LAPORAN KEGIATAN
ACADEMIC CURRICULUM DEVELOPMENT
TAHUN ANGGARAN 2007

BAHAN AJAR
PROGRAM STUDI OSEANOGRAFI

PROGRAM STUDI OSEANOGRAFI
FAKULTAS PERIKANAN DAN ILMU KELAUTAN
UNIVERSITAS DIPONEGORO
SEMARANG
2007

HYDRODYNAMICS

BY :

DADANG K. MIHARDJA

Institut Teknologi Bandung

Attendance Policy

- Attendance is highly recommended
- Attendance will be used as determining factor when your grade is on the borderline and a condition for the following of exam (min 80 %).

Silabus Ringkas

- Membahas review prinsip dan konsep dasar fluida, gerak elemen fluida, prinsip kontinuitas, gaya-gaya inertia, gaya-gaya yang bekerja, persamaan momentum : persamaan Euler dan Navier-Stokes, pengantar turbulensi, dan pengantar dinamika fluida geofisika.

- Tujuan memberikan pemahaman tentang kinematika dan dinamika fluida, berbagai ragam kinematika dan gaya-gaya yang bekerja dalam gerak fluida, serta persamaan pengaturnya. Selain itu diberikan pula pemahaman awal(pengantar) tentang turbulensi dan dinamika gerak dalam skala planeter.

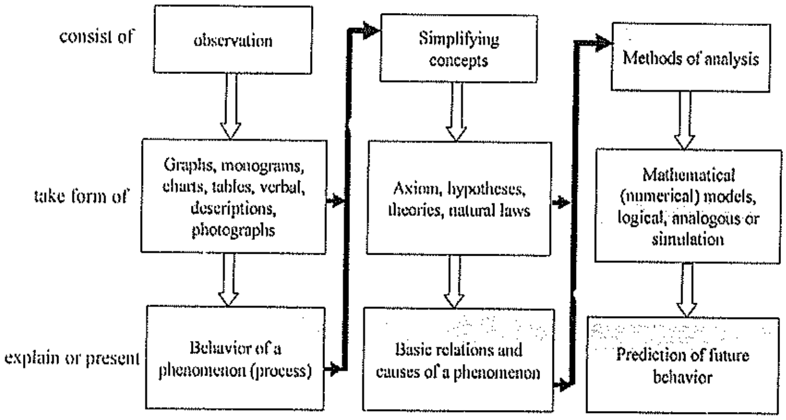
References

1. **Le Mehute,B.,**(1976): **An Introduction to Hydrodynamics and Water Waves.**, Springer Verlag, 315 hal.
2. **Cusman-Roisin, B.**, (1994): **Introduction to Geophysical Fluid Dynamics.**, Prentice Hall, 320 hal.
3. **Sharpe, G.J.**, (1992): **Solving Problem in Fluid Dynamics.**, Longman Scientific & Technical., 342 hal.
4. **Raisinghania, M.D.**, (2003): **Fluid Dynamics (With Hydrodynamics).**, S. Chand & Co. Ltd., Ram Nagar, New Delhi., 996 hal.
5. **Cengel, Y.A., and J.M. Cimbala.**, (2006): **Fluid Mechanics; Fundamentals and Applications.**, McGraw-Hill Inter.Ed., 956 hal.

Sistem Penilaian

- Tugas : 10 %
- Quiz : 30 %
- Midtest : 30 %
- Ujian Akhir : 30 %

Block Diagram of Modeling Procedure



consist of

observation

Simplifying concepts

Methods of analysis

take form of

Graphs, monograms, charts, tables, verbal, descriptions, photographs

Axiom, hypotheses, theories, natural laws

Mathematical (numerical) models, logical, analogous or simulation

explain or present

Behavior of a phenomenon (process)

Basic relations and causes of a phenomenon

Prediction of future behavior

Sumber : Tolmazin, D., (1985): Elements of Dynamics Oceanography., Allen & Unwin Inc, USA., hal. 38 fig. 2.16

CONTENTS

MID TEST
!!!

CHAPTER I

INTRODUCTION

Fluid Mechanics/Hydrodynamics

- **Fluid Statics - normal stress (pressure) only**
- **Fluid Dynamics - both normal and tangential stresses**
- **Fluid kinematics - Lagrangian and Eulerian**
- **Continuum - macroscopic, statistical**
- **Fluid particle is defined as an infinitesimal portion of the fluid as a continuum, which possesses individuality**

Introduction

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.

Introduction (cont...)

The mechanics of Fluids vs. Solids

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 i.e.	Solids can sustain a shear force; 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.

Introduction (cont...)

The mechanics of Fluids vs. Solids

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.

Introduction (cont...)
Liquid vs. Gas

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.'*

DEFINITION

- **The science which deals with the** MOTION OF LIQUID **in** MACROSCOPIC SENSE
- **Essentially a field which is regarded as applied mathematics because it deals with the** MATHEMATICAL TREATMENT **of basic equations for a** FLUID CONTINUUM **obtained on** PURELY NEWTONIAN BASIS

HYDRODYNAMICS VS HYDROLICS

- Hydrodynamics is also the FOUNDATION of hydraulics and oceanography.
- The physical concept of hydrodynamics is CENTER POINT of hydrodynamics lecture for understanding the PHYSICAL PHENOMENON by the MATHEMATICAL FORMULATION.

BASIC CONCEPT

- Studies of theoretical fluid mechanics are BASED ON the concept of an ELEMENTARY MASS OR PARTICLE OF FLUID. This particles may be considered as a corpus (kumpulan) alienum (a foreign body in the mechanics of continuum).
    - AN AID toward the UNDERSTANDING of PHYSICAL MEANING OF DIFFERENTIAL EQUATIONS GOVERNING the fluid motion

bersambung...

