Cylinder Wake Feedback Control

Development of Water Tunnel Experimental Setup

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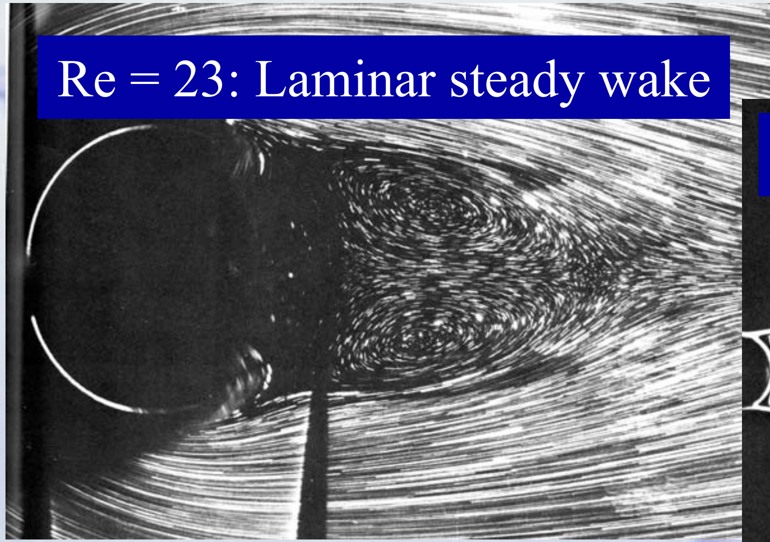
Objectives

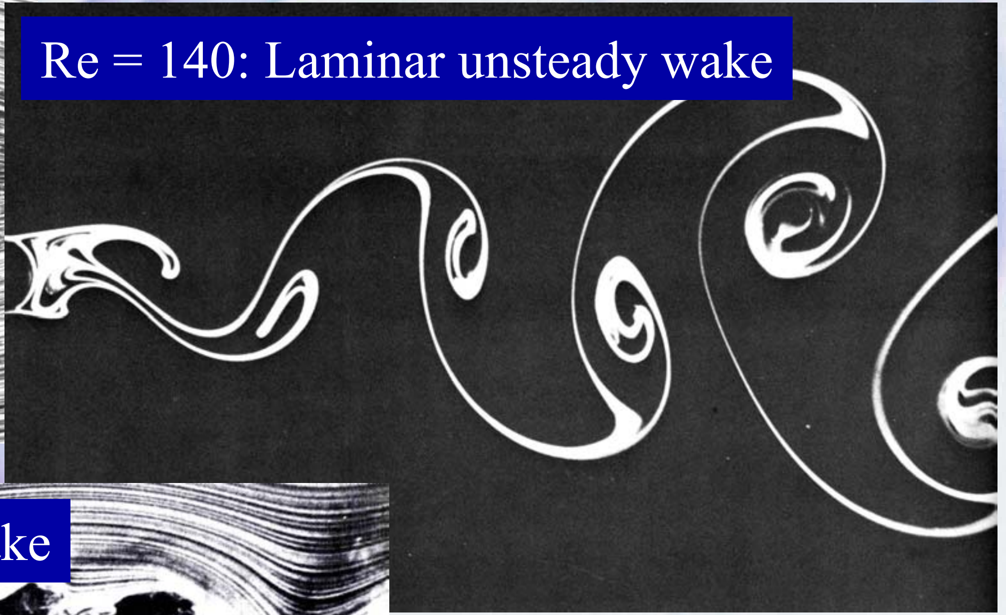
- Create a cylinder wake experiment suitable for control including sensors, actuators and the model itself
- Provide Hardware and Software to integrate the experiment with Matlab / Simulink

