SPC 307

Aerodynamics

Lecture 1

February 2, 2016

Course Materials

drahmednagib.com

COURSE OUTLINE

- Introduction to Aerodynamics
- Review on the Fundamentals of Fluid Mechanics
- Dynamics of an Incompressible and Inviscid flow field
- Viscous Boundary Layers.
- Characteristic parameters for airfoil and wing aerodynamics.
- Incompressible flows around airfoils of infinite span
- Incompressible flows around wings of finite span
- Aerodynamic design considerations
- Introduction to compressible flows
- A brief Introduction to Computational Fluid Dynamics.

Introduction to Aerodynamics

- Learn why aerodynamics is important in determining the performance characteristics of airplanes
- Develop a basic understanding of fluid properties such as density, temperature, pressure, and viscosity and know how to calculate these properties for a perfect gas
- Learn about the atmosphere and why we use a “standard atmosphere” model to perform aerodynamic calculations; learn how to perform calculations of fluid properties in the atmosphere
- Learn the basic components of an airplane and what they are used for.

Prerequisite Course:

- **Fluid Mechanics - ENGR 207**

Classification of fluids - Definition of viscosity – surface tension - Hydrostatic pressure- Buoyancy - Bernoulli's equation and its application for ideal fluid - stream lines- velocity and acceleration in two dimensional flow – Differential Analysis of fluid flow (continuity equation – Navier-Stokes equations) - Moody diagram - Incompressible Flow through Networks of Pipes – Unsteady Flow in Conduits

Dynamics of an Incompressible and Inviscid flow field

- Understand what is meant by inviscid flow, and why it is useful in aerodynamics
- Learn how to use Bernoulli's equation and how static and dynamic pressure relate to each other for incompressible flow
- Know the basic process in measuring (and correcting) air speed in an airplane
- Have a physical understanding of circulation and how it relates to aerodynamics
- Learn the assumptions required for potential flow
- Be able to use potential flow functions to analyze the velocities and pressures for various flow fields
- Understand how potential flow theory can be applied to an airplane

Viscous Boundary Layers

- Develop a basic understanding of boundary layers and their impact on aerodynamic flows
- Be able to obtain solutions for basic laminar flows and use the results to estimate properties, such as boundary layer thickness, shear stress, and skin friction
- Describe the characteristics of turbulent boundary layers, and how they compare to laminar boundary layers
- Understand how drag is impacted by laminar and turbulent boundary layers, including friction and separation
- Be able to estimate turbulent boundary layer properties, such as boundary layer thickness, shear stress, and skin friction
- Be able to complete a control volume analysis of a boundary layer flow
- Describe why turbulence models are important and how they are used
- Learn how to calculate the heat transfer and heat-transfer rate for a constant- property flow

Characteristic parameters for airfoil and wing Aerodynamics

- Understand the basic geometric parameters that define airfoil and wing shapes
- Know the basic aerodynamic forces and moments and be able to define their nondimensional coefficients for airfoils and wings
- Have a general understanding of the impact of airfoil geometry on the resulting aerodynamics, including the effects of camber and thickness
- Know how flow around a wing is different from flow around an airfoil and be able to estimate the impact of wing geometry on lift and drag
- Know the contributing factors to airplane drag and lift

Incompressible flows around airfoils of infinite span

- Understand and be able to use the physical and mathematical concepts of circulation and lift
- Be able to explain how potential flow theory is used to model flow for airfoils
- Understand the physical meaning and use of the Kutta condition
- Be able to estimate the lift and moment acting on an airfoil using thin-airfoil theory
- Understand the usefulness and limitations of thin-airfoil theory
- Know ways potential flow theory can be used to model airfoils other than thin airfoil theory
- Be able to explain why laminar flow airfoils have different geometries than airfoils used at higher Reynolds numbers
- Have a basic understanding of high-lift systems on aircraft, and how they create lift depending on where they are placed on a wing

Incompressible flows around wings of finite span

- Understand the difference between airfoils and wings and know the physical processes that cause those differences
- Be able to describe the impact of wing-tip vortices on the flow around the airfoil sections that make up a wing
- Understand the concepts behind Lifting-Line theory and be able to use the results to predict the lift and induced drag of a wing
- Understand the basic approach and usefulness of panel methods and vortex lattice methods
- Understand how delta wing aerodynamics differ from traditional wing aerodynamics, and be able to compute the aerodynamic forces acting on a delta wing
- Be able to explain why some tactical aircraft use leading-edge extensions (strakes) and how they work
- Describe the asymmetric flow patterns that can take place around an aircraft flying at high angles of attack, and know the physical processes that cause the flow

Aerodynamic design considerations

- Understand that aerodynamic design decisions are rarely made without considering multidisciplinary design factors
- Have a good idea of how to increase lift on an airplane, and how to modify an airplane in order to achieve aerodynamic improvements
- Learn about drag reduction and how important reducing drag is to aircraft development programs
- Study aircraft from the past and see how aerodynamic considerations were ncluded in the design

Introduction to Compressible Flows

- Understand the basic thermodynamic concepts that form the basis of high-speed flow theory.
- Develop a basic physical understanding of the second law of thermodynamics.
- Be able to use the isentropic flow relationships in analyzing the properties of a flow field.
- Develop the ability to analyze flow in a stream tube, and understand how a converging-diverging nozzle works.
- Introduction to shockwaves types.

A brief Introduction to Computational Fluid Dynamics.

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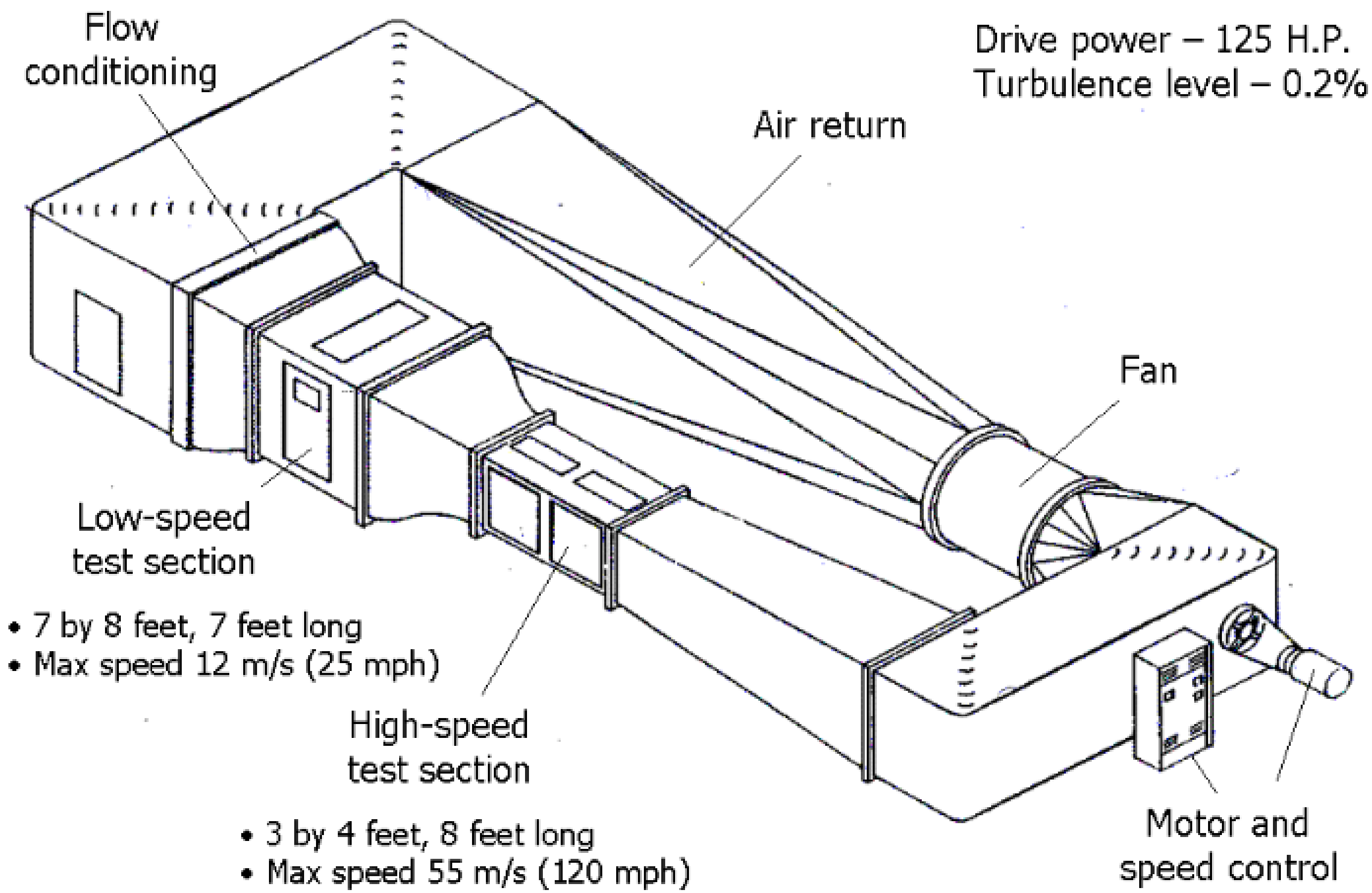
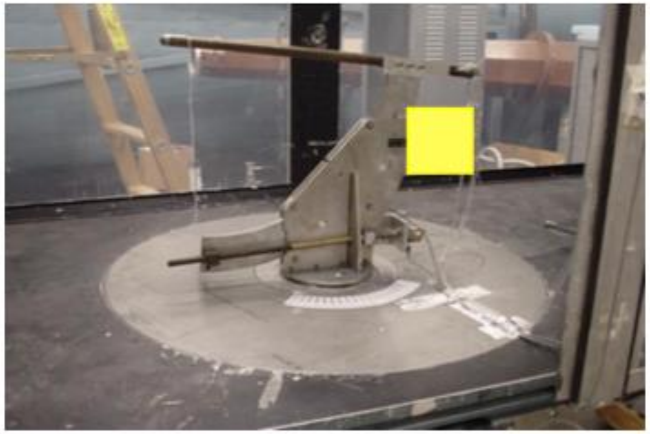
Introduction to Experimental Aerodynamics