BASIC CONCEPT

- **Particle of fluid is called** MATERIAL POINT.
- **The elementary fluid particle is assumed to be** HOMOGENEOUS, ISOTROPIC AND CONTINUOUS **in the macroscopic**
- THE MOLECULAR PATTERN AND BROWNIAN MOTIONS WITHIN THE PARTICLE, **a subject deals with in the kinematics theory of fluid are not taken into account**

bersambung...

BASIC CONCEPT

- **The laws of fluid mechanics are obtained by** INTEGRATION OF LAWS GOVERNING THE BEHAVIOR OF A FLUID PARTICLE ALONG A LINE OR THROUGHOUT AN AREA OR A VOLUME
- **Studies in hydrodynamics may be divided into two different parts.**
  - **Establishing the general differential equations which** GOVERN THE MOTION **of an elementary particle of fluid**
  - **Study of different mathematical methods used to integrated these basic differential equation.** (THE BERNOULLI EQUATION)

bersambung...

BASIC CONCEPT

- **Relations between fluid particles :**
  - The fluid particles may be DEFORMED and each particle may have a particular MOTION which DIFFER QUITE MARKEDLY from motion of others particles
  - The forces exerted (ditekan) between fluid particles are the PRESSURE FORCES AND THE FRICTION FORCE
  - The friction forces per unit area in given direction, called the SHEAR STRESS τ, is assumed to be either zero (ideal or perfect fluid), or proportional to the coefficient of viscosity (μ).

$$\tau = \mu \frac{d\vec{V}}{dt}$$

NEWTONION & HYDRODYNAMICS

- **"Hydrodynamics is primarily CONCERNED WITH a Newtonion fluid**
- *Newton's First Law* :

Every body continues in its state of rest or uniform motion via straight line UNLESS it is compelled by an EXTERNAL FORCE to change that state.

bersambung...

NEWTONION & HYDRODYNAMICS

- *Newton's Second Law:*

The rate of change of momentum is PROPORTIONAL to the APPLIED FORCE and the place in direction in which the FORCE ACTS:

$$\boxed{\vec{F} = \frac{d\left(m\vec{V}\right)}{dt}}$$

FLUID CHARACTERISTIC

- A Fluid is SOFT and EASILY deformed
- The fluid molecules are spaced further a part and intermolecular forces are SMALLER THAN SOLID, and they (molecules) have more FREEDOM OF MOVEMENT
- Liquid can be EASILY DEFORMED but NOT EASILY COMPRESSED

bersambung...

FLUID CHARACTERISTIC

- GASES (AIR, O2, ETC) have even GREATER MOLECULAR SPACING and FREEDOM OF MOTION with negligible cohesive intermolecular force and as a consequence are easily deformed (and compressed)
- The different between solids and fluids can be explained qualitatively ON BASIS OF MOLECULAR STRUCTURE, a more specific distinction is based on how they deform under the action of an external load

bersambung...

FLUID CHARACTERISTIC

- A Fluid is defined as substance that DEFORMS CONTINUOUSLY when acted on BY A SHEARING STRESS of any magnitude.(shearing stress, force per unit area, is created whenever a tangential force acts on surface).
- Solid or metal: usually a very SMALL DEFORMATION but not CONTINUOUSLY DEFORM

bersambung...

FLUID CHARACTERISTIC

- Some materials such as slurries, tar, putty, and soon: will behave as a solid but if the stress exceed some critical value, the substance will flow. (The study of such materials is called Rheology
- The molecular structure of fluids is important in distinguishing one fluid from another but it is not possible to study the behavior of fluids at rest or in motion
  - Characterize the behavior by considering the average, or macroscopic, value of the quantity of interest.
  - The velocity of fluid is the average velocity

bersambung...

FLUID CHARACTERISTIC

- The volume (of particle) <u>IS SMALL COMPARED WITH THE PHYSICAL DIMENSIONS</u> of the system of interest but <u>LARGE COMPARED WITH THE AVERAGE DISTANCE BETWEEN MOLECULES</u>
- For gases for normal pressure and temperatures the spacing is on the order of 10^{-6} mm gases. For liquids: 10^{-7} mm

bersambung...

