2.016: Hydrodynamics

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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

$$\rho = 1.2\, kg/m^3$$

  - Dynamic Viscosity

$$\mu = 1.82\times10^{-5}\, N\cdot s/m^2$$

  - Kinematic Viscosity

$$\nu = \mu/\rho$$
$$= 1.51\times10^{-5}\, m^2/s$$

- Water
  - Density

$$\rho = 998\, kg/m^3 \text{ (fresh water)}$$
$$\rho = 1025\, kg/m^3 \text{ (seawater)}$$

  - Dynamic Viscosity

$$\mu = 1.0\times10^{-3}\, N\cdot s/m^2$$

  - Kinematic Viscosity

$$\nu = 1\times10^{-6}\, m^2/s$$

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

Photos removed for copyright reasons.

Odyssey, MIT SeaGrant

ABE, WHOI

Ship Hydrodynamics

Racing Yachts

Fast Ferries

Photos removed for copyright reasons.

Naval Vessels

Research Vessels

CONTAINER SHIPS &
CARGO TRANSPORTS

Photo by Dennis Shum

Offshore Engineering

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

Photos removed for copyright reasons.

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

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

Petrogras Rig Sinking off Brazil
Due to explosion onboard

Genesis Spar Platform

Photos removed for copyright reasons. Please see:

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

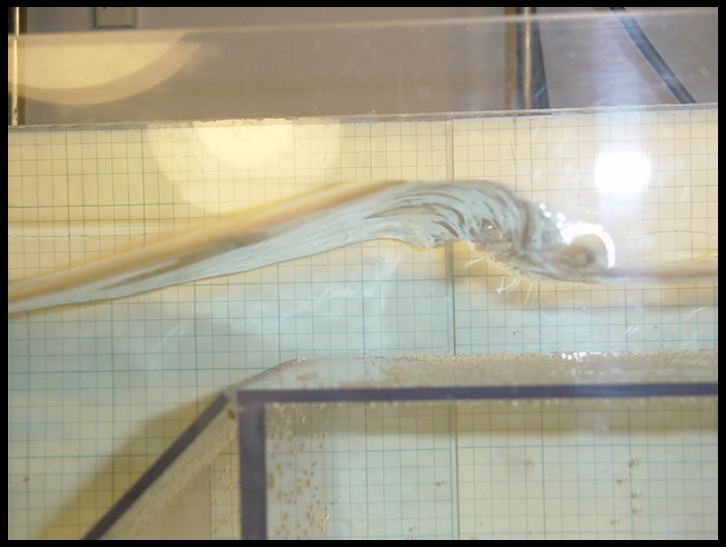
Biologically Inspired Vehicles?!?