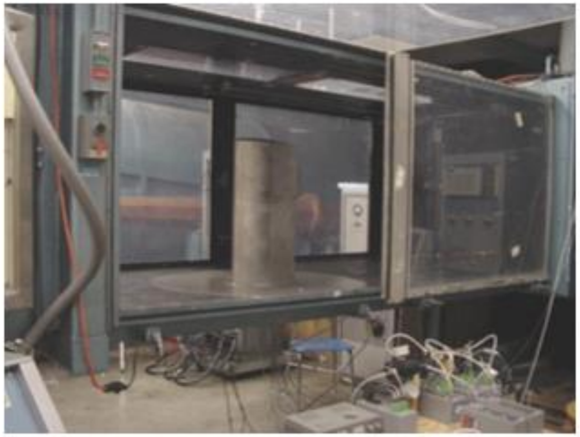
Wind Tunnel

ODU Low Speed Wind Tunnel – KH 143



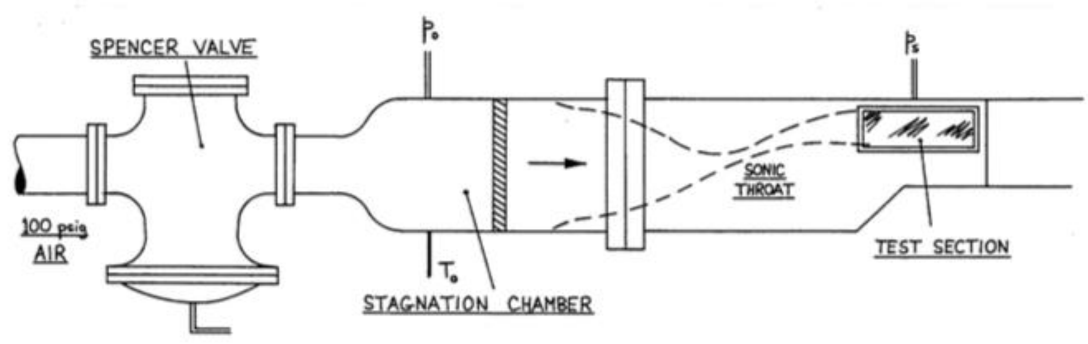
Wind Tunnel





Wind Tunnel

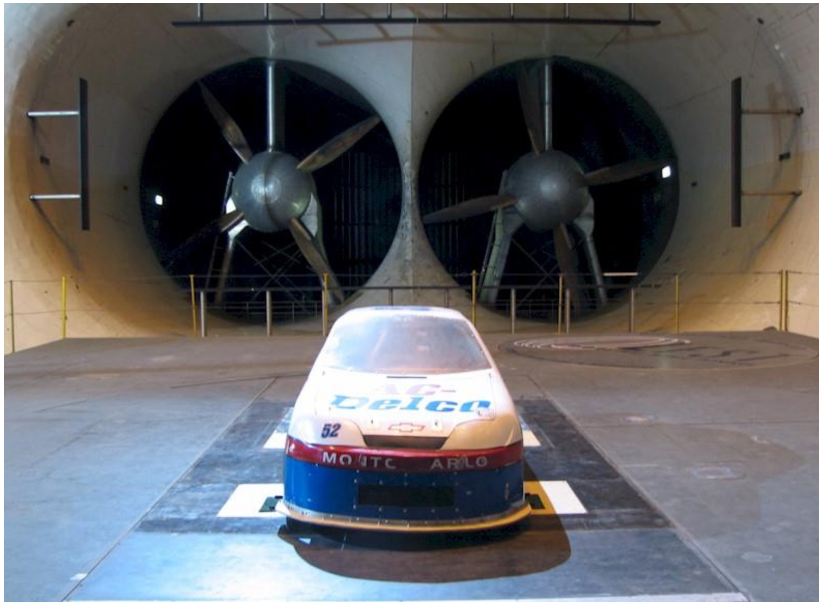
ODU Supersonic Wind Tunnel – KH 143



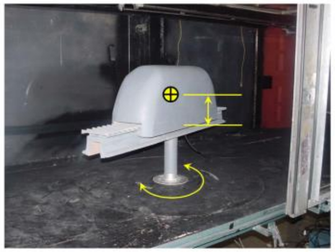
Wind Tunnel

The MIT / NASA Langley Magnetic Suspension/Balance System
NASA Langley Research Center 6/11/1991 Image # EL-1996-00037