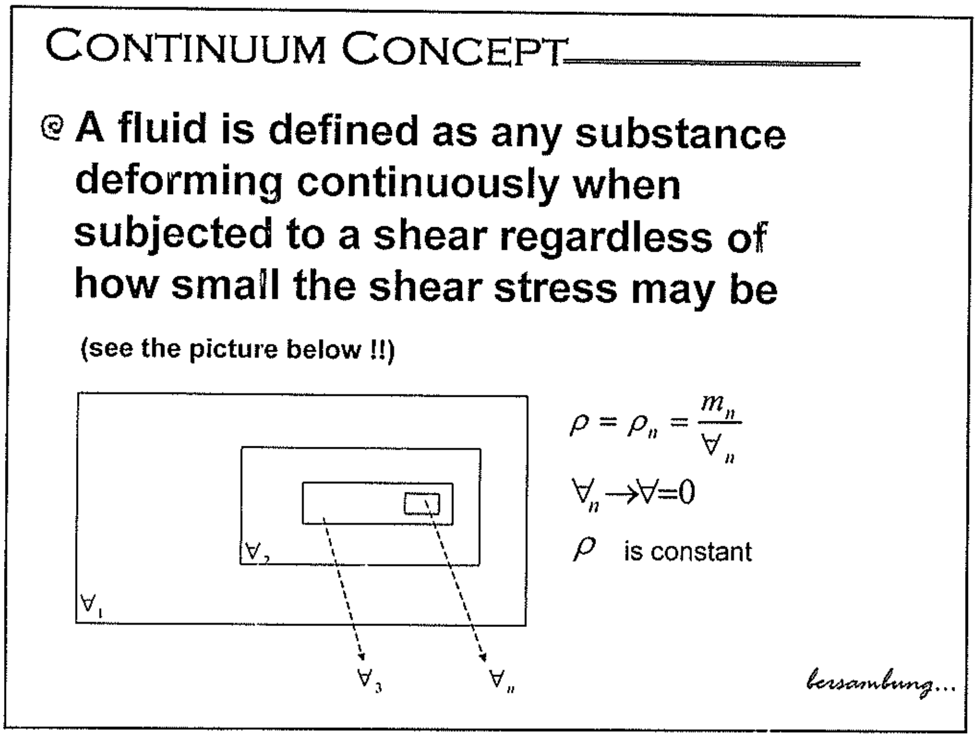
FLUID CHARACTERISTIC

- The number of molecules per cubic millimeter is on the order of 10^{18} (gases) and 10^{21} (liquids)
- Assume that all the fluid characteristics (pressure, velocity etc) vary continuously throughout the fluid

bersambung...

CONTINUUM CONCEPT

- The Fluid is TREATED as a continuum (**CONTINUUM CONCEPT**)
- In a case where the SPACING BETWEEN (AIR) MOLECULES BECOMES LARGE, the CONTINUUM CONCEPT IS NO LONGER ACCEPTABLE



CONTINUUM CONCEPT

- A fluid is defined as any substance deforming continuously when subjected to a shear regardless of how small the shear stress may be

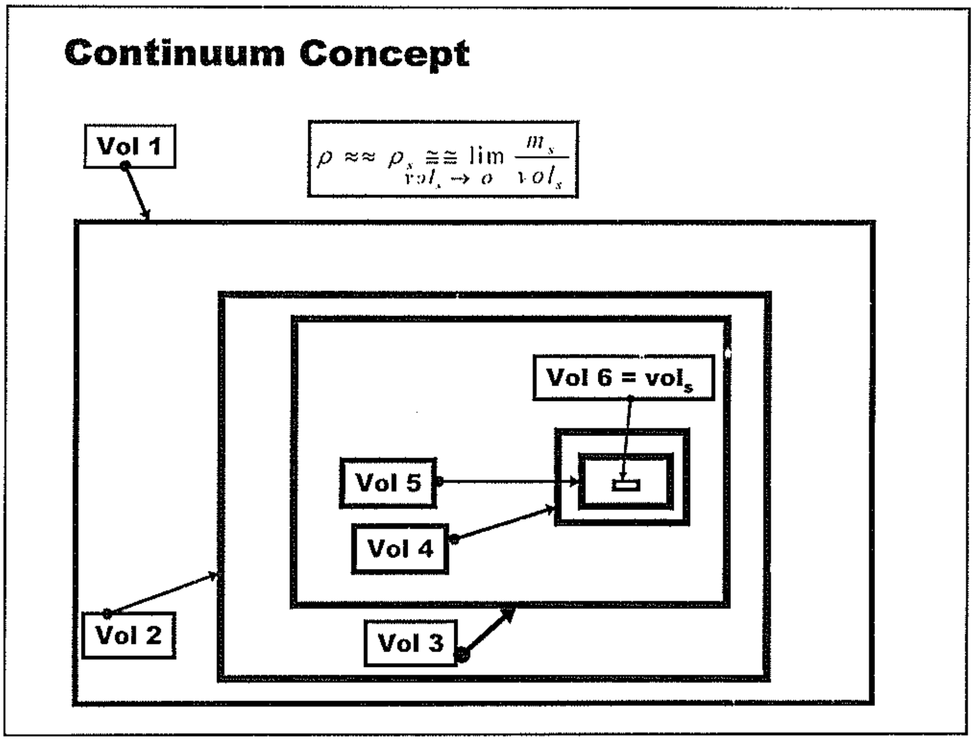
(see the picture below !!)

$$\rho = \rho_n = \frac{m_n}{\forall_n}$$

$\forall_n \to \forall = 0$

ρ is constant

bersambung...

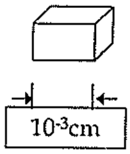


Continuum Concept

$$\rho \approx\approx \rho_s \cong\cong \lim_{vol_s \to o} \frac{m_s}{vol_s}$$

Continuum

- In a continuum, the physical variable at a point in space is the averaged value of the variable in a small sphere.
- How good is the assumption?



$3x10^{10}$ molecules of air

FLUID PARTICLE

- Elementary mass of fluid is assumed to be either infinity small or small enough that all parts of the element can be considered to have the same velocity of translation $\overset{u}{V}$ and the same density ρ
- $\forall_a$ (Volume of air) = 10^{-9} cm^3, contains = 3 x 10^{10} molecules
- Studies of theoretical fluid mechanic are based on the concept of an elementary mass or particle of fluid

CHAPTER 2

BASIC EQUATIONS

FLUID MECHANICS PROBLEMS

@ **The unknowns in fluid mechanics problems:**

$\rightarrow \overset{u}{V} = f\left(x, y, z, t\right)$

$\rightarrow \rho = f_1\left(x_1, y_1, z_1, t\right)$ if ρ konstan

→ In hydrodynamics two equations are necessary :

- ⊕ $\overset{u}{V} = \left(u, v, w\right)$ vectorial eq. and $\eta = \eta\left(x, y, z, t\right)$ ordinary equation
- ⊕ Continuity eq. and momentum eq.
- ⊕ For gases : $\overset{u}{V}, p, \rho$ and T

→ The equation of state and the principle of the conservation of energy must be added for compressible fluid.

