SPC 407
Supersonic & Hypersonic Fluid Dynamics

Lecture 1

September 18, 2016

Course Materials

drahmednagib.com

Course Materials

piazza.com/alexu.edu.eg/fall2016/spc407

Google Form

https://goo.gl/forms/jaT0P0FmSgkSCgz33

COURSE OUTLINE

COURSE OUTLINE

- Introduction to Experimental Aerodynamics
- Introduction to Compressible Flow
- Conservation Equations for Inviscid Flows
- One Dimensional Flow
- One Dimensional Flow with Heat Addition and Friction
- Oblique Shocks
- Expansion Waves
- Quasi-One-Dimensional Flow
- Numerical techniques for Steady Supersonic Flow
- Hypersonic Flow
- Properties of High-Temperature Gases
- High-Temperature Flows: Basic Examples
- Computational Fluid Dynamic Solutions of Hypersonic Flows

Grades Distribution

- Homework Assignments (10%).
- Matlab and Fluent Assignments (15%).
- Midterms (30%) (2 Midterms).
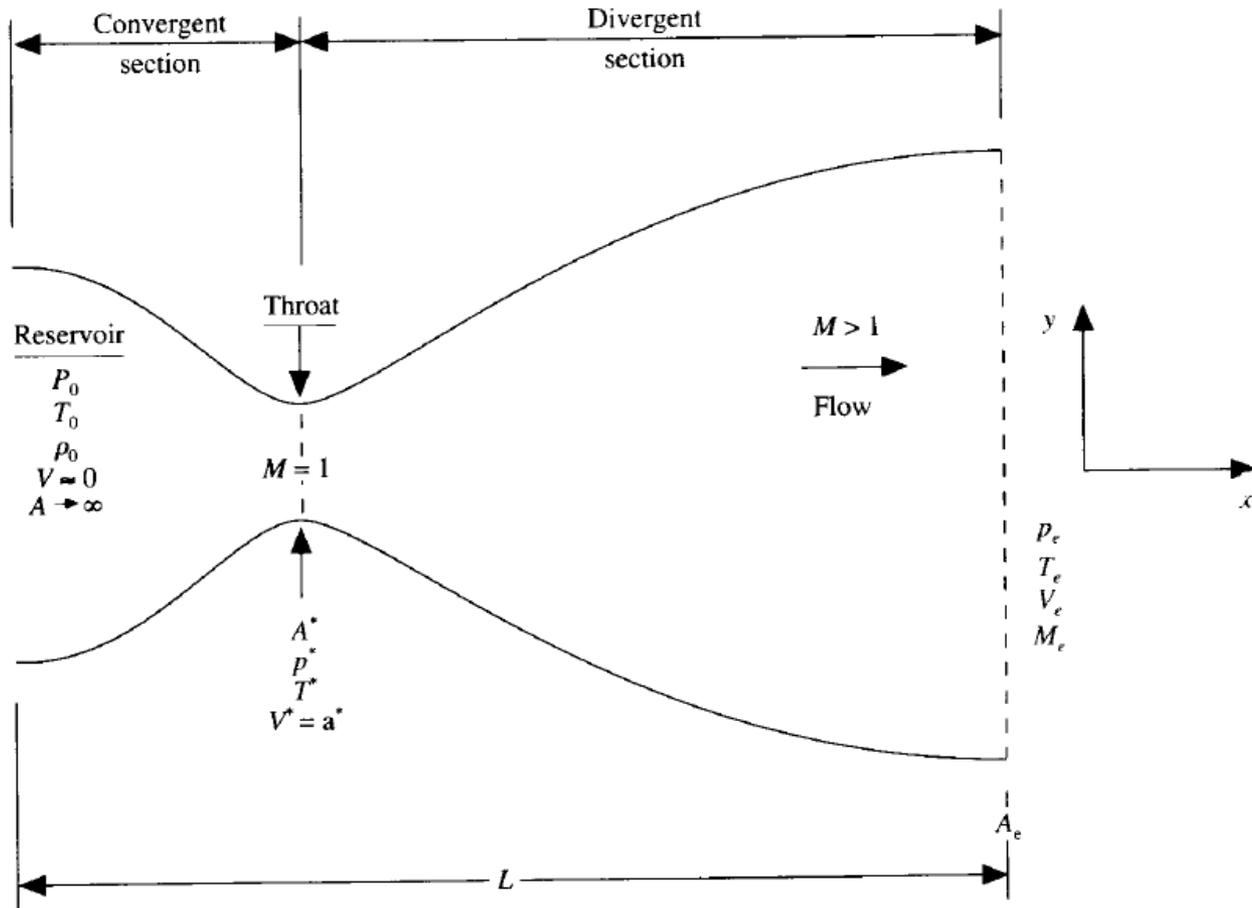- Project (15%).
- Final Exam (30%).

Matlab Assignment

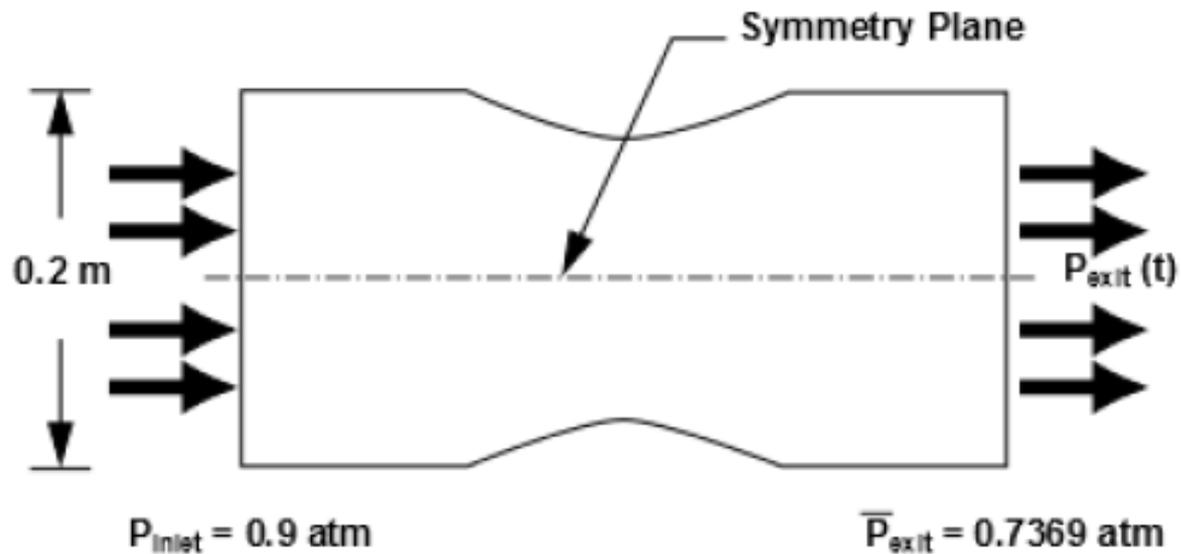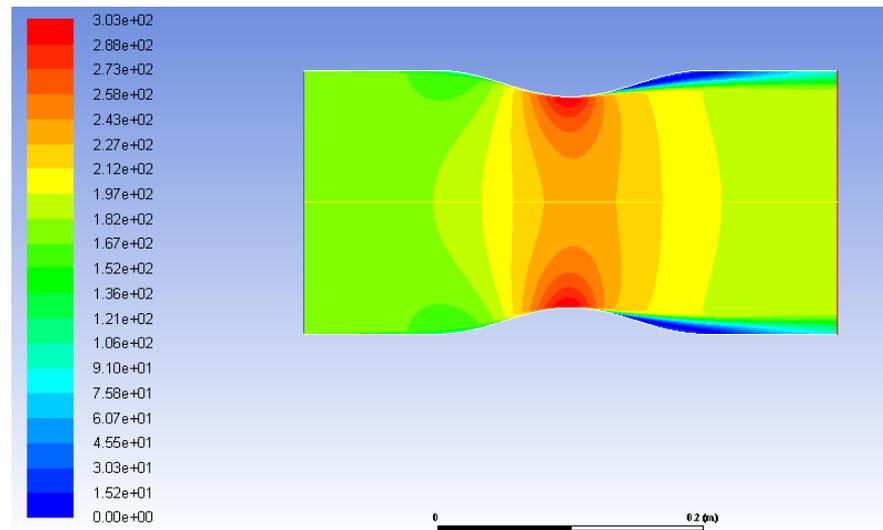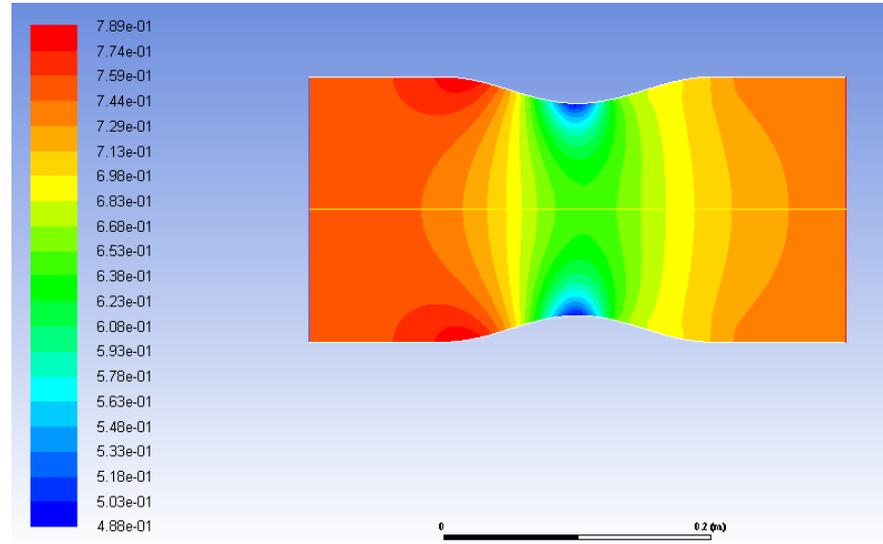**FIG. 7.1**
Schematic for subsonic-supersonic isentropic nozzle flow.
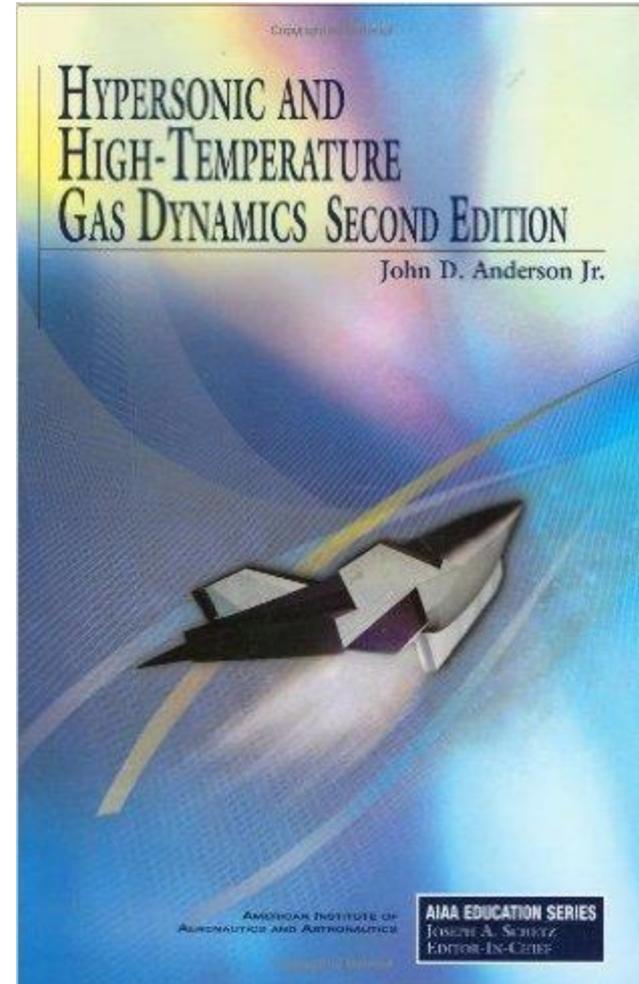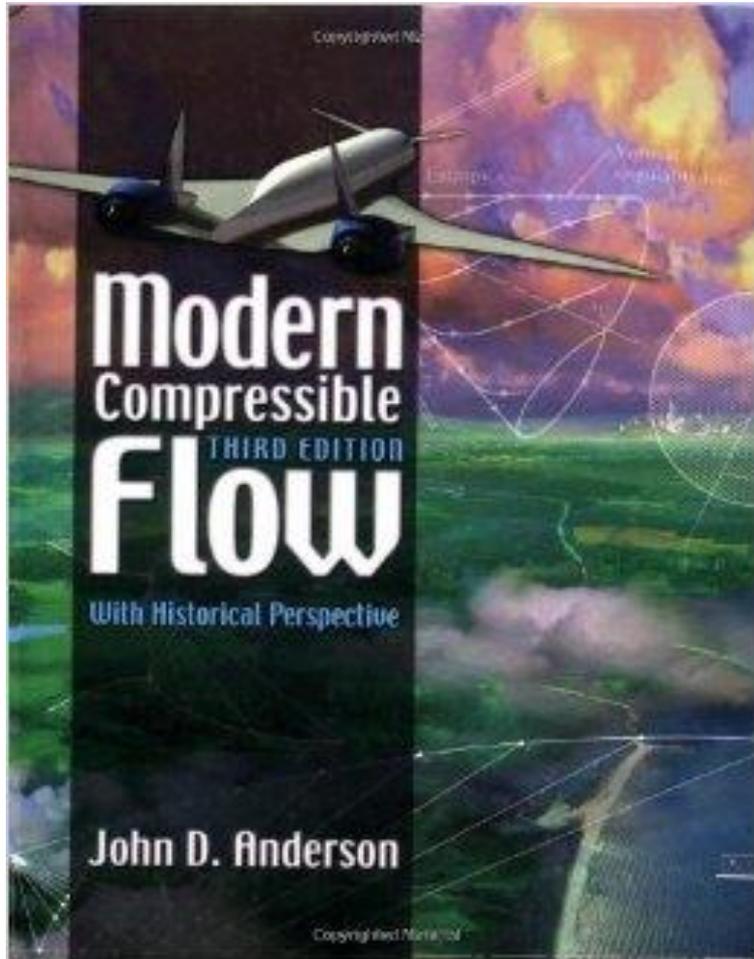
Fluent Assignment