Wind Tunnel



Wind Tunnel



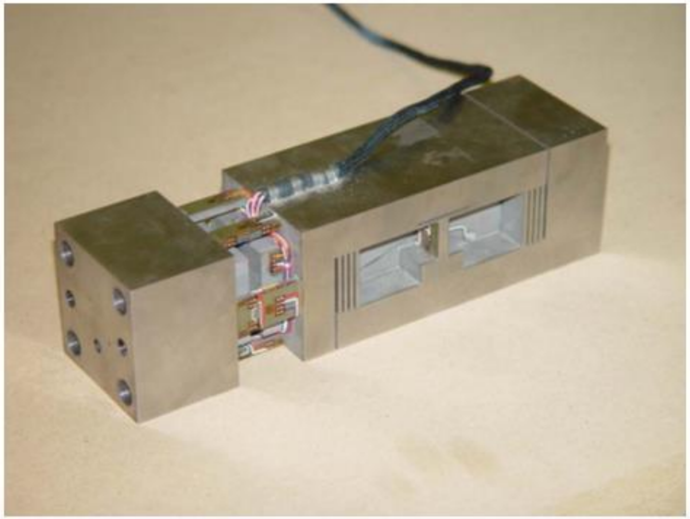
Internal Balances

- Below – FF-10 wind tunnel balance

  6 components
- Right – HRC-3 wind tunnel balance

  3-components
- Below right – ATI-Gamma general purpose balance

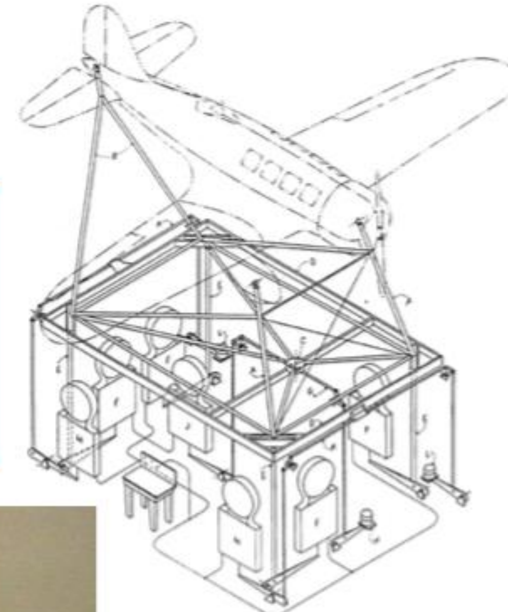
  6 components



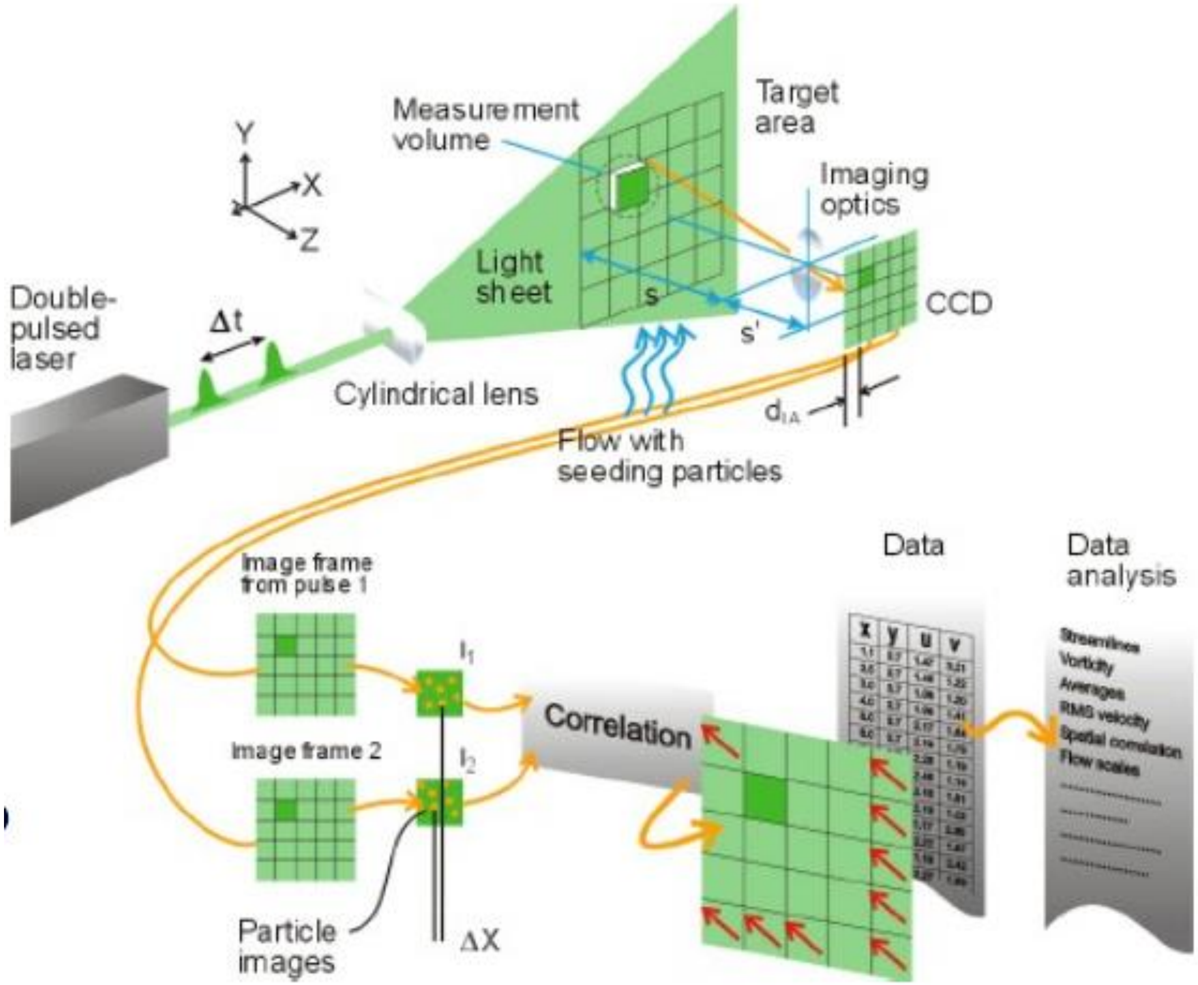
Wind Tunnel

External Balances

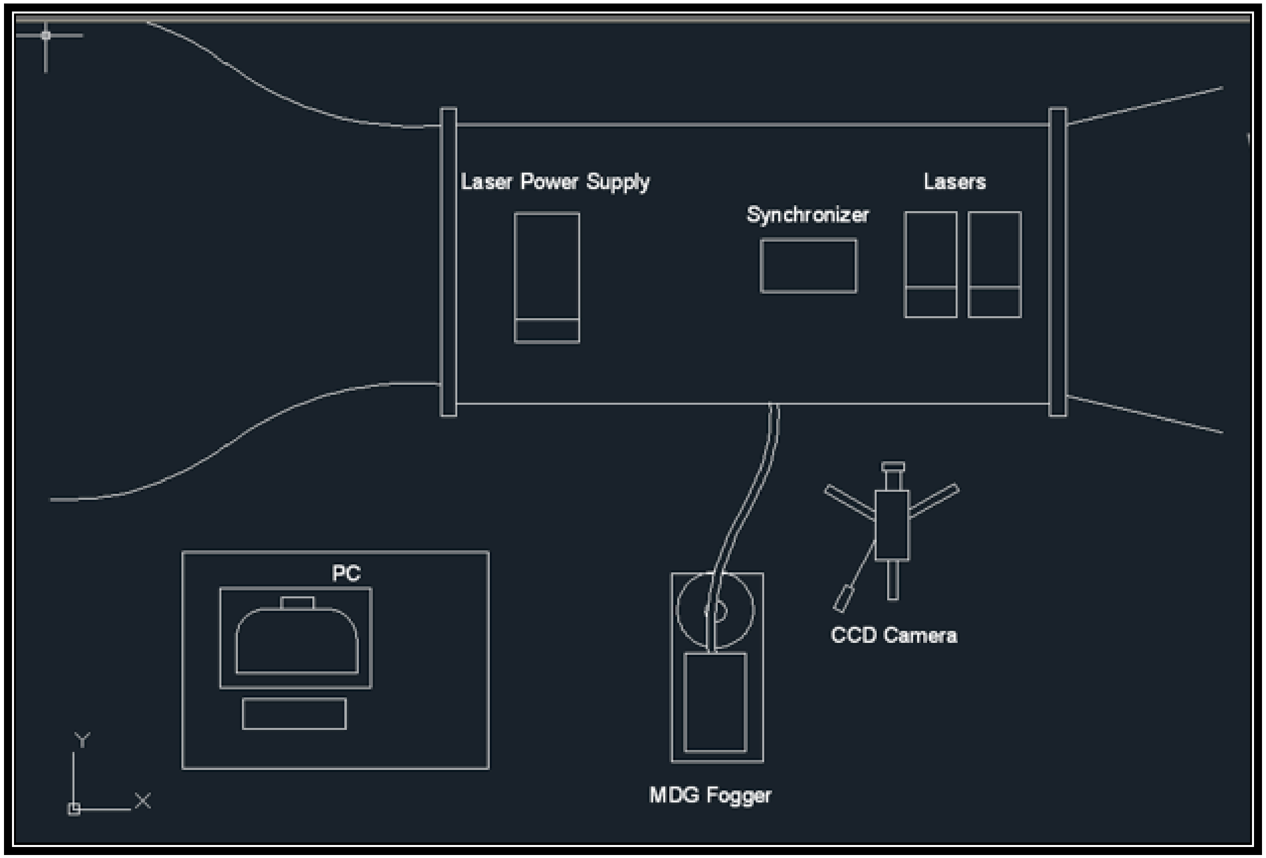
- Right upper – Langley Full-Scale Tunnel
- Right lower – Texas A&M
- Upper center – Aerotech
- Low center – Wright Brothers
- Below – U. Washington



Particle Image Velocimetry (PIV)



Particle Image Velocimetry (PIV)



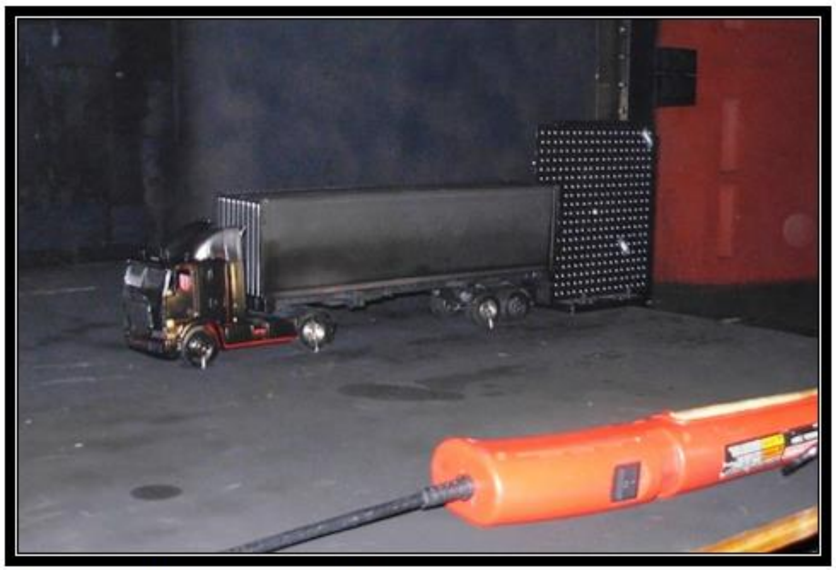
Picture #1 shows the general layout of the experiment. The tested truck is located inside the test section below the lasers and the synchronizer.

Particle Image Velocimetry (PIV)

Picture #2 heavy-duty truck mounted on a plywood.

Picture #3 dual Nd: YAG laser.

Particle Image Velocimetry (PIV)

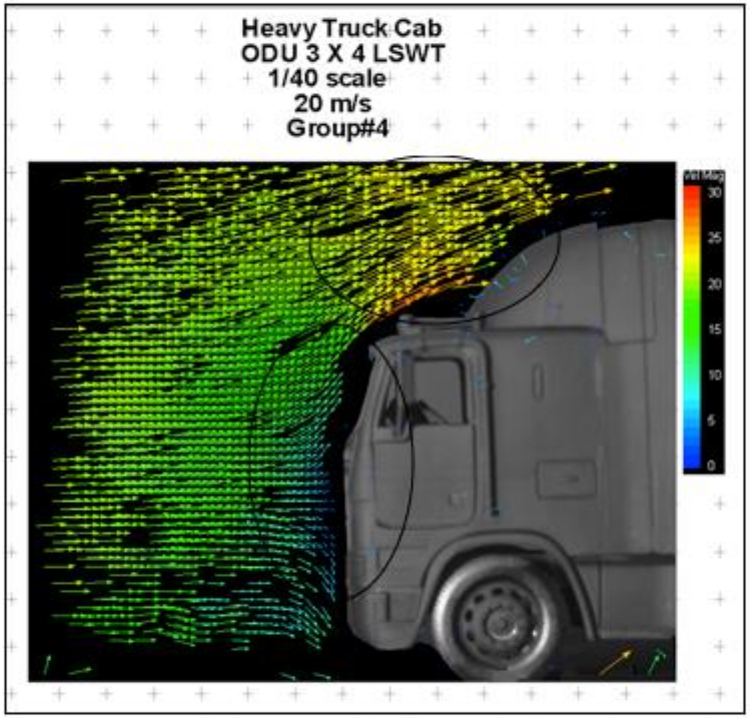


Picture #8 optics alignment target.