PRINCIPLES OF CONTINUITY

- "The principle expresses the conservation of matter, i.e. fluid matter in a given space cannot be created or destroyed"
- In incompressible homogeneous fluid; the principle is expressed by the conservation of volume
- The continuity principle gives relationship between the velocity , the density , and the space coordinate and time

For incompressible: $\frac{\partial u}{\partial t}+\frac{\partial v}{\partial t}+\frac{\partial w}{\partial t}=0$

THE MOMENTUM PRINCIPLE

- "The principle expresses the relationship between the applied forces F on a unit volume of matter of density ρ , and the inertia forces $\left(\frac{d\left(\rho \vec{V}\right)}{dt}\right)$ of this unit volume of matter in motion"
- The inertia forces are due to the natural tendency of bodies to resist any change on their motion
- In Newton's second Law: "The rate of change of momentum is proportional to the applied force and the place in direction in which the force acts "

THE MOMENTUM PRINCIPLE

$$\vec{F} = \frac{d(m\vec{V})}{dt} \rightarrow \vec{F}_{x,vol} = \rho\frac{d(\vec{u})}{dt}, \vec{F}_{y,vol} = \rho\frac{d(\vec{v})}{dt}, \vec{F}_{z,vol} = \rho\frac{d(\vec{w})}{dt}$$

Which : $\rho = \frac{m}{vol} \rightarrow F_{vol_x} = \frac{F_x}{vol}$

EQUATION OF STATE

- **" The equation expresses the relationship which always exits between pressure (*p*), density (ρ), and absolute temperature (*T*)"**
- **For perfect gas :** $\frac{p}{\rho gRT} = 1$ **or** $\frac{p}{\omega RT} = 1$
  universal gas constant (R=53.3 ft/oR)
  ω= specific weight

PRINCIPLE OF CONSERVATION OF ENERGY

- The principle expresses the conservation of the total energy (internal energy and mechanical energy → The first law of thermodynamics).
- For adiabatic flow; that is, where no heat is added or removed from the fluid mass. $p/\rho^{1/2} = C$, $\kappa = \frac{c_p}{c_v}$ (adiabatic constant)
- In Hydrodynamics problems; it is not necessary to further consider the equation and the equation of conservation of total energy → ρ and T will be assumed constants/variable without influence upon the phenomenon under consider.

BOUNDARY CONDITION

- Free surface condition
  - At free surface where the pressure is known and generally equal to atmospheric pressure
  - Two conditions must be specified
    - Dynamic condition : Stating the value of pressure
      $$\frac{dp}{dt} = \overset{r}{u}\frac{\partial p}{\partial x} + \overset{r}{v}\frac{\partial p}{\partial y} + \overset{ur}{w}\frac{\partial p}{\partial z} + \frac{\partial p}{\partial t} = 0$$
    - Kinematics condition : Stating that the particle at free surface remains at free surface
      $$z = \eta(x, y, t) \rightarrow w = \frac{\partial \eta}{\partial t} + u\frac{\partial \eta}{\partial x} + v\frac{\partial \eta}{\partial y}$$

BOUNDARY CONDITION

- **Fixed Solid Boundaries**

$$\overset{u}{V} = 0$$

More generally : $\overset{u}{V} g \nabla F = 0$

$$u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} + w\frac{\partial F}{\partial z} = 0$$

- **Movable solid boundaries**

$$\frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} + w\frac{\partial F}{\partial z} = 0$$

- **Infinite distance condition**

$\overset{u}{V} = c$ for $x \rightarrow \pm\infty$

CHAPTER 3

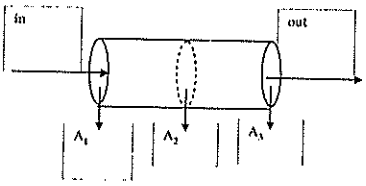
THE CONTINUITY EQUATION

PRINCIPLES OF CONTINUITY

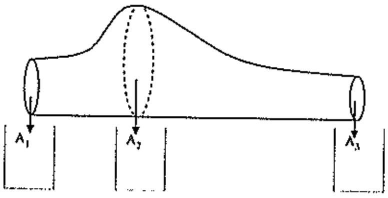
- The Law of the conservation of mass: Principle of Continuity
- The Principle states that the rate of increase of the fluid mass (in time interval *dt)* contained within a given space must equal to the difference between the rates of influx and efflux of mass
- The principle of continuity expresses the conservation of mass in a given space occupied by a fluid

EXAMPLES

- The discharge for steady flow in a pipe is constant



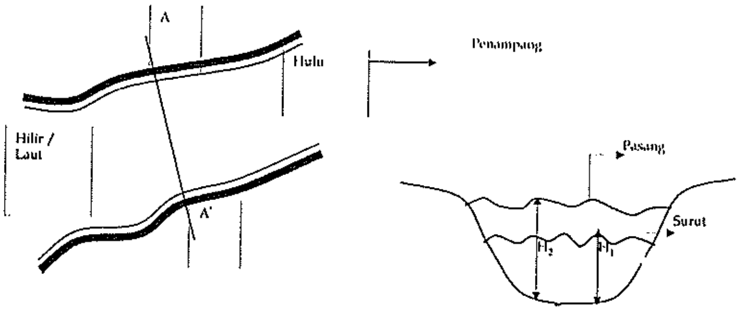
- The discharge for steady flow in a pipe with different section



A2 > A1 > A3

EXAMPLES

- In a River



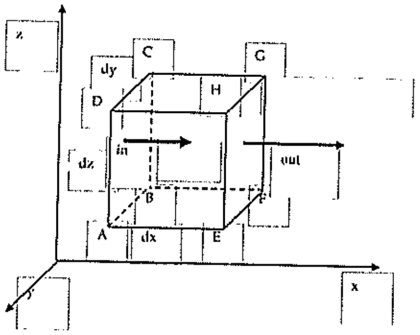
- CONCLUSION

  The changes in diameter will followed by a changes in velocity

$$\rho \; VA = C$$

THE CONTINUITY RELATIONSHIP

- The Continuity relationship is obtained by considering that change of fluid mass inside the volume *dx dy dz* during the time *dt* is equal to the difference between the rates of influx into efflux out of the considered volume during the same interval of time