Figure 6.1: Problem Specification

Symmetry Plane

0.2 m

P_{exit} (t)

P_{Inlet} = 0.9 atm

$\overline{P}_{exit}$ = 0.7369 atm

Fluent Assignment

References

Introduction to Experimental Aerodynamics

Wind Tunnel

ODU Low Speed Wind Tunnel – KH 143

Flow conditioning

Air return

Drive power – 125 H.P.
Turbulence level – 0.2%

Fan

Low-speed test section

- 7 by 8 feet, 7 feet long
- Max speed 12 m/s (25 mph)

High-speed test section

- 3 by 4 feet, 8 feet long
- Max speed 55 m/s (120 mph)
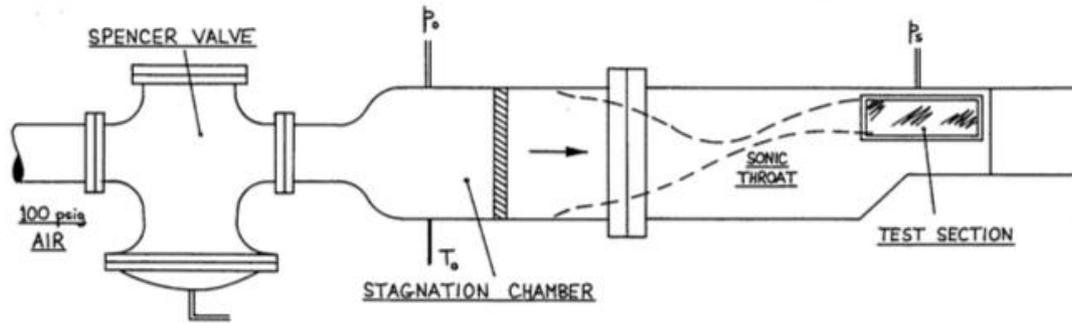
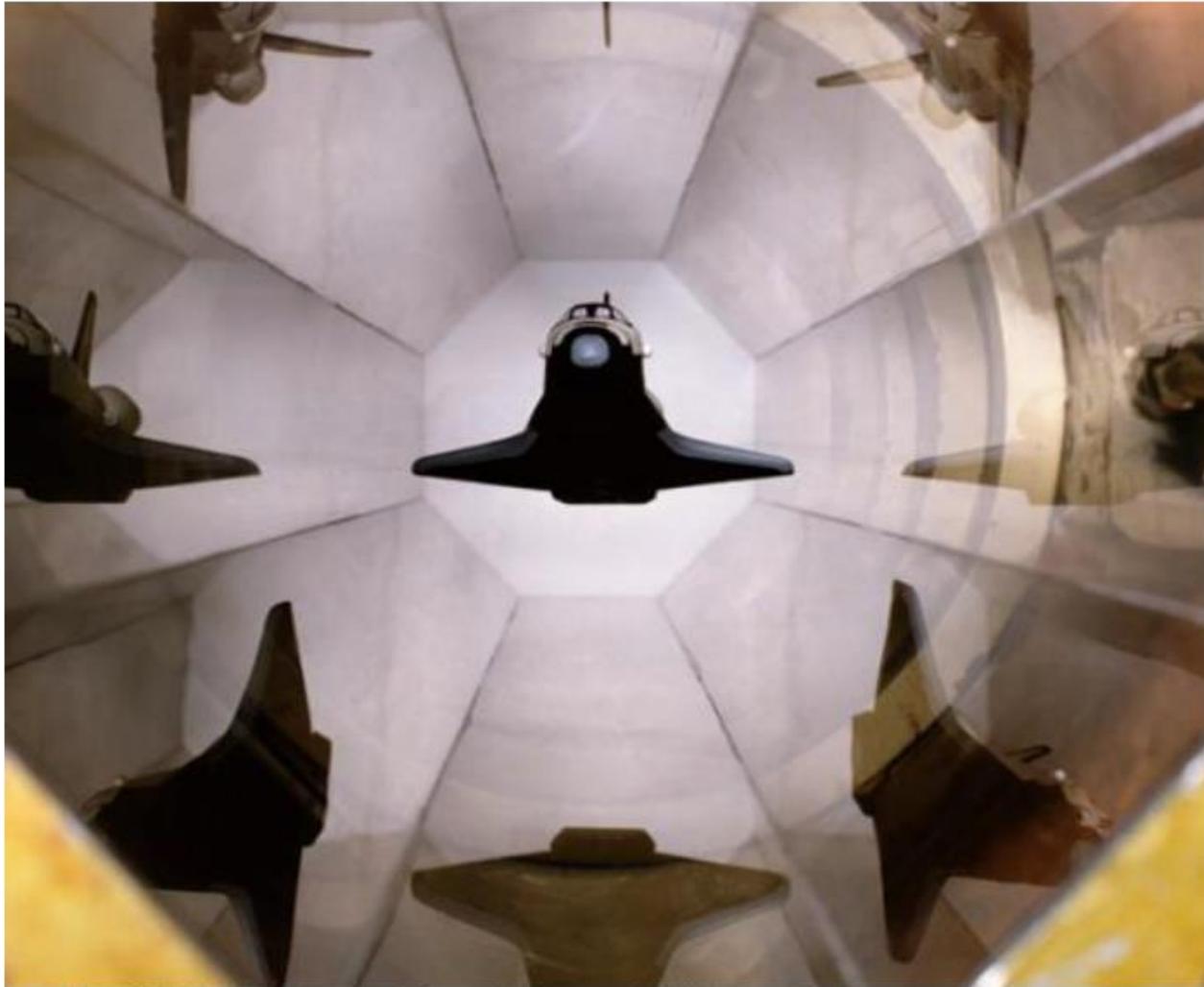Motor and speed control
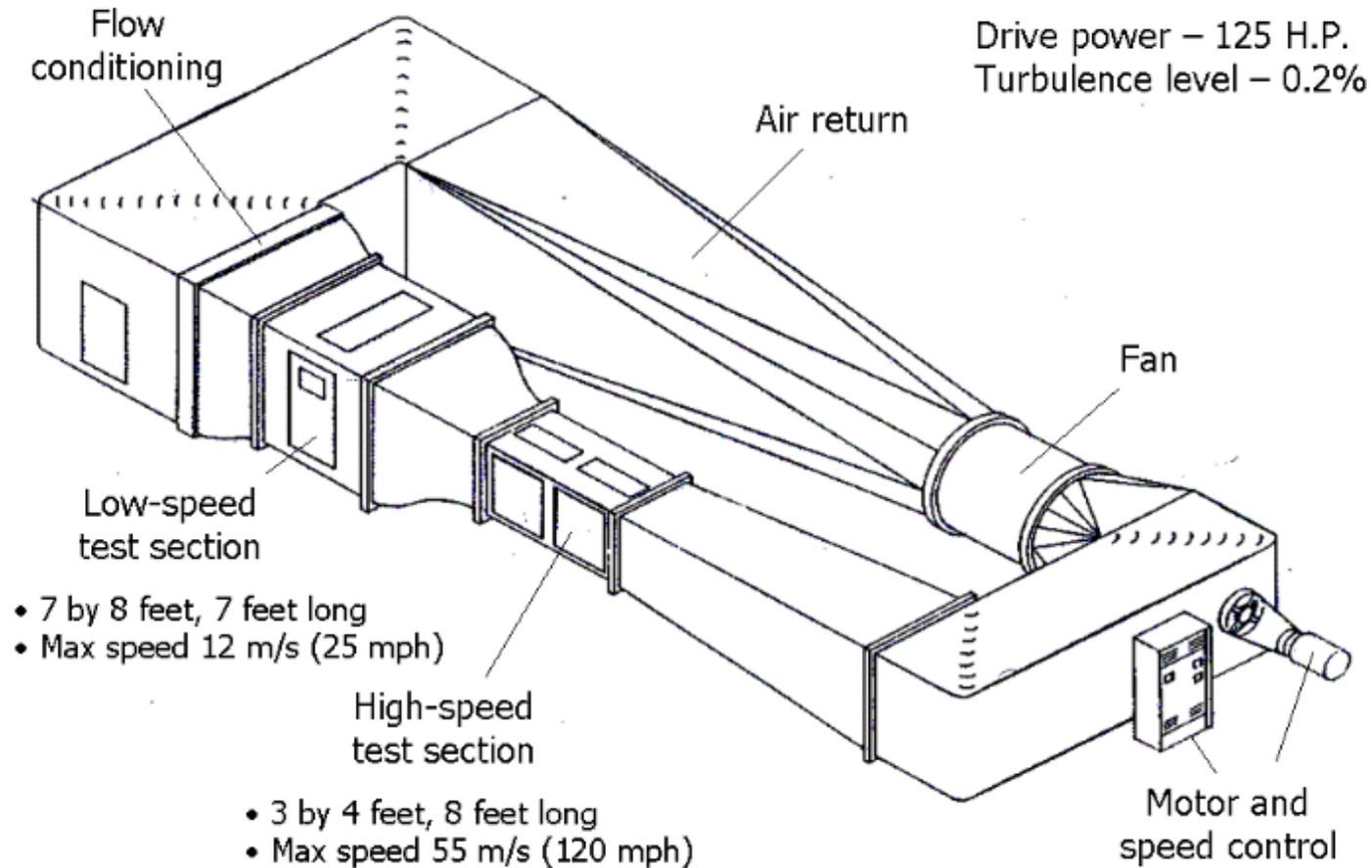
Wind Tunnel