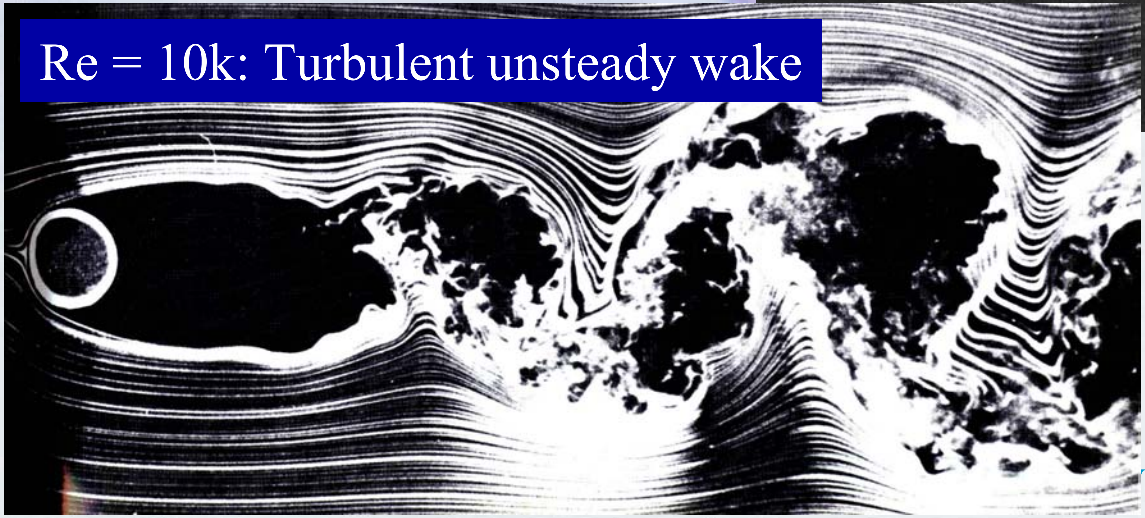
Why a 2D Cylinder Wake?

- Simplest Geometry with an absolute instability in the recirculation zone
- Many technical applications
- Natural and open loop forced cylinder wake has been well researched in the past
- Flow is not responsive to active, non-feedback control

Influence of Re







Experiment Design Blocks

- Cylinder Wake Experiment
  - Hardware
    - Fluid Dynamics
      - Model
      - Tunnel
    - Flow Sensor
    - Actuator
  - Software
    - Control Algorithm
    - DAQ / I/O
      - DAQ
      - Interfacing
      - RT Processing

Fluid Dynamics Issues

- Low Reynolds Number
  - Low Flow Speed
    - Negligible dynamic pressure
    - Turbulence Level increases
    - Convection
  - Small Model Size
    - Difficulty finding small sensors
    - Machining, precision issues
- Absolute Instability
  - Flow will be disturbed by infinitesimally small objects
- High Aspect Ratio
  - Model Accuracy
  - Runout, machining Problems

Actuator Issues

- High Positioning Accuracy required
- Actuation needs to be two-dimensional, uniform across span
- Closed Loop, Real Time Capabilities

Sensor Issues

- Non-Intrusive
- Multiple Sensor Locations
- Real Time capable
- High Positioning Accuracy Requirements for Sensors
- Reproducibility

Fluid Dynamic Options

- Re=120 , St = 0.2
- Wind Tunnel
  - U_{inf} = 5 m/s, D = 0.36 mm
  - f = 2.77kHz
- Water Tunnel
  - U_{inf} = 30 mm/s, D = 4.97 mm
  - f = 1.2 Hz

⇒ Use Water Tunnel

⇒ Re 10k U_{inf} = 10 m/s, D = 15 mm
f = 13.3 Hz; still laminar flow

$$Re = \frac{U_{inf} \cdot D}{\nu};$$

D = Cylinder Diameter

U_{inf} = Freestream Velocity

ν = Kinematic Viscosity

$$\nu_{H_2O} = 1 \cdot 10^{-6}$$

$$\nu_{Air} = 15 \cdot 10^{-6}$$

$$St = \frac{f \cdot D}{U_{inf}}$$

f = Frequency

Actuator Options

- Rotate Cylinder
  – Chosen initially because of ease of implementation
  – Non-straight cylinder introduced additional forcing velocities
- Translate Cylinder
  – More complex setup
  – No run-out issues

=> translate

Sensor Options - HF

- Hot Film Probes
  + Tried and proven technology
  + Commercially available
  + Relatively inexpensive
  + Excellent frequency response
  - Intrusive
  - Tricky to calibrate and operate in water
  - Difficult to position precisely
  - Usually only one velocity component

Sensor Options - LDA

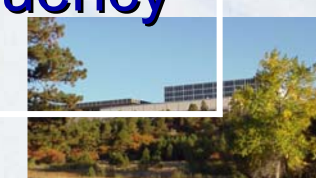
- Laser Doppler Anemometry
  - + Non intrusive
  - + Up to 3 independent velocity components
  - + Commercially available
  - + good frequency response
  - - very expensive
  - - only one sensor location per unit, does not lend itself to multi-sensor studies
  - - software usually not real time capable

