

13.021 – Marine Hydrodynamics Lecture 1

Introduction

Marine hydrodynamics is a large and diverse subject and only a few topics can be covered in an introductory course. Some course objectives to keep in mind throughout the semester are the following:

- Model testing similitude.
- Effect of waves on resistance and ship motion.
- Interaction between bodies and ideal fluids.
- Viscosity and surface tension

Why study Marine Hydrodynamics?

Studying marine hydrodynamics provides a greater understanding of a wide range of phenomena of considerable complexity involving fluids. Another benefit is that it allows predictions to be made in many areas of practical importance. Fluid mechanics is a way of looking at a group of particles without having to study each particle separately.

A fluid at rest – hydrostatics – is a trivial case of fluid mechanics where no stresses due to fluid motion exist.

Fluids have to be moving to be non-trivial. Fluid mechanics is fundamentally non-linear.

The mechanics of Fluids vs. Solids

Most of us have taken some courses on solids or related to solids. Even those who haven't can get an intuitive feeling about some physical properties of a solid. Thus a comparison of solids and fluids will give some guidelines on which properties can be translated to fluids and on what terms.

Differences

Fluids	Solids
Fluids have no shape	Solids have a definite shape
Fluids cannot sustain a shear force, i.e. a fluid is always in motion	Solids can sustain a shear force; i.e. they remain static
Stress is a function of the rate of strain, thus a fluid had a ‘dynamic’ state	Stress is a function of strain, thus a solid maintains a static or ‘quasi-static’ state.
The static properties of a fluid cannot be extended to dynamic properties.	The static properties of a solid can be extended to dynamic properties.

Similarities

The continuum hypothesis is used for both fluids and solids.
The fundamental laws of mechanics apply to both fluids and solids.
- Newton’s law of motion (conservation of momentum)
- Conservation of Mass
- First law of thermodynamics (conservation of energy)

The constitutive law relating stress and rate of strain also apply to both.

Sometimes it is hard to differentiate a liquid from a solid. This can be seen in the examples such as honey, jelly, paint, ...

Liquid vs. Gas

Note that there are two separate terms that we are talking about here. Liquid and fluid. According to Webster’s Dictionary, a fluid is ‘*a body whose particles move easily among themselves. Fluid is a generic term, including liquids and gases as species. Water, air, and steam are fluids.*’ A liquid is ‘*Being in such a state that the component parts move freely among themselves, but do not tend to separate from each other as the particles of gases and vapors do; neither solid nor aeriform.*’

A liquid is generally incompressible and does **not** fill a volume by expanding into it. A gas on the other hand, is compressible and expands to fill any volume containing it.

Why is a liquid incompressible?

The main difference between the study of hydrodynamics and the study of aerodynamics is the property of incompressibility. Hydrodynamic properties are generally incompressible while aerodynamic properties

are compressible.

Consider the following proof.

Measuring the speed of sound in a medium will give a measure of compressibility of that medium.

U: Characteristic fluid velocity

C: Speed of sound in the medium

M: Mach #

$$M \equiv \frac{U}{C}$$

$C_{inair} = 300 \text{ m/s}$	$C_{inwater} = 1200 \text{ m/s}$
$\frac{\rho_{air}}{\rho_{water}} = 10^{-3}$	$\frac{C_{air}}{C_{water}} = \frac{1}{4}$

Typically,

$$U_{air} \gg U_{water}$$

Therefore

$M_{inair} = O(1)$	$M_{inwater} \ll 1$
compressible	incompressible

The Mach number is a measure of compression that can relate the speed of the fluid to the speed of sound. Thus in the case of water, the Mach number is very small, indicating a very small measure of compressibility. This ratio is negligible and shows that water is virtually incompressible.

Note: An incompressible fluid does not mean constant density.