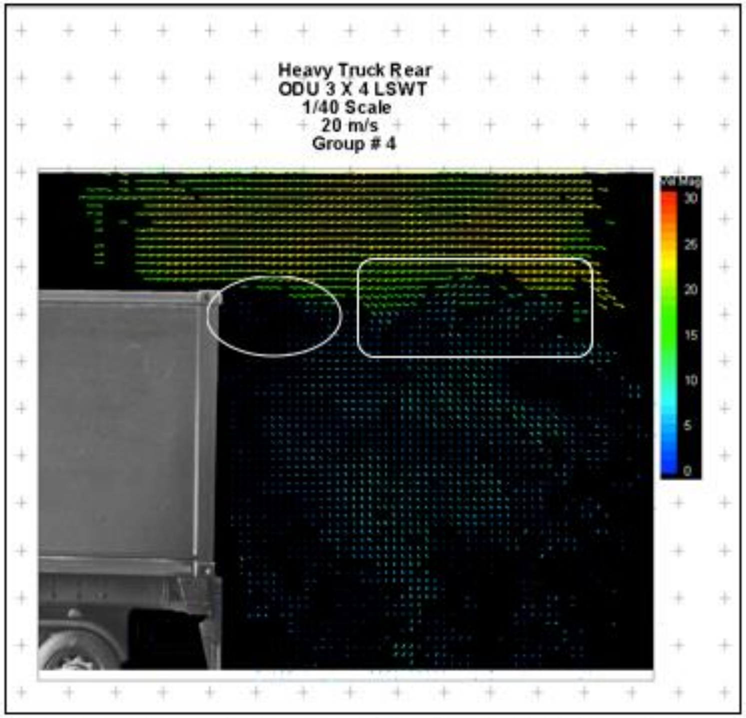
Picture #9 Layout.

Particle Image Velocimetry (PIV)

Particle Image Velocimetry (PIV)

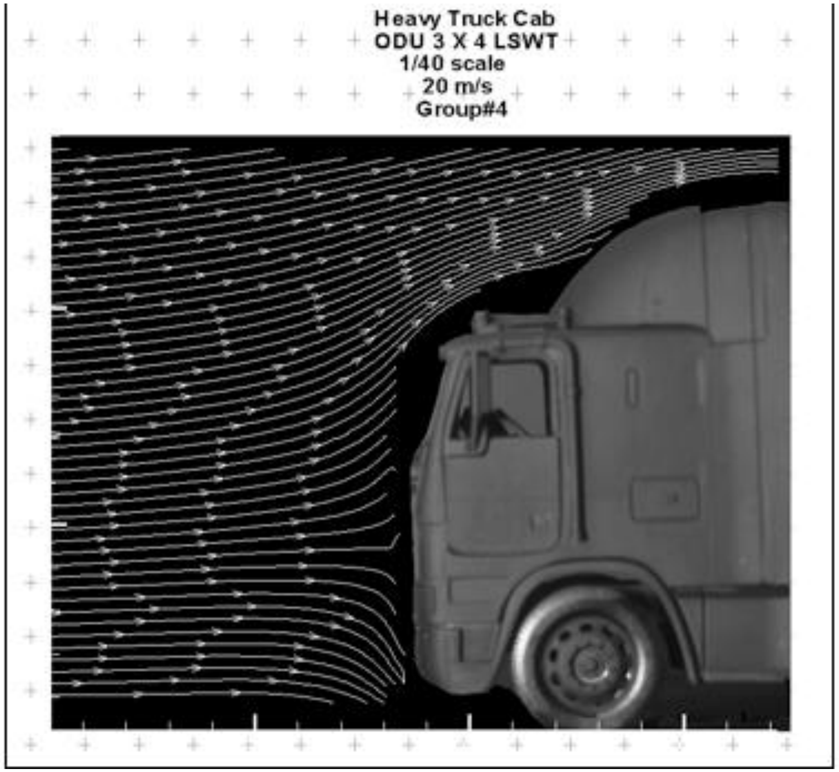


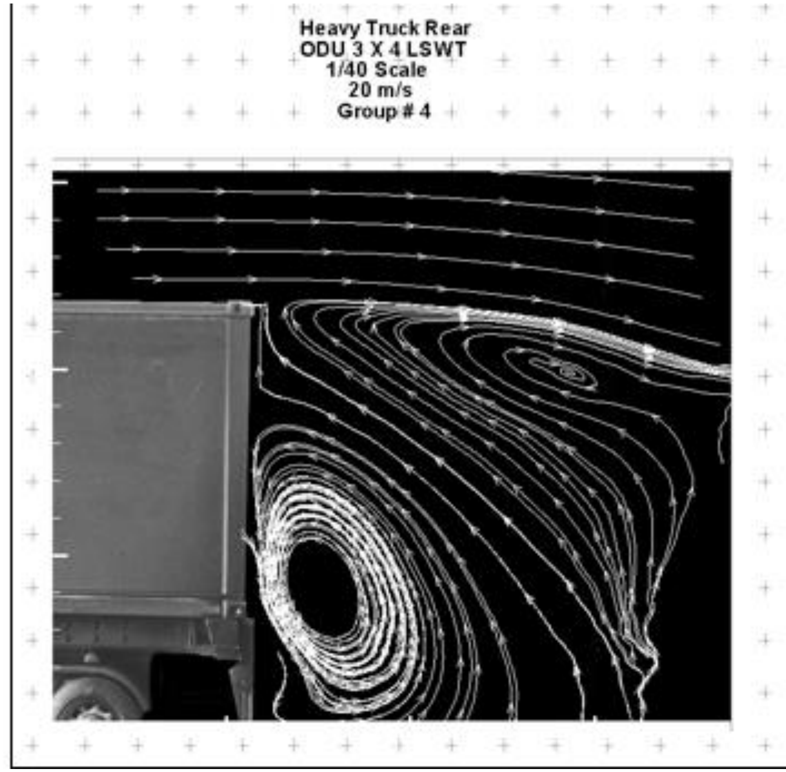
Picture #12 overall character of the flow at the front of the cabin.



Picture #13 overall character of the flow behind the trailer.

Particle Image Velocimetry (PIV)

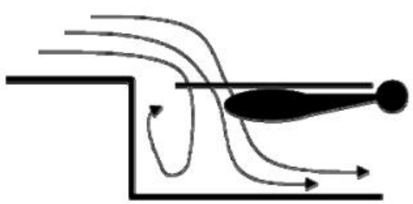




Particle Image Velocimetry (PIV)

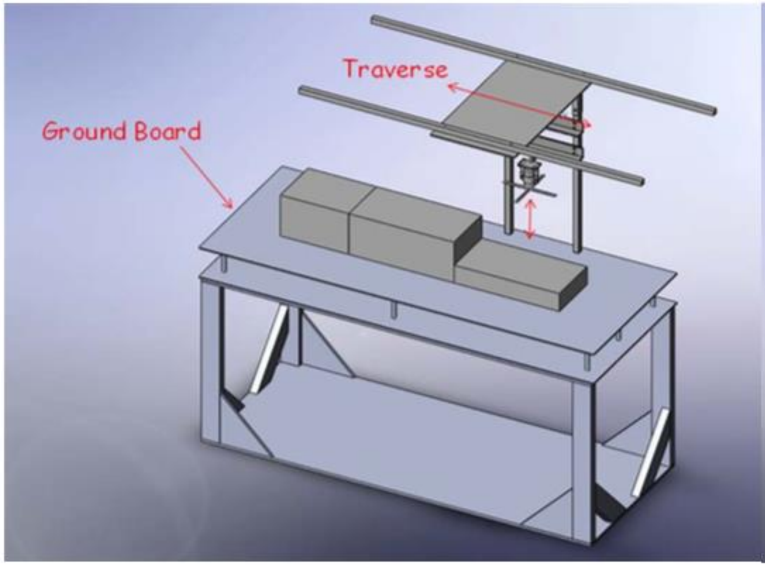
Case Study: PIV Measurements

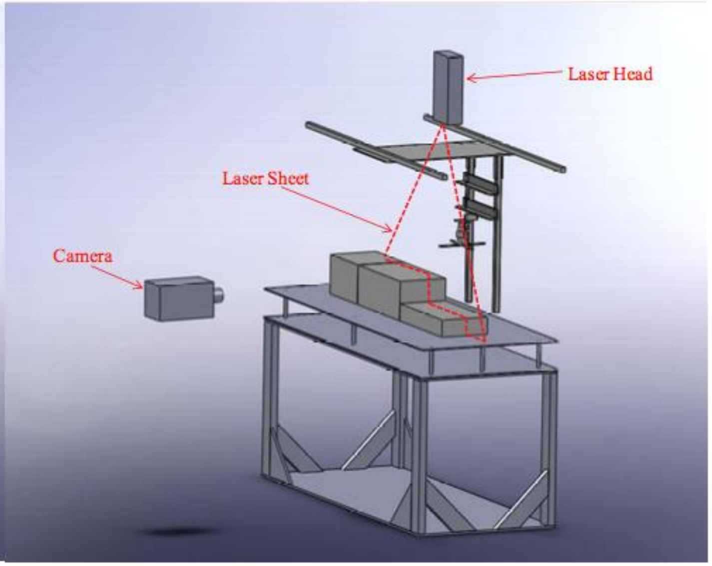
- Interaction of Rotor Downwash and Ships Airwake
  - ODU LSWT – Large test section
  - Simplified frigate model and fixed pitch rotor
- Motivation
  - Landing a helicopter in the “airwake”’ of a bluff body ship superstructure
  - Frigate and MH-60 Seahawk Helicopter



Particle Image Velocimetry (PIV)