- 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…

MIT Dept. Mechanical Engineering, 2005

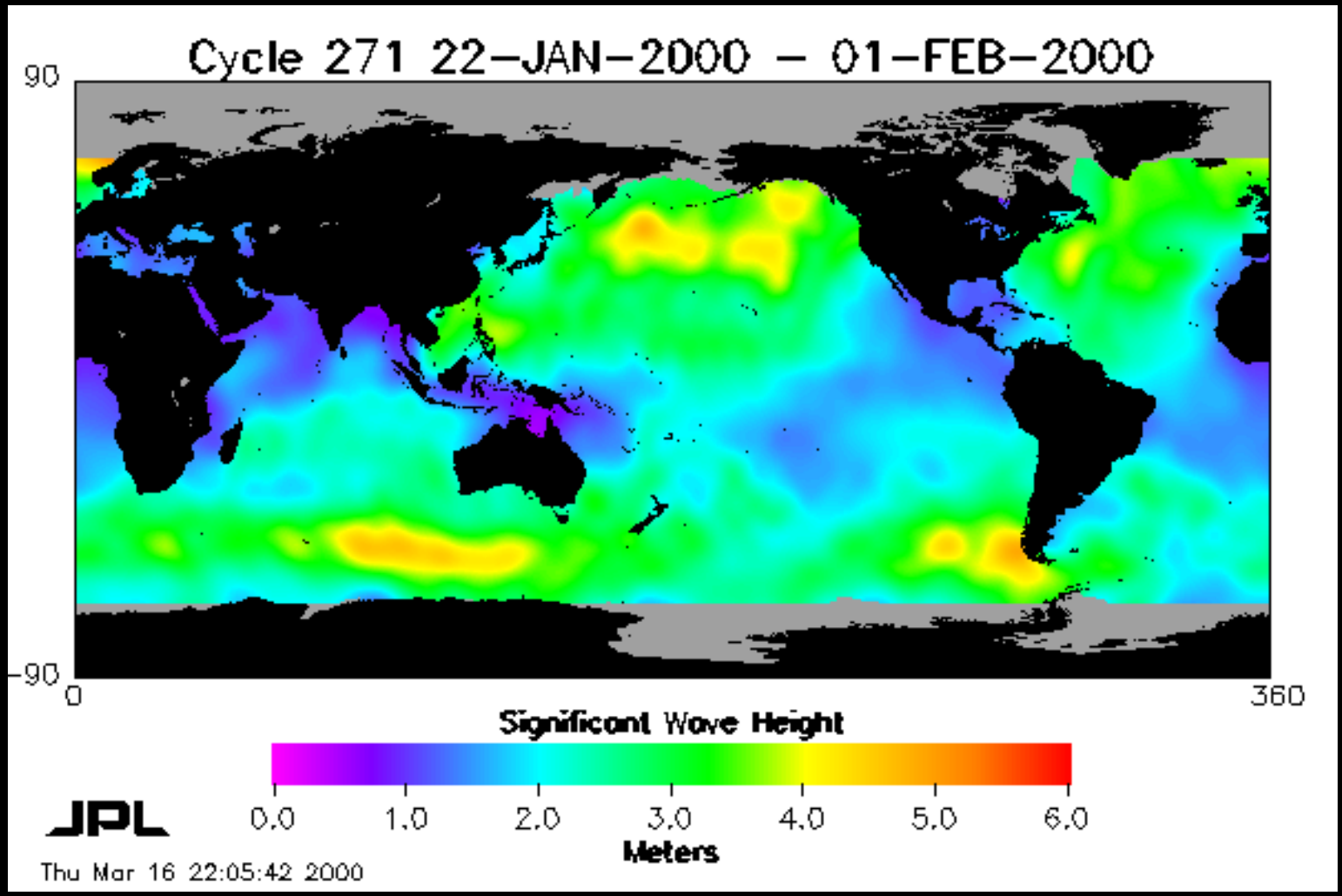
Ocean Waves

Photos removed for copyright reasons.



