Flow Physics and Control for Internal and External Aerodynamics

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MINNOWBROOK, AUGUST 23, 2009

The objective of this meeting is to explore….

In conjunction with this theme one could ask whether the CONTROL OR ENHANCEMENT OF INSTABILITIES IS A NEW FRONTIER in FLUID MECHANICS?

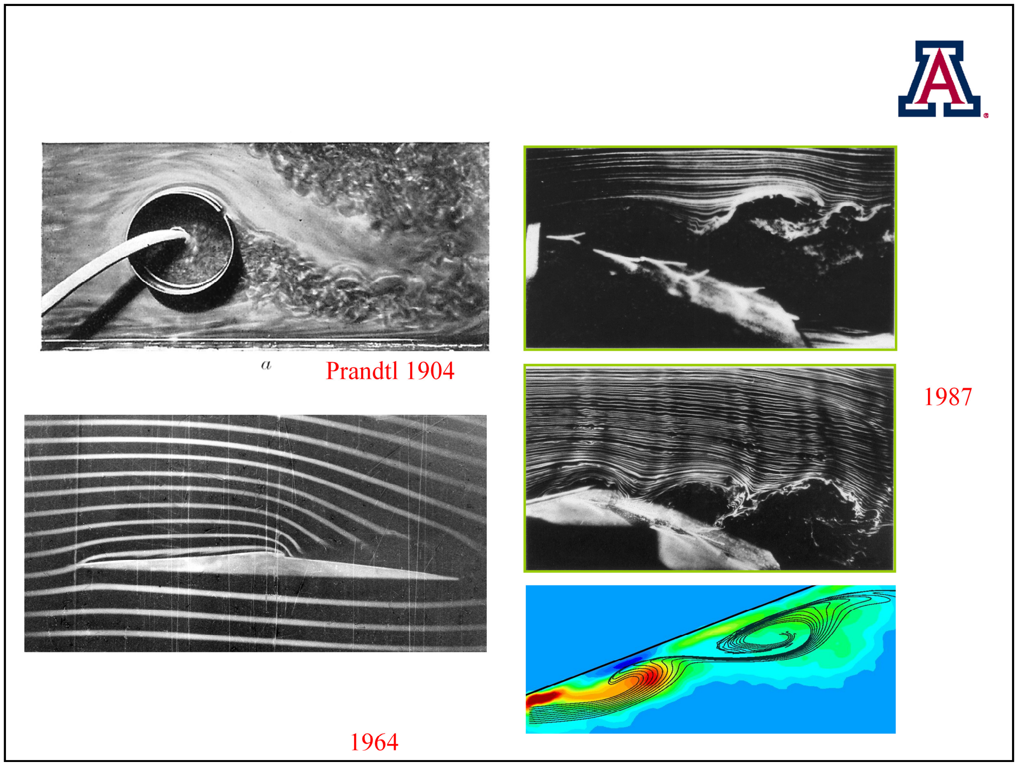
SYNOPSIS

Exploitation of instabilities generated by spanwise vorticity in 2D or quasi 2D flows

Streamwise vorticity is it secondary or primary instability

Interaction between pairs of streamwise vortices and mean shear flows as a building blocks for controlling turbulent shear flows

In a away of introduction I shall start with what we know best namely



Traditional ways to control separation is either by removal of spanwise vorticity (SUCTION) or by addition of negative vorticity BLOWING

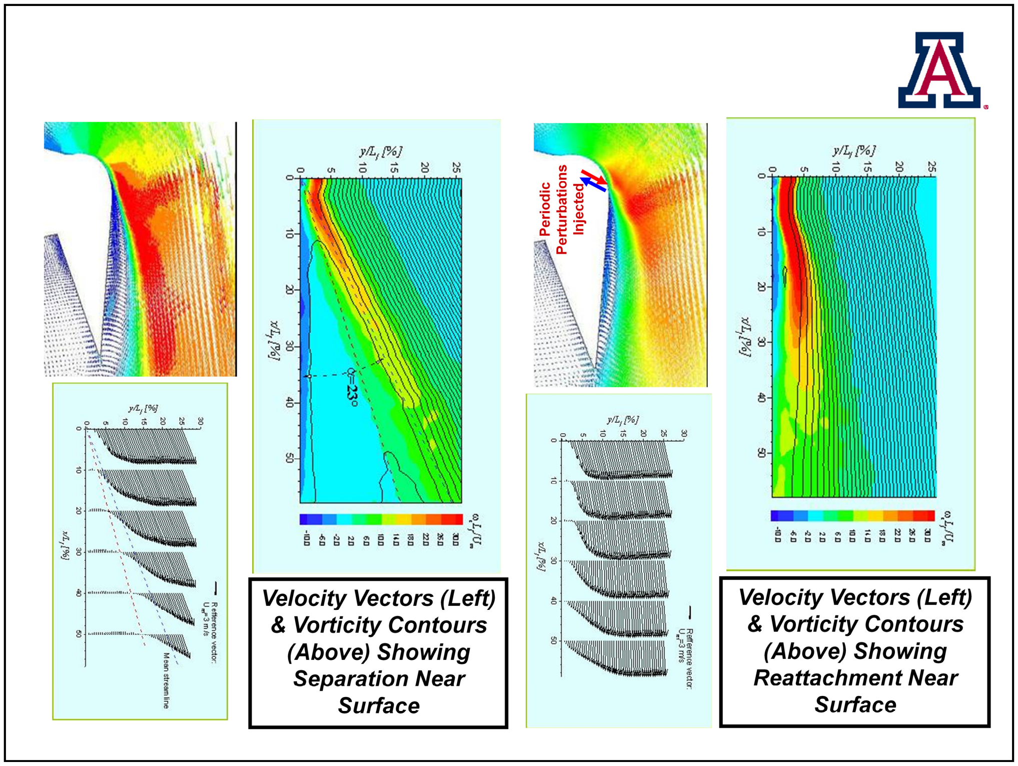
IIN A WAY OF INTRODUCTION

If we consider Separation, it was controlled by suction, steady blowing, and periodic excitation.

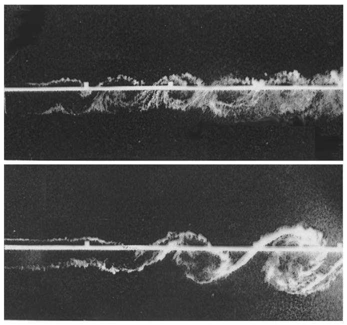
All these were based on 2D experience with slots spanning the flow and adding or removing spanwise vorticity

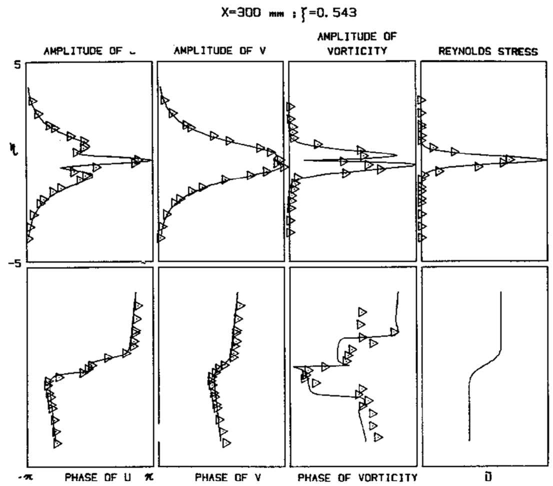
When the flow is separated there is a mixing layer existing above solid surface

It is sensitive to small disturbances and if these are amplified by externally imposed small amplitude fluctuations resulting in reattachment.



