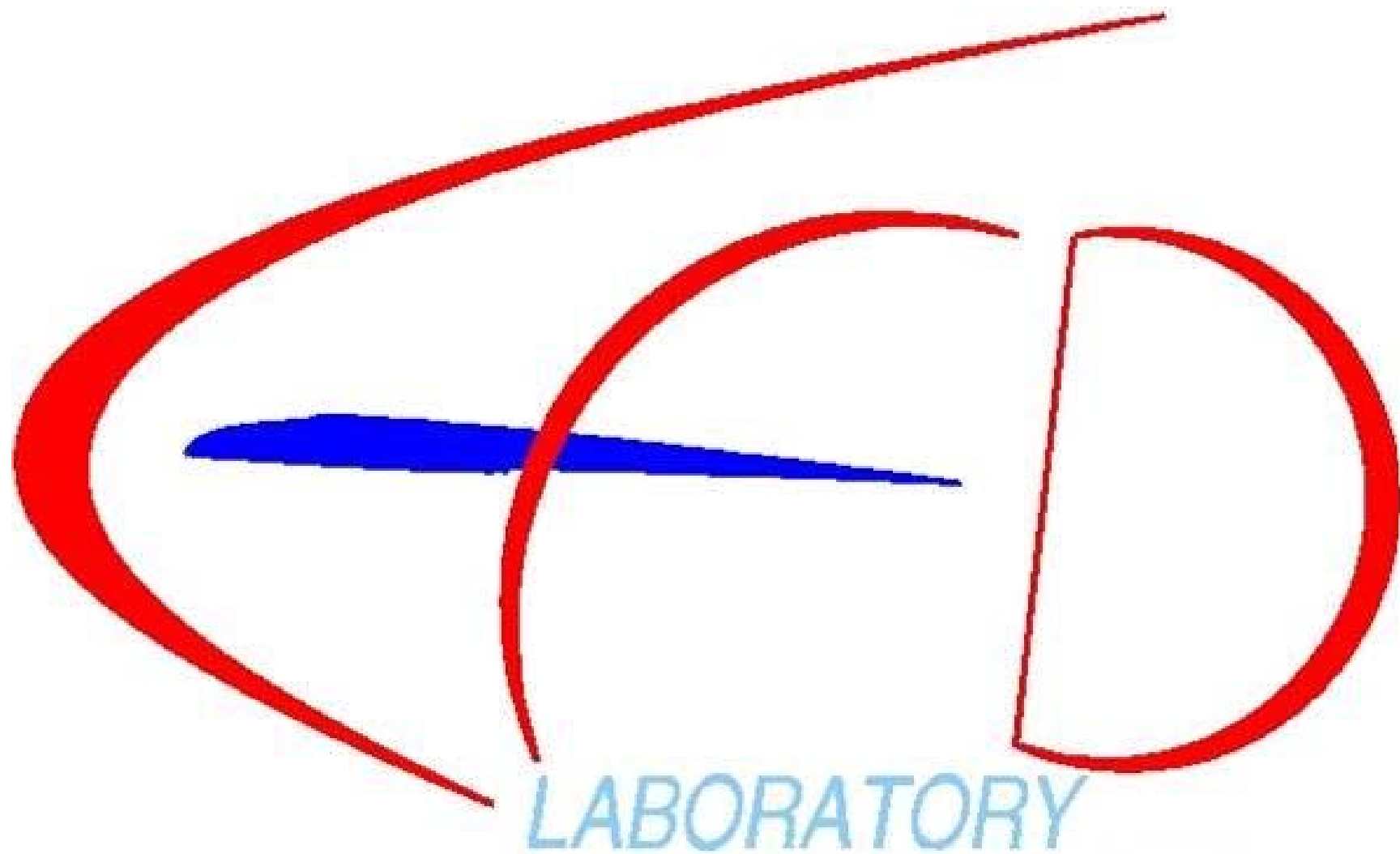




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Sting Influence on Vortex Breakdown on a 65 Degree Delta Wing in Transonic Flow



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O.J.Boelens,
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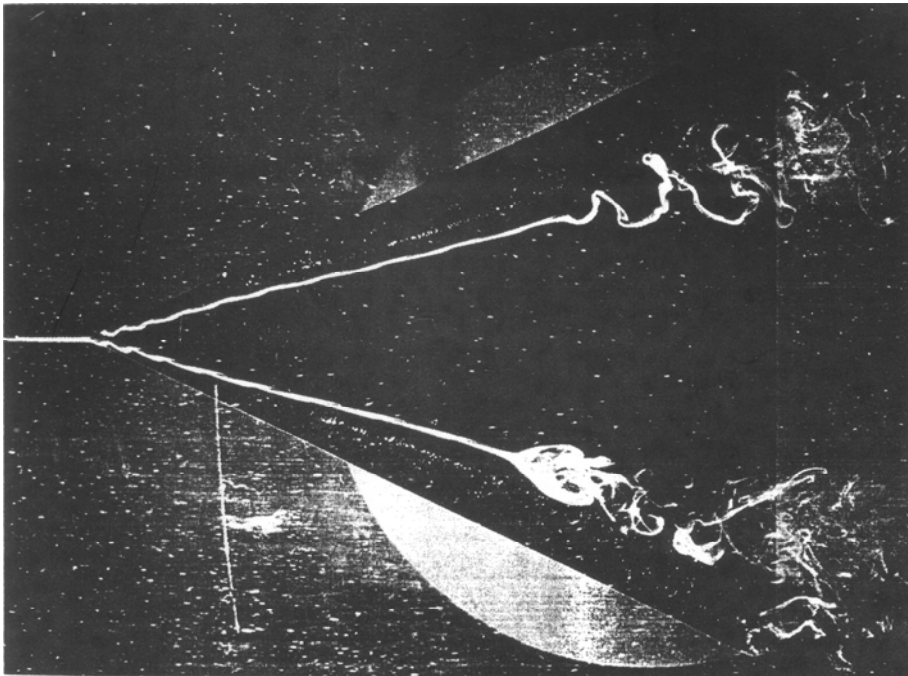


R.M.Cummings,
United States Air Force Academy,
Colorado Springs,
USA

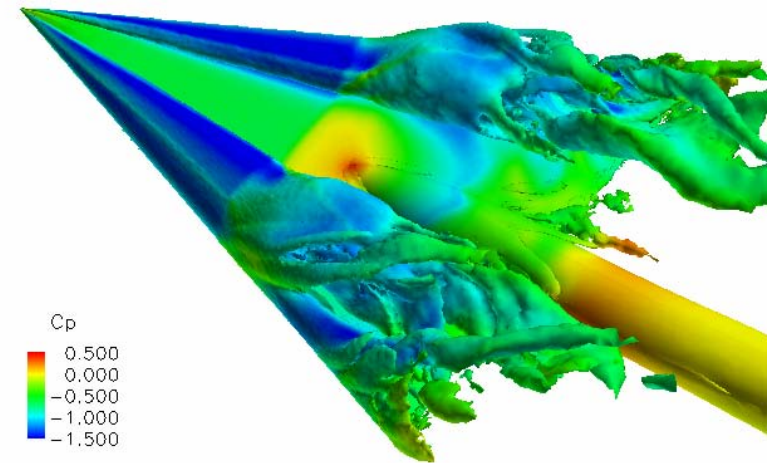
W.Fritz,
EADS, Germany



3rd International Symposium on Integrating
CFD and Experiments in Aerodynamics

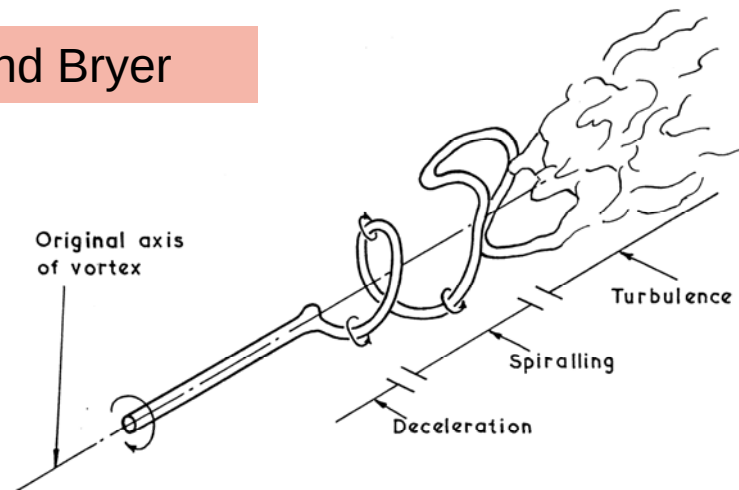


Sharp Leading Edge Delta Wing
 $M = 0.85$, $\alpha = 23.0^\circ$, $Re = 6,000,000$
 Iso-surface of X-vorticity colored by pressure