Sensor Options - PIV

- Particle Image Velocimetry
  - + Many sensor locations
  - + Non-intrusive
  - + Separate velocity components
  - + Easy to calibrate and position
  - + moderately expensive
  - - Limited time resolution
  - - No real-time system commercially available, only off-line processing

PIV System Development & Accomplishments -1

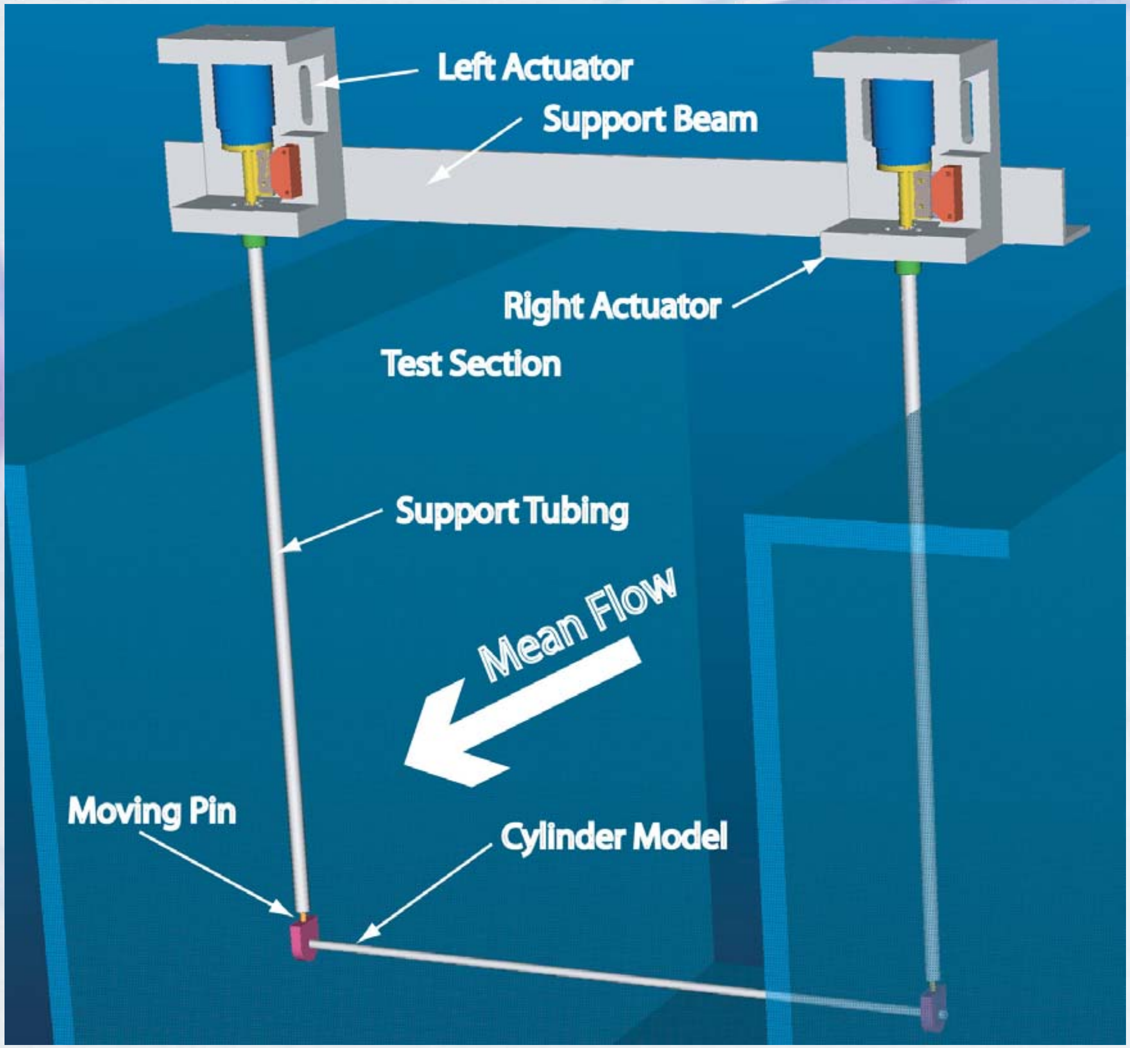
In-House System	Original System COTS
On-line operation, real time	Only off-line operation
Advanced trigger capabilities	Limited synchronization options
Interfaces to Matlab, LabVIEW, Tecplot, C	Only ASCII export
Modular, open architecture, easy to modify, hardware independent	"Black Box" closed, fixed system, no customization possible
>3k Vectors/s in direct Correlation	~2k Vectors/s in frequency domain