CONTINUITY EQUATION

- **Perubahan massa fluida terhadap** WAKTU

At time t: $\rho \, dx \, dy \, dz$

After dt $(t + dt)$: $\left(\rho + \frac{\partial \rho}{\partial t} dt\right) dx \, dy \, dz$

Change of fluid mass: $\frac{\partial \rho}{\partial t} \; dt \;\; dx \;\; dy \;\; dz$.....(1)

CONTINUITY EQUATION

@ **Perubahan massa fluida terhadap** RUANG

Massa fluida yang masuk pada dt : $\rho u \, dy \, dz \, dt$

Massa fluida yang keluar pada dt : $\left(\rho u + \frac{\partial(\rho u)}{\partial x} dx\right) dy \; dz \; dt$

Change of fluid mass: $- \frac{\partial(\rho u)}{\partial x} dt \; dx \; dy \; dz$.....(2)

CONTINUITY EQUATION

@ **Perubahan massa fluida terhadap** WAKTU = **perubahan total massa fluida terhadap** RUANG

$$\frac{\partial \rho}{\partial t} = - \left(\frac{\partial(\rho u)}{\partial x}\right) \qquad \text{1-D}$$

$$\frac{\partial \rho}{\partial t} = - \left(\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z}\right) \qquad \text{3-D}$$

GENERAL EQUATION OF CONTINUITY

$$\boxed{\frac{\partial \rho}{\partial t} + \rho \; div \; \vec{V} + \vec{V} grad \; \rho = 0}$$

PHYSICAL MEANING

- $\frac{\partial \rho}{\partial t}$ **adalah perubahan densitas terhadap waktu yang merupakan perubahan lokal**

  Untuk fluida inkompresibel $\frac{D\rho}{Dt}=0$

  Untuk pergerakan tunak $\frac{\partial \rho}{\partial t}=0$

- $\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)$ **atau** $\rho\left(\vec{\nabla}.\vec{\upsilon}\right)$ **menyatakan turunan kecepatan terhadap ruang dalam arah pergerakan didalam ruang yang ditinjau**

PHYSICAL MEANING

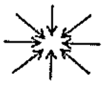
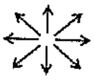
- $u\frac{\partial \rho}{\partial x}+v\frac{\partial \rho}{\partial y}+\frac{\partial \rho}{\partial z}$ **atau** $\vec{v}\ grad\ \rho$ **adalah perubahan densitas ruang berkenaan dengan koordinat ruang pada waktu yang ditinjau, biasanya** $grad\ \rho$ **mempunyai nilai yang sangat kecil sehingga dalam perhitungan dapat diabaikan.**

  Jadi perumusannya adalah

$$\frac{\partial \rho}{\partial t}+\rho\, div\, \vec{v}=\frac{\partial \rho}{\partial t}+\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)=0$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \longrightarrow \text{Untuk Fluida Inkompresibel}$$

PHYSICAL MEANING

$\vec{\nabla}.\vec{v}>0$ atau $div\,\vec{v}>0$		DIVERGEN POSITIF (KONVERGEN) KOMPRESIBEL
$\vec{\nabla}.\vec{v}<0$ atau $div\,\vec{v}<0$		DIVERGEN KOMPRESIBEL
$\vec{\nabla}.\vec{v}=0$ atau $div\,\vec{v}=0$		NON DIVERGEN INKOMPRESIBEL

THE CONTINUITY EQUATIONS FOR DIFFERENT CONDITIONS OF FLOWS

Flow condition	**Continuity Equation**
Aliran 1D untuk Fluida Inkompresibel	$\frac{\partial u}{\partial x}=0$
Aliran 2D untuk Fluida Inkompresibel	$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0$
Aliran 3D untuk Fluida incompressible	$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$
Aliran Tak Tunak untuk Fluida Kompresibel pada kecepatan normal (gelombang akustik, gelombang kejut)	$\frac{\partial \rho}{\partial t}+\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)=0$
Aliran Tak Tunak untuk Fluida Kompresibel pada Kecepatan Tinggi	$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$

CHAPTER 4

INERTIA FORCES

PERS. NEWTON

- Untuk menggerakkan massa M yg konstan
- Untuk mengubah gerakan yg sudah ada, diperlukan gaya (F) yg menyebabkan percepatan (a)

$$\Sigma \overset{\vee}{F} = M\frac{d\overset{\vee}{v}}{dt}$$

Gaya yang bekerja Gaya Inersia

PERS. NEWTON

$$M\frac{d\overset{\vee}{v}}{dt} = inersia$$

- **Gaya inertia yg menggambarkan "PERLAWANAN(RESISTANCE) ALAMI" dari suatu materi bermassa M untuk suatu perubahan dlm suatu gerak**

$$\frac{M}{unitVol} = \rho.(unitVol) \equiv \rho$$

ACCELERATION

- **Two types of inertia forces may be distinguished. Depending on the type of acceleration or elementary motion considered:**
  - LOCAL ACCELERATION: **corresponding to a variation of the velocity of translation or derivative of velocity with respect to time**
  - CONVECTIVE ACCELERATION: **corresponding to a variation of velocity of deformation and rotation or derivative of velocity with respect space.**