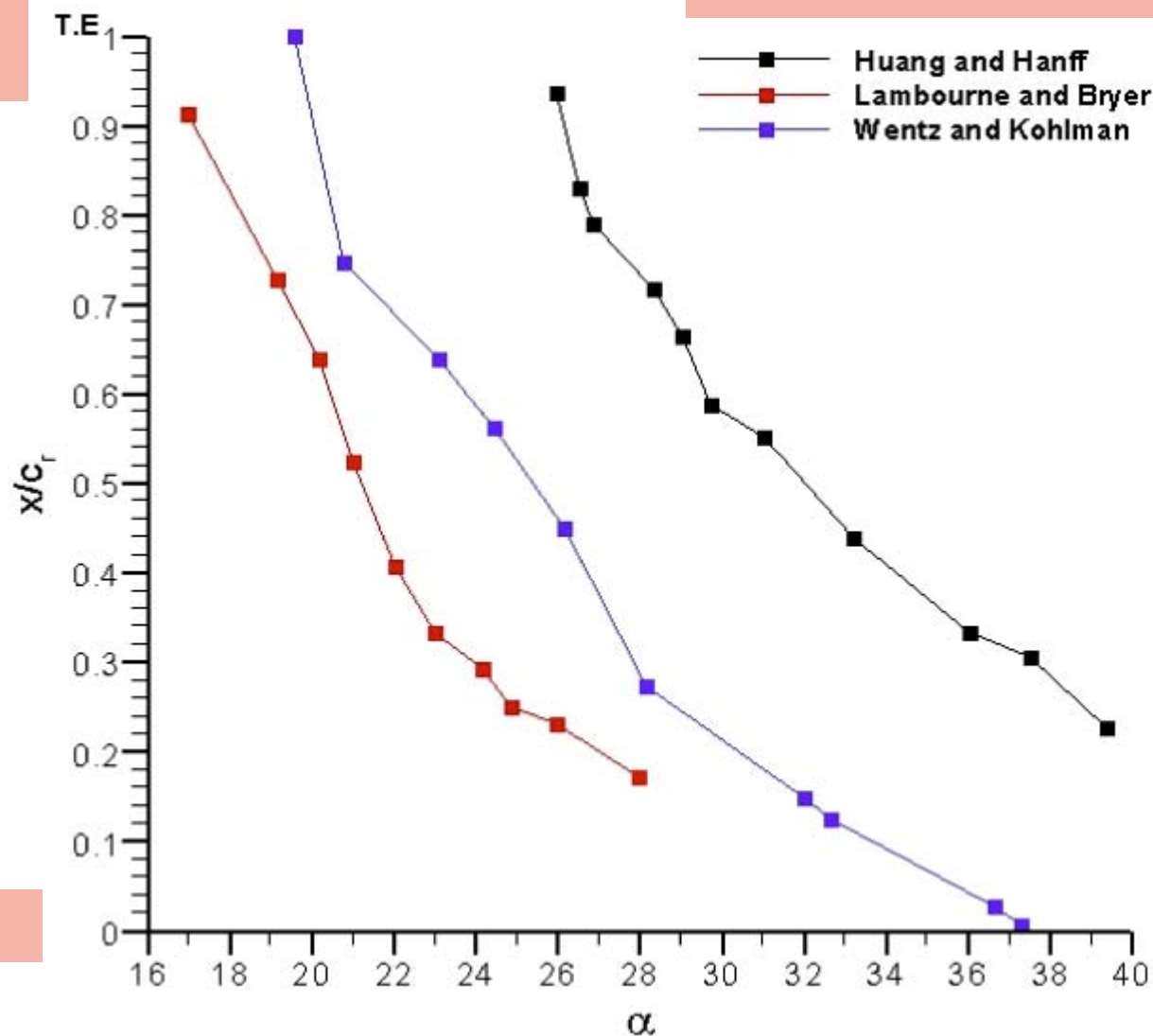
USAFA

Lambourne and Bryer



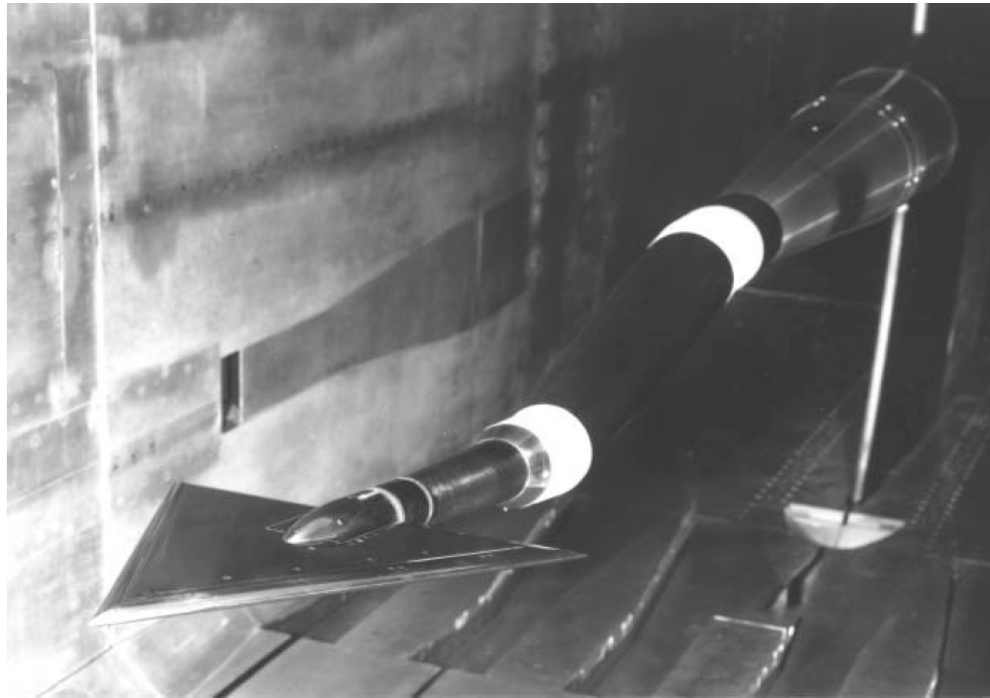
Trailing
Edge

Subsonic Tests



APEX

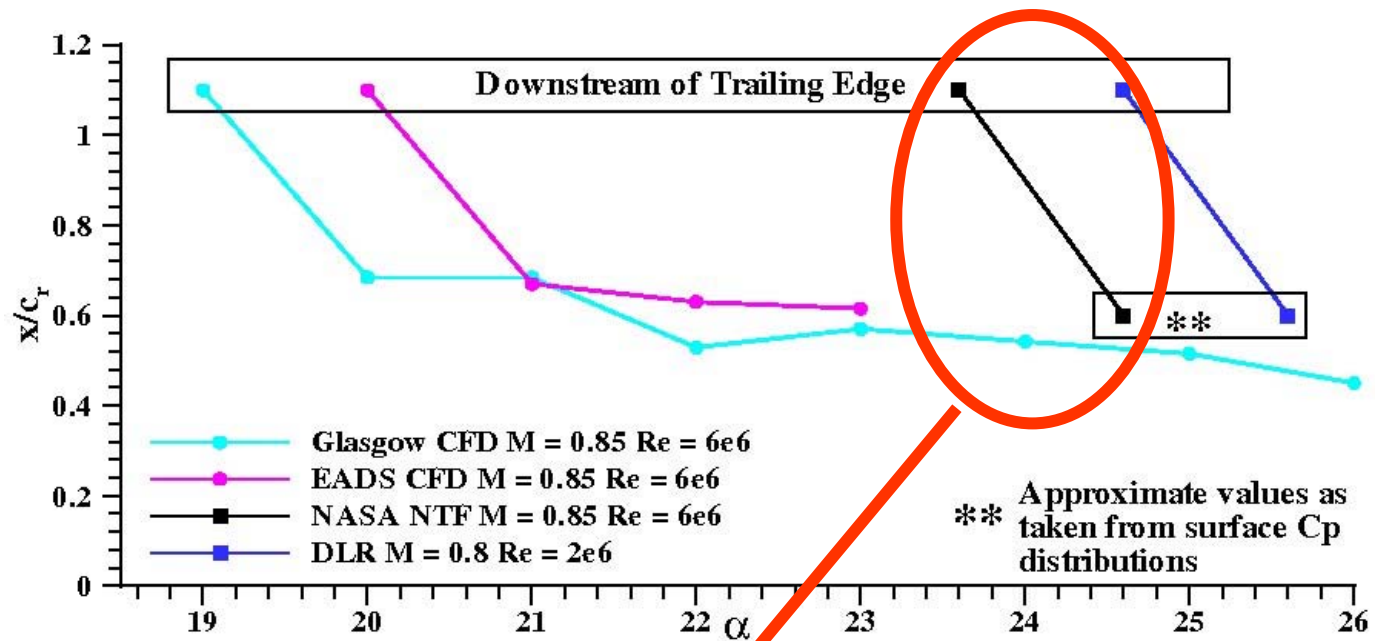
4 degrees



L-91-6963

- NASA Langley NTF tests (Chu and Luckring)
 - 65 degree sharp LE
 - Surface pressure measurements
 - Range of freestream Mach numbers
 - 0.4 and 0.85
- These tests formed starting point for VFE-2

Transonic Tests

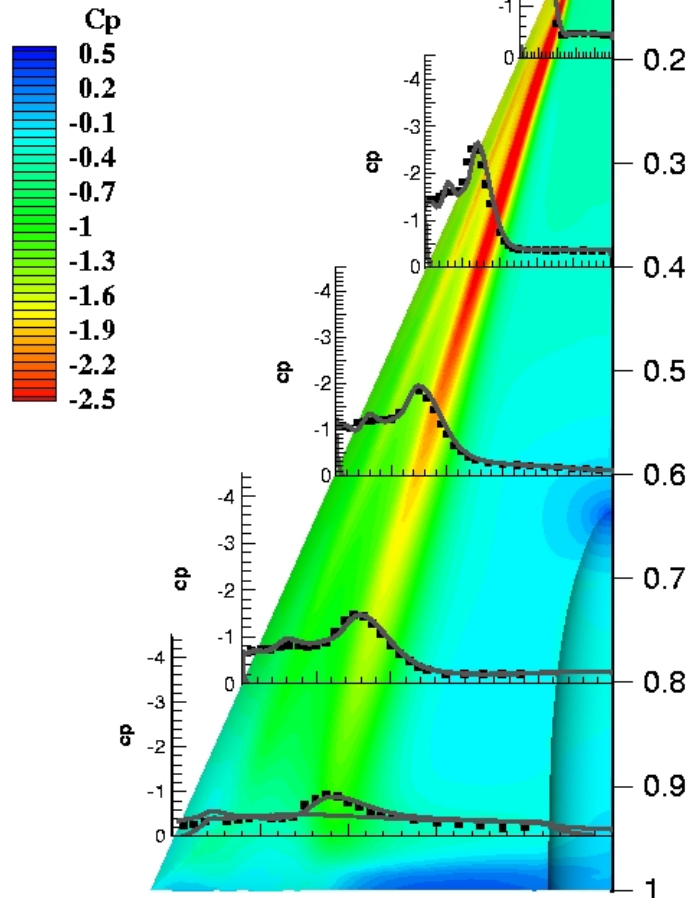


Question: why does breakdown move towards the apex so suddenly?