MIT Dept. Mechanical Engineering, 2005

Random Ocean Waves



Significant Wave Height

Wave Energy Spectra

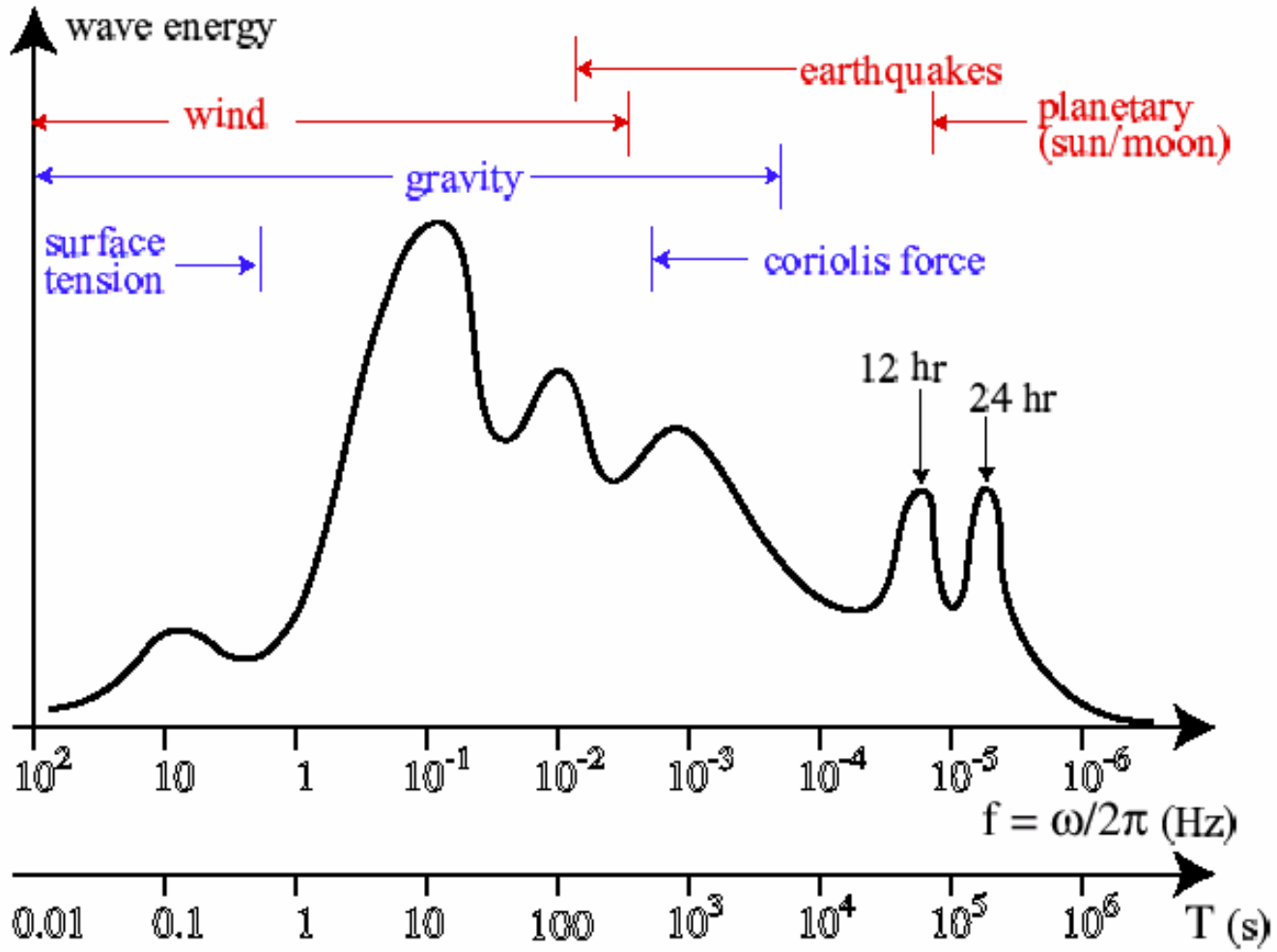


FIGURE 1. Wave energy spectra. Red text indicates wave generation mechanisms and blue text indicates damping/restoring forces.

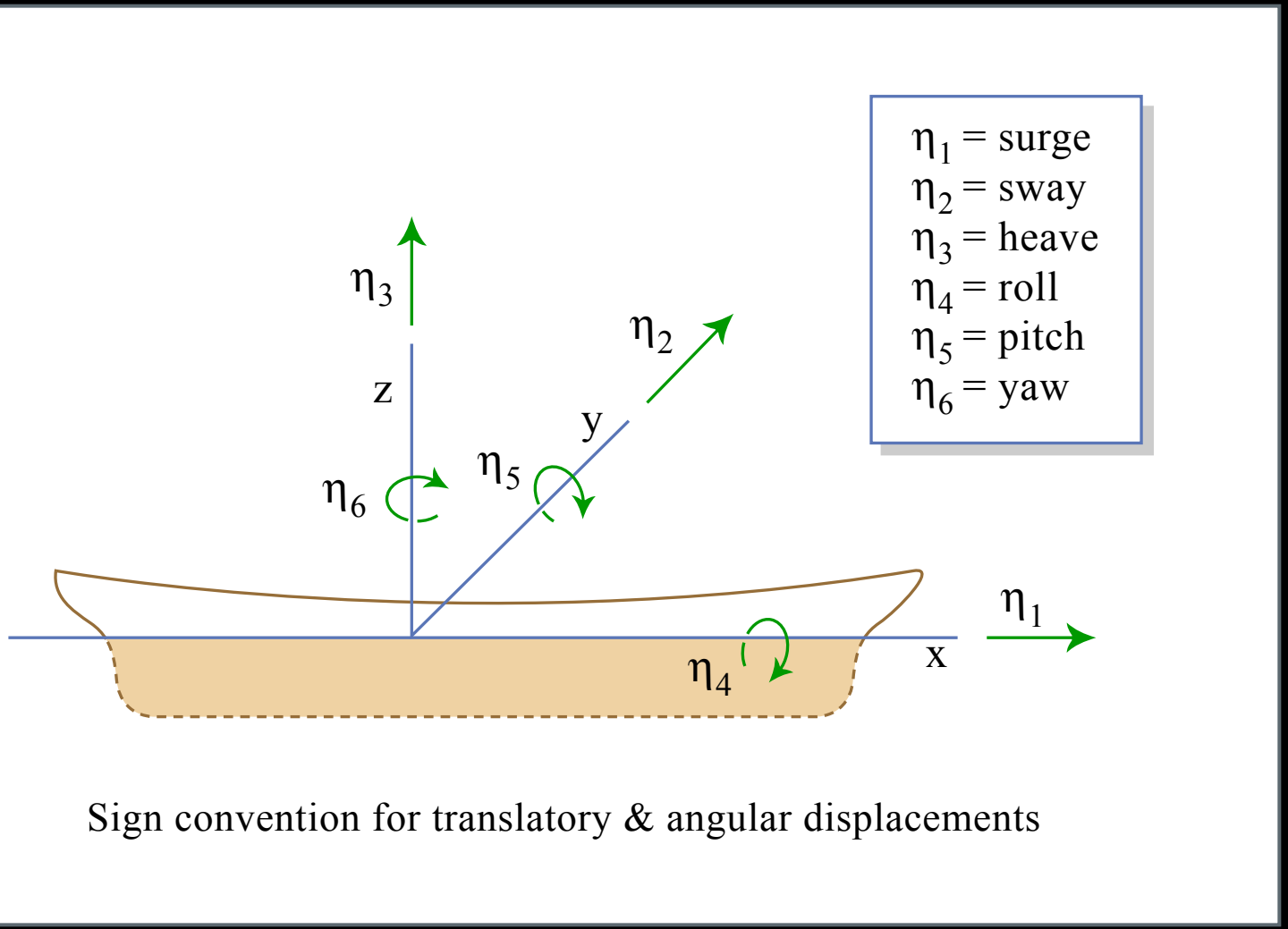
Wake Instability

Figure removed for copyright reasons.