VARIATION OF VELOCITY

- **Translation:** u, v
- **Dilatational deformation:**

$$\frac{\partial u}{\partial x}dx \qquad \frac{\partial v}{\partial y}dy$$

- **Shear deformation:**

$$\frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)dy \qquad \frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)dx$$

- **Rotation:**

$$-\frac{1}{2}\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)dy \qquad \frac{1}{2}\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)dx$$

LOCAL ACCELERATION

- **1st, The velocity stays in the same time direction along a straight line & changes in magnitude. If the velocity increases at a given, which involves a positive local acceleration, the inertia of the mass of fluid in motion tends to slow down or** VISE VERSA
- **2nd, The velocity maintains the same magnitude, but changes its direction. In this case the inertia force is due to the centrifugal acceleration**
- **3rd, The velocity changes at a given point both in magnitude and direction**

CONVECTIVE ACCELERATION

- Convective acceleration results from any LINEAR OR ANGULAR DEFORMATION, or from A CHANGE IN ROTATION OF FLUID PARTICLES, imposed by external forces F.
- The velocity at a given time changes with respect to distance
- Sometimes called field acceleration
- Makes NON UNIFORM flow
- Expansion or contraction of a compressible fluids is the sum of linear deformations and also results in corresponding inertia forces.

MATHEMATICAL EXPRESSION

- Inertia force-x

$$\underbrace{\frac{\partial u}{\partial t}}_{\text{Local acceleration}} + \underbrace{u\frac{\partial u}{\partial x}}_{\text{acceleration of linear deformation}} + \underbrace{\frac{1}{2}v\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)+\frac{1}{2}w\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)}_{\text{acceleration in angular deformation}} + \underbrace{\frac{1}{2}w\left(\frac{\partial u}{\partial z}-\frac{\partial w}{\partial x}\right)-\frac{1}{2}v\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)}_{\text{acceleration in rotation}}$$

ON SOME APPROXIMATIONS

- **Local acceleration is Neglected:**
  - This occurs when the velocities ARE SLOW and their variations with time are VERY SLOW.
- Examples
  - Flow in a porous medium: variation of the ground water table with respect to time
  - Flood wave in river
  - Variation of level an a reservoir
  - Emptying of basin by a small valve

ON SOME APPROXIMATIONS

- **Convective acceleration is Neglected:**
  - When V is small, V^2 is negligible and the convective inertia term is negligible in comparison with the other terms expressing the local inertia and applied forces. Such motion are called "slow motions"
- Examples:
  - Periodic gravity wave theory
  - Flow in porous medium
  - Motion of a small sphere in a viscous fluid

GEOSTROPHIC ACCELERATION

- This force is important in the study of Tidal motion, oceanic circulation, and storm surge
- An additional inertia force due to the rotation of the earth
- It is called the Coriolis effect
- Different parts of the earth rotate at different speeds, DEPENDING UPON THEIR DISTANCE FROM THE EARTH'S AXIS

MECHANISMS

- North-South:
  - Hence a fluid particles in the northern hemisphere moving toward equator, FINDS ITSELF OVER A PORTION OF THE EARTH WHICH ROTATES FASTER THAN WHERE IT COMES FROM. And deflected the direction to the west

MECHANISMS

- West-East:
    - A fluid particles which rotates with the earth. Its velocity about the earth's axis creates a centrifugal force.
    - Since the fluid particle moves at the same speed as the earth, this force just balances the component of gravity force which is perpendicular to the earth's axis.
    - If now it moves eastward with respect to the earth along a parallel in the northern hemisphere, the particles experience an additional centrifugal force.

MECHANISMS

- West-East:
    - Since the particle is moving faster than the speed for which the balance is possible, the particle tends to move further away from the earth's axis
    - Therefore, it is deflected towards the equator, where even though the distance from the earth's center in the same, the distance to the earth's axis is increased.

TERMS OF THE GEOSTROPHIC

- **The Geostrophic inertial forces is composed of three terms:**
  - A horizontal component $2\rho\omega U \sin \Phi$ perpendicular to and to the left of U. In the southern hemisphere Φ is negative, and the horizontal component $2\rho\omega U \sin \Phi$ is directed to the right of U
  - A horizontal component $2\rho\omega U \cos \Phi$ directed toward the west, and generally negligible as the motions are generally so nearly horizontal that W/U is very small
  - A vertical component $2\rho\omega U_E \cos \Phi$ directed downward, which is added or subtracted to the gravity, and which is also negligible compared to gravity.

CHAPTER 5

APPLIED FORCES

KINDS OF FORCES

- **Internal forces:**
  - hasil interaksi bagian dalam massa fluida
  - Aksi = reaksi
  - Seimbang dalam pasangan
  - Penjumlahannya nol
- **External Forces:**
  - Surface forces
  - Body forces

EXTERNAL FORCES

- **Surface forces:**
  - Bekerja dipermukaan
  - Gaya luar yang menyebabkannya
  - Tarikan molekular (viskositas)
  - Berkurang sgt cepat m'jauh dr permukaan
  - Terbagi dlm 2 bagian:
    - Normal (tekanan)
    - Shearing forces (gaya geser)

BODY FORCES

- **The Capillary forces:**
  - Disebabkan oleh perbedaan gaya tarik molekuler antara 2 media/lapis
- **The geostrophic force:**
  - Disebabkan oleh percepatan (gaya) Coriolis
  - Kadang-kadang dipandang sebagai body force yang serupa dgn gravity force walaupun suatu inertia force

bersambung...

GRAVITY FORCES

- **Gravity forces:**
  - Gaya badan ini, serupa dgn inertia force, yg proportional dgn massa fluida dan percepatan yg disebabkan oleh gaya luar (gravitasi bumi, bulan, matahari dan benda langit lainnya).
  - $\vec{w} = \rho.\vec{g}$, $\vec{g}$ percepatan gravitasi
  - Gaya ini tidak bergantung pada gerakan (massa partikel), apakah benda itu diam atau bergerak gaya ini besarnya sama.

bersambung...

