Introduction to Aeronautics

ARO 101 Sections 03 & 04

Sep 30, 2015 thru Dec 9, 2015

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Week #2 Lecture Material

Topics For Week #2

- **Reviewing Units & Unit Conversions –** **Inconsistent units.** ***Some tricks on how to convert units quickly and correctly.***
- **Properties of Fluids** (Gases & Liquids) **that Relate to Aerodynamics -**
  - ✓ ***Temperature***
  - ✓ ***Pressure***
  - ✓ ***Density***
  - ✓ ***Velocity***
- **Flow Velocity & Streamlines –** ***Understanding how fluids move. Envisioning how they move around a body immersed in a fluid.***
- **The Ideal Gas Law –** ***Understanding this important Equation of State & how to use it.***

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Systems Of Units

(And some "tricks" to help you out with unit conversions)

- ***Recall how I have instructed you to never use inconsistent units? The classic example of these are the "Pound-mass" (British) and the "Kilogram-force" (SI):***

Pound-mass to Pound-force

$1\ lb_m \times 32.2\ ft/sec^2 = 1\ lb_f$

Kilogram to Kilogram-force

$1\ kg \times 9.8\ m/sec^2 = 1\ kg_f$

INCONSISTENT!

Only works on earth!

Slug to Pound-force

$1\ sl \times 1\ ft/sec^2 = 1\ lb_f$

✓ **CONSISTENT!**

Works everywhere!

Kilogram to Newton

$1\ kg \times 1\ m/sec^2 = 1\ N$

1 slug = 32.2 lb_m

Just convert inconsistent units to consistent units & move on!

9.8 Newtons = 1 kg_f

- **Conversion Problem:** ***Convert 250 knots to ft/sec*** (NOTE: Knots = Nautical Miles Per Hour)

$$\frac{250\ \cancel{Nmi.}}{\cancel{hr.}} \times \frac{6076\ ft.}{\cancel{Nmi.}} \times \frac{1\ \cancel{hr.}}{3600\ sec.} = \frac{421.9\ ft.}{sec.}$$

Or you can memorize:

$$\frac{1.69\ ft./sec.}{Knot}$$

Systems Of Units

(Quick way to convert temperature, pressure, & density values)

- ***Inevitably, you will come to memorize the standard day, sea level temperature, pressure, and density values for air. Knowing these can make for a very effective means to convert between units:***

TEMP: **288.16 °K = 518.69 ° R** ***(ALWAYS convert °C & °F to absolute first!)***

Convert: $251\,°K \times \dfrac{518.69\,°R}{288.16\,°K} = 451.8\,°R$

PRESS: **1.0 atm = 14.69 lb/in^2 = 2116.2 lb/ft^2 = 101325 N/m^2**

Convert: $12.5\,PSI \times \dfrac{101325\,N/m^2}{14.69\,PSI} = 86219.4\,N/m^2$

DENSITY: **0.0023769 sl/ft^3 = 1.225 kg/m^3**

Convert: $1.089\,kg/m^3 \times \dfrac{.0023769\,sl/ft^3}{1.225\,kg/m^3} = .0021130\,sl/ft^3$

Properties of Fluids - Temperature

- ***Temperature is actually not a fundamental unit of measure (as are Mass, Space, and Time). Although in aeronautics we treat it as one.***
- ***Temperature of a fluid is actually a measure of the mean (average) molecular Kinetic Energy (KE) internal to the fluid.***
  - ✓ ***KE – analogous to how rapidly fluid molecules are vibrating and colliding with each other. Implies velocity.***
  - ✓ ***The higher the vibration the higher the fluid temperature.***
  - ✓ ***Boltzmannn's constant relates temperature to average fluid KE by:***