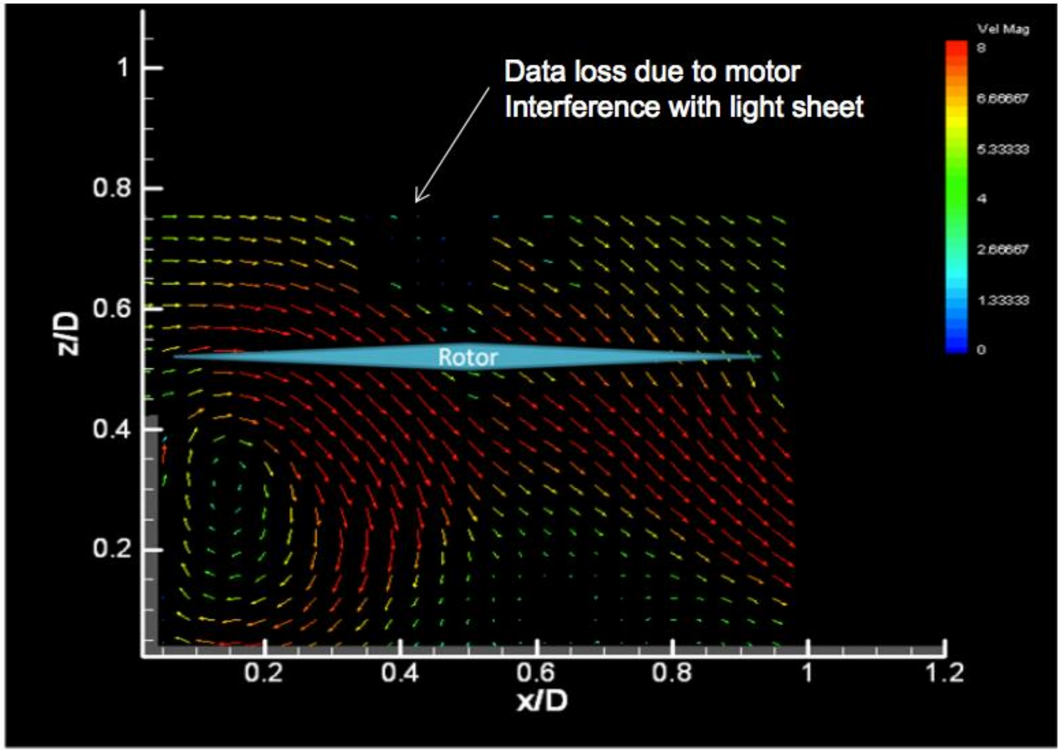
- Electric motor drives rotor, mounted on traverse
- Overhead window with Dual Yag Laser shining through
- Side window allows camera to view laser sheet





Particle Image Velocimetry (PIV)

- Flow over landing deck with rotor



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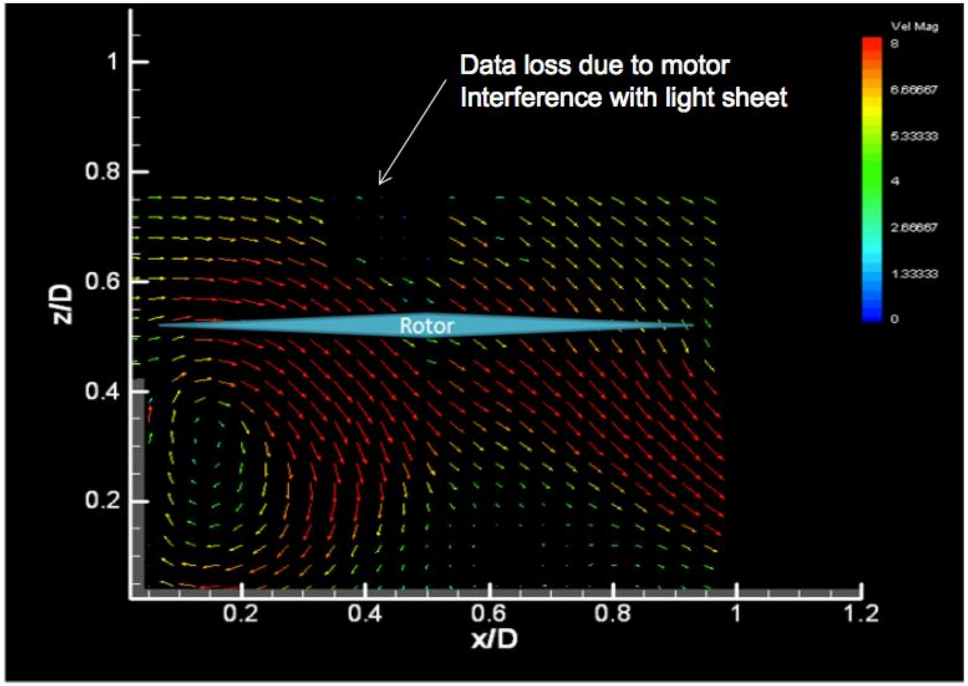
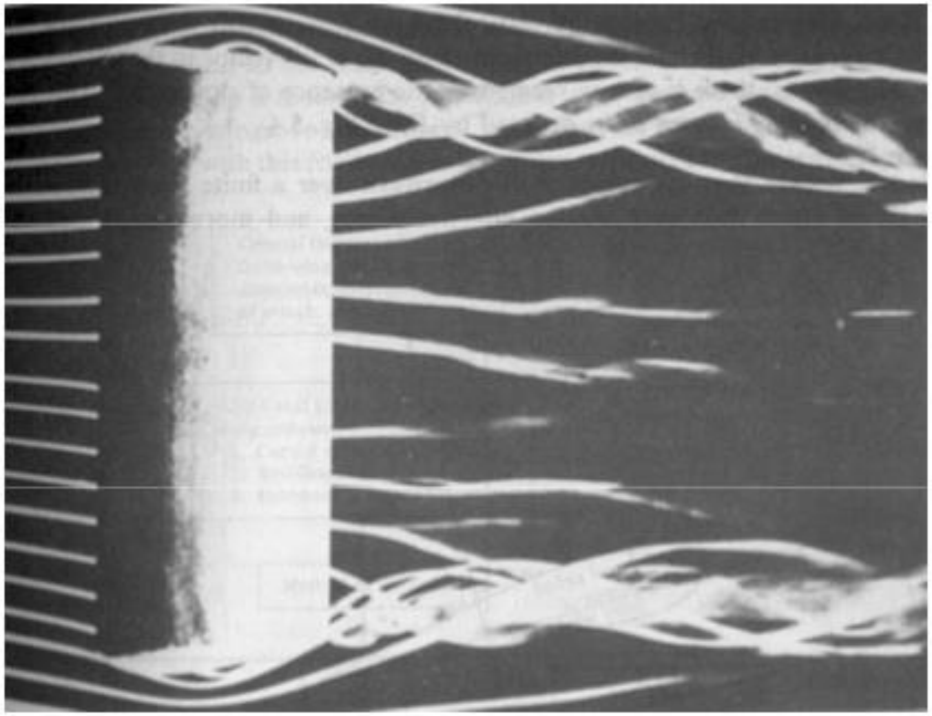
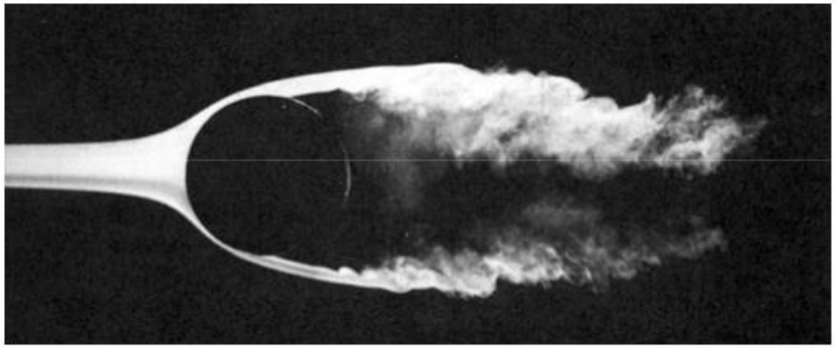