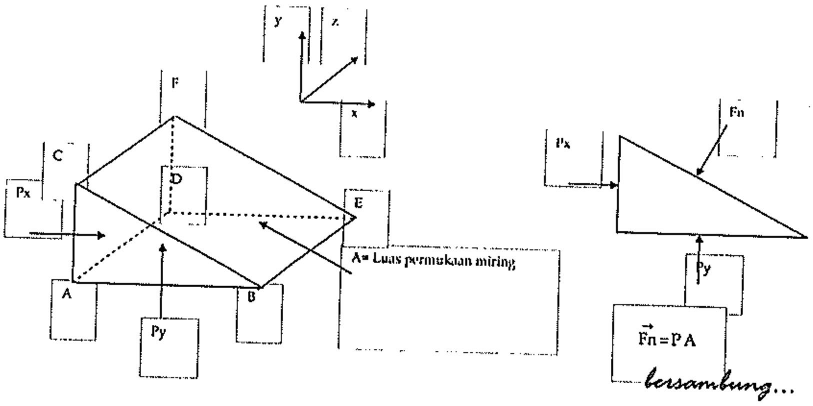
GRAVITY FORCES

- **Komponen-komponen gaya**
  - Sumbu X : $X = - \frac{\partial}{\partial x}(\rho g Z) \quad = 0$
  - Sumbu Y : $Y = - \frac{\partial}{\partial y}(\rho g Z) \quad = 0$
  - Sumbu Z : $Z = - \frac{\partial}{\partial z}(\rho g Z) \quad = - \rho g$

bersambung...

PRESSURE FORCES

- Sebagai hasil dari komponen gaya normal dari gaya molekuler didekat batas.



tersambung...

PRESSURE FORCE

- Px : gaya normal atau gaya tekanan yang bekerja pada bidang ADFC
- Py : gaya normal atau gaya tekanan yang bekerja pada bidang ABED
- sb X : $Px\ ds \sin\alpha - P\ ds \sin\alpha = 0$

  $ds \sin\alpha\ (Px - P) = 0$

  $Px - P = 0$ $\qquad P = Px$
- sb Y : $Py\ ds \cos\alpha - P\ ds \cos\alpha = \rho g\ dxdy/2$ → diabaikan

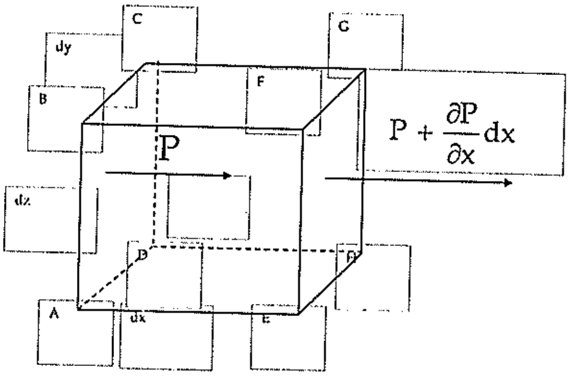
  $Py\ ds \cos\alpha - Pds \cos\alpha = 0$

  $ds \cos\alpha\ (Py - P) = 0$

  $Py - P = 0$

  $P = Py$
- Kesimpulan yang dapat diambil adalah bahwa P = Px = Py yaitu bahwa tekanan itu SAMA untuk semua arah pada satu partikel fluida.

PRESSURE FORCE



PRESSURE FORCES

Gaya pada ABCD : P x luas ABCD = P dy dz

Gaya pada EFGH : $-\left(P+\frac{\partial P}{\partial x}dx\right) x \, \text{luasEFGH} = -\left(P+\frac{\partial P}{\partial x}dx\right) dy\, dz$

Perbedaannya :

a.Sumbu x : $-\frac{\partial P}{\partial x} dx\, dy\, dz$

b.Sumbu y : $-\frac{\partial P}{\partial y} dx\, dy\, dz$

c.Sumbu z : $-\frac{\partial P}{\partial z} dx\, dy\, dz$

Laju perubahan gaya tekanan per unit volume dalam bentuk vektor $\overset{u}{\nabla} p$

GERAK FLUIDA & GRADIEN TEKANAN

- Gerak fluida tidak ditentukan oleh nilai absolut tekanan tapi oleh perbedaannya antara titik/lokasi
- Contoh gerak/aliran sungai dari temapt yang tinggi ke tempat yang rendah sebagai representasi perbedaan tekanan antara hulu dan hilir.

TEKANAN & GRAVITASI

- Gaya total yg disebabkan oleh gaya tekanan dan gaya gravitasi per unit volume.

$$\nabla p + \nabla \rho g z = \nabla \left(p + \rho g z \right)$$

- Kuantitas ($p+\rho gz$) konstan pd keadaan hidrostatik

VISCOUS FORCES

- gaya yang ditimbulkan akibat adanya viskositas fluida yang disebabkan oleh transfer momentum secara molekular atau adanya transfer energi.
- Gaya gesekan(τ) $\cong$ viskositas(μ)& deformasi sudut
- Jika $\nabla^2 \vec{V} \approx 0$ → gaya viskous bisa diabaikan. Hal ini dapat terjadi pada fluida ideal, dan didaerah diluar lapisan batas pada fluida riil.
- Kadang—kadang dimungkinkan mengabaikan hanya satu bagian dari suku-suku gesekan.