Wind Tunnel

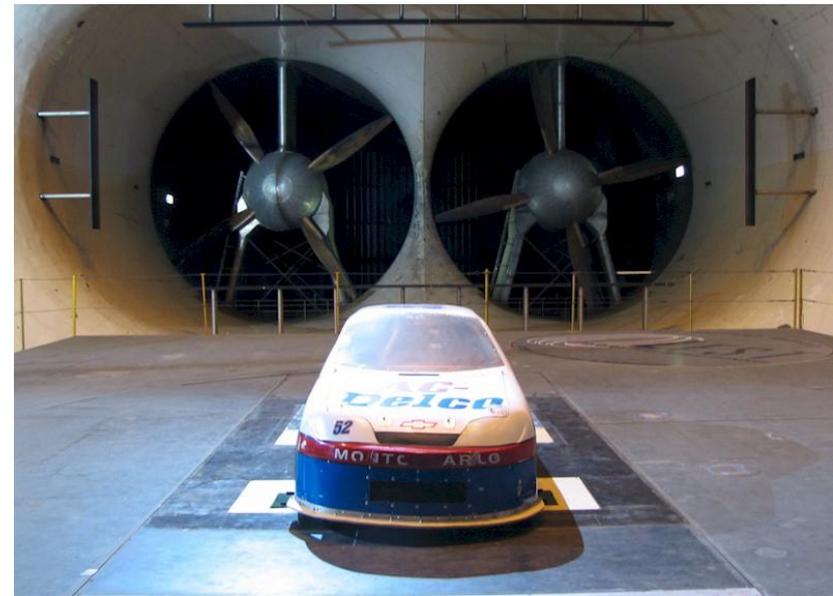ODU Supersonic Wind Tunnel – KH 143

Wind Tunnel

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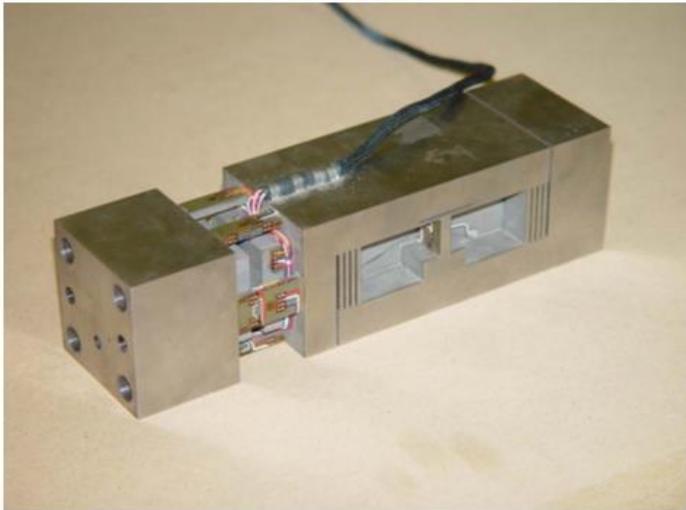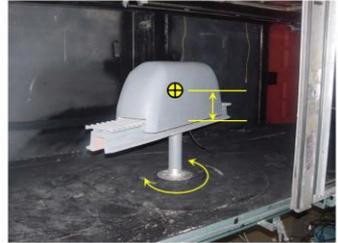
Wind Tunnel

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
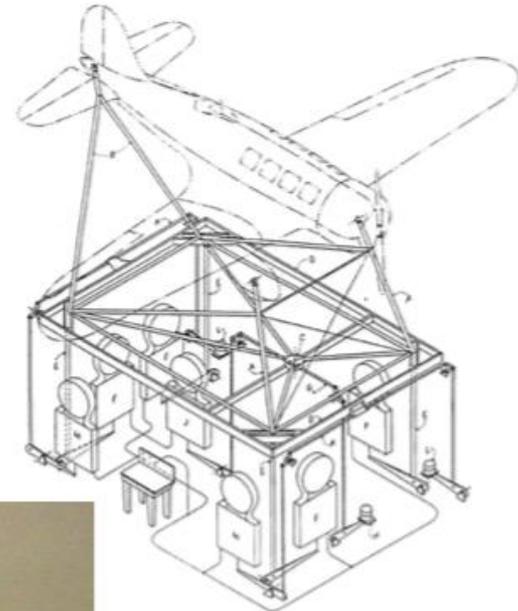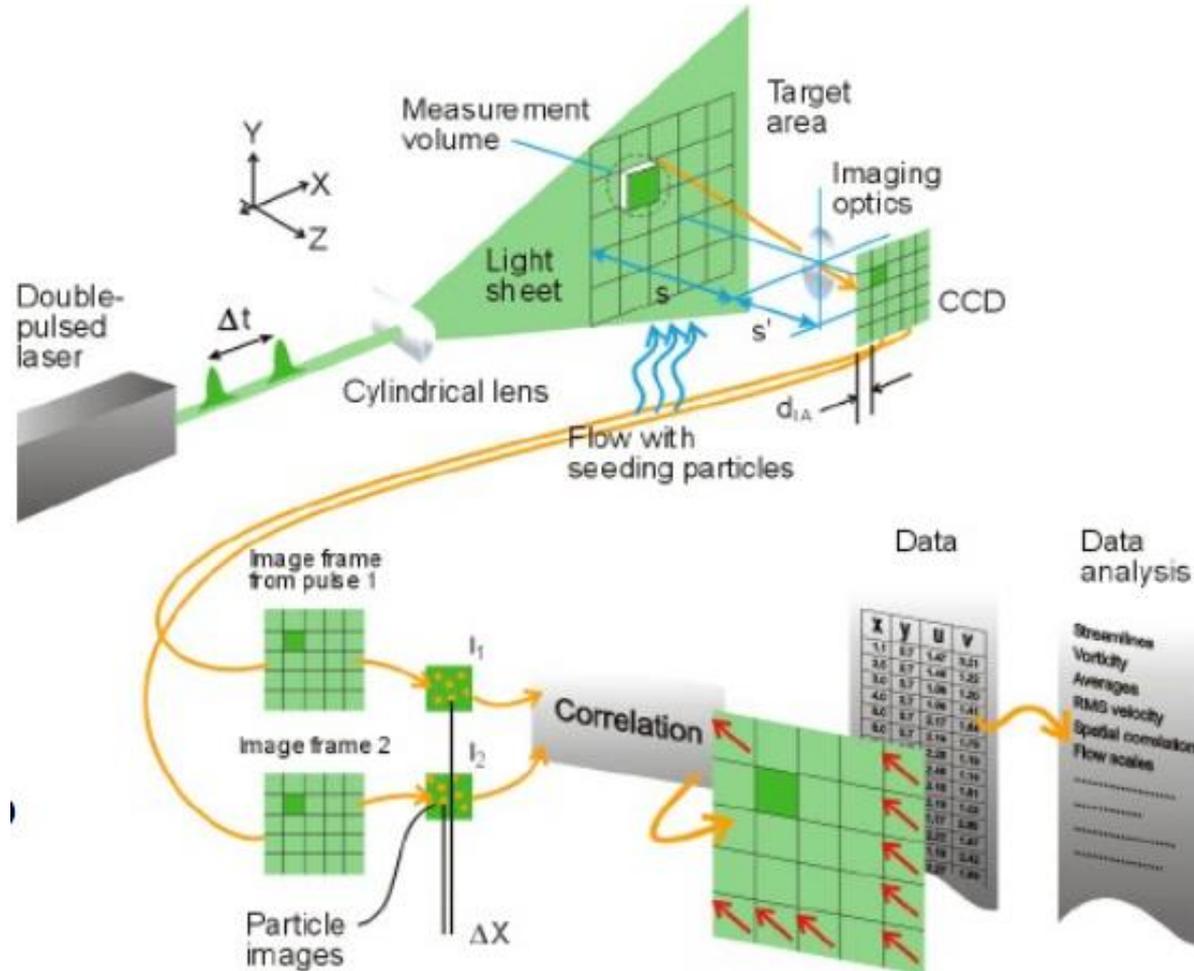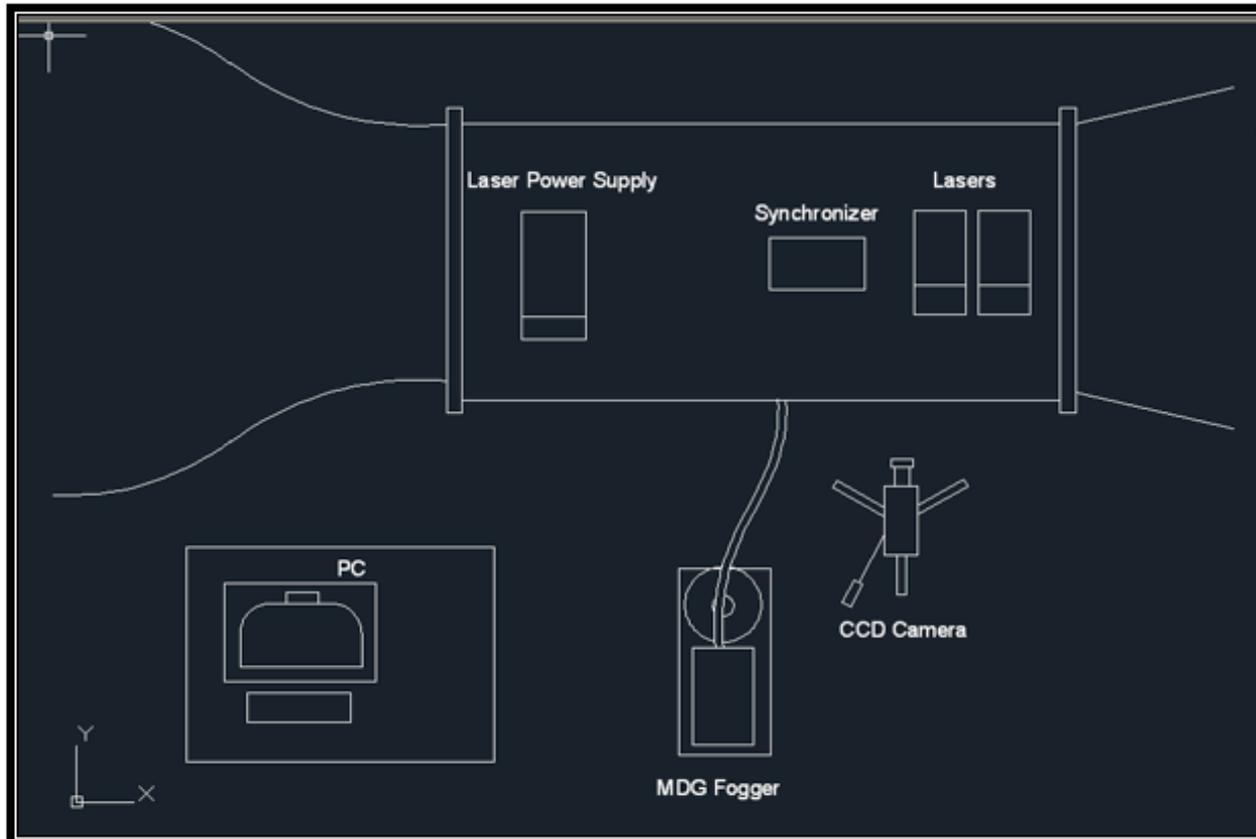- Below – U. Washington

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.