$$KE = \tfrac{1}{2} * m * v^2 = (3/2) * k * T$$

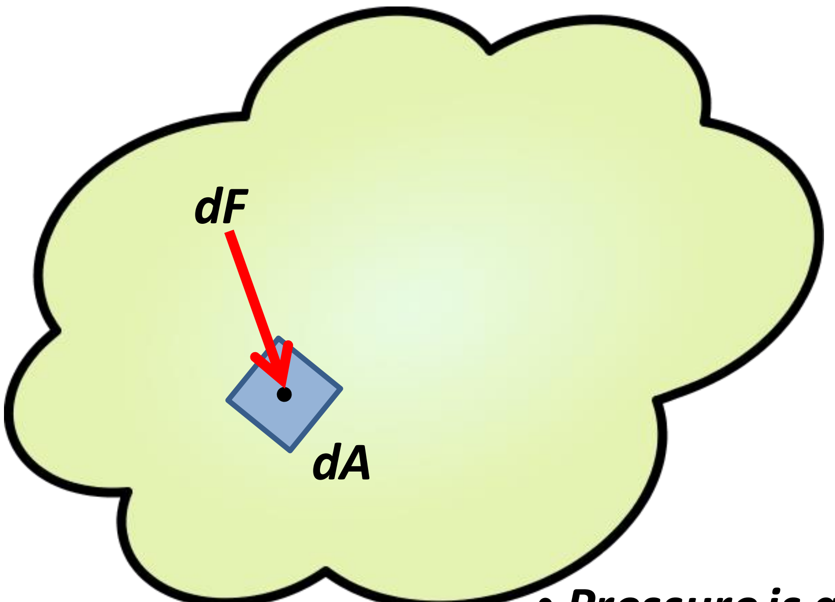
where k = Boltzmann's constant = 1.38×10^{-23} J/°K

- ***In week #3, when we study and learn how to model the atmosphere, we will see how temperature is the single most important independent variable that describes our atmosphere.***

Properties of Fluids - Pressure

• ***Pressure* (P) – *"The normal*** (perpendicular to surface) ***force per unit area exerted on a surface due to the time rate of change of momentum of fluid particles impacting that surface."***

Arbitrary volume of fluid



dA is an incremental area within the fluid that bounds a point of interest.

dF is an incremental force acting on ***dA*** at the point of interest due to fluid pressure.

We can mathematically define the fluid pressure as follows:
P = limit(***dF***/***dA***) as the size of ***dA*** gets smaller and smaller and approaches zero.
(This is called an integral form. You will learn about such forms in MAT 115 & beyond)

• ***Pressure is a point property. As such the value of pressure can be different at any point in the field as conditions change.***

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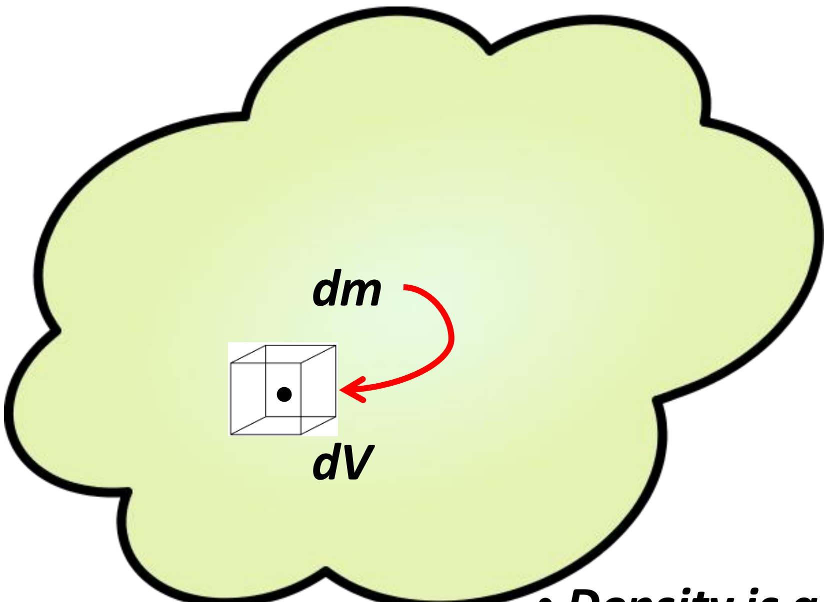
Properties of Fluids - Density

- ***Density*** (ρ) ***– "The amount of mass of a fluid contained within a defined unit volume." The greater the mass of fluid within that volume, the higher the fluid density.***

Arbitrary volume of fluid



dV is an incremental volume within the fluid that bounds a point of interest.

dm is an incremental mass of the fluid contained within the volume ***dV***.

We can mathematically define the fluid density as follows:

ρ = limit(***dm***/***dV***) as the size of ***dV*** gets smaller and smaller and approaches zero.

(This is called an integral form. You will learn about such forms in MAT 115 & beyond)

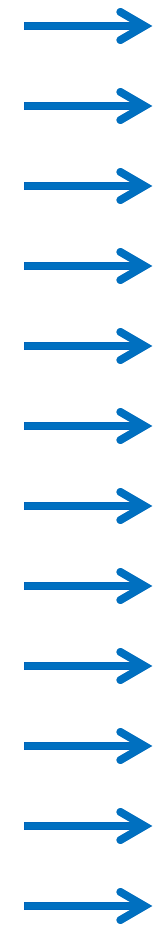
- ***<u>Density is a point property</u>. As such the value of density can be different at any point in the field as conditions change.***

Fluid Velocity Fields - UNIFORM

(Steady, Level Flow with No Obstructions)

The velocity <u>at any point in this flow field</u>:
a) Has the same magnitude (speed) and
b) Is oriented in the same direction.