PIV shows it quantitatively

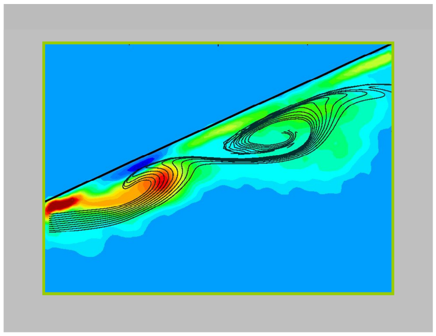


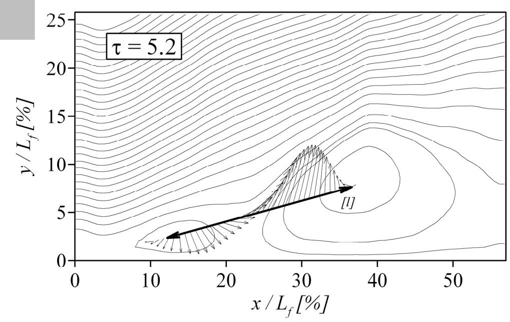


The linear stability approach to a turbulent mixing layer helped us to understand the process and it did very well

predicting details of periodically forced flow and indicated what frequencies were needed for most effect at a given location

Eddies inclined downward toward the low velocity stream

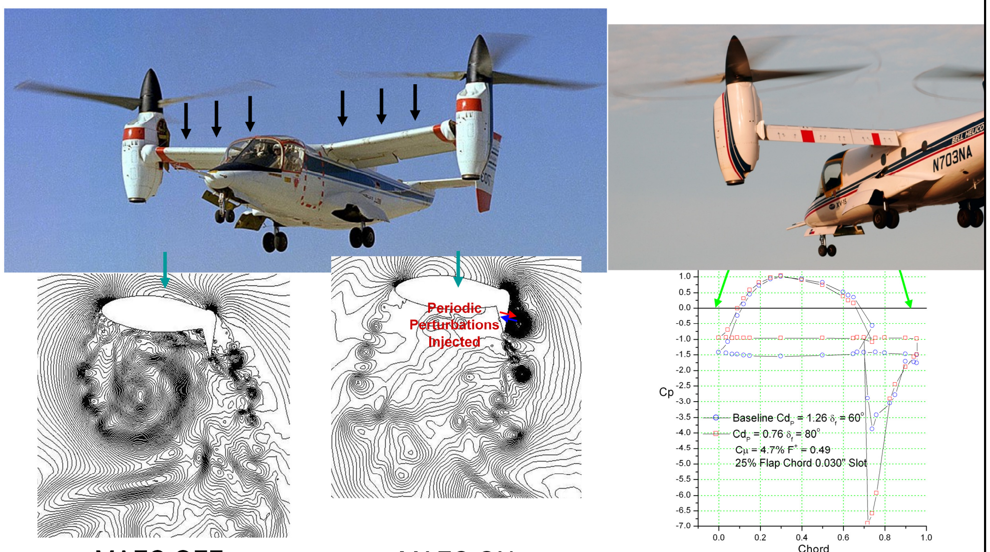




In a global sense, the instability generated eddies remove fluid from the surface lowering the pressure.

The idea is proven by PIV measurement

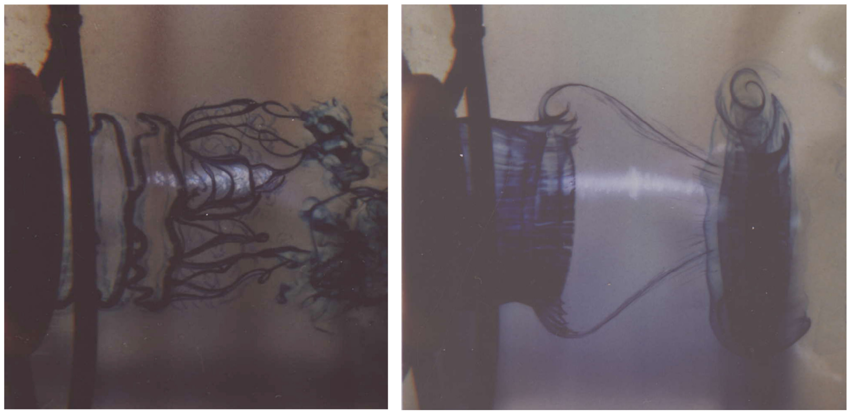
Separated Flow Around Deflected Flap



MAFC OFF   MAFC ON

This concept allowed the flow to be attached and alleviated the download.

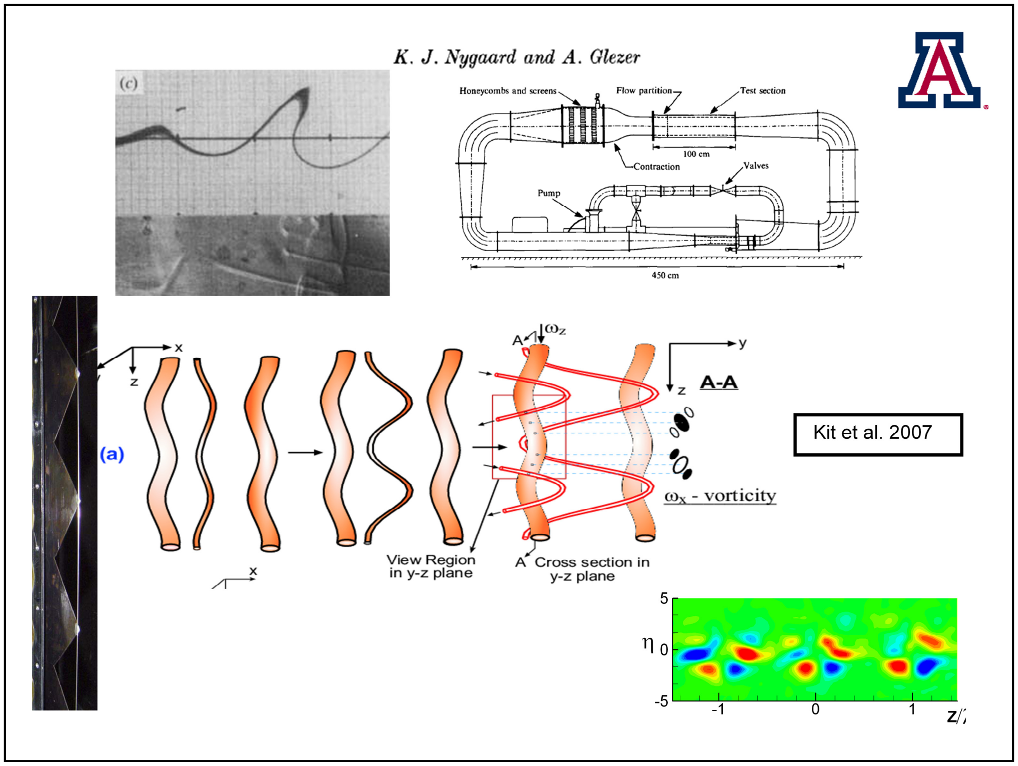
This is in a way of introduction but it is not the main topic of my talk



But here I would like to depart from the introduction

Why is it that when we do not force the (spanwise) azimuthal in this case K_H eddies WE NOTE STRONG STREAMWISE VORTICES that seem to be as significant at times as the other ones