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

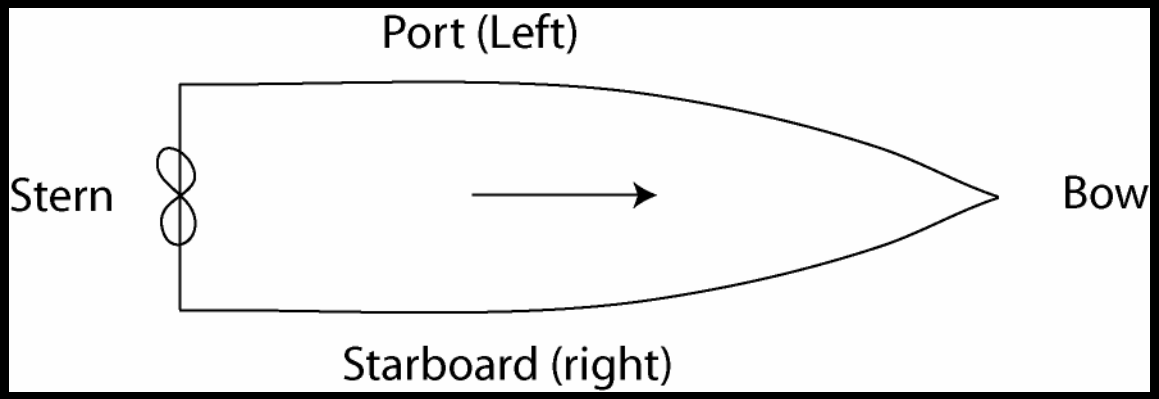


Sign convention for translatory & angular displacements

Right hand rule rules!

Figure by MIT OCW.

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

Syllabus

- Part I: Introduction to Marine Hydrodynamics
  - Basic Fluid Properties
  - Hydrostatic Pressure
  - Basic Principles of Hydrodynamics
- Part II: Free Surface Waves and Wave Forces on Offshore Structures and Vehicles
  - Linear Wave Theory: Boundary Value Problem; Simplifying assumptions
  - Dispersion Relationship
  - Unsteady Bernoulli's Equation, Dynamic Pressure
  - Incident wave forces on bodies
  - Added Mass, Damping, & Hydrostatic restoring coefficients (Strip theory)
  - Equations of motion for Seakeeping; natural frequency

Syllabus

- Part III: Viscous Flows and Free Surface Flows
  - Viscous Lift and Drag;
  - Drag and resistance of streamlines and bluff bodies
  - Vortex Induced Vibrations (VIV); Morrison's Equation (Offshore Platforms)
  - Ship Resistance Testing
  - Rudders and Propellers, Cavitation and Flow Noise
  - Navier Stokes Equations: Separated Flows and Boundary Layers *
- Part IV: Geophysical Fluid Dynamics*
  - Major ocean circulations and geostrophic flows;
  - Heat balance in the ocean;
  - Influence of wind stress
  - Coriolis force, Tidal forces, geostropic currents
  - Equations of motion

* time permitting

Grading

- **Grading Policy:**
  - Homework: 15%
  - Laboratory: 20%
  - 2 In-class Exams: 30%
  - Final Exam: 35%
- Exam #1 In class: 10/6 Thursday
- Exam #2 In class: 11/17 Thursday
- Final Exam: TBA

Labs

- Lab Safety Brief
  - Tomorrow 9am
- Lab #1 Added Mass:
  - Friday 9/23
- Lab #2 Waves
  - Friday 10/14
- Lab #3 Ship Resistance
  - Friday 11/4
- Lab #4 Group Project
  - TBA, reports due 12/2, presentations 12/9
- Labs due on the following THURSDAY in class.

Recitations

- During non-lab weeks recitations will be held Fridays from 9-11 am.
- These recitations will cover additional examples and course material as necessary.
- Additional exam reviews may also be scheduled by the TA.

Homeworks

- Weekly problem sets will be assigned and are due the following week unless otherwise noted.
- Homework solutions are expected to be the result of individual effort.
- Group discussions of the concepts covered on the homework and review of the course material is encouraged.
- HW handed out on Tuesdays, due the following Tuesday.