Freestream Tracer Injection



Oil dripped on array of wires shows wingtip vortex



Direct injection of smoke shows laminar separation on a cylinder in crossflow

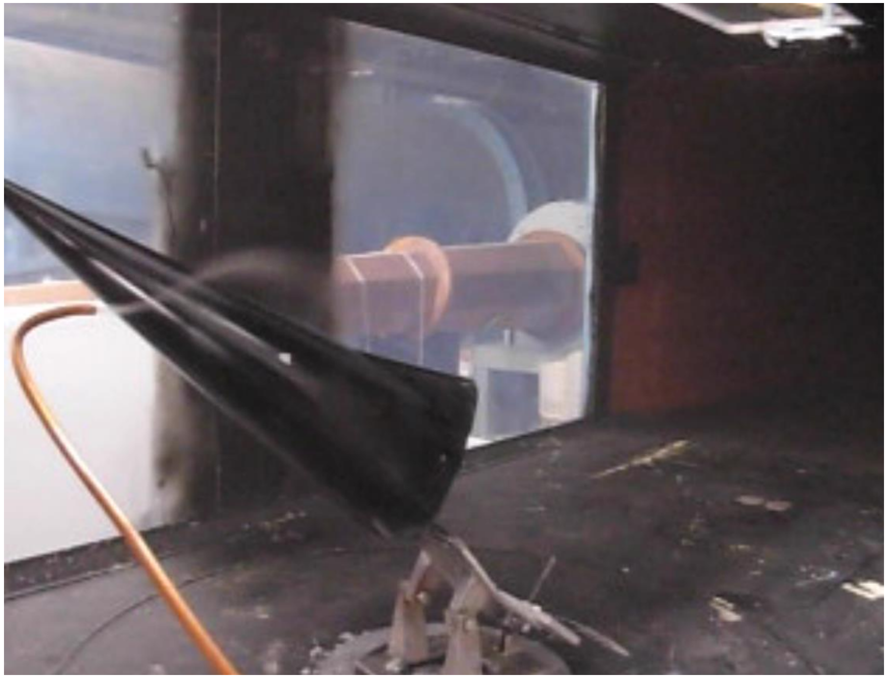
Freestream Tracer Injection

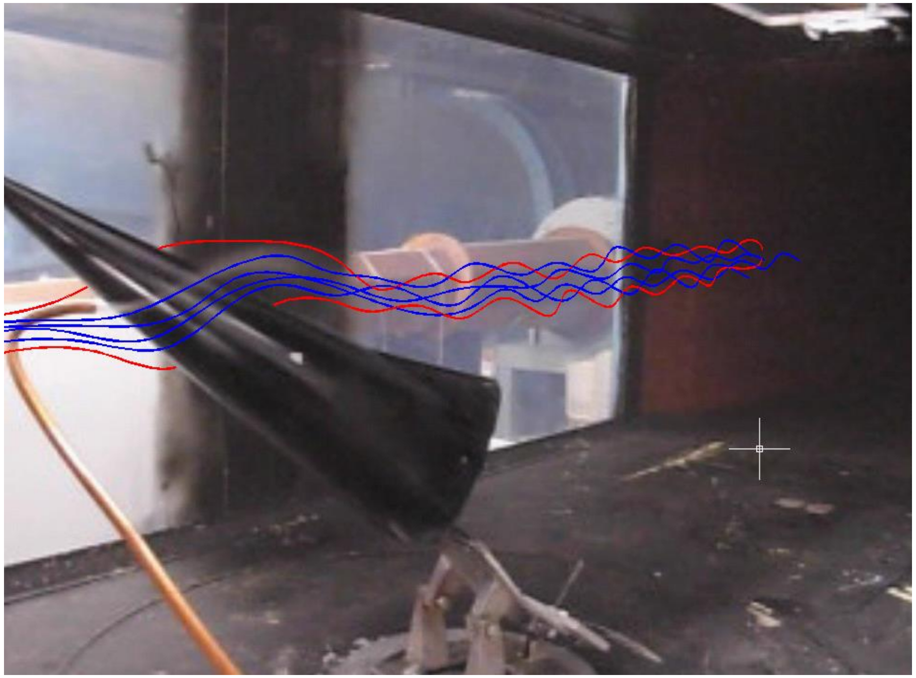
Propylene Glycol "Smoke" Generator

Wand used with full- scale automotive testing

Freestream Tracer Injection

Propylene Glycol “Smoke” Generator

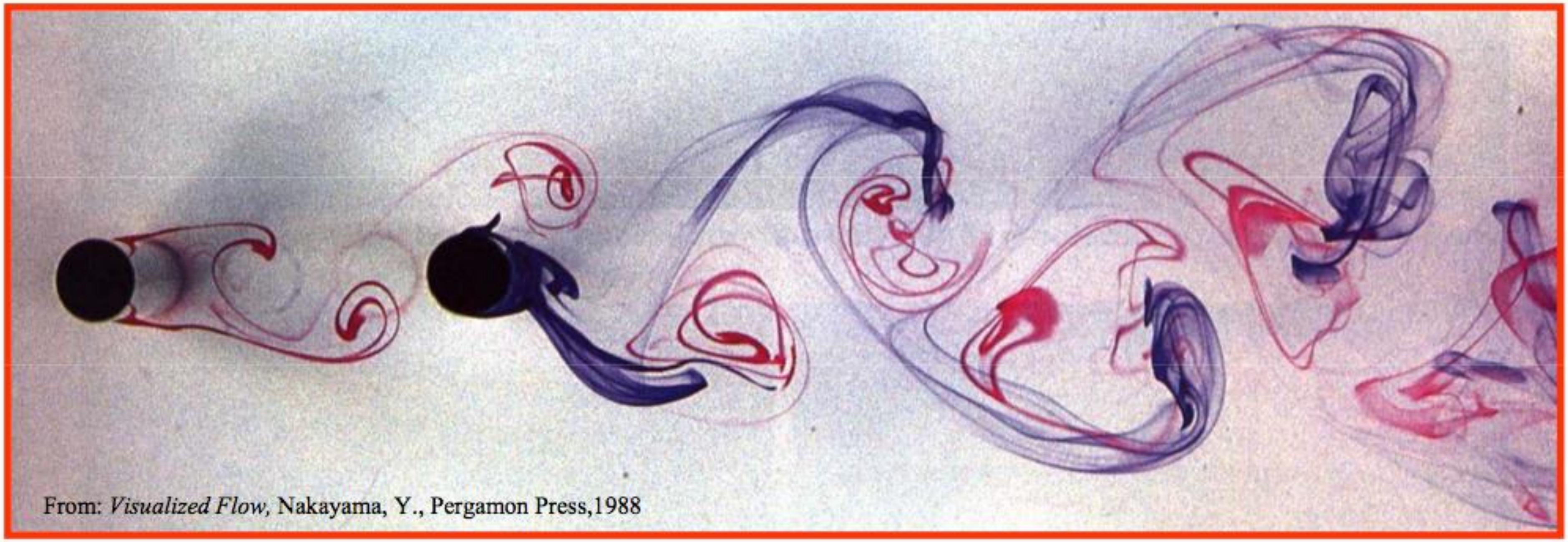




Forebody

<u>Freestream Tracer Injection</u>

Hydrodynamic (Dye)



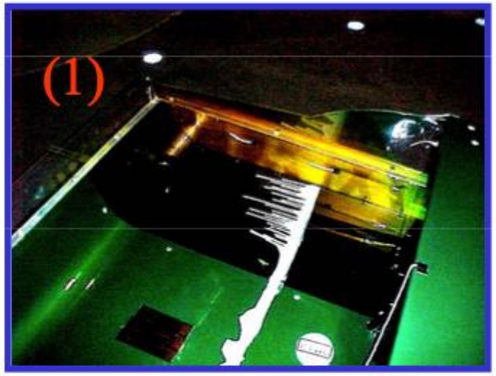
Karman vortex street following two cylinders

Freestream Tracer Injection

Oil FLow

Oil film stripe on automobile body panels

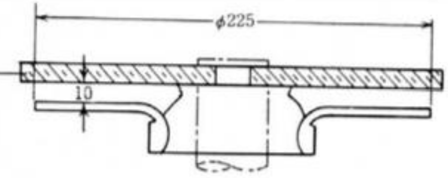
- shows interference of driver compartment on spoiler flow (1)
- interference of support strut on front flow deflector (2)



Freestream Tracer

Tufts

Procedure and materials are similar to aerodynamic methods

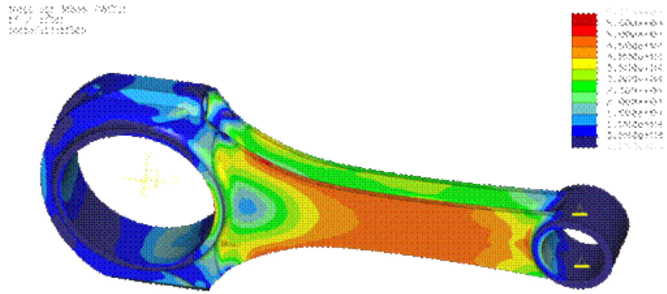


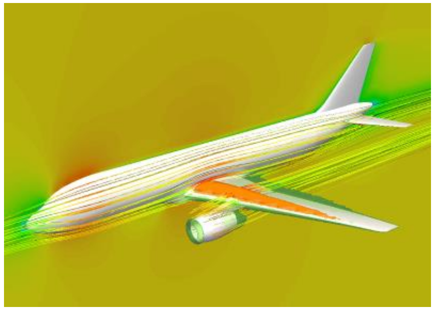
Example:
pump impeller rotating at 1200 rpm in water

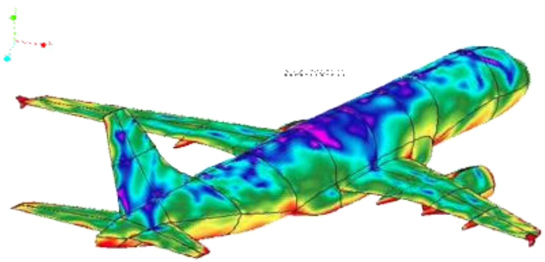
From: *Visualized Flow,* Nakayama, Y., Pergamon Press, 1988

