13.012: Hydrodynamics for Ocean Engineers

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Lecture 1
What is Hydrodynamics?

- **Hydrodynamics v. Aerodynamics**
  - Water is almost 1000 times denser than air!
- **Marine Hydrodynamics**
  - Design of underwater vehicles, ships, platforms
  - Waves, wave energy,
  - External flows around ships, hydrofoils, propellers, etc.
  - Added Mass!
  - Flow-structure interactions
Fluid Properties @20ºC

- **Air**
  - Density
    \[ \rho = 1.2 \text{ kg/m}^3 \]
  - Dynamic Viscosity
    \[ \mu = 1.82 \times 10^{-5} \text{ N} \cdot \text{s/m}^2 \]
  - Kinematic Viscosity
    \[ \nu = \frac{\mu}{\rho} = 1.51 \times 10^{-5} \text{ m}^2/\text{s} \]

- **Water**
  - Density
    \[ \rho = 998 \text{ kg/m}^3 (\text{fresh water}) \]
    \[ \rho = 1025 \text{ kg/m}^3 (\text{seawater}) \]
  - Dynamic Viscosity
    \[ \mu = 1.0 \times 10^{-3} \text{ N} \cdot \text{s/m}^2 \]
  - Kinematic Viscosity
    \[ \nu = 1 \times 10^{-6} \text{ m}^2/\text{s} \]
Ocean Exploration & Hydrodynamics

• 70-75% of the earth’s surface is covered by water.
• The earth’s oceans are one of our least explored resources.
• Many exciting discoveries lie waiting in the deep: such as Food, medicines, energy, and water.
• Good engineering is needed to advance current ocean exploration capabilities and to assure that our ocean resources will persist for generations to come.
• Understanding marine hydrodynamics can help us to design better ocean vessels and to understand physical ocean processes.
Underwater Vehicles & Submarines

USN Submarine

Alvin, WHOI

Odyssey, MIT SeaGrant

ABE, WHOI
Ship Hydrodynamics

Naval Vessels

Fast Ferries

Built by International Catamarans
Tasmania, Hobart

Racing Yachts

Prada at Americas Cup 2000

CONTAINER SHIPS &
CARGO TRANSPORTS

Photo by Dennis Shum

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Offshore Engineering

The offshore platform must be designed to simultaneously withstand hurricane force waves and winds.

http://www.offshore-technology.com/projects/ursa/

The Ursa unit is located approximately 130 miles south-east of New Orleans.

Petrobras Rig Sinking off Brazil Due to explosion onboard
Biologically Inspired Vehicles?!?

• The study of fish and other aquatic animals has led to engineering designs for underwater vehicles inspired by these creatures amazing ability to exist in the ocean.

• This mimicking of nature is widespread through science and engineering and is referred to as biomimetics…
Ocean Waves
Linear Wave Problem

A solution to the linearized wave problem can be found mathematically. While this is not appropriate in all ocean cases (such as breaking waves) it is an excellent starting point.
Particle Orbits

- **Shallow Water**: $h/\lambda \leq 1/20$
- **Intermediate Depth**: $1/20 < h/\lambda < 1/2$
- **Deep Water**: $h/\lambda > 1/2$

~$\lambda/2$
Random Ocean Waves


Significant Wave Height
Wave Energy Spectra

Figure 1. Wave energy spectra. Red text indicates wave generation mechanisms and blue text indicates damping/restoring forces.
Wake Instability

Figure 4.12.6. Streak lines in the wake behind a circular cylinder in a stream of oil. (From Homann 1936a.)
Hydrodynamic Forces on Vessels

• Linear wave theory
• Added mass!!!
• Wave forces on bodies
• Viscous forces on bodies:
  – Skin Friction Drag
  – Vortex shedding, Vortex induced vibrations
• Viscous damping
Ship Motions

\[ x_1 = \text{surge} \]
\[ x_2 = \text{sway} \]
\[ x_3 = \text{heave} \]
\[ x_4 = \text{pitch} \]
\[ x_5 = \text{roll} \]
\[ x_6 = \text{yaw} \]
Nomenclature

- Length on Waterline (LOW)
- Beam (width of vessel at widest point)
- Midships (center of ship)
- Draft (depth of the keel below the water)
- Keel = part of the vessel extending below the hull
Propellers and Foils

The fundamental question in propulsion and maneuvering: What is the best, least-energy means to transport a system along a desired trajectory?

1. Minimize hydrodynamic resistance (Prandtl 1914): Reduce boundary layer friction and flow separation
2. Match propulsor to achieve desired thrust: Iterate propulsor and hull design to account for interactions

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Boundary layers develop along the walls in pipe flow. A cross sectional view shows the layer at the top and the bottom creating a symmetrical profile. The flow in the middle is fastest since it has not been slowed by the momentum transfer in the boundary layers.

Boundary layers develop along the aerofoil shown above. The velocity profile changes shape over the curved leading edge. Towards the trailing edge the flow tends to separate as a result of an adverse pressure gradient.

(pictures courtesy of Iowa Institute of Hydraulic Research, University of Iowa)
This picture is a side view of the large eddies in a turbulent boundary layer. Laser-induced fluorescence is again used to capture the quasi-periodic coherent structures. Flow is from left to right.

Contributor: Prof. M. Gad-el-Hak, University of Notre Dame
This picture is a top view of the near-wall region of a turbulent boundary layer showing the ubiquitous low-speed streaks. Flow is from left to right and laser-induced fluorescence is used to visualize the streaks.

Contributor: Prof. M. Gad-el-Hak, University of Notre Dame