$M = 0.4$, $Re = 6e6$

— CFD Results, 18.5°

- NTF Wind tunnel results, 18.4°

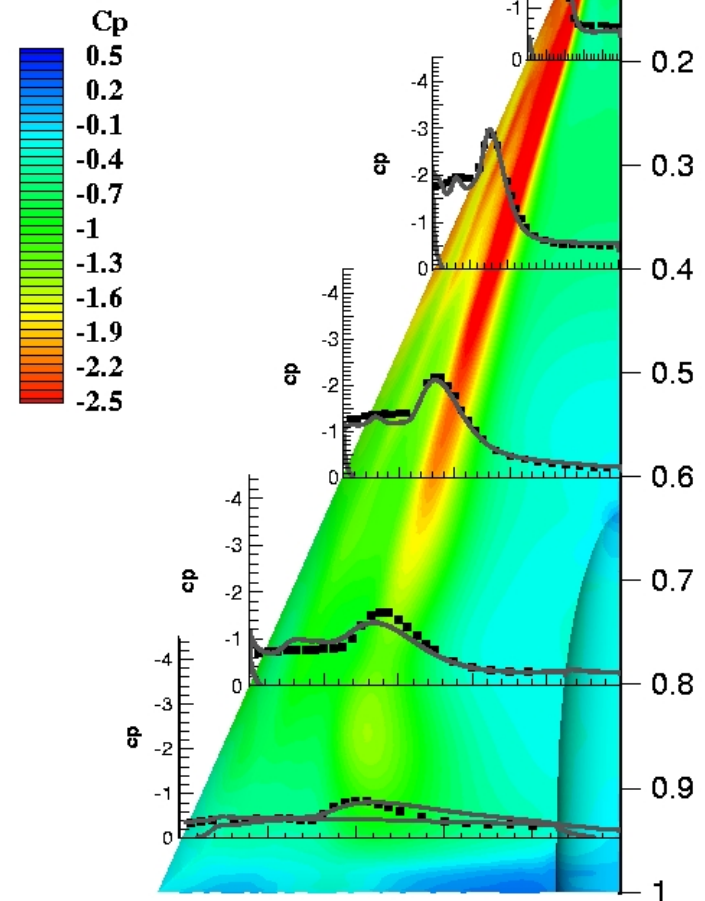


No Breakdown

$M = 0.4$, $Re = 6e6$

— CFD Results, 23°

- NTF Wind tunnel results, 23.5°



Breakdown

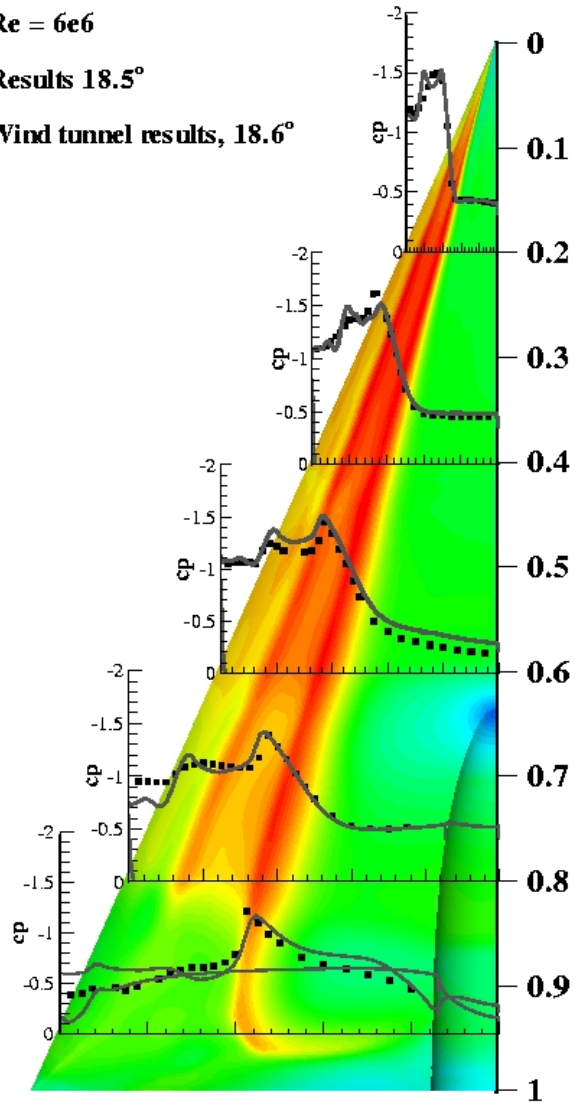
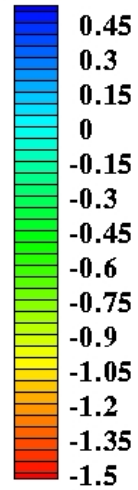
Mach 0.4