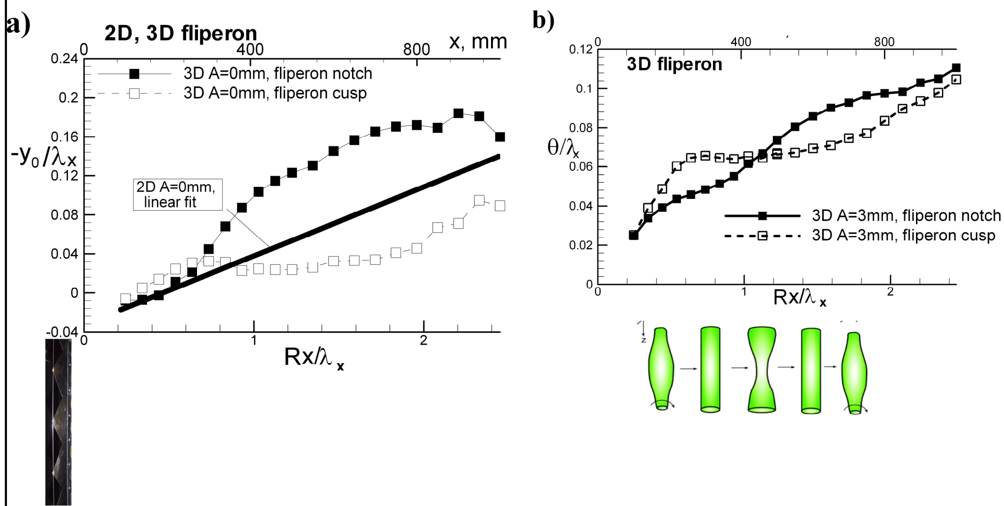
We thought of them as SECONDAY and in some instances they very well may be

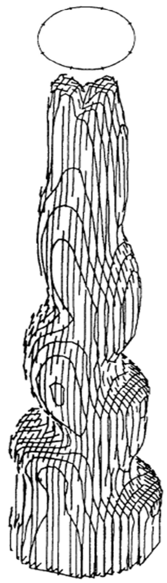


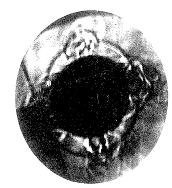
In the early 1980s when Ari joined TAU I tried to set him on this problem and got this facility built together with heating elements for actuation along the span, but other than nice pictures little came of it

A few years back KIT and I used a chevron trailing edge fliperon that oscillated

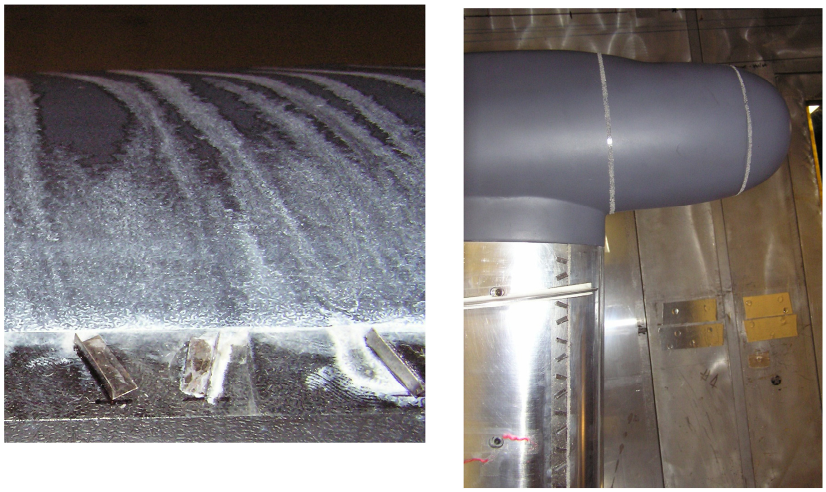
Secondary instability

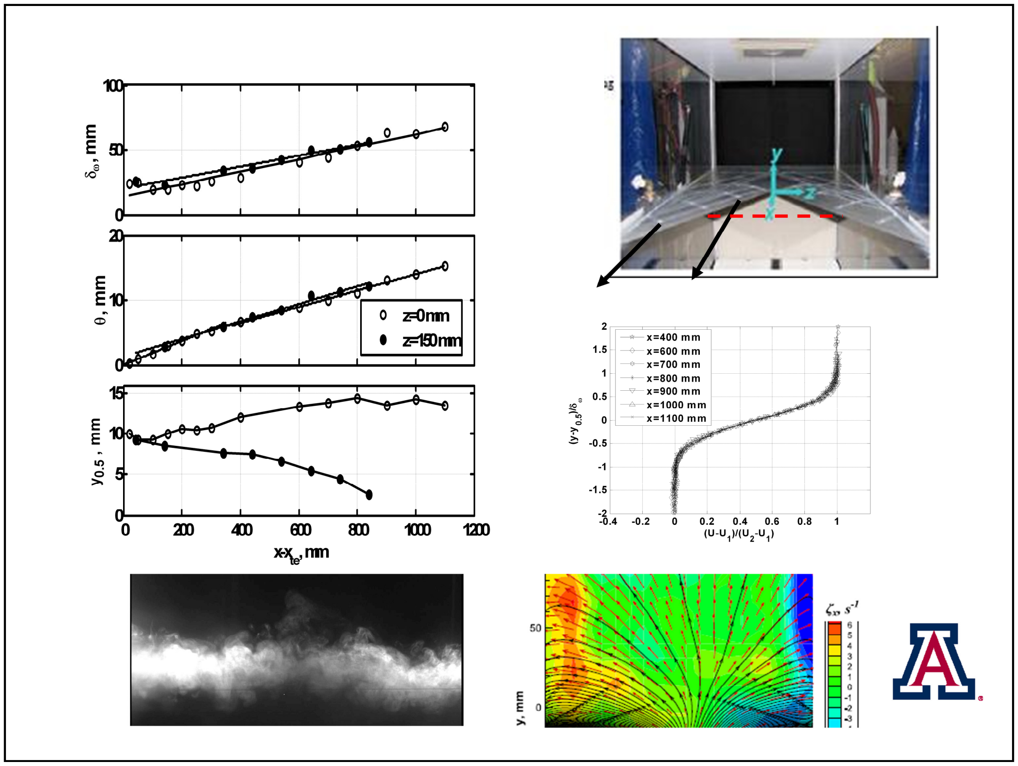

a)
2D, 3D fliperon
x, mm
0
400
800
0.24
0.2
0.16
0.12
0.08
0.04
0
-0.04
-y0/λx
3D A=0mm, fliperon notch
3D A=0mm, fliperon cusp
2D A=0mm, linear fit
0
1
2
Rx/λx
b)
3D fliperon
0
400
800
0.12
0.1
0.08
0.06
0.04
0.02
0
θ/λx
3D A=3mm, fliperon notch
3D A=3mm, fliperon cusp
0
1
2
Rx/λx





Certain phenomena could be explained but the feeling was that this is not a secondary phenomenon.