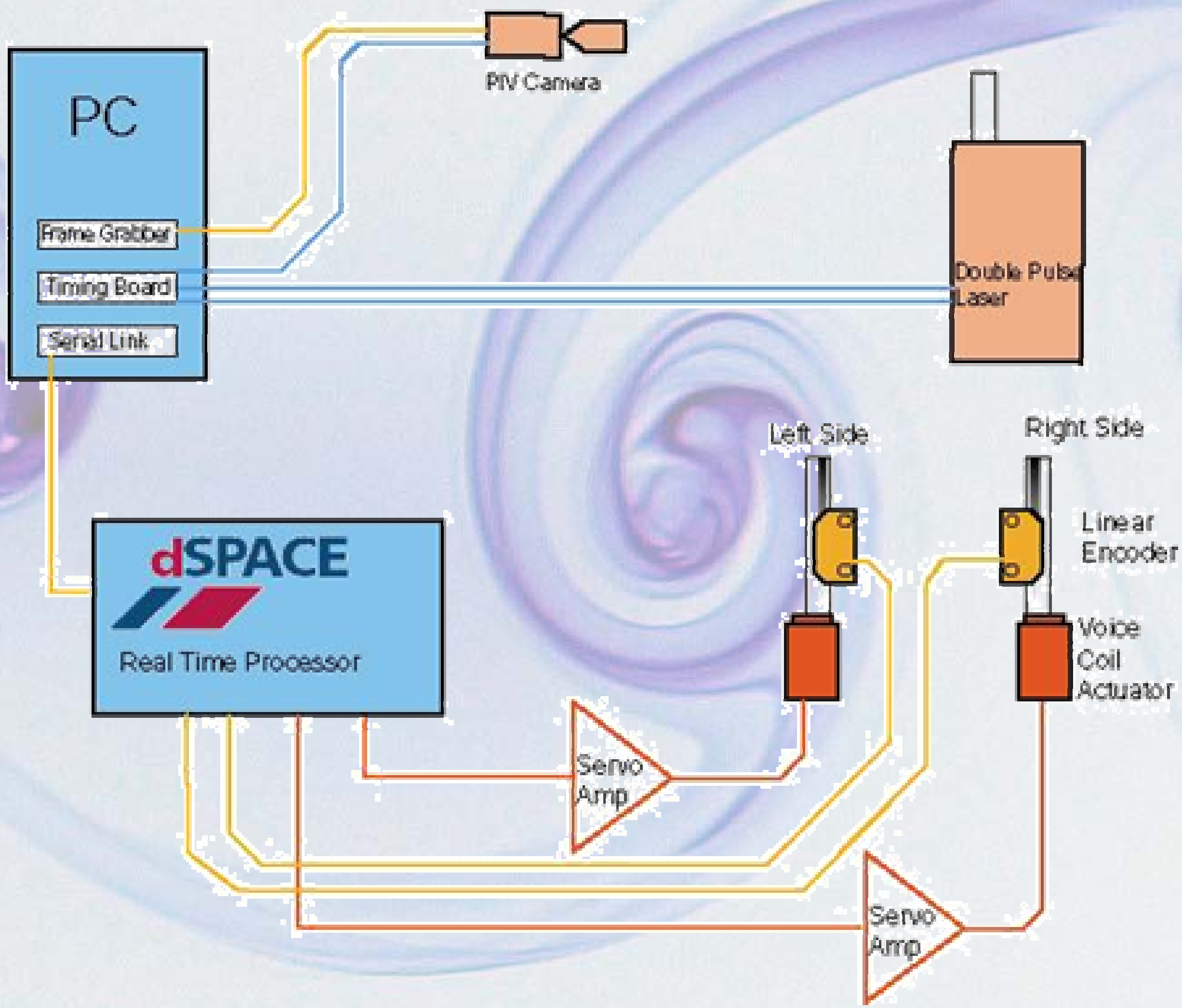
PIV System Development & Accomplishments -2

In-House System	Original System COTS
Data available on-line in PC Memory – 1000x faster	Data needs to be uploaded from Processor (slow)
Source code owned by AF, available public domain for non-commercial use	No access to source code, additional license is $14k
$3500 for Hardware	$40,000 for Hardware
Data acquisition process one order of magnitude faster	-
Multi-Sensor Real time capability	-