Therefore, we can draw the fluid flow paths (called streamlines) for this uniform flow field quite simply… see the next slide



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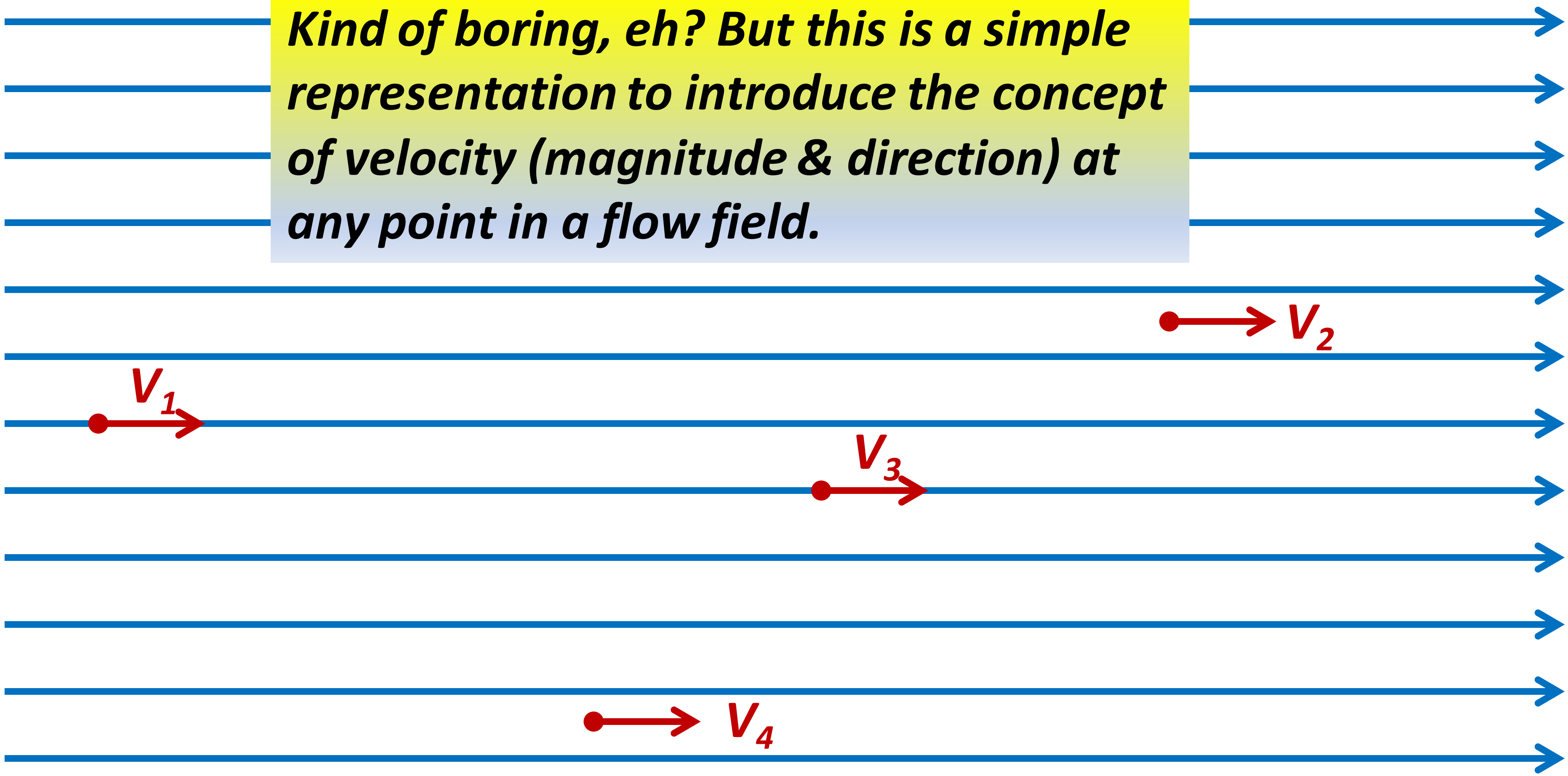
Fluid Velocity Fields - UNIFORM

(Streamline Representation)

Kind of boring, eh? But this is a simple representation to introduce the concept of velocity (magnitude & direction) at any point in a flow field.



We shall come to find that <u>how the velocity changes throughout the flow field</u> impacts how aerodynamic forces are created.

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Fluid Velocity Fields Around Bodies

(Steady, Level Flow About