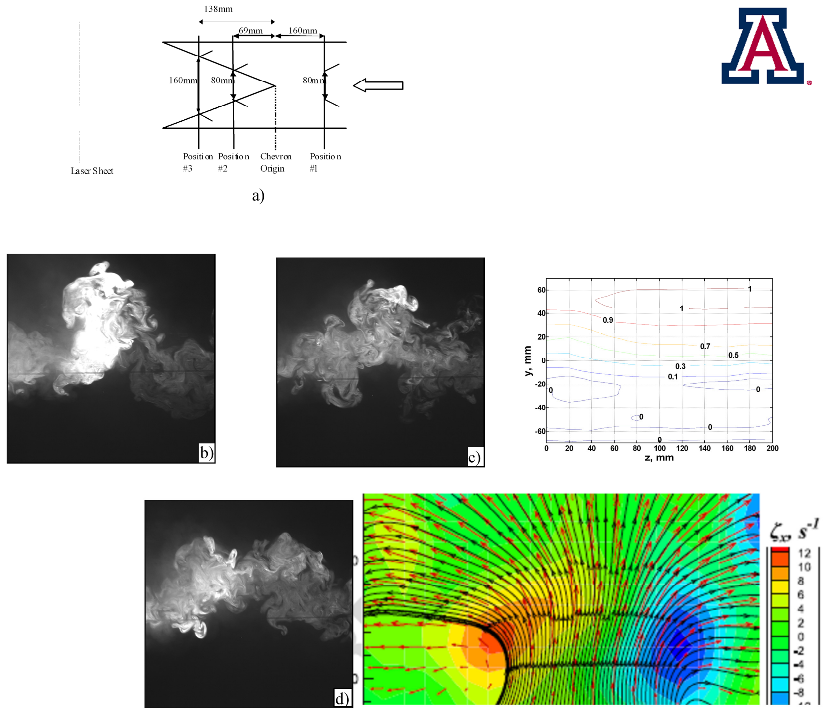




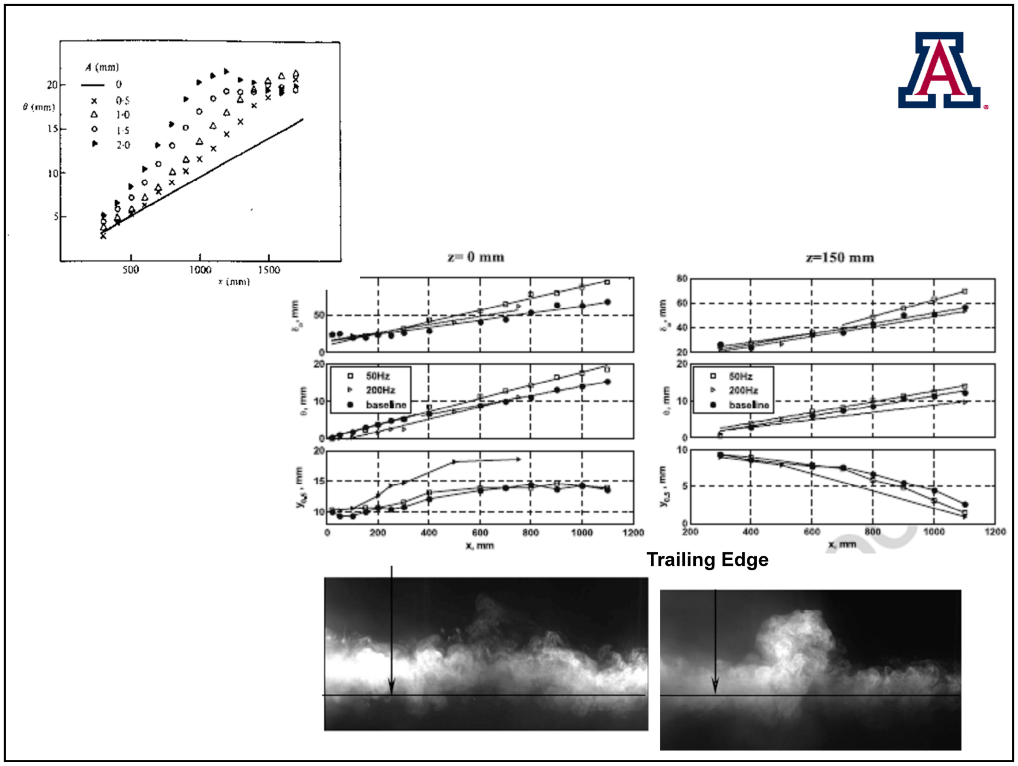
The most significan observation is that the mixing layer speads out as if it were 2D origination at the local TE

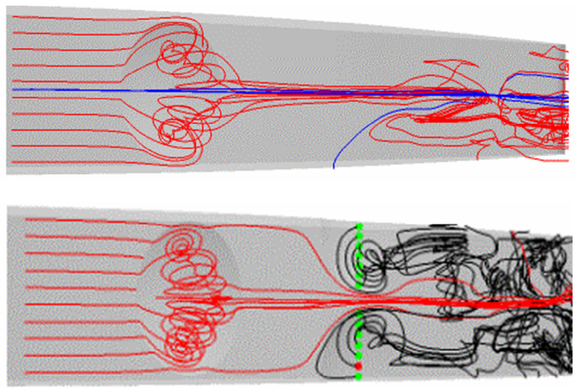
But the location of the CENTER is not known and it does the opposite to what intuition would have suggested

Traversing the flow in a horizontal diectio one see a wake profile and vertical vorticity that bendes to the streamwisw direction LIFTING LOW SPEED FLUID IN THE CENTE

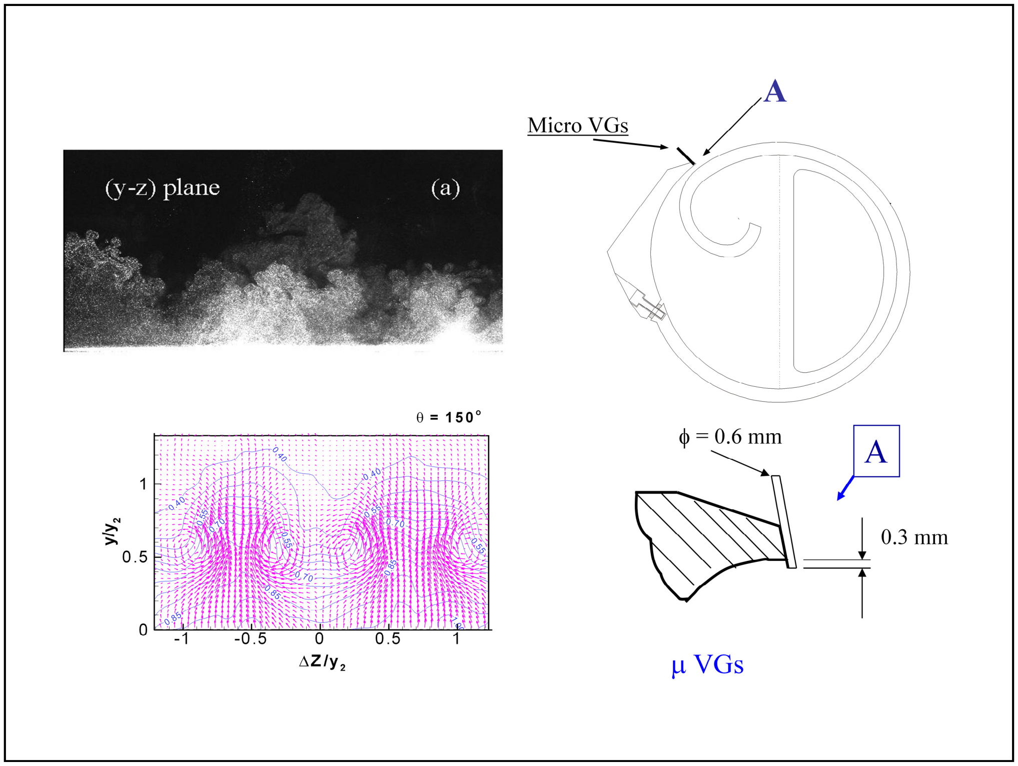


138mm
69mm
160mm
160mm
80mm
80mm
Position #3
Position #2
Chevron Origin
Position #1
Laser Sheet
a)
b)
c)
y, mm
z, mm
d)
ζ_x, s^{-1}