$M = 0.85$, $Re = 6e6$

— CFD Results 18.5°

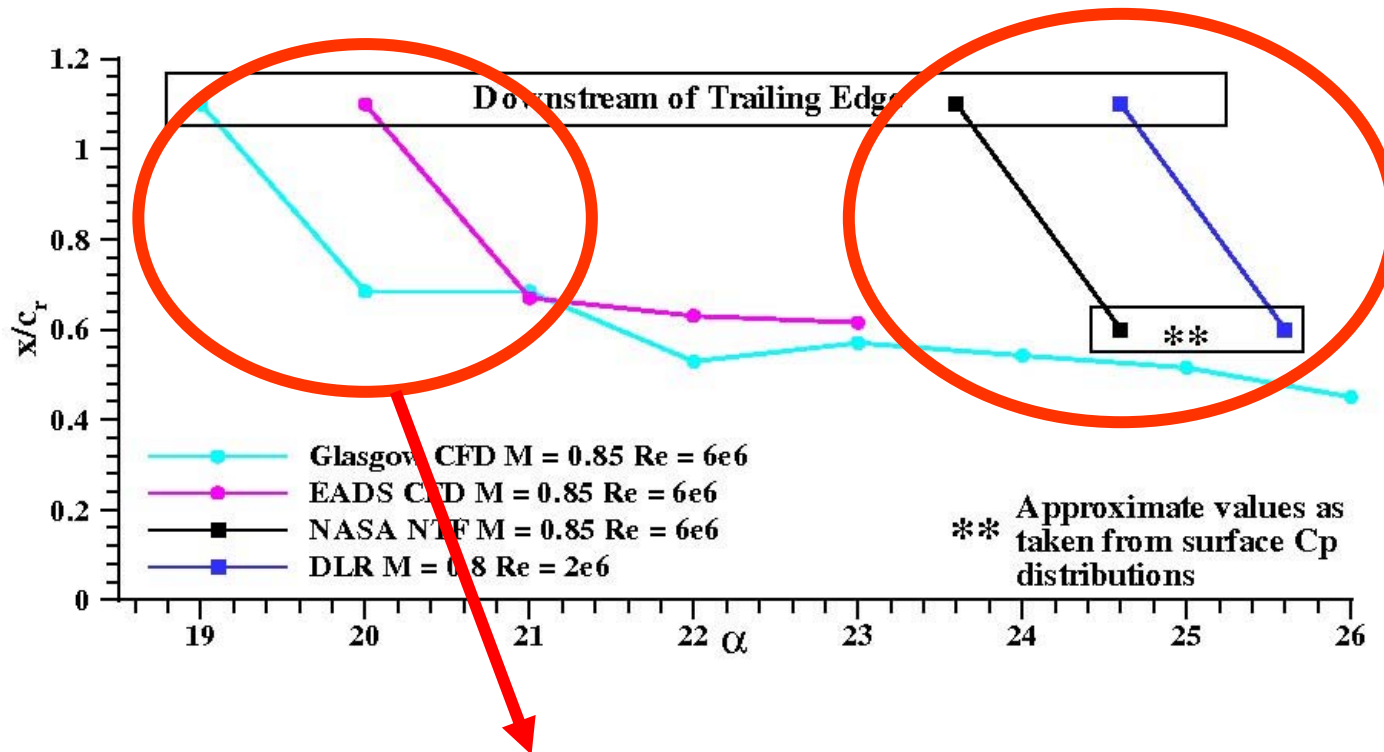
- NTF Wind tunnel results, 18.6°

C_p



No Breakdown

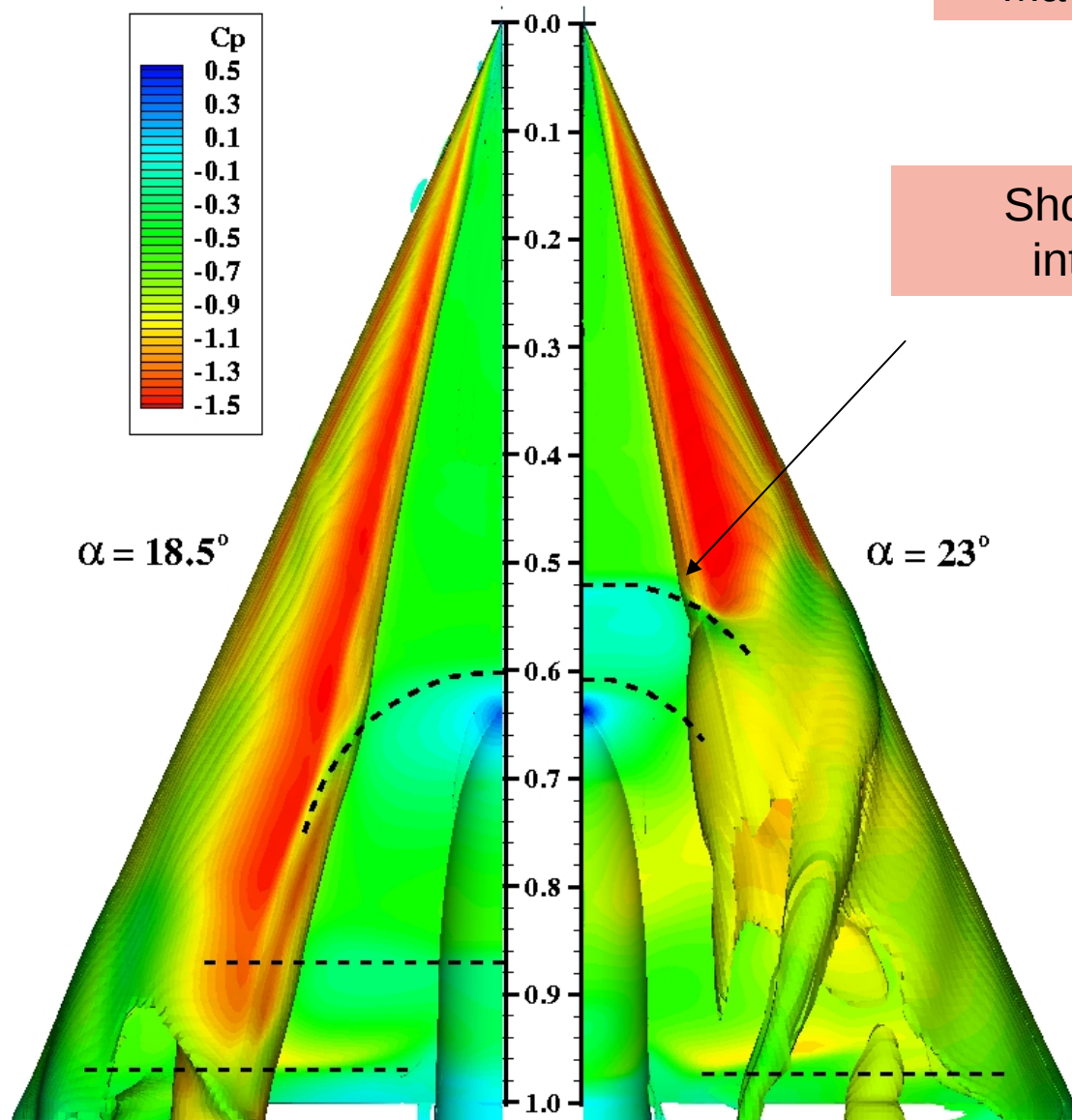
Mach 0.85



Question: why is critical angle different in measurements and CFD?

Mach 0.85

Shock-vortex
interaction



CFD Sensitivity Study

Participants:

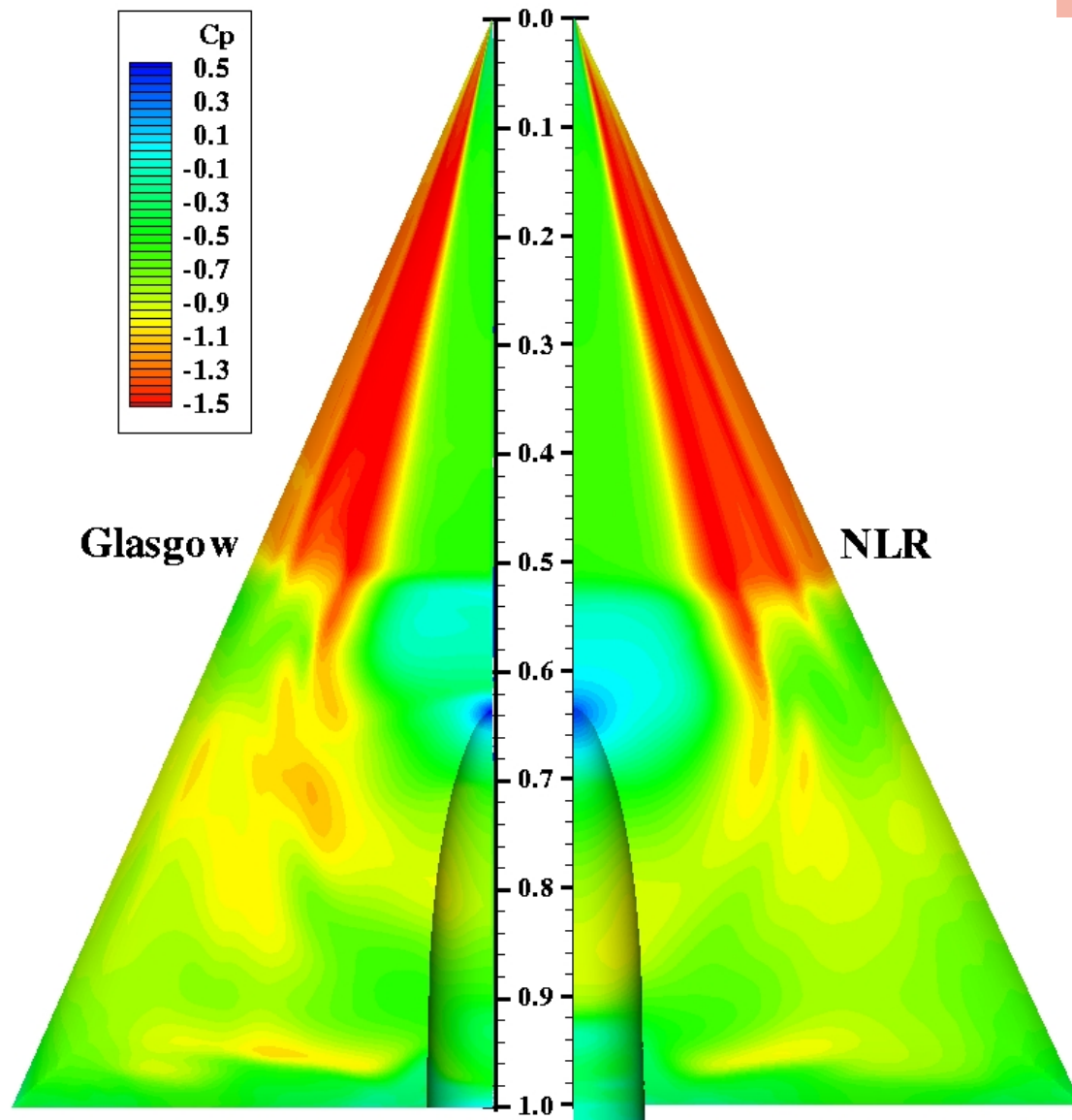
EADS	Flower	10.6m	k-w and RSM
NLR	Enflow	4m	k-w with RC
Glasgow	PMB	7m (2.4m)	k-w with RC, NLEVM
USAFA	Cobalt	6m	SA-DES

Tests:

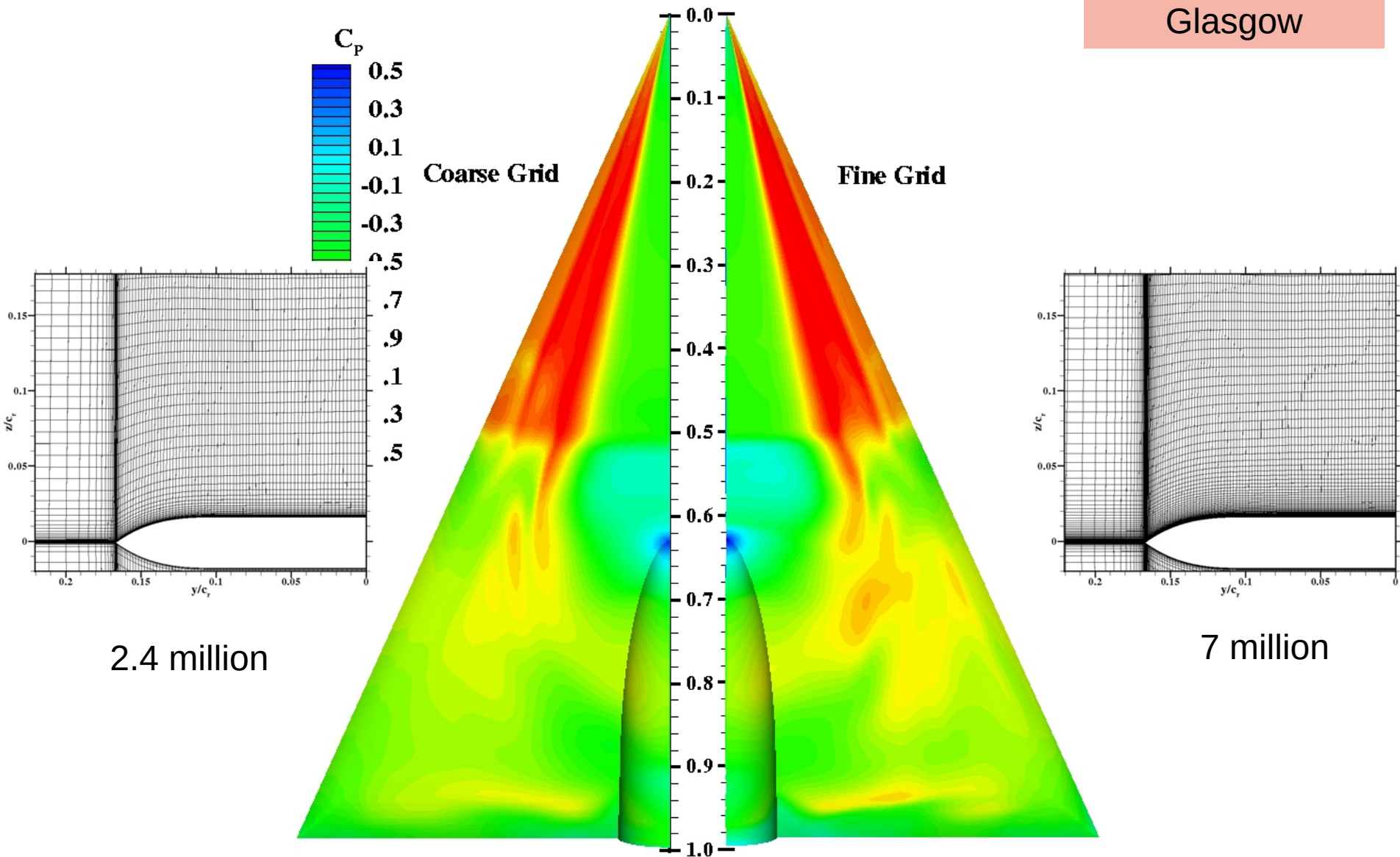
Code-to-Code	Glasgow, NLR, EADS
Grid refinement	Glasgow coarse and fine
Turbulence Model	k-w, k-w with RC, RSM, NLEVM
Time Accuracy	Glasgow (steady) and USAFA (DES)

Purpose:

- (1) Interested in the mechanism – does the sting shock always trigger the breakdown?
- (2) Interested in the influence of the shock strength and the axial flow on the critical angle