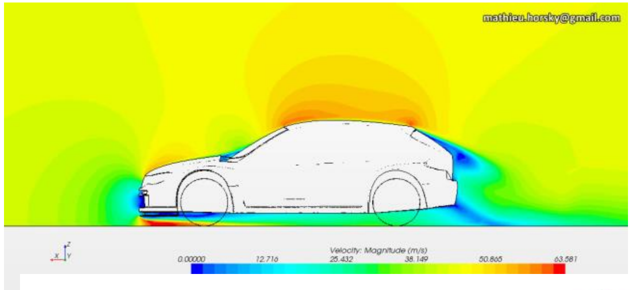
Recent Computational Methodology

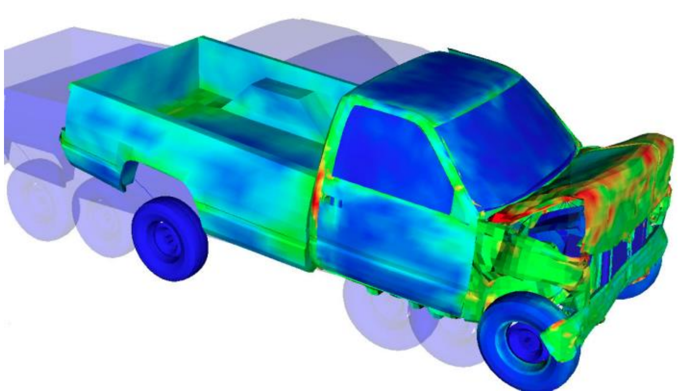
	Solid Mechanics-Structural Analysis	Fluid Dynamics
Solved by	Finite Element Analysis	Computational Fluid Dynamics (CF

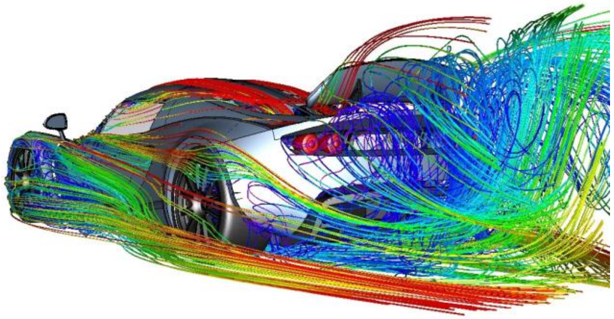




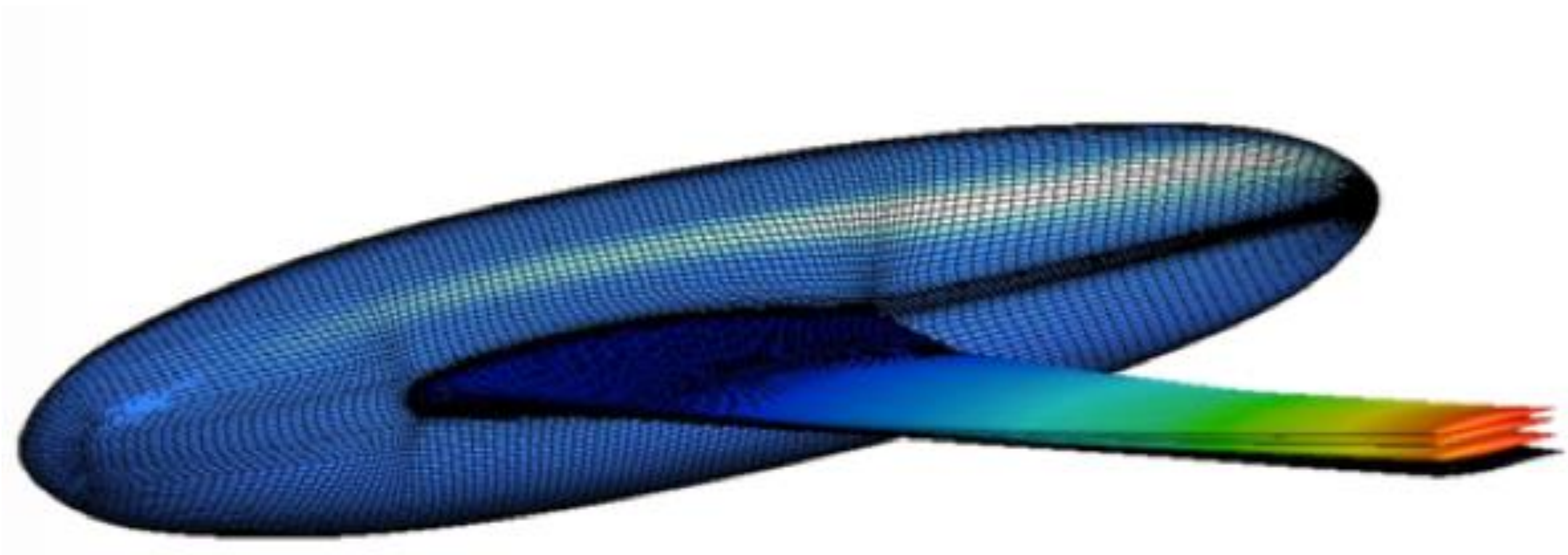








Recent Computational Methodology



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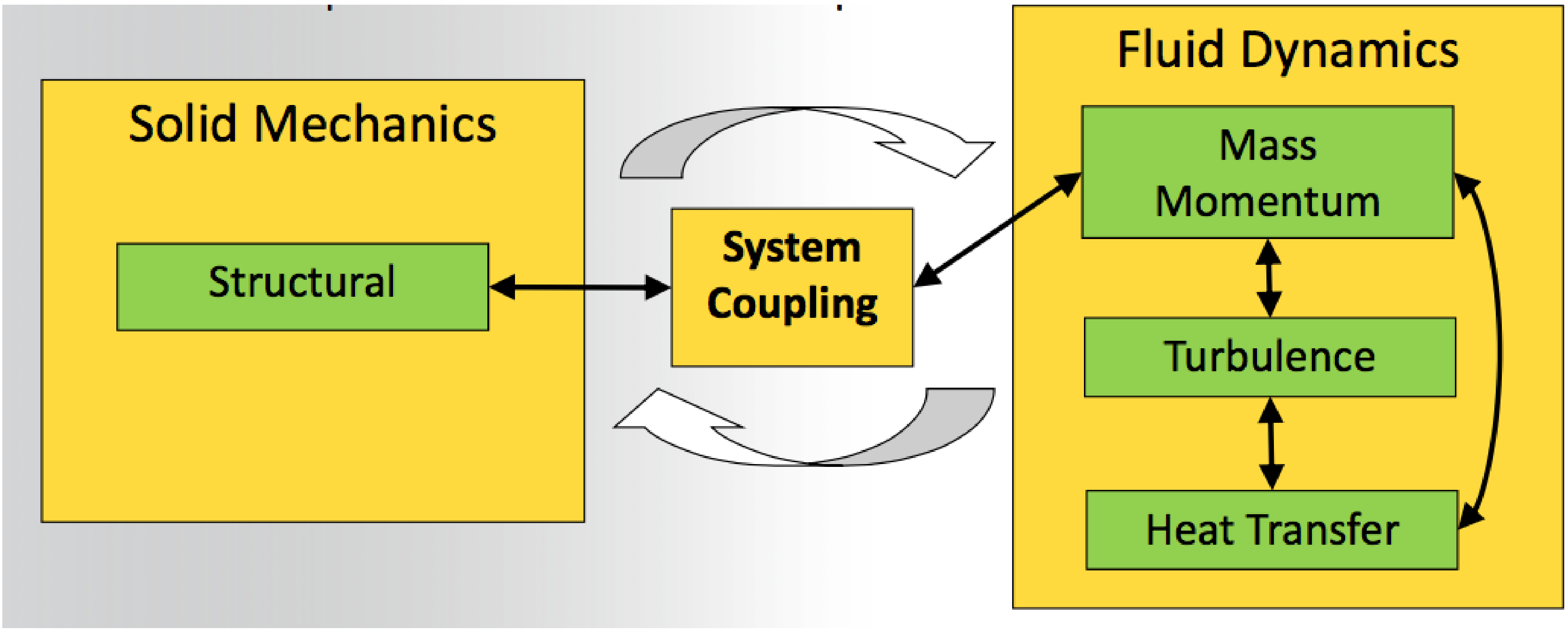
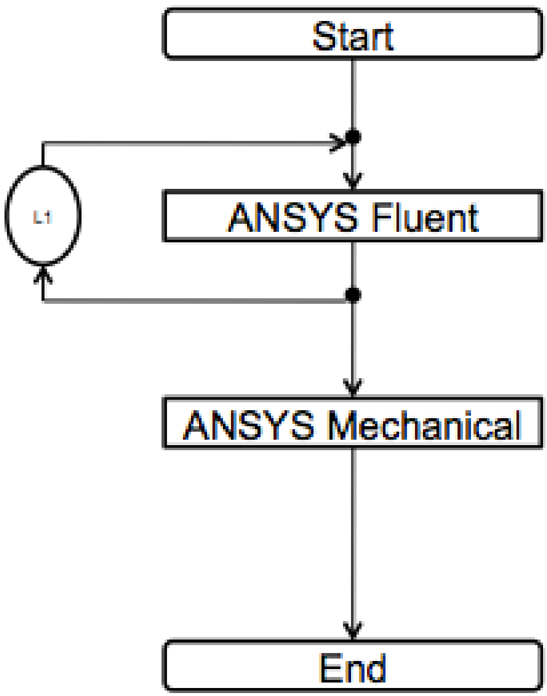
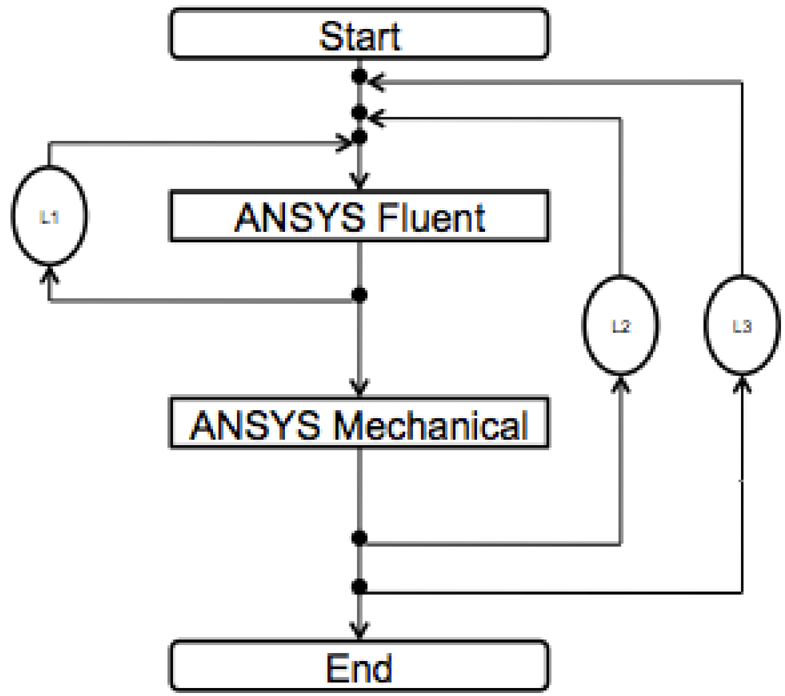