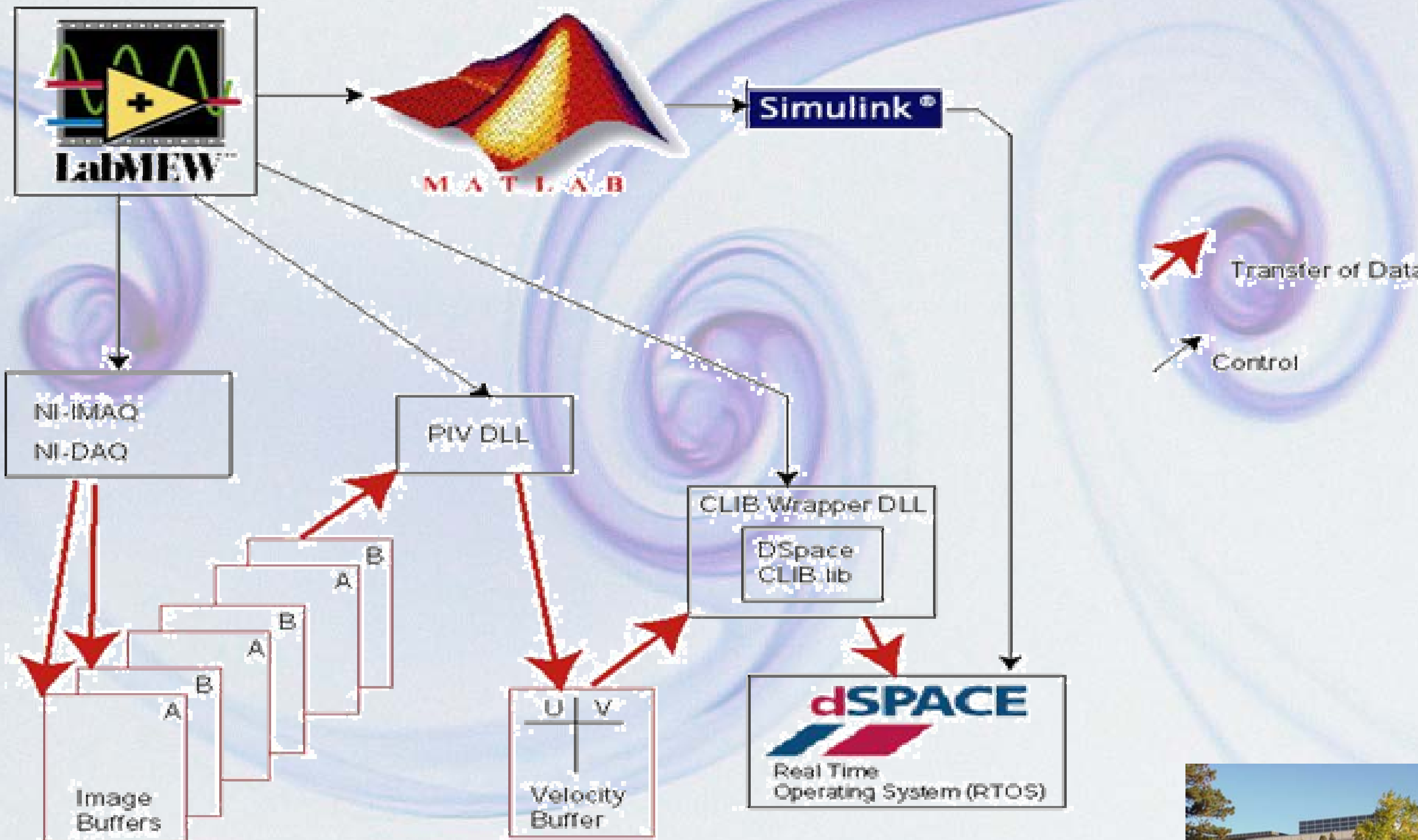
Cylinder Model



Computer System



Software Layout



Challenges Ahead

- Open loop system response measurements
- Development and implementation of control algorithm
- Implementation and test of CLIB interface between PC and Real Time Processor
- Overall timing analysis

Summary

- Conceptual design, implementation and test of a low Re Cylinder wake experiment suitable for closed loop feedback control
- Developed and tested a real time PIV system from scratch
- Ready to gather open loop data for POD model and estimator / controller development