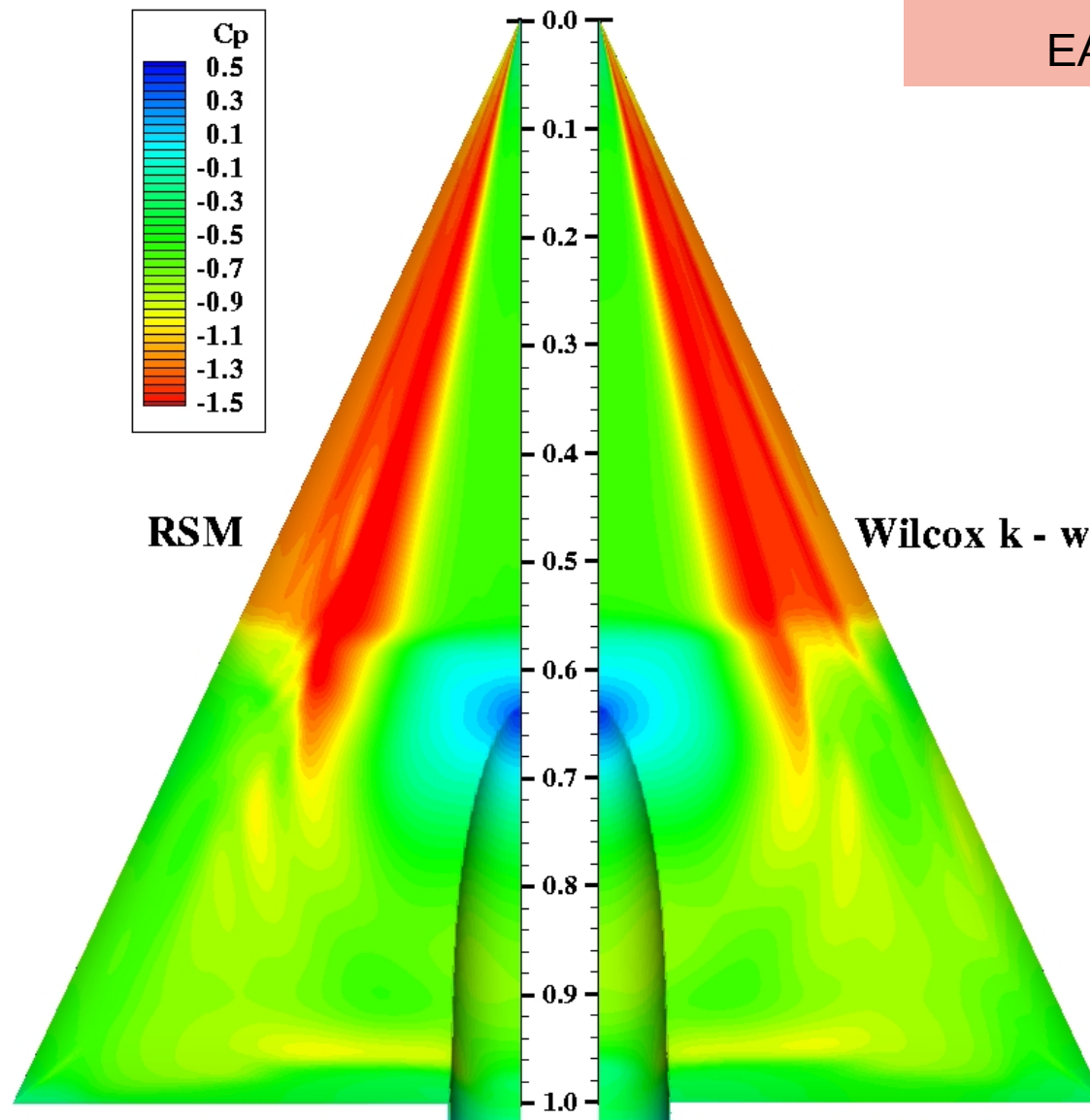


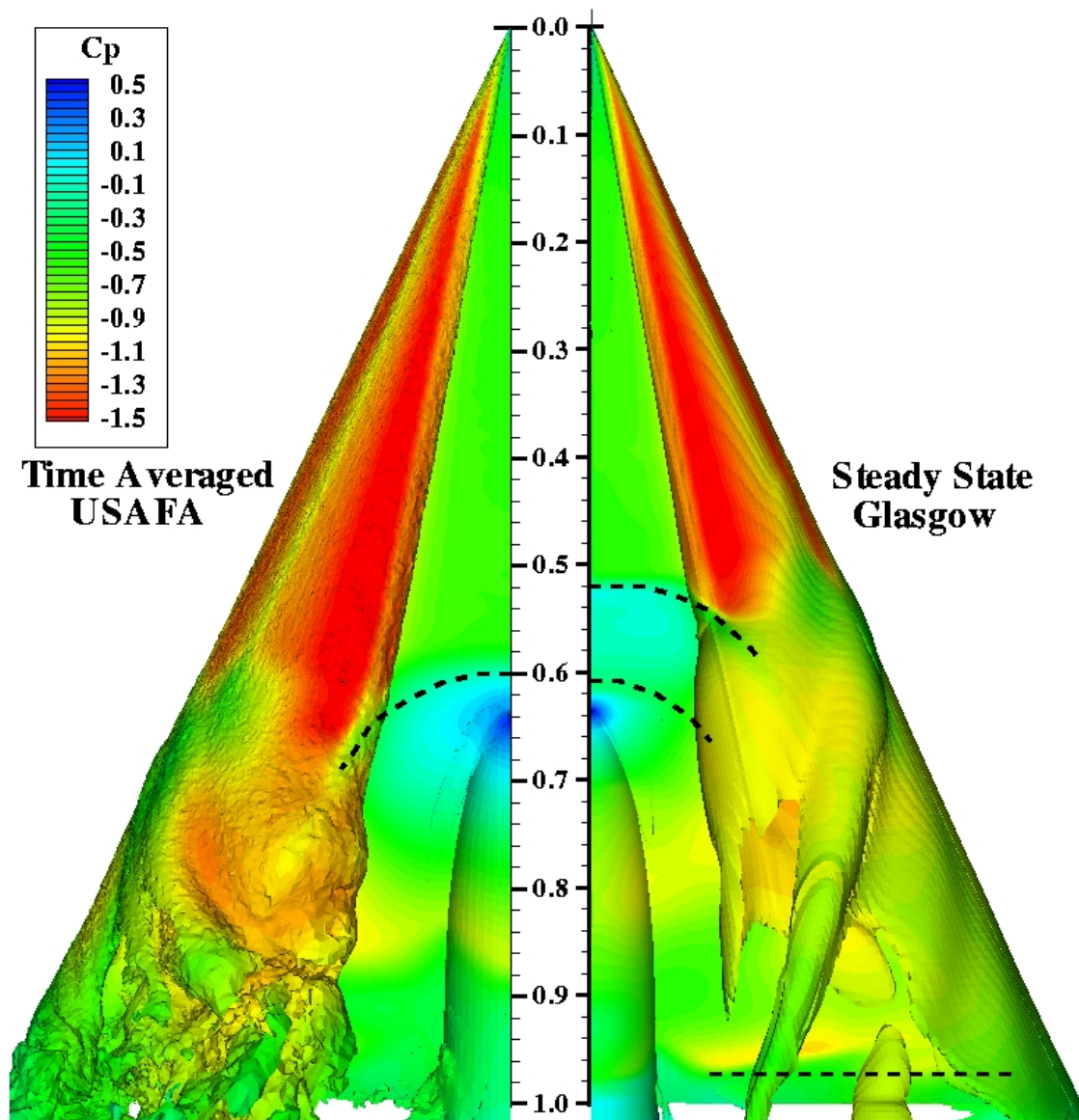
Grid Refinement Glasgow



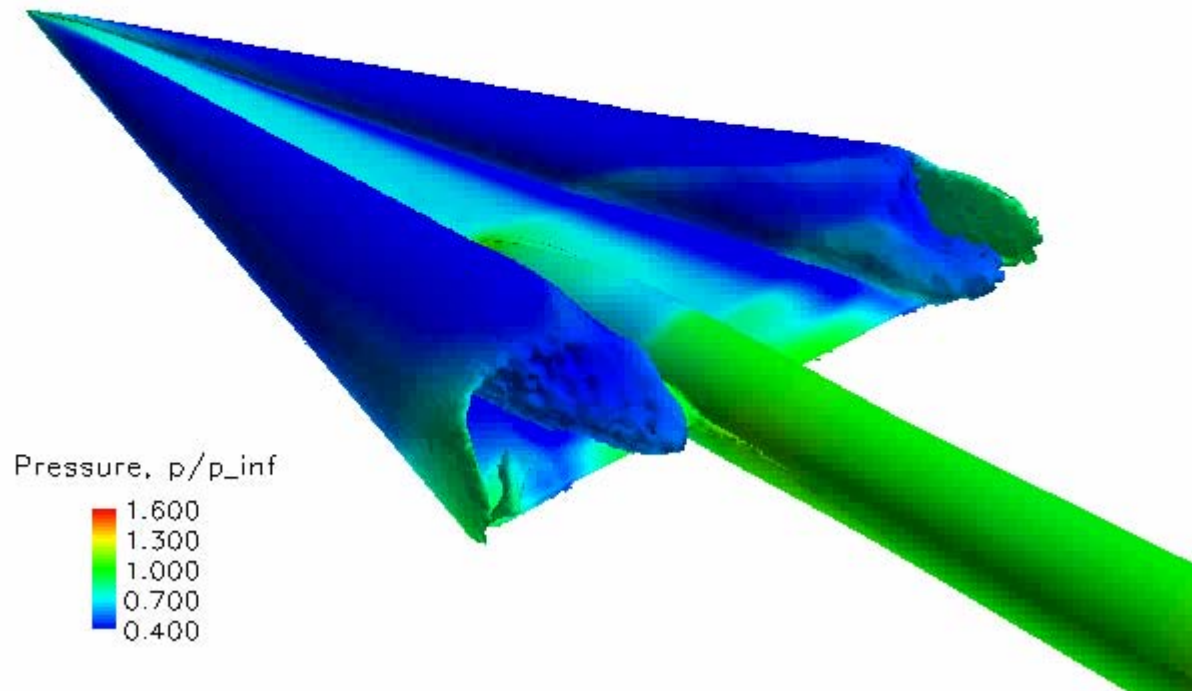
Turbulence Model

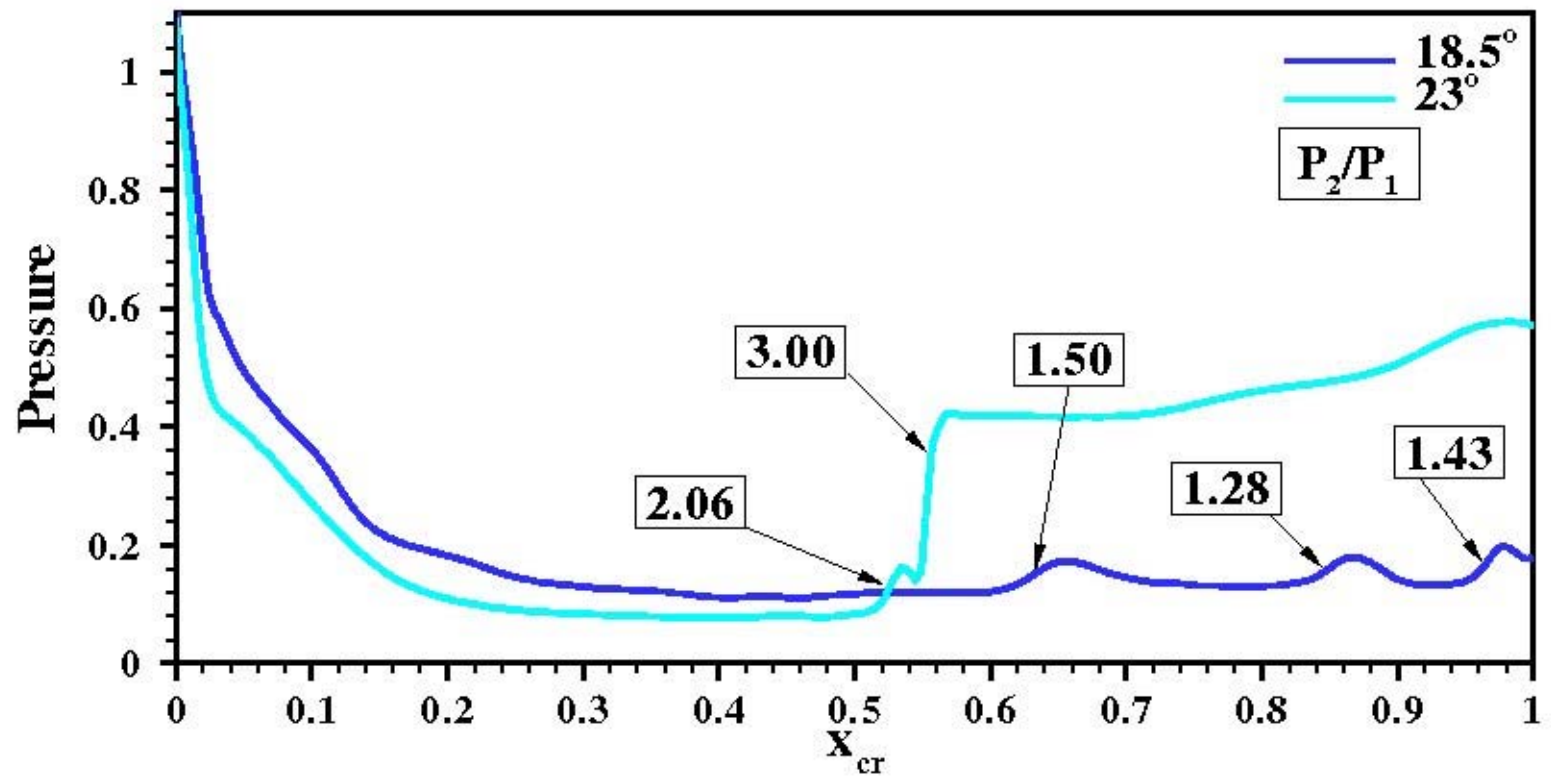
EADS



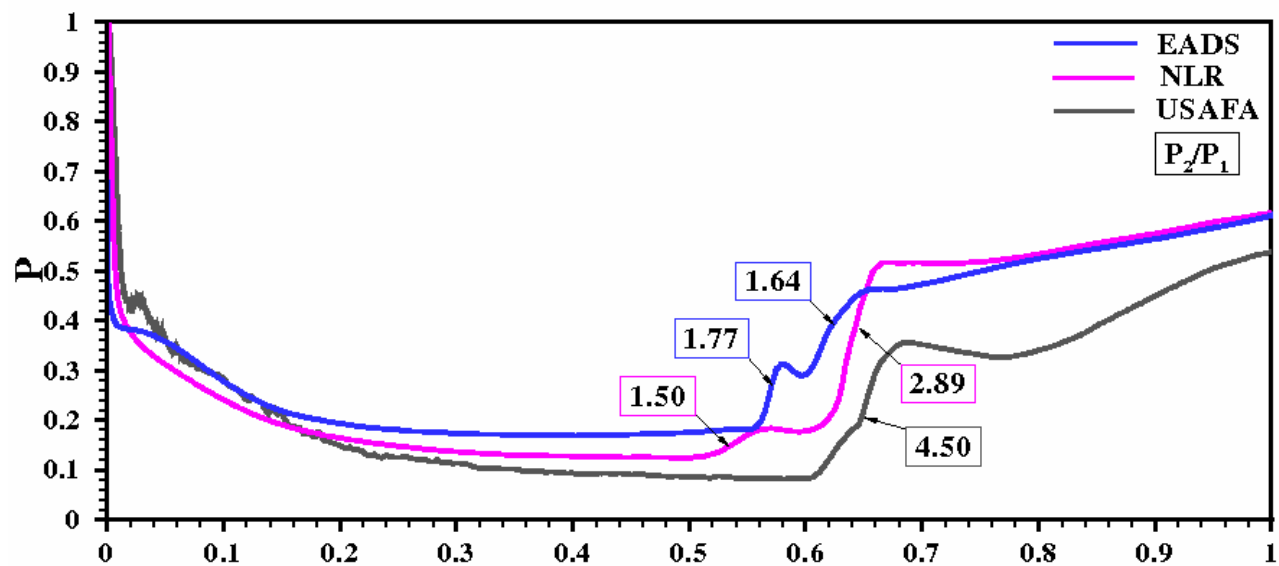
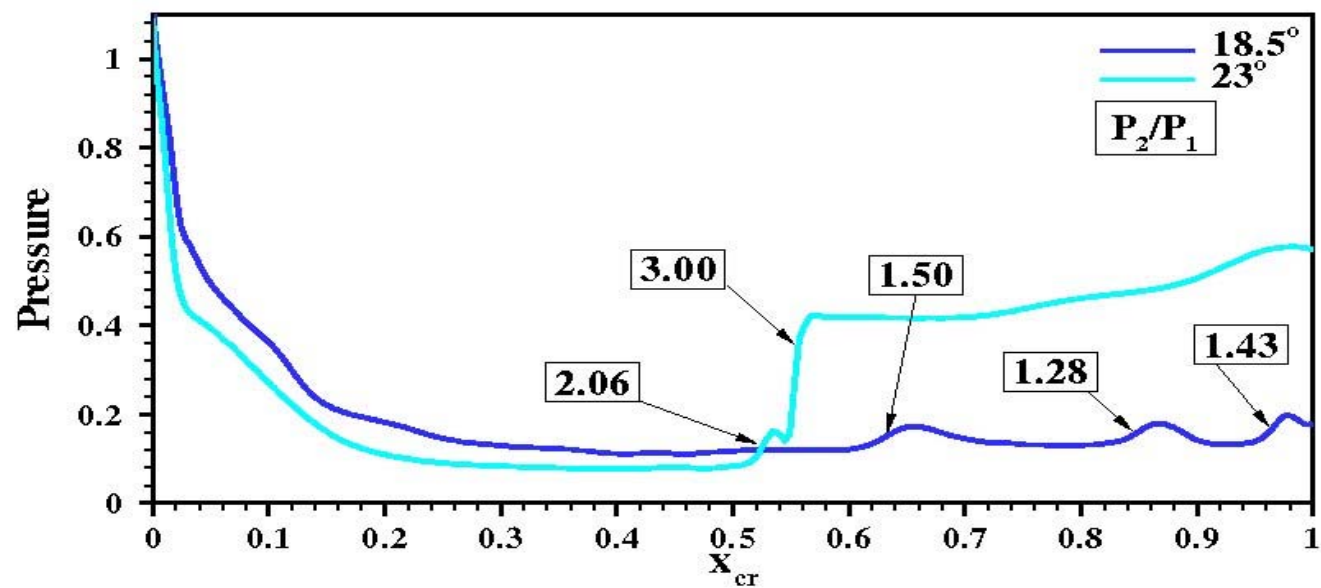