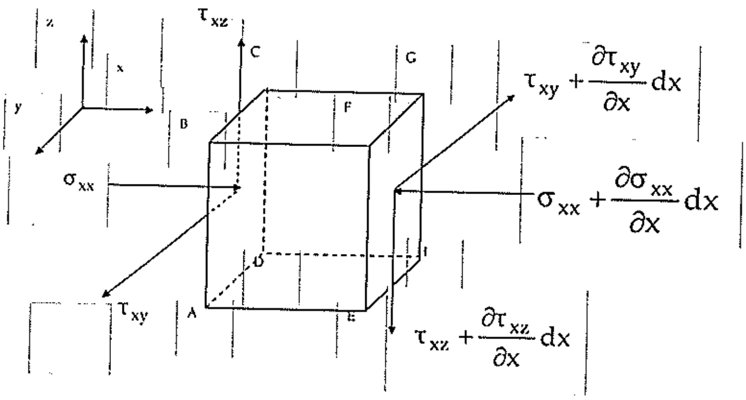
$$\frac{\partial^2 u}{\partial x^2} = \frac{\partial^2 u}{\partial y^2} \rightarrow \frac{\partial^2 u}{\partial x^2} \text{ Bisa diabaikan}$$

SURFACE FORCES

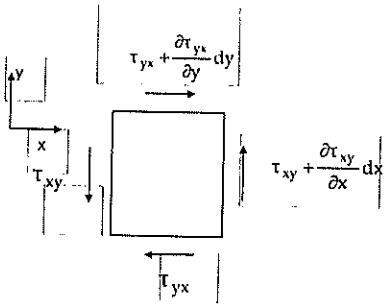
- Tinjauan teoritis tanpa melihat sifat/proses fisis bisa menyatakan gaya permukaan secara umum untuk berbagai macam gerak (pada fluida ideal, viskous atau gerak turbulen), dan macam fluida (kompresible atau inkompresible).
- Walaupun demikian nilai gaya permukaan dinyatakan berbeda jika meninjau sifat fisisnya.

LAME COMPONENT

- Ada 9 komponen gaya dalam kubus



LAME COMPONENT



FUNGSI DISIPASI

- Energi ditransformasikan atau diubah menjadi panas oleh adanya perubahan volume atau oleh gesekan yang diperoleh dari penambahan kerja yang dilakukan oleh gaya luar.
- **Kerja=gaya luar x jarak perubahan**
- Kerja yg dilakukan oleh gaya tekanan

$$p\,dy\,dz\,u\,dt-\left(p+\frac{\partial p}{\partial x}dx\right)dy\,dz\left(u+\frac{\partial u}{\partial x}dx\right)dt$$

- Kerja yang dilakukan oleh seluruh gaya2 dalam arah sb. x adalah:

$$\sigma_{xx}\,dy\,dz\,u\,dt-\left(\sigma_{xx}+\frac{\partial\sigma_{xx}}{\partial x}dx\right)dy\,dz\left(u+\frac{\partial u}{\partial x}dx\right)dt$$
$$+\tau_{xy}\,dy\,dz\,u\,dt-\left(\tau_{xy}+\frac{\partial\tau_{xy}}{\partial x}dx\right)dy\,dz\left(u+\frac{\partial u}{\partial x}dx\right)dt$$
$$+\tau_{xz}\,dy\,dz\,u\,dt-\left(\tau_{xz}+\frac{\partial\tau_{xz}}{\partial x}dx\right)dy\,dz\left(u+\frac{\partial u}{\partial x}dx\right)dt$$

FUNGSI DISIPASI

- Total kerja per unit vol yg dirubah dalam panas per unit periode waktu disebut "dissipation function"
- Fungsi tersebut sebagai fungsi deformasi linier dan sudut:

$$\phi=\lambda(\mathrm{div}V)^2+\mu\left[2\left(\frac{\partial u}{\partial x}\right)^2+2\left(\frac{\partial v}{\partial y}\right)^2+2\left(\frac{\partial w}{\partial z}\right)^2+\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)^2+\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)^2+\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2\right]$$

CHAPTER 6

MOMENTUM EQUATION

PREFACE

- **Pers. Momentum diperoleh dgn menyamakan gaya-gaya yg bekerja (applied forces) dgn gaya inertia untuk satu unit vol. fluida.**
- **Hukum Newton II**

$$\Sigma \overset{\varpi}{F} = m\frac{d\overset{\omega}{v}}{dt}$$

Gaya yang bekerja
Gaya Inersia

PREFACE

PERSAMAAN MOMENTUM

Momentum yang diberikan oleh gaya yang bekerja dan digunakan untuk bergerak akan menimbulkan gaya inersia.

- **Persamaan ini bekerja pada** 1 PARTIKEL FLUIDA.
- **Akan dijelaskan 2 persamaan untuk menjelaskan pers. Momentum:**
  - **Pers. Euler**
  - **Pers. Navier Stokes**

PERSAMAAN EULER

- **Persamaan Euler merupakan persamaan momentum yang hanya mengandung suku2 berikut:**
  - **Gaya inertia=gaya gravitasi+tekanan**

	Gaya Inersia per unit volume	Gaya Gravitasi + Gaya Tekanan per unit volume
Sumbu x	$\frac{du}{dt}$	$-\frac{\partial P^*}{\partial x}$
Sumbu y	$\frac{dv}{dt}$	$-\frac{\partial P^*}{\partial y}$
Sumbu z	$\frac{dw}{dt}$	$-\frac{\partial(P+\rho gz)}{\partial z}$

- **Persamaan ini berlaku pada FLUIDA IDEAL**
- **Gaya Geser / Gesekan ≈ 0**

PERSAMAAN NAVIER-STOKES

- Berlaku untuk fluida viskous:
- Persamaan umum:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial(p+\rho gz)}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

- Gaya viscous hanya berlaku:
  - Fluida yg memiliki voskositas
  - Distribusi yg tidak seragam

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