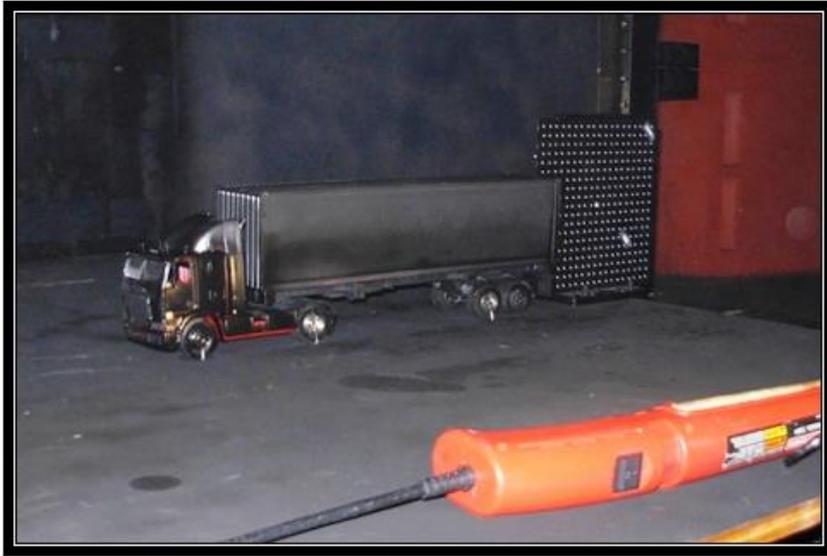# Particle Image Velocimetry (PIV)

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

Picture #3 dual Nd: YAG laser.

Particle Image Velocimetry (PIV)
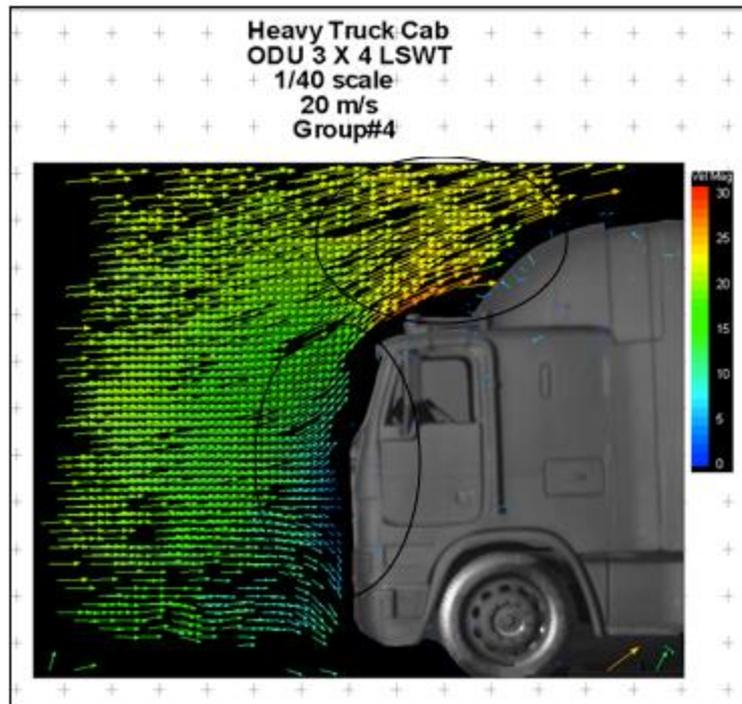

Picture #8 optics alignment target.
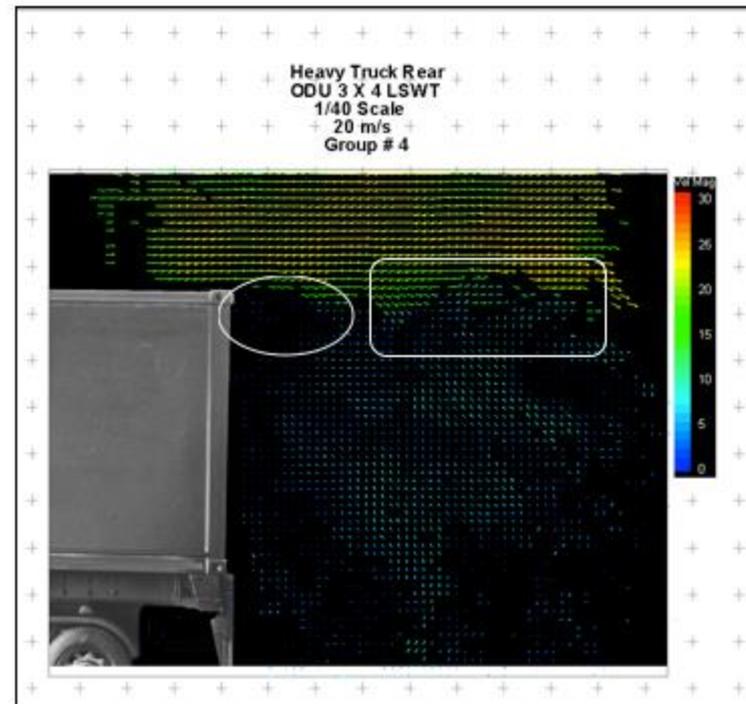

Picture #9 Layout.

Particle Image Velocimetry (PIV)
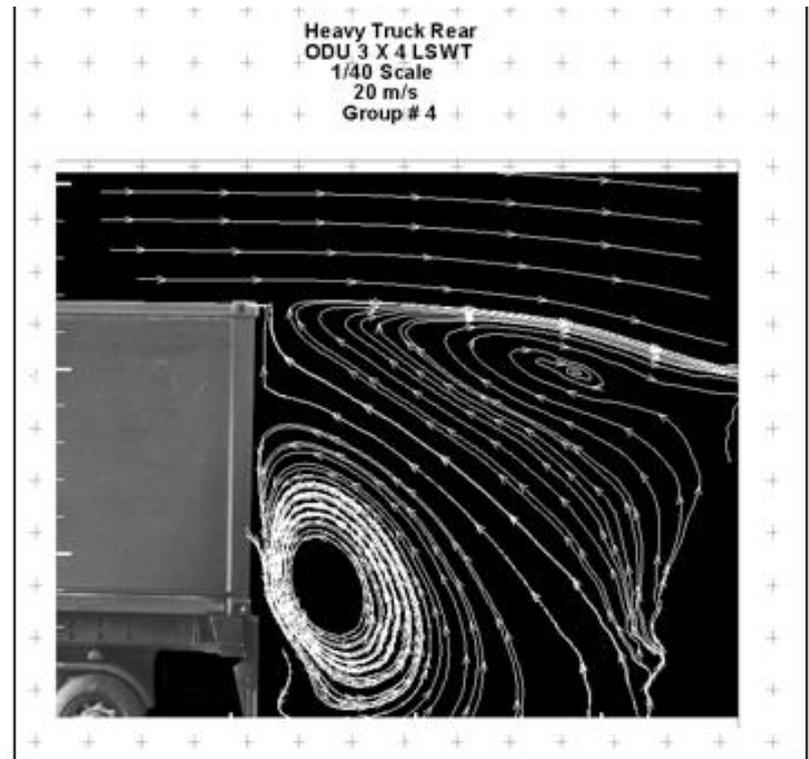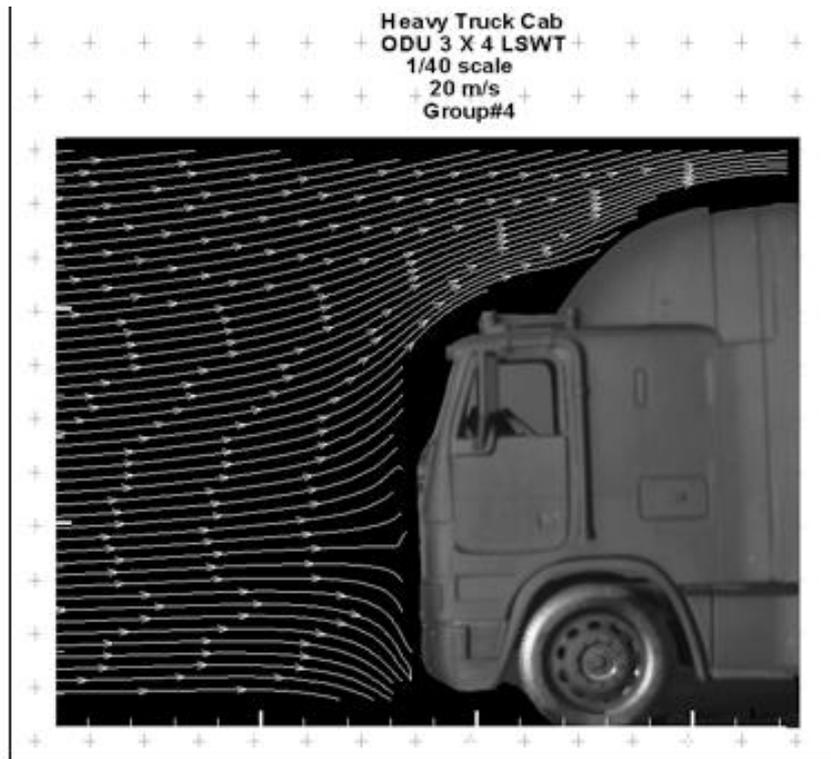
Particle Image Velocimetry (PIV)

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)
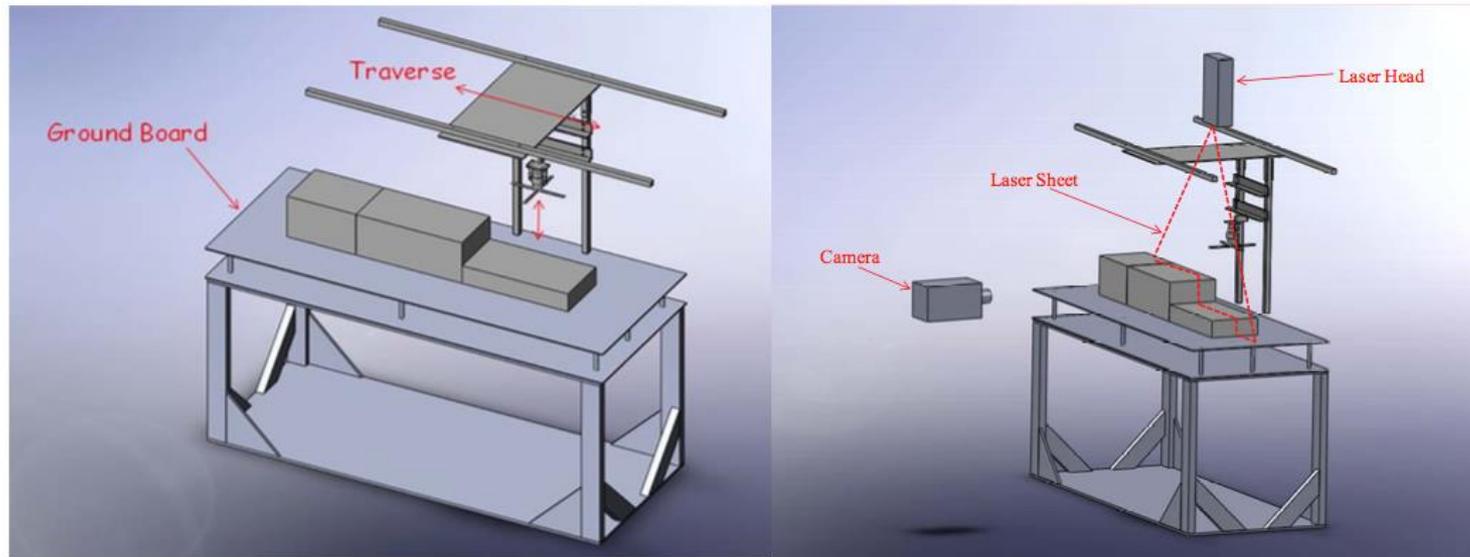
Particle Image Velocimetry (PIV)