Sharp Leading Edge Delta Wing
 $M = 0.85$, $\text{Alpha} = 23.0^\circ$, $\text{Re} = 6,000,000$
Iso-surface of χ -vorticity colored by pressure

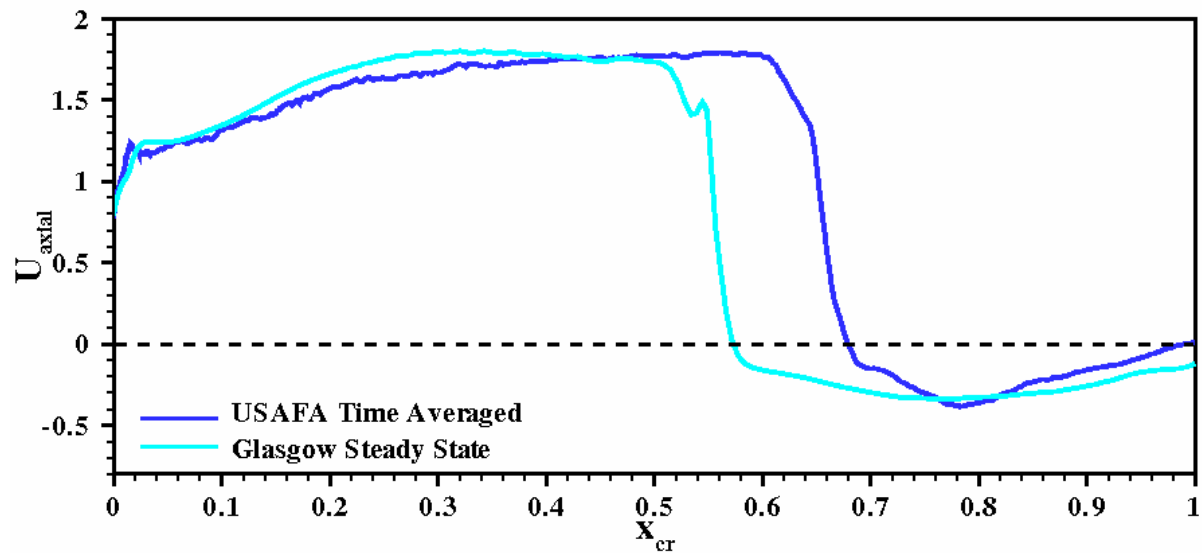
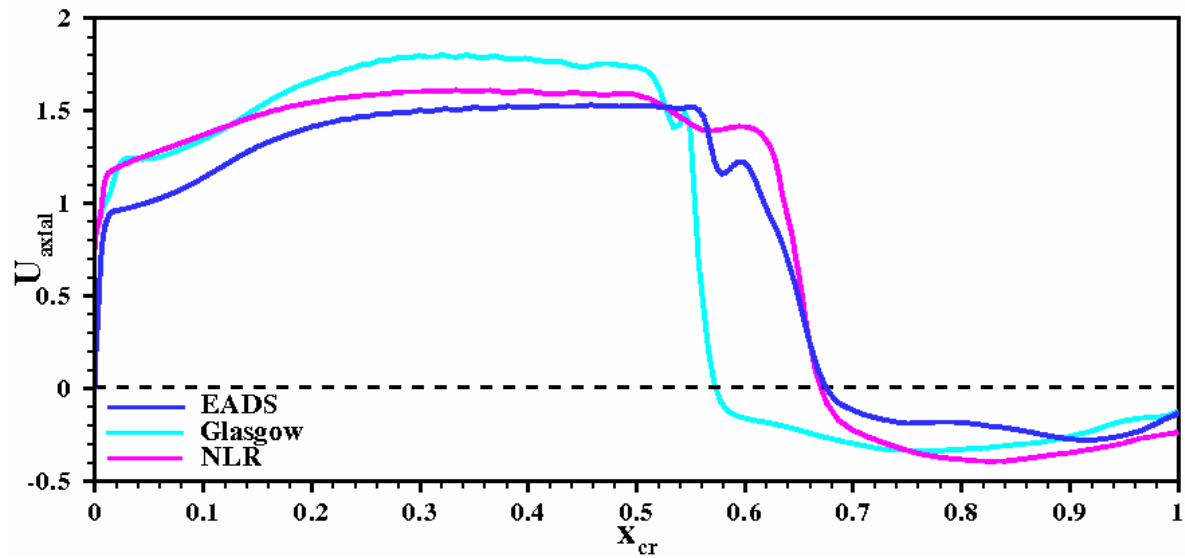




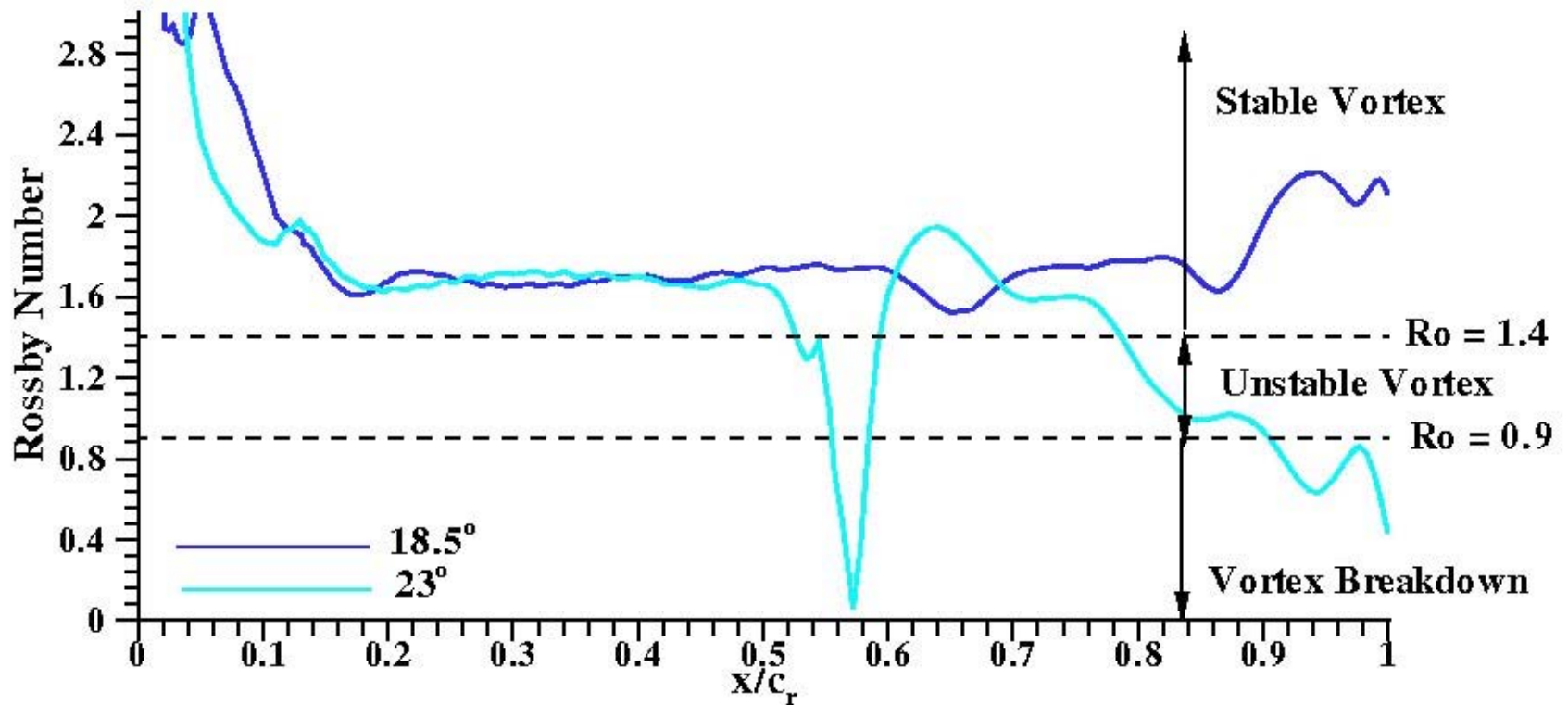
On-wing pressure gradient along symmetry plane