	Finite Element Analysis	Computational Fluid Dynamics (CFD)
Commercial Software	Ansys Mechanical, Abaqus	Ansys Fluent, Ansys CFX, open-foam

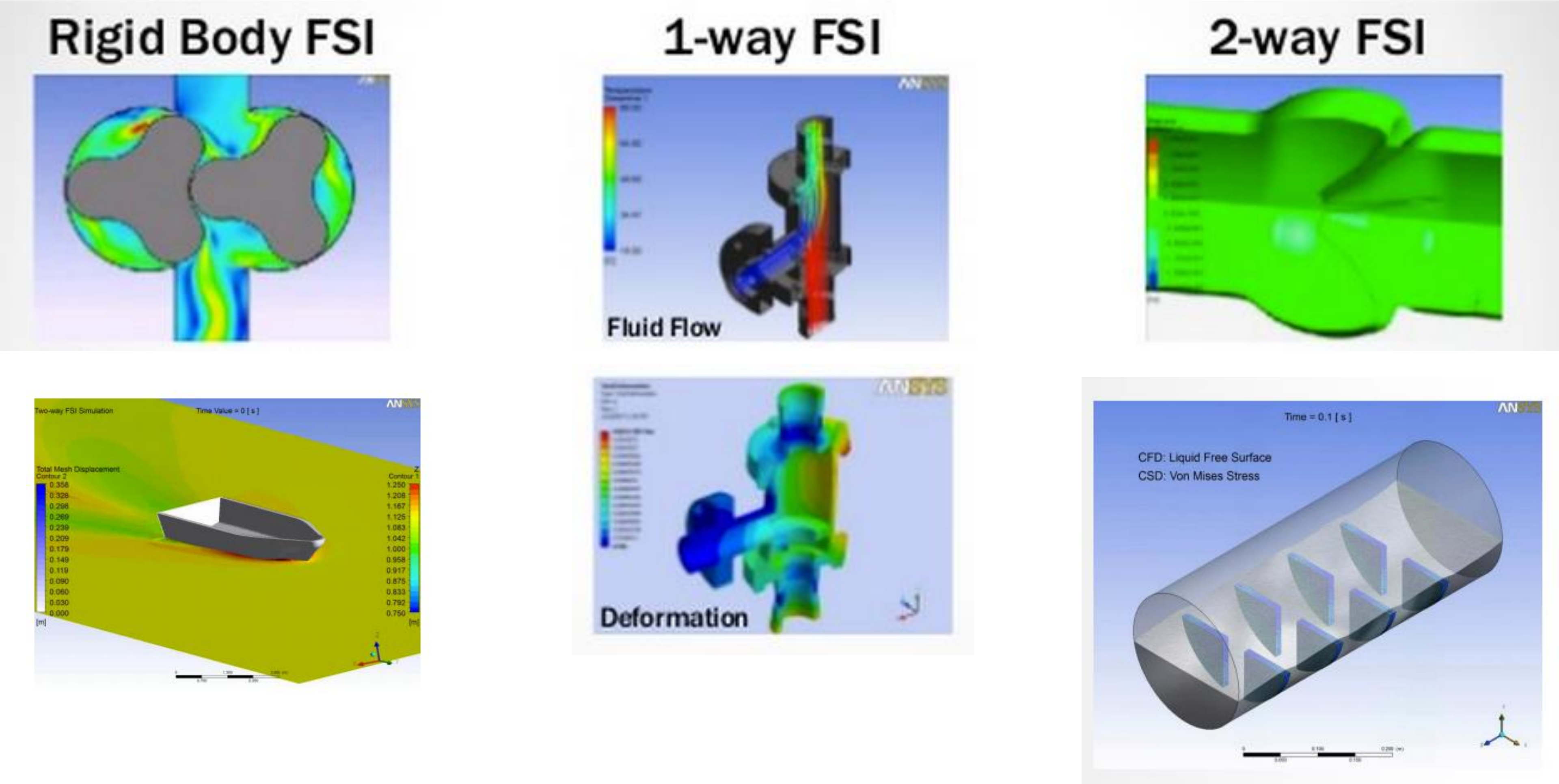
Recent Computational Methodology

1 way FSI vs Two way FSI



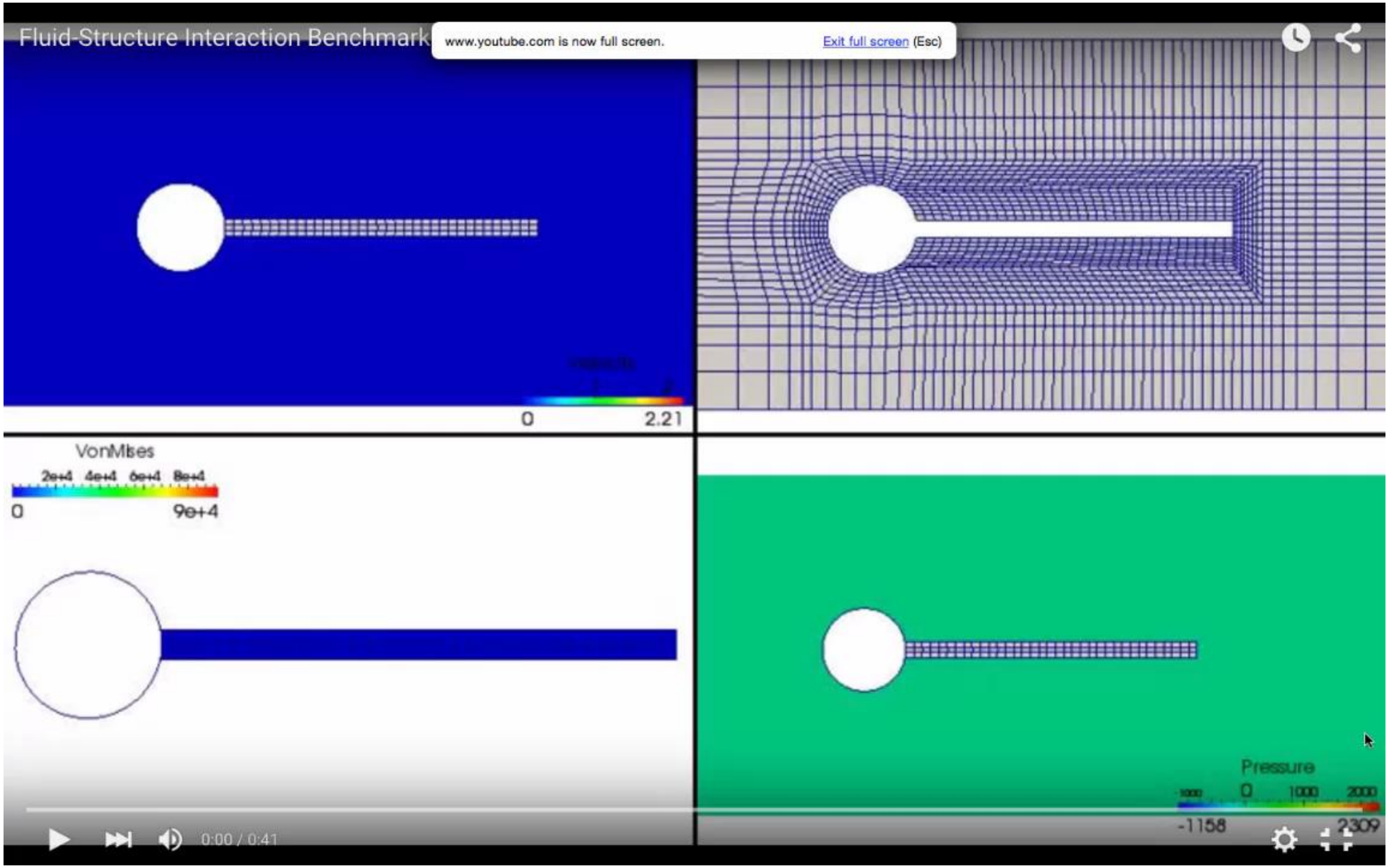


Recent Computational Methodology



Recent Computational Methodology

Turek-Hron Incompressible Fluid-Structure Interaction Benchmark problem



https://www.youtube.com/watch?v=mt2wv5P5zaY

F-35 Project

https://www.youtube.com/watch?v=7WnQROVmik4