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
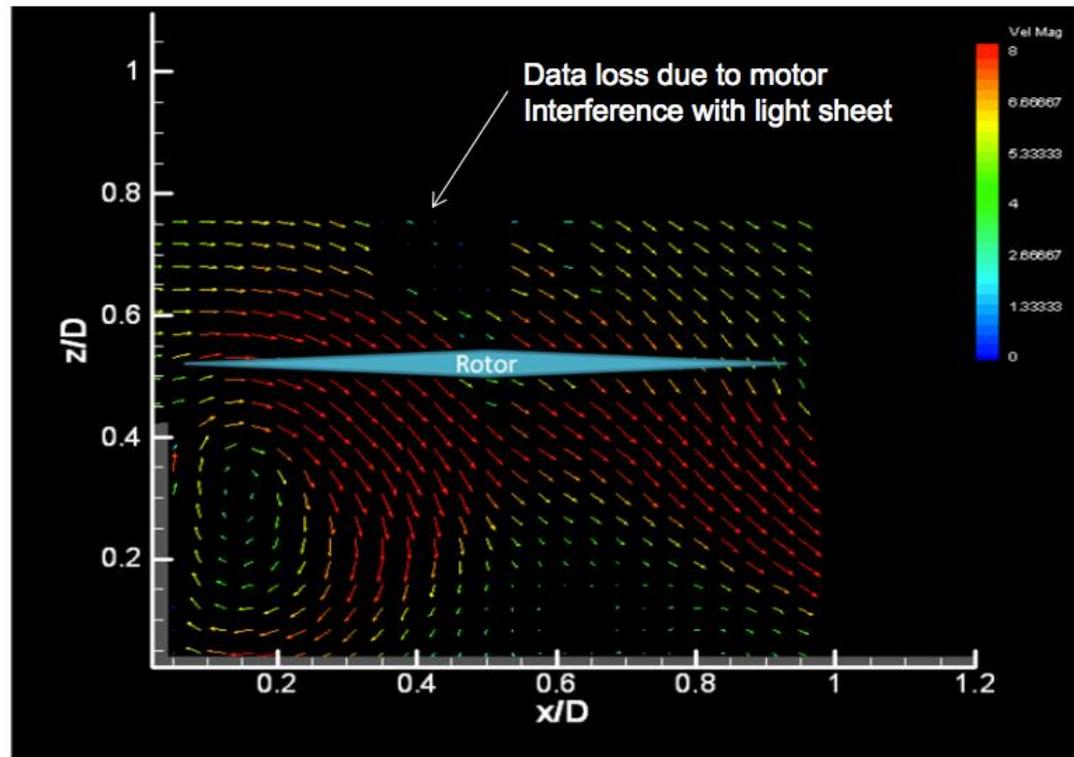 - Frigate and MH-60 Seahawk Helicopter
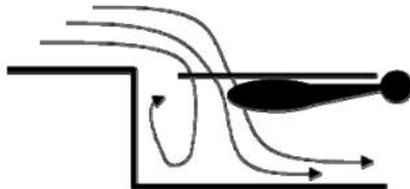
Particle Image Velocimetry (PIV)

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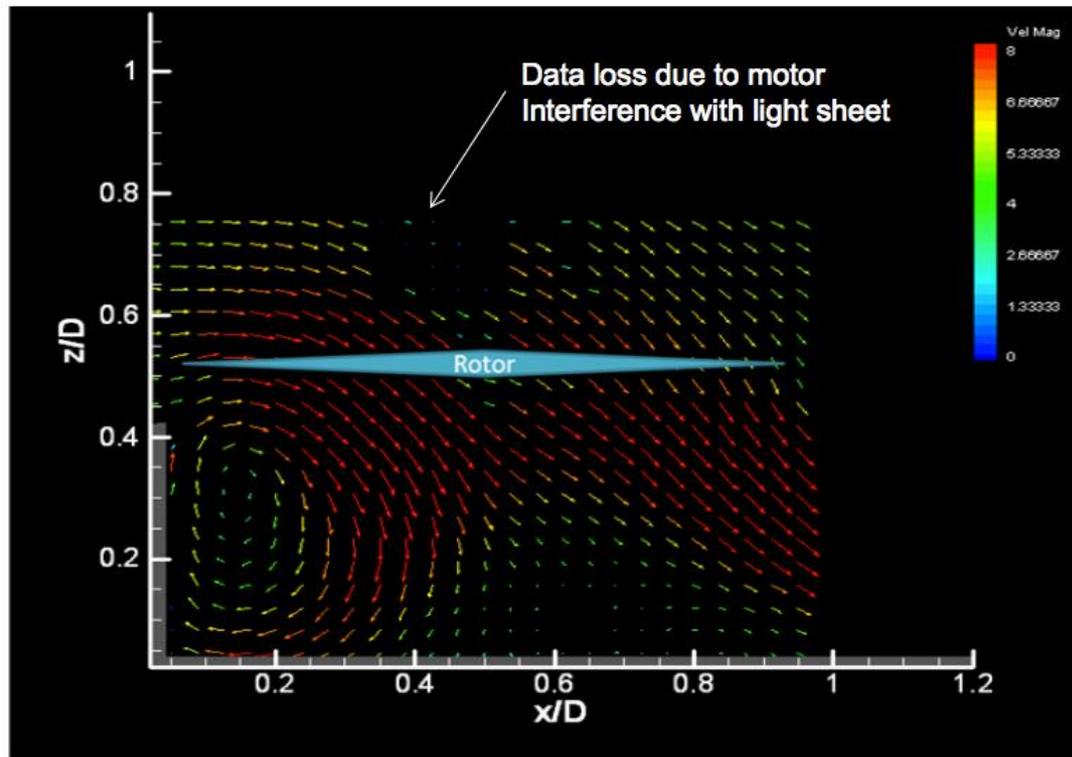- Side window allows camera to view laser sheet

Particle Image Velocimetry (PIV)
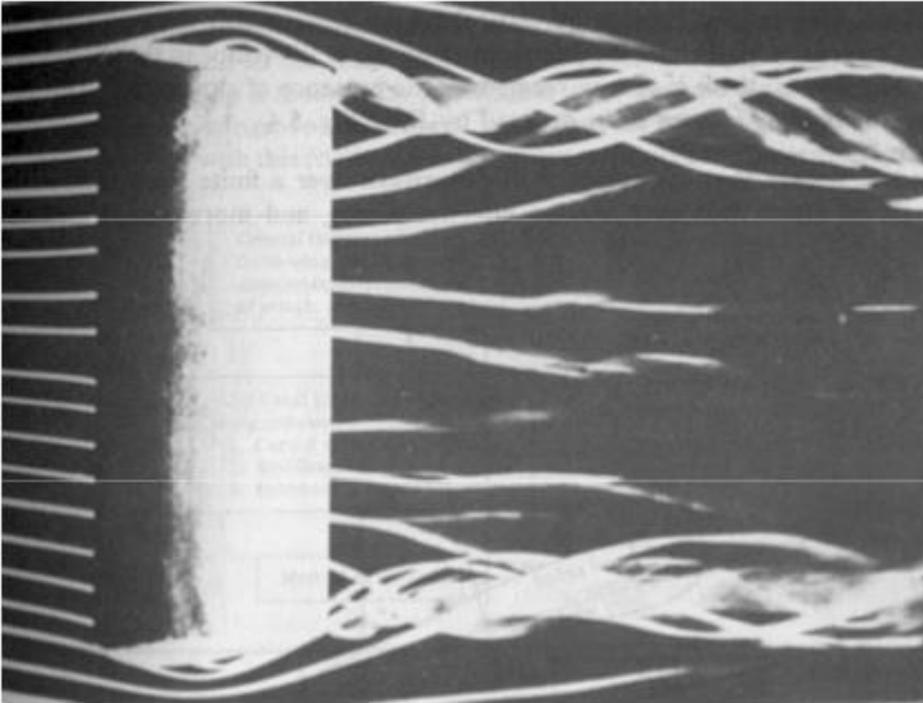
- Flow over landing deck with rotor
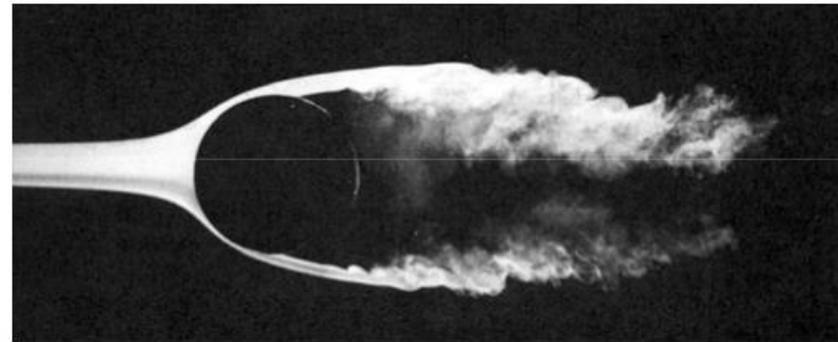
Particle Image Velocimetry (PIV)

- Flow over landing deck with rotor

Freestream Tracer Injection

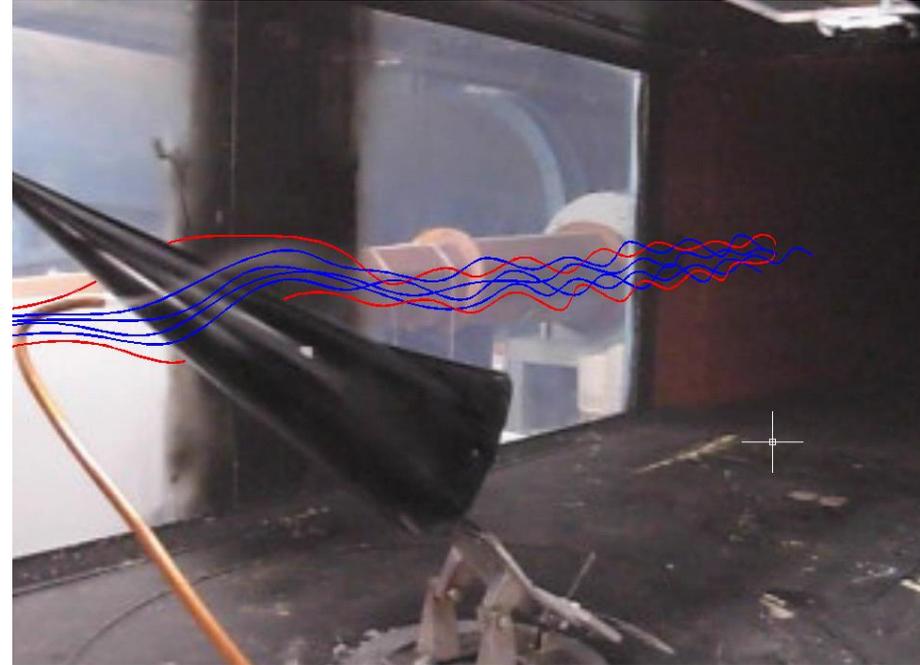Oil dripped on array of wires shows wingtip vortex

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

Freestream Tracer Injection
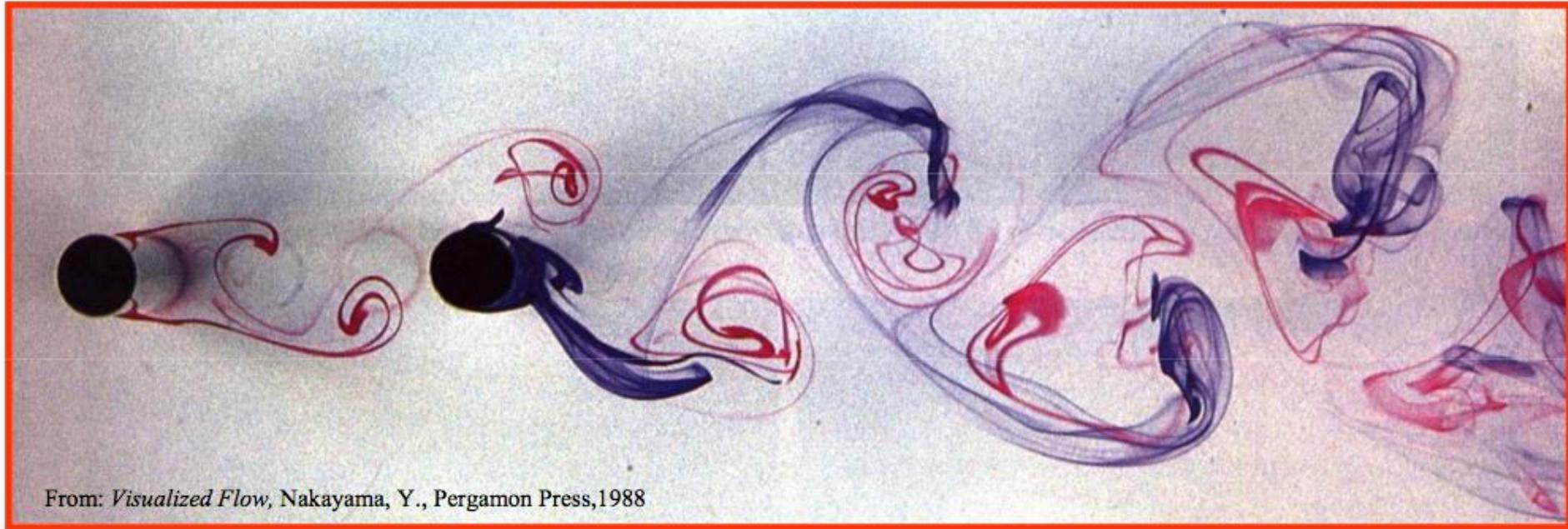## Propylene Glycol "Smoke" Generator