Axial Velocity Distribution Along Vortex Core

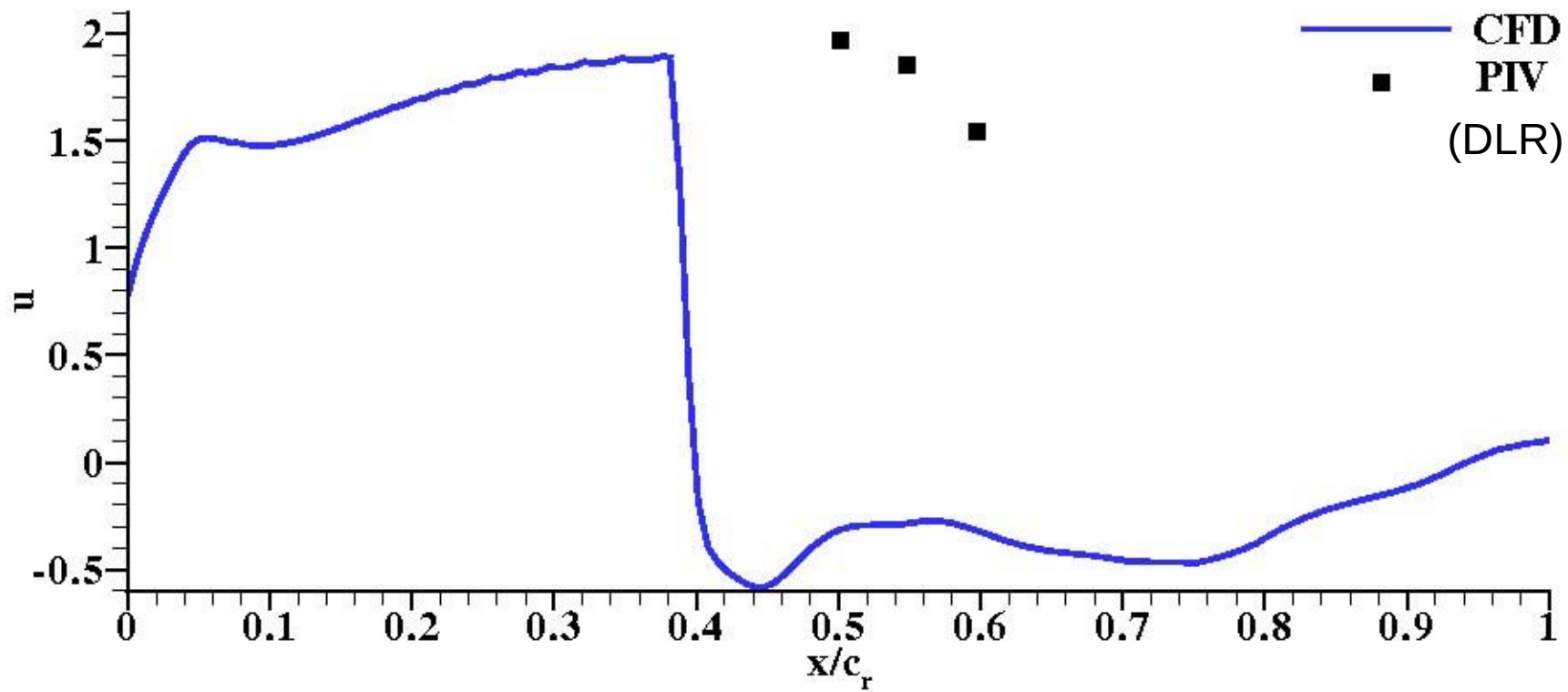


Rossby number=axial component/azimuthal component



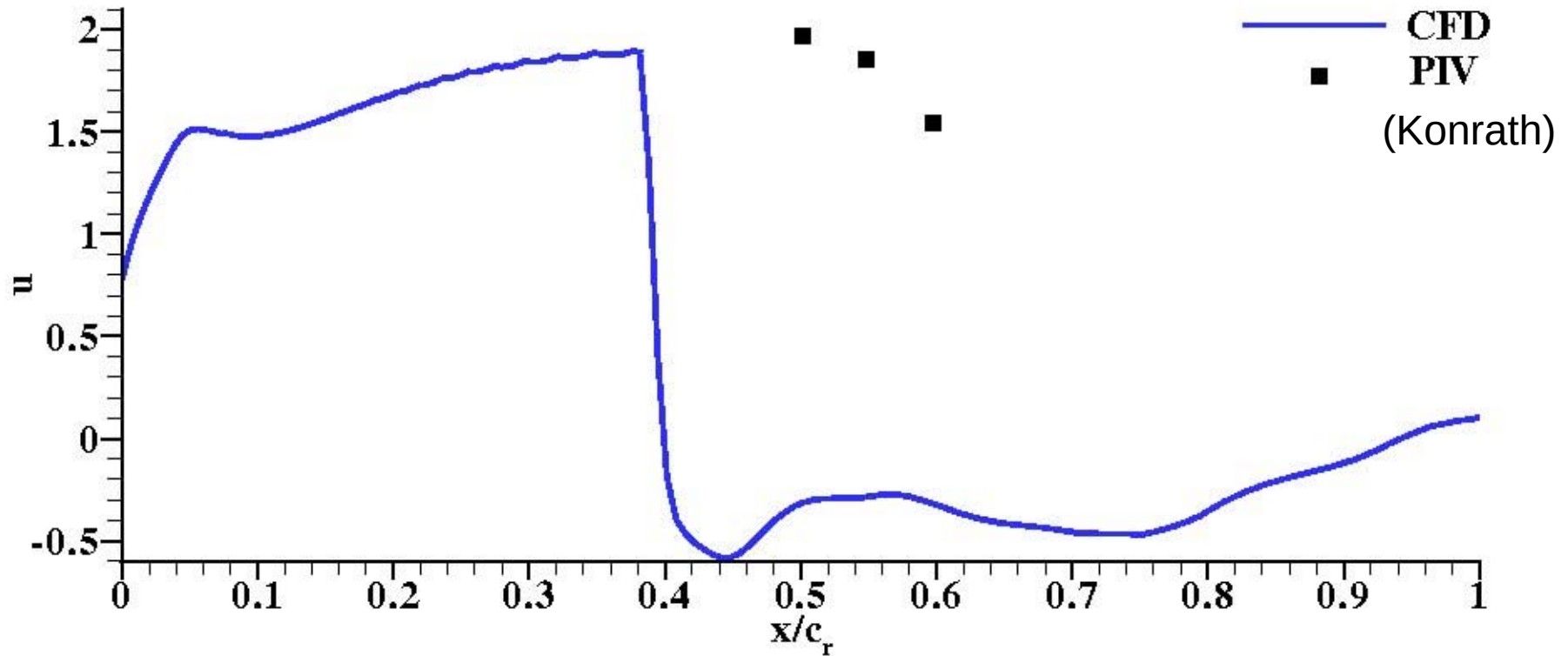
Robinson et al, AIAA Journal, 1994

Ashley et al, J Fluids and Structures, 1991



Mach 0.8, incidence 26 degrees, Re=3 million

On same scale but not that illuminating!



Mach 0.8, incidence 26 degrees, Re=3 million

Comments

- Here balance is between
 - Axial flow
 - Sting shock strength
- Closely coupled CFD-Experimental effort needed to nail this problem
- More to be extracted from the CFD trends

Incidence	Breakdown	Maximum Axial Speed	Maximum Pressure Ratio
18.5	No	1.74	1.50
19	No	1.76	1.67
20	Yes	1.74	3.73
21	Yes	1.74	4.87
22	Yes	1.79	4.67
23	Yes	1.80	5.25

Incidence	Breakdown	Maximum Axial Speed	Maximum Pressure Gradient
PSP measurements to locate shocks			
18.5	No	1.74	1.50
19	No	1.76	1.67
20	Yes	1.74	3.73
21	Yes	1.74	4.87
22	Yes	1.79	4.67
23	Yes	1.80	5.25
PIV slices (from apex to TE) to assess axial flow			

Conclusions

- sting-shock and primary vortex
 - sudden upstream motion of breakdown
- critical angle consistently different
 - large scatter in published measurements also
 - More coordinated effort needed
- artefact of the experimental setup