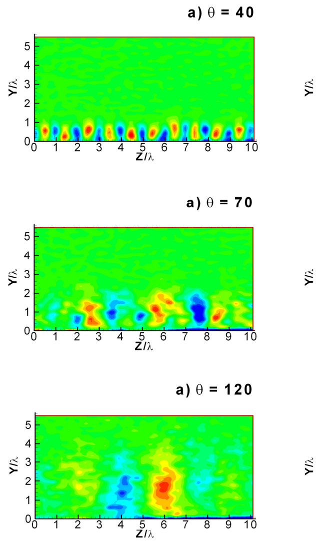

A (mm)
0
0·5
1·0
1·5
2·0
θ (mm)
x (mm)
z= 0 mm
z=150 mm
50Hz
200Hz
baseline
x, mm
Trailing Edge

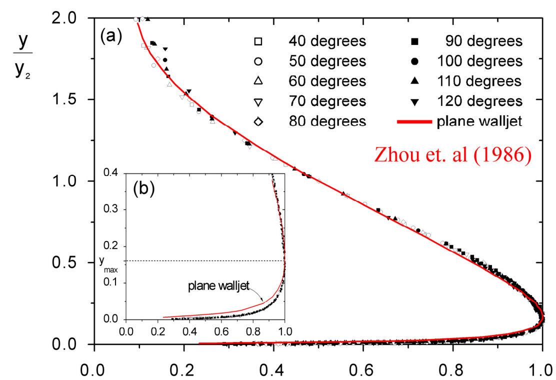


Rolf Sondergaard, Suichuan Ou, and Richard B. Rivir 2006

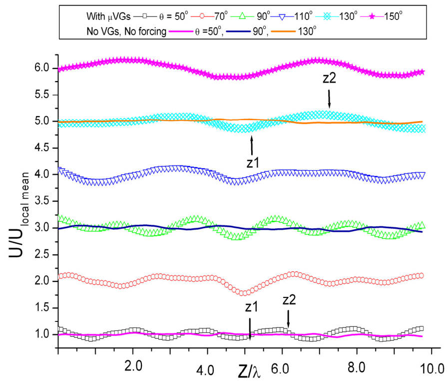

(y-z) plane
(a)
θ = 150°
y/y2
ΔZ/y2
Micro VGs
A
ϕ = 0.6 mm
A
0.3 mm
μ VGs

λ = 12.7 mm



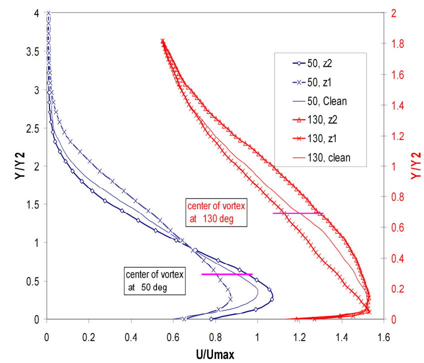


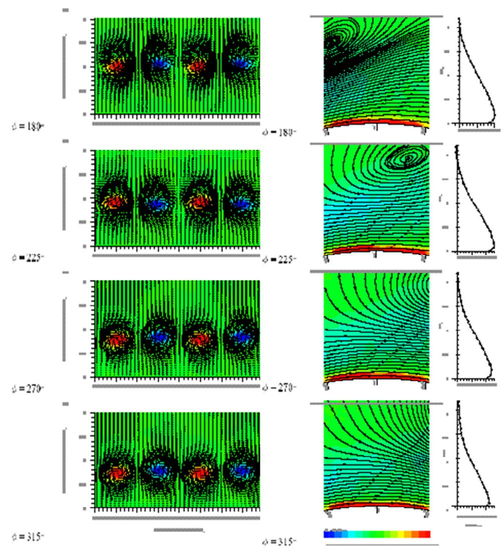
Micro VGs with different spacing (λ) evolved into the same scale far downstream



The development of the spanwise distortion of U with $R\theta$

Normal distribution of U showing distortion resulting from quasi-steady longitudinal vortices.

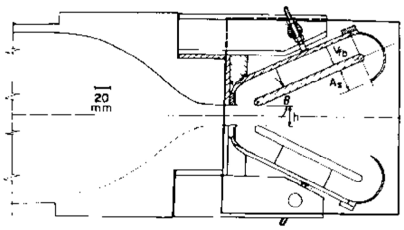


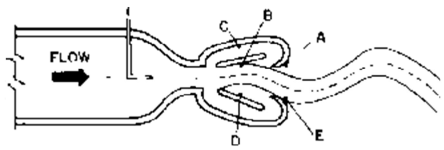


Streamwise vortices may interact in a destructive manner with spanwise periodic excitation the addition of perodic excitation on a circular cylinder did not delay separation on the contrary.

It regulated the streamwise vortices and perhaps strengthened them. They simply bobbed up and down on the spanwise eddies.

- Development of fluidic oscillators in 1950's
- Produce a jet that is sweeping like a wind shield wiper
- Most AFC methods (especially for 2D) aim to enhance spanwise vorticity



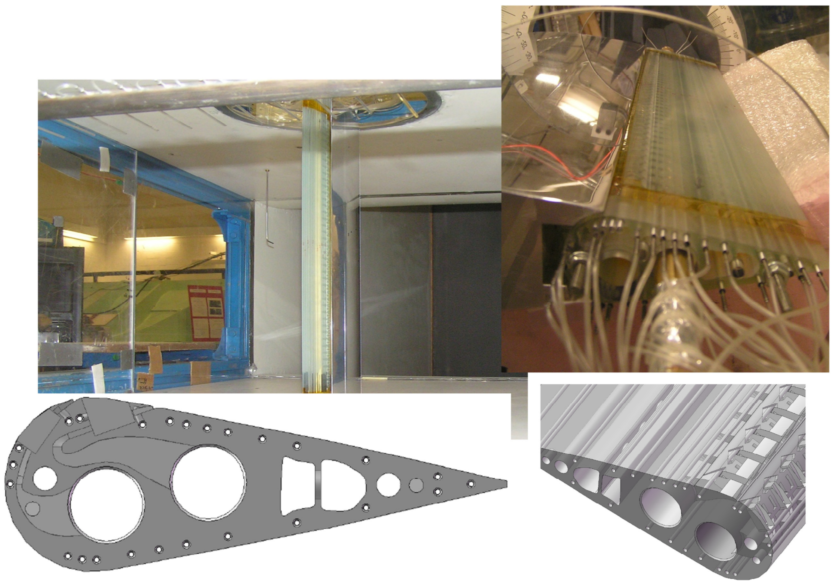


Fluidic Oscillators developed in Harry Diamond Research Labs

Explain principle

Presentation aims to prove the functionality of spanwise sweeping jets for Separation based on 4 experiments

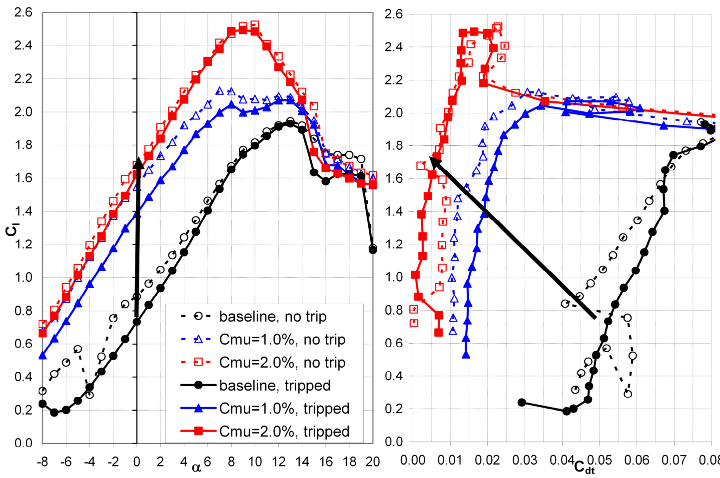
NACA-0021



We decided to have a proper test using SLA made actuators integrated with the flap

The material was transparent, initial access to each feedback channel was provided plugs were used to block the access

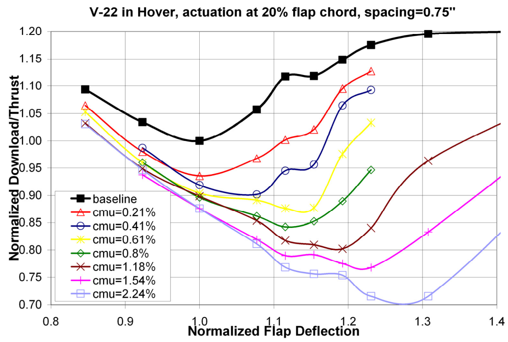
NACA-0021



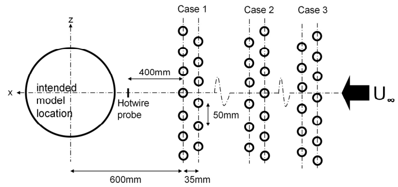
For α=0 and flap deflected 20º baseline C_L=0.7 and it increases to 1.7 using sweeping jets at Cμ=2% and Re=0.4M.

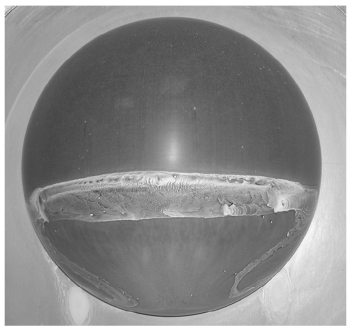
Tripping is most significant for the baseline

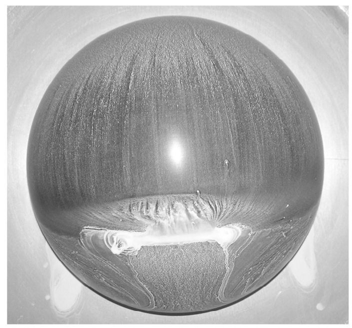
V-22 1/10th-Scale Powered Model in Hover



Gap between rotors and model to measure only aerodynamic forces of downwash on wiUsing sweeping jets the resuls waas twice as good as using periodic excitation.

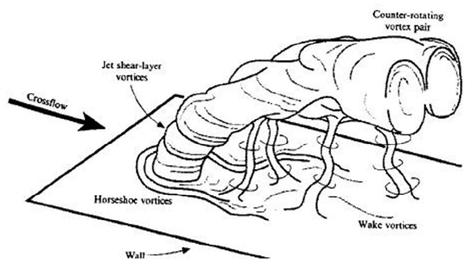




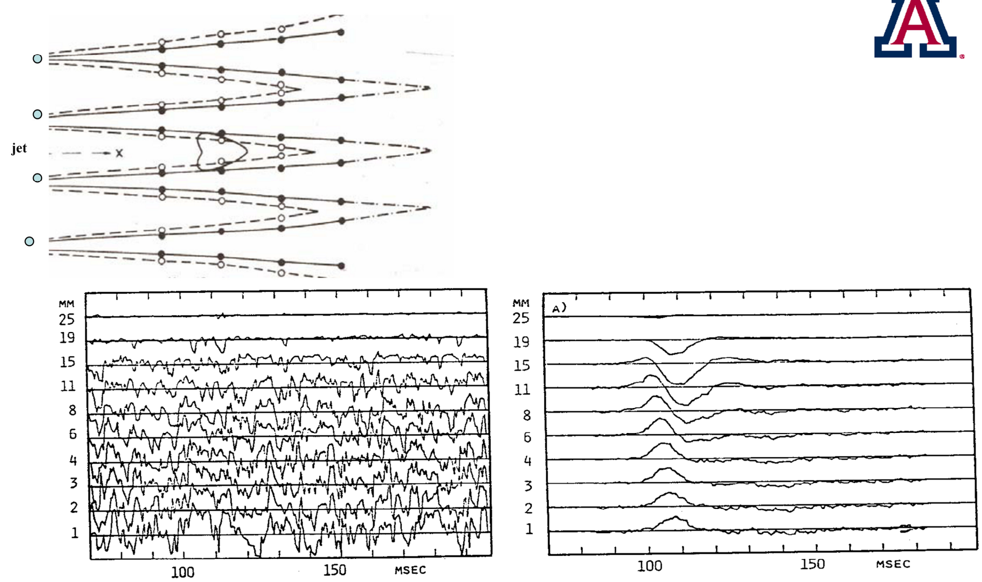


The Eurica moment cam when flow around a turret was investigated. Since the turret heightscales with the BL thickness

Streamwise vortices appeared and they persevered for a long distance



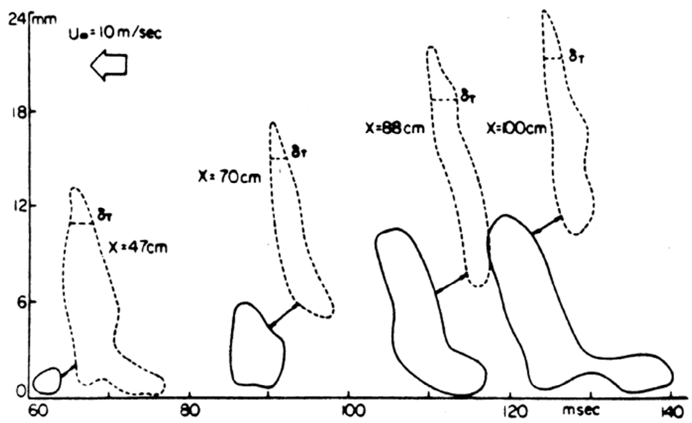
Fric & Roshko 1994 V_r=4



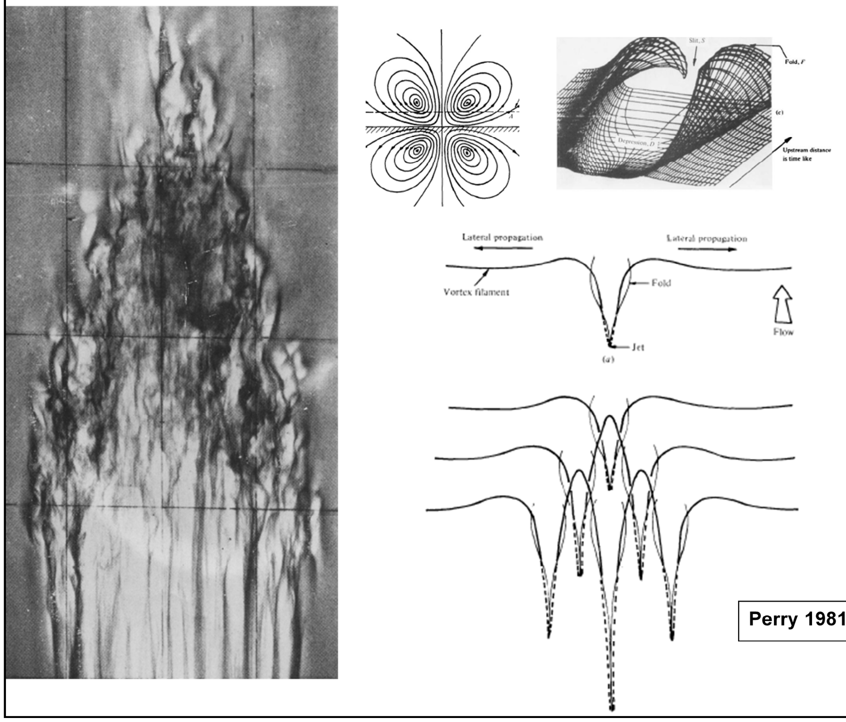
It brought to the foreground the question if this is not what bypass transition is all about and how important is its role in the structure of the TBL.

It usually occurs around a roughness spot, a small necklace vortex destabilizes the BL and generates aSPOT

The Latter survives

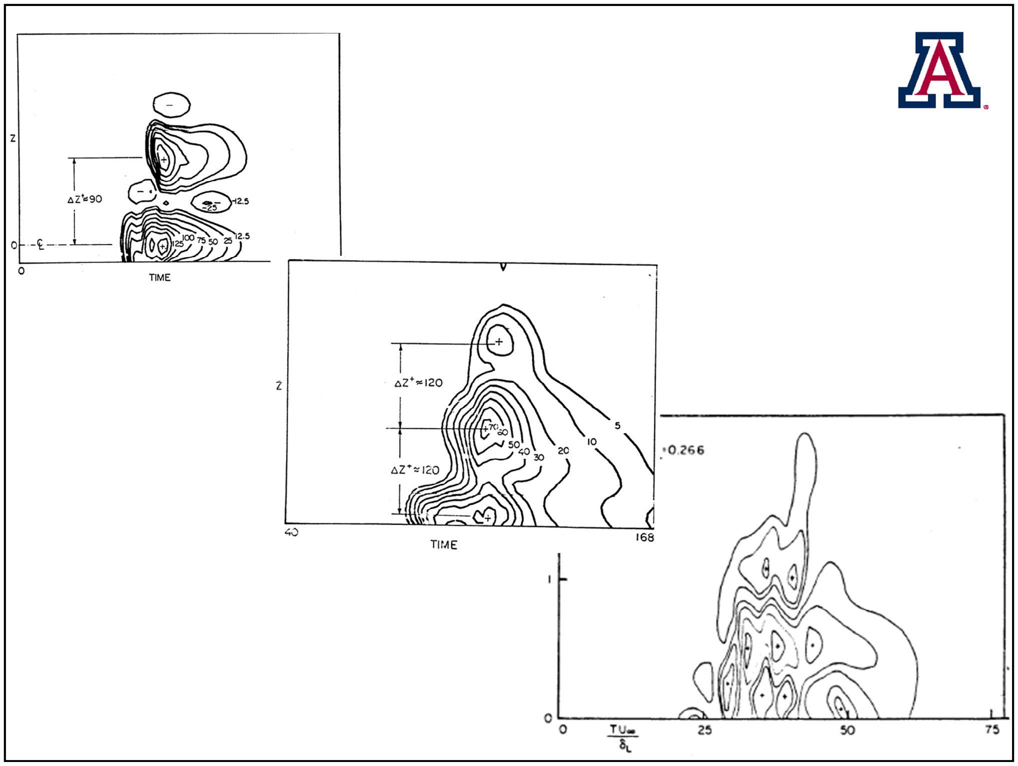


With some pattern recognition the structure directly downstream of the perturbation looked like this

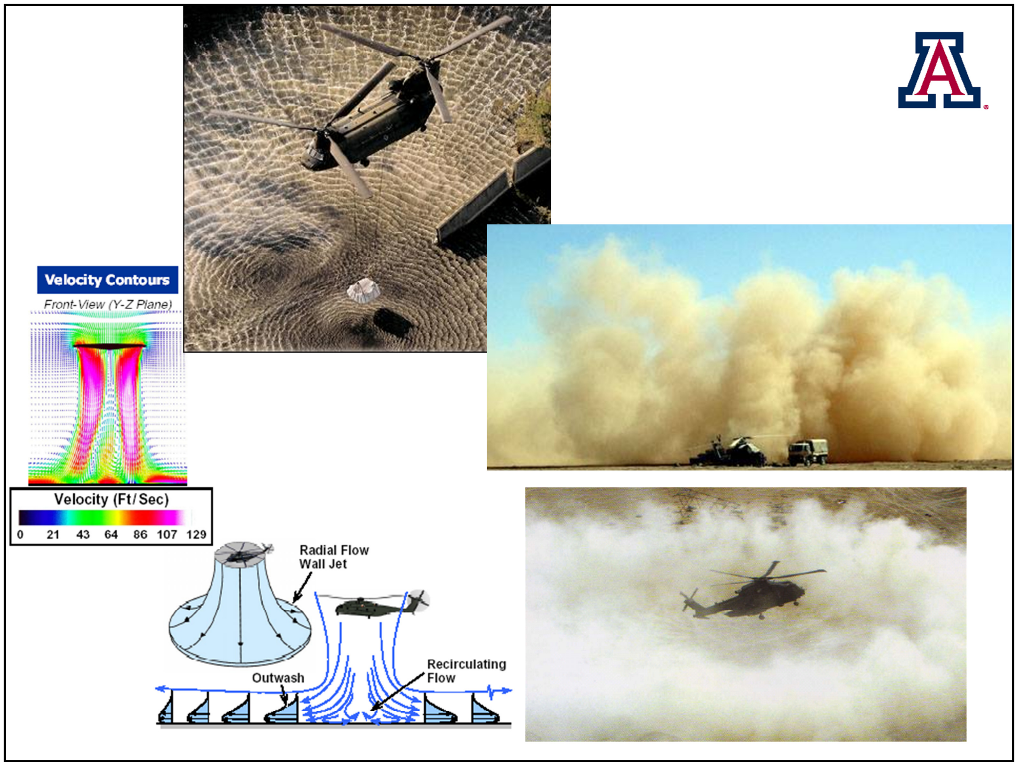


So what is it that is generated by the perturbation and what were we able to see downstream

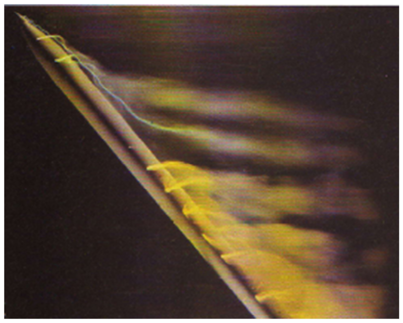
JUST the Center Region

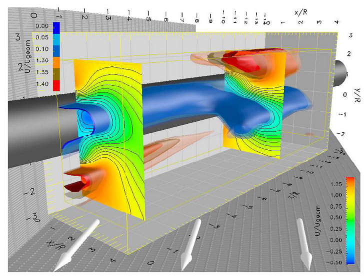


We were able to educe the growth pattern from 2 Vortices to 3 to 5 etc.



And so the interaction between streamwise and spanwise vortices and the mean shear flow may be a problem of primary interest and we only recently have the tools to tackle it





Werle 1987

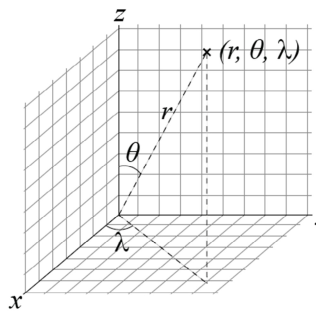
CONCLUSIONS

Exploiting instabilities rather than forcing the flow is advantageous

Simple 2D concepts may not always work

Non linear effects may result in first order effect

nteraction between spanwise & streamwise vortices may have a paramount effect on the mean flow, but this interaction may not always be beneficial



$$\eta = \cos\Theta$$

$$V_r = -\frac{f'(\eta)}{r}$$

$$V_\Theta = -\frac{f(\eta)}{r(1-\eta^2)^{1/2}}$$

$$V_\lambda = \frac{H(\eta)}{r(1-\eta^2)^{1/2}}$$

$$\frac{P - P_\infty}{\rho} = \frac{\mathcal{P}(\eta)}{r^2}$$

$$\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 V_r) + \frac{1}{rsin\Theta}\frac{\partial}{\partial\Theta}(sin\Theta V_\Theta) = 0$$

$$V_r\frac{\partial V_r}{\partial r} + \frac{V_\Theta}{r}\frac{\partial V_r}{\partial\Theta} - \frac{V_\Theta^2 + V_\lambda^2}{r} + \frac{1}{\rho}\frac{\partial P}{\partial r} = -\frac{1}{r}\frac{\partial}{\partial\Theta}\overline{v_\Theta v_r} - \frac{\cot\Theta}{r}\overline{v_\Theta v_r}$$

$$V_r\frac{\partial V_\Theta}{\partial r} + \frac{V_\Theta}{r}\frac{\partial V_\Theta}{\partial\Theta} + \frac{V_\Theta V_r}{r} - \frac{V_\lambda^2}{r}\cot\Theta + \frac{1}{\rho r}\frac{\partial P}{\partial\Theta} = -\frac{3\overline{v_r v_\Theta}}{r} - \frac{1}{r}\frac{\partial\overline{v_\Theta^2}}{\partial\Theta}$$

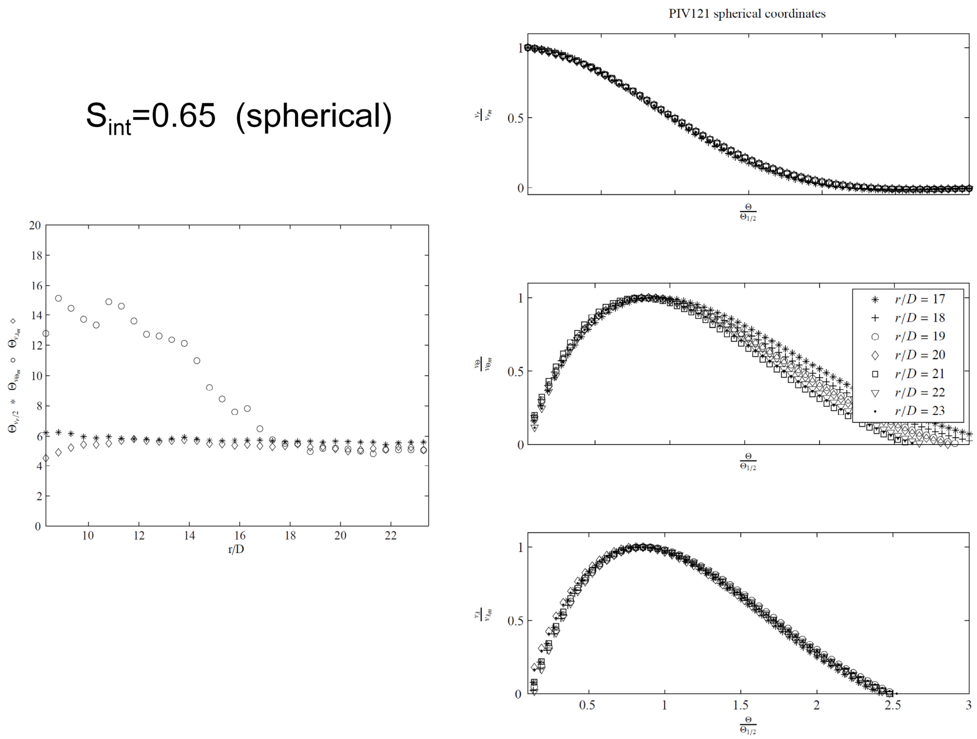
$$V_r\frac{\partial V_\lambda}{\partial r} + \frac{V_\Theta}{r}\frac{\partial V_\lambda}{\partial\Theta} + \frac{V_\lambda V_r}{r} + \frac{V_\Theta V_\lambda}{r}\cot\Theta = -\frac{1}{r}\frac{\partial}{\partial\Theta}\overline{v_\lambda v_\Theta} - \frac{3\overline{v_r v_\lambda}}{r} - \frac{2\cot\Theta}{r}\overline{v_\lambda v_\Theta}$$

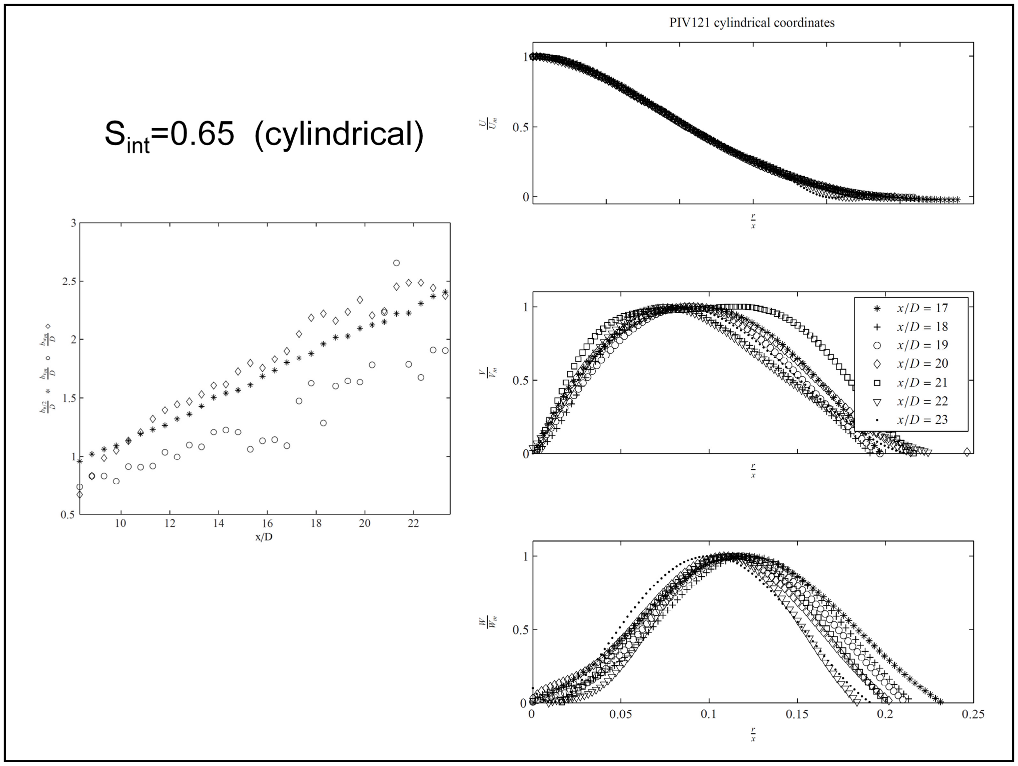
$$\overline{v_r^2} \simeq \overline{v_\Theta^2} \simeq \overline{v_\lambda^2} \qquad \frac{\partial}{\partial r} \ll \frac{\partial}{\partial\Theta}$$

There is a solution of the NS equations for LAMINAR FLOW and a road map for self similarity in Turbulent flows.

Self similar turbulent shear flows were most useful in helping us understand fundamental physics of a problem e.g., Mixing layers

S_{int}=0.65 (spherical)




S_int=0.65 (cylindrical)
PIV121 cylindrical coordinates
x/D
x/D = 17
x/D = 18
x/D = 19
x/D = 20
x/D = 21
x/D = 22
x/D = 23