Wand used with full- scale automotive testing

Freestream Tracer Injection
Propylene Glycol "Smoke" Generator

Forebody

Freestream Tracer Injection
Hydrodynamic (Dye)

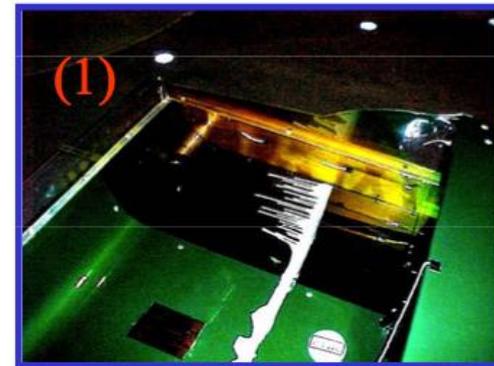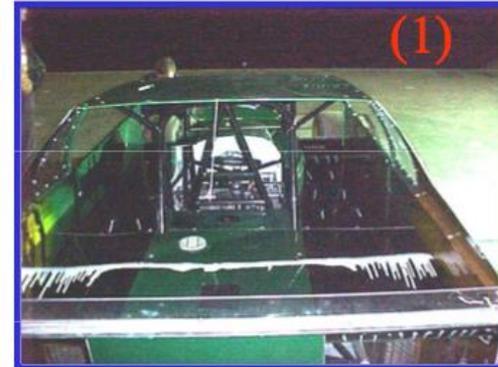From: *Visualized Flow,* Nakayama, Y., Pergamon Press,1988

Karman vortex street following two cylinders

Freestream Tracer Injection
Oil FLow

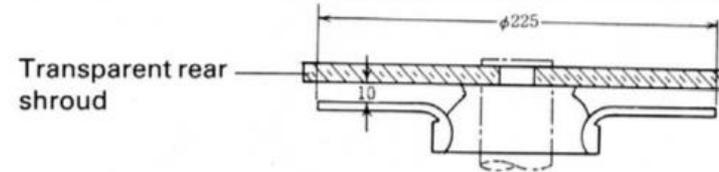Oil film stripe on automobile body panels

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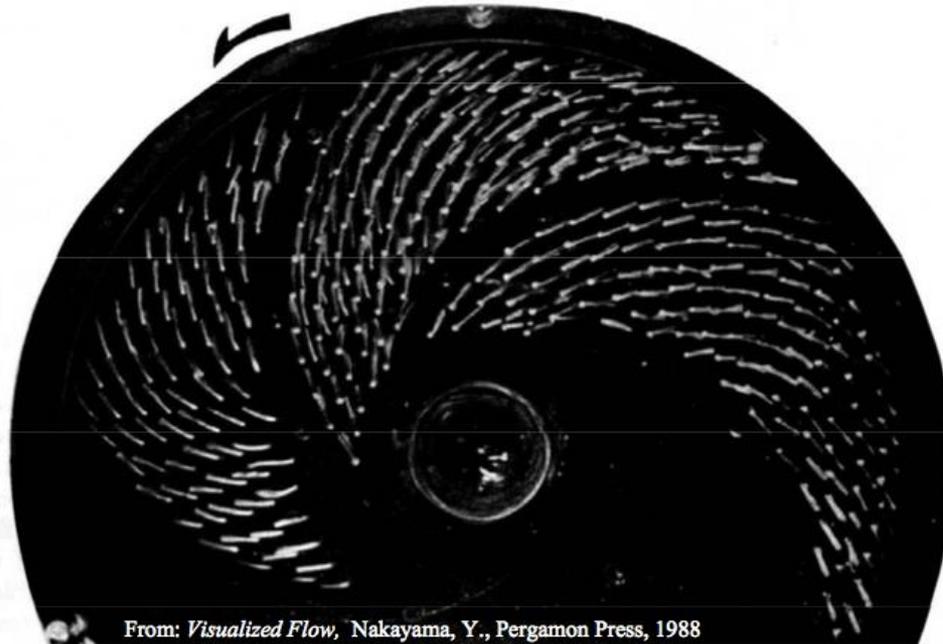
Freestream Tracer
Tufts

Procedure and materials are similar to aerodynamic methods
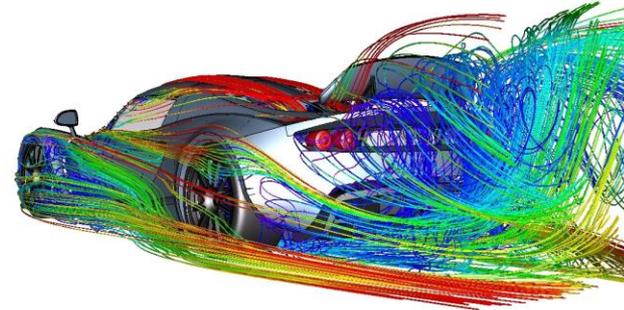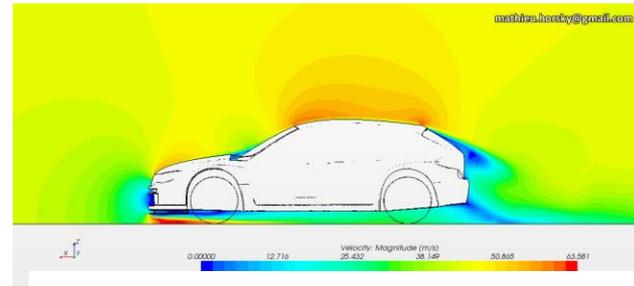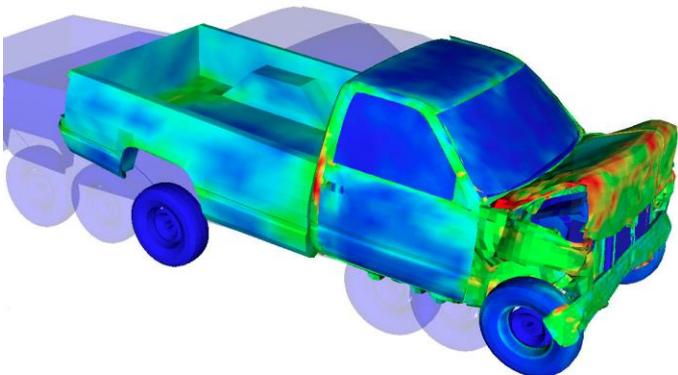
Example:
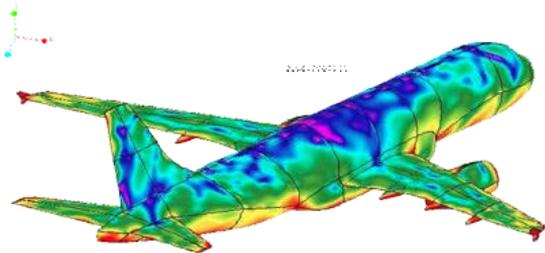pump impeller rotating at 1200 rpm in water

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

Recent Computational Methodology

Recent Computational Methodology

	Solid Mechanics-Structural Analysis	Fluid Dynamics
Solved by	Finite Element Analysis	Computational Fluid Dynamics (CF
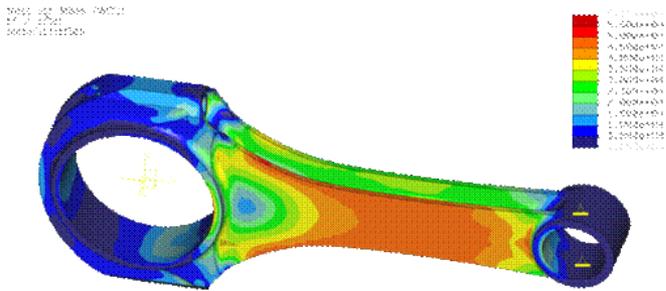
Recent Computational Methodology
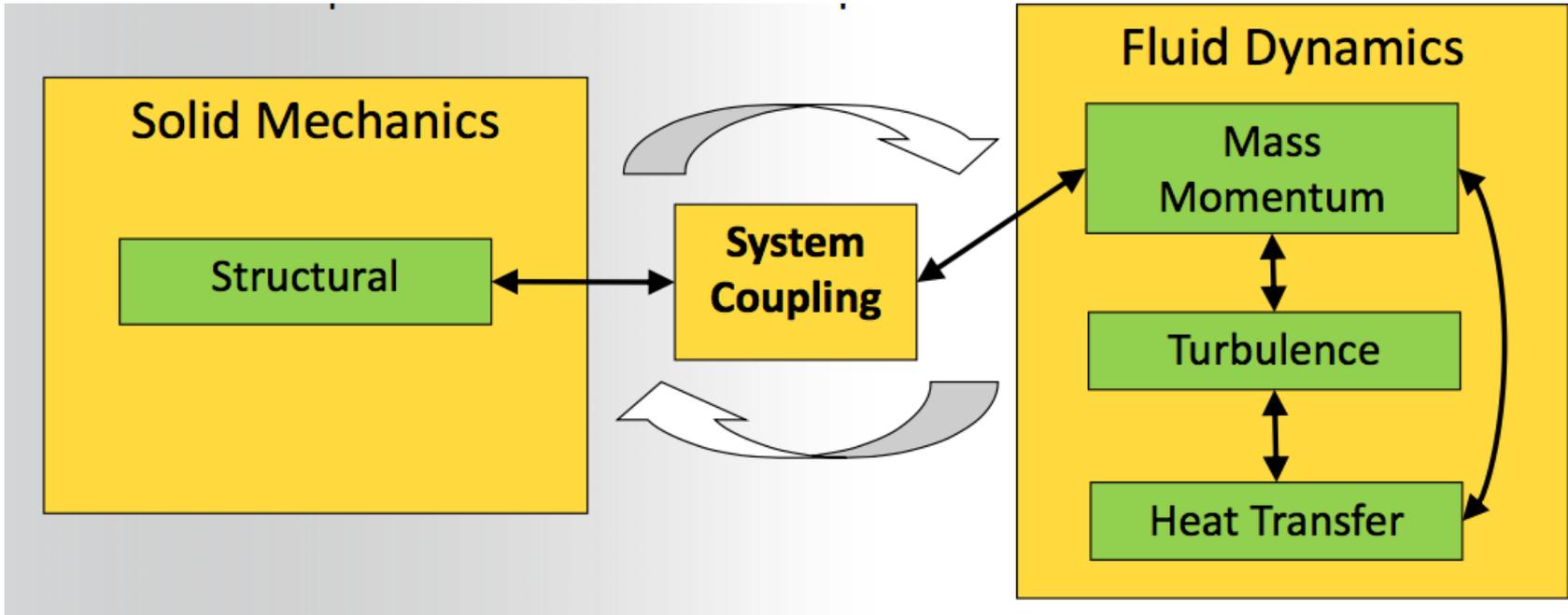
	Finite Element Analysis	Computational Fluid Dynamics (CFD)
Commercial Software	Ansys Mechanical, Abaqus	Ansys Fluent, Ansys CFX, open-foam

Recent Computational Methodology

1 way FSI   vs   Two way FSI

Recent Computational Methodology
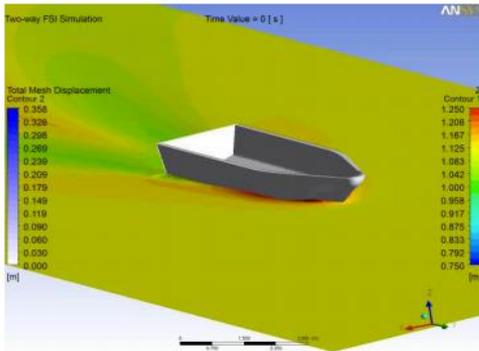
Recent Computational Methodology

Recent Computational Methodology

Turek-Hron Incompressible Fluid-Structure Interaction Benchmark problem

Video Link

F-35 Project
[Video Link](#)

Course Overview

Course Overview

COMPRESSIBLE FLOW

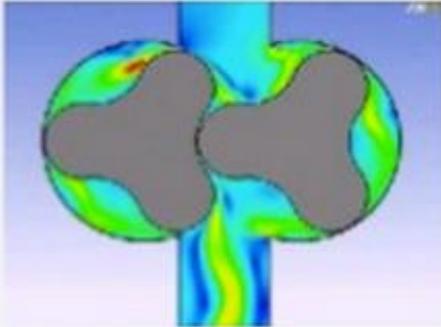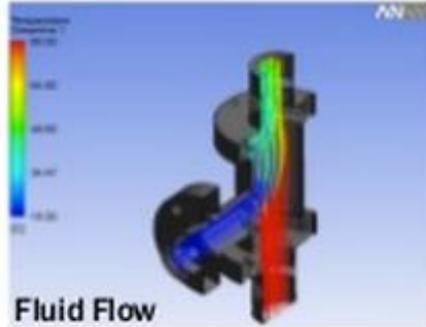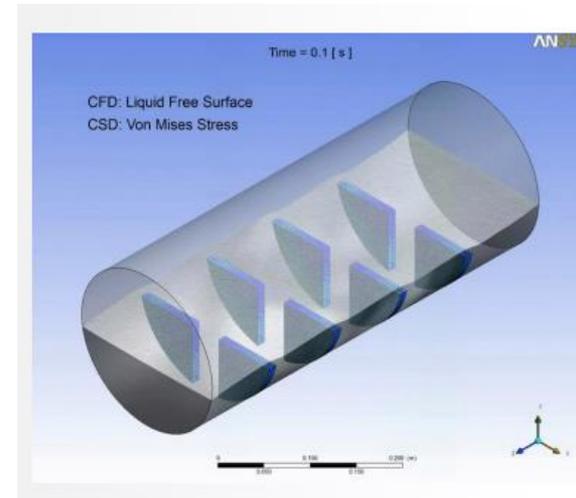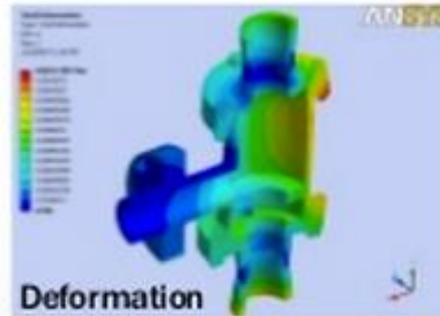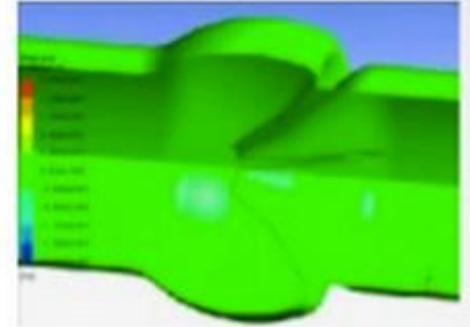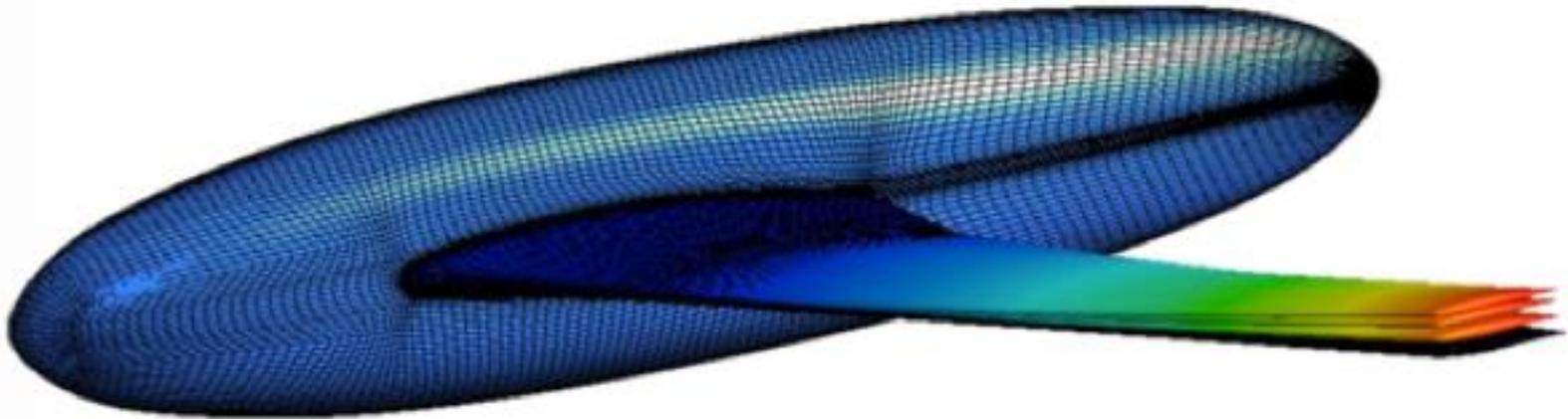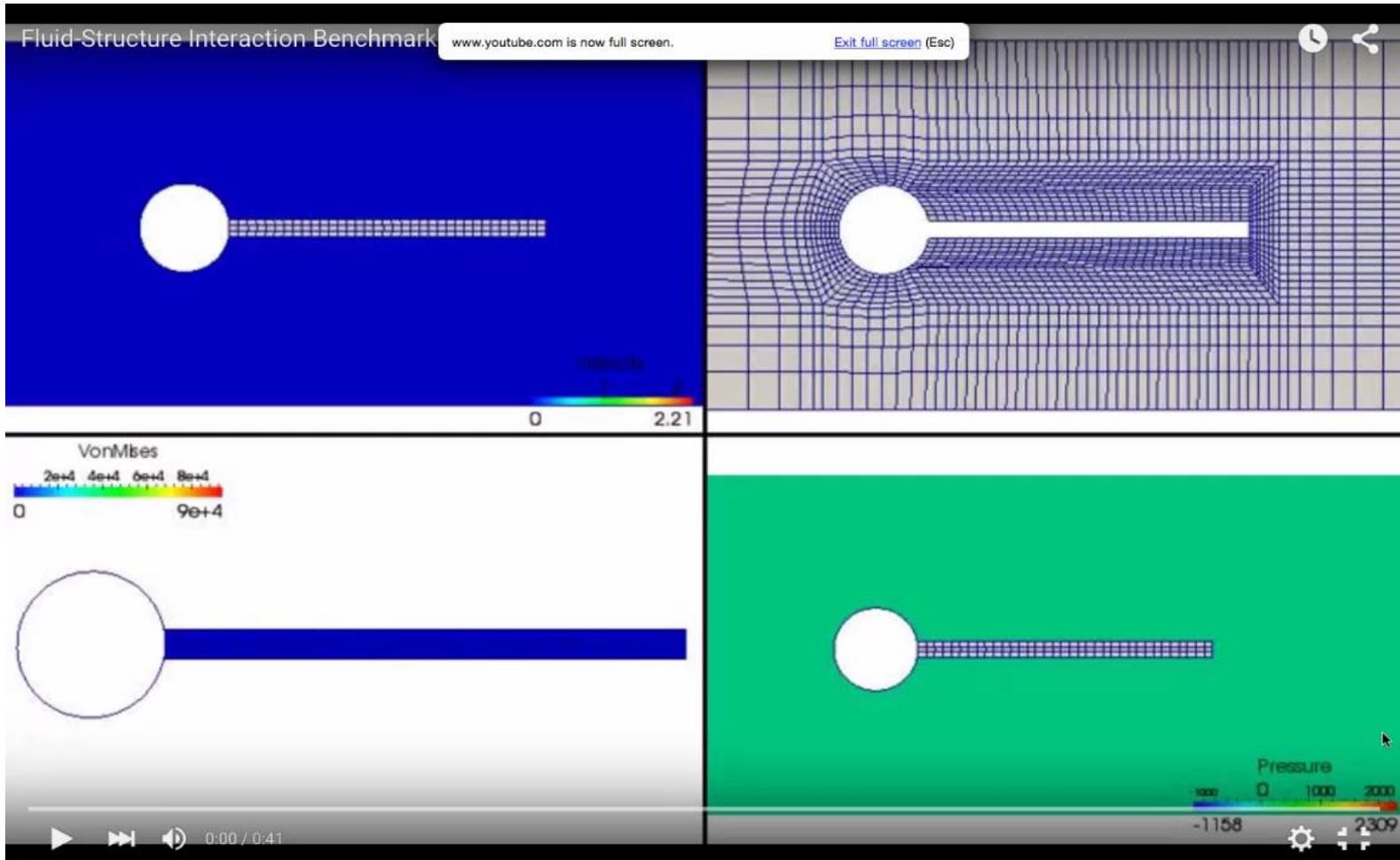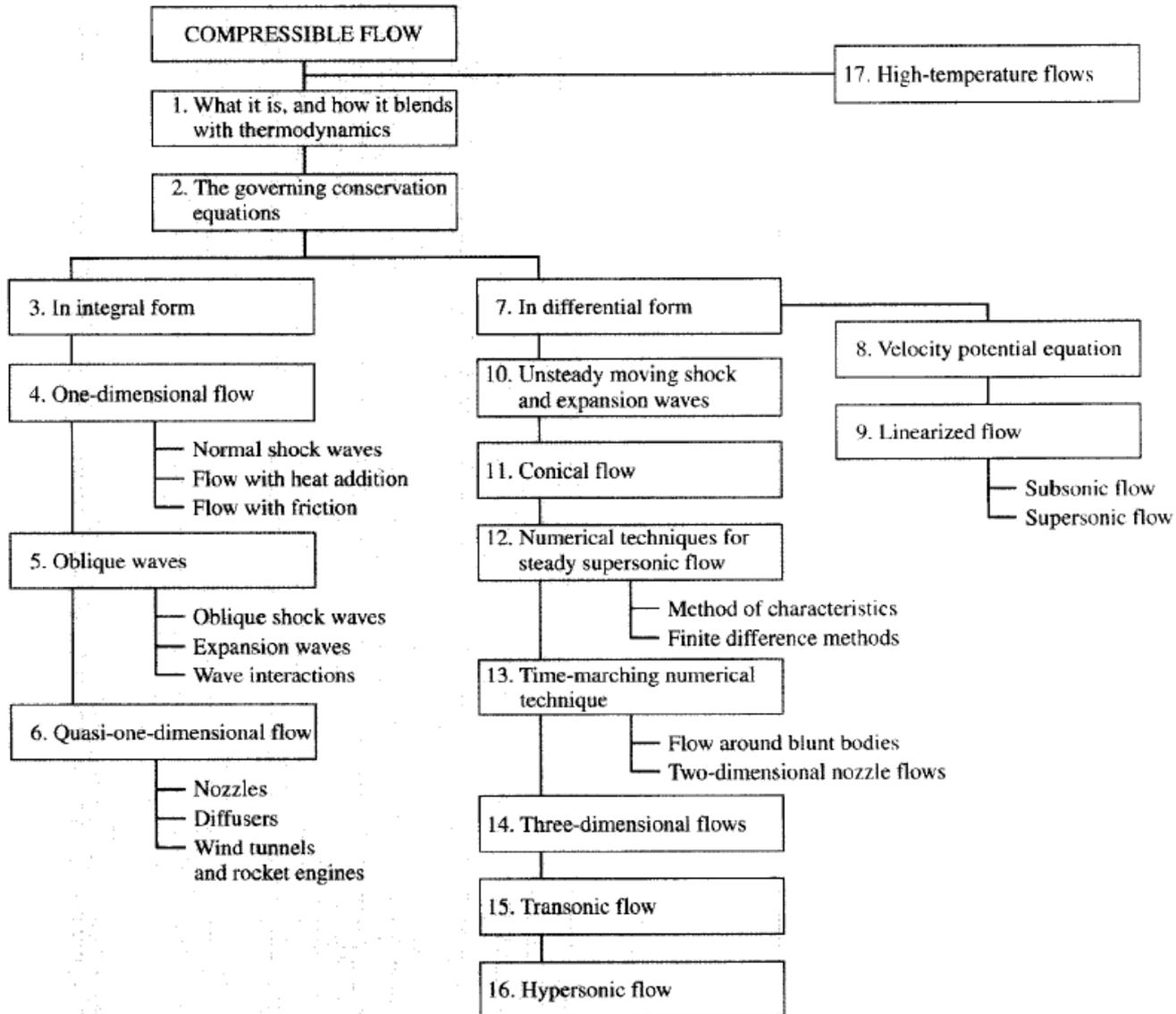1. What it is, and how it blends with thermodynamics

2. The governing conservation equations

17. High-temperature flows

3. In integral form

4. One-dimensional flow
— Normal shock waves
— Flow with heat addition
— Flow with friction

5. Oblique waves
— Oblique shock waves
— Expansion waves
— Wave interactions

6. Quasi-one-dimensional flow
— Nozzles
— Diffusers
— Wind tunnels and rocket engines

7. In differential form

8. Velocity potential equation

9. Linearized flow
— Subsonic flow
— Supersonic flow

10. Unsteady moving shock and expansion waves

11. Conical flow

12. Numerical techniques for steady supersonic flow
— Method of characteristics
— Finite difference methods

13. Time-marching numerical technique
— Flow around blunt bodies
— Two-dimensional nozzle flows

14. Three-dimensional flows

15. Transonic flow

16. Hypersonic flow

46

Flow Regimes

$M < 1$

V_∞
$M_\infty < 0.8$

(a)

b

V

Shock wave

$M < 1$ $M > 1$ $M < 1$

$0.8 < M_\infty < 1.0$

(b)

Bow shock   Trailing-edge shock

$M < 1$ $M > 1$

$1.0 \leqslant M_\infty < 1.2$

(c)
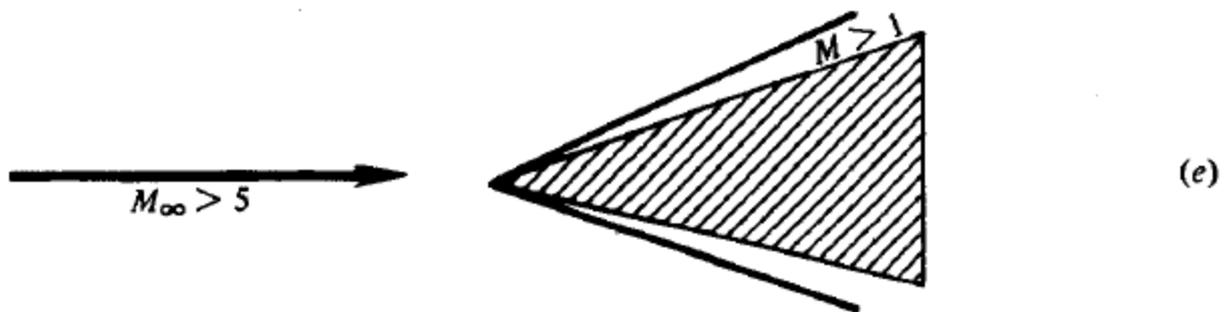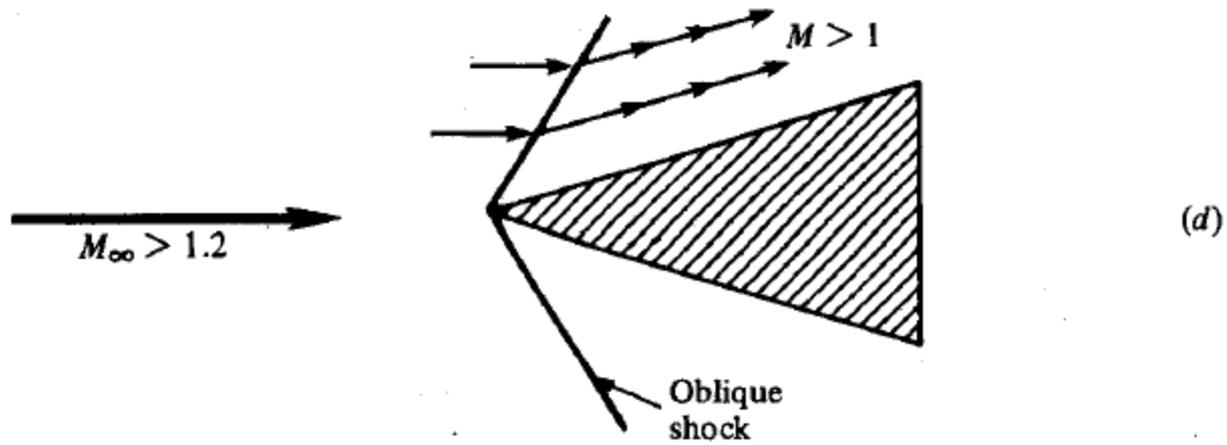
Flow Regimes
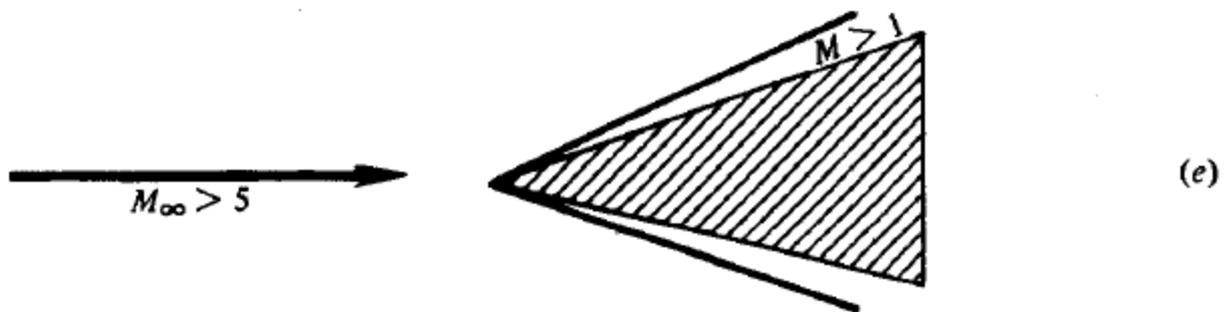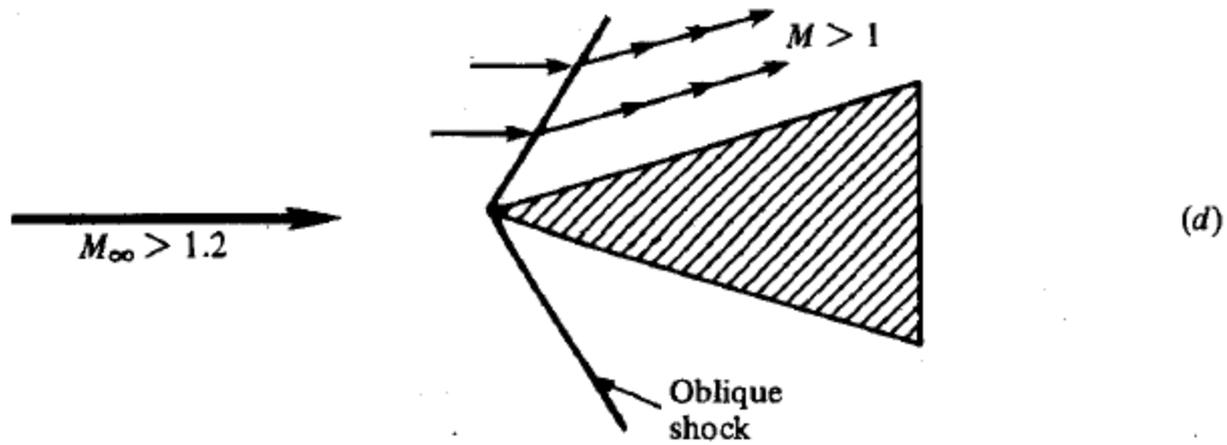
Flow Regimes

Historical Review

Fokker Trimotor – 1930 – 160 km/hr

Douglas DC-3 Airliner – 1936 – 190 km/hr

Boeing 777 – 1989 – 892 km/hr

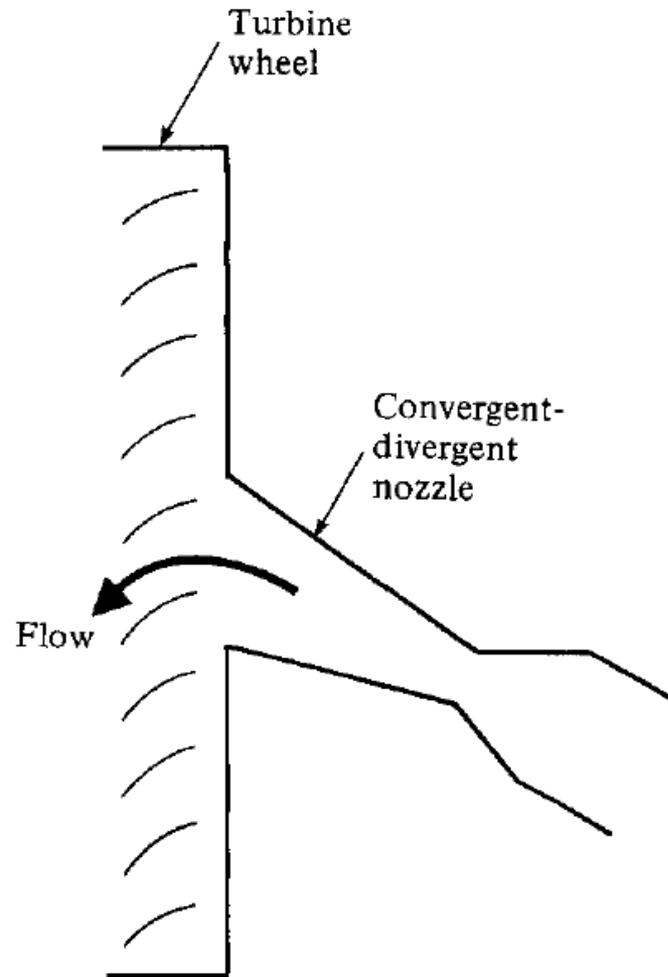# Concord– 1969 to 2003

F35 − 2015

Commercial Airplane Requirement

- Number of passengers.
- Range of kilometers.
- Cruising speed of km/hr.
- Top speed of km/hr.
- Landing speed not to exceed km/hr.
- Rate of climb (m/min).
- Service Ceiling of km.
- Max. gross weight of kg.

Historical Marks

Delaval Turbine - 1893

Bell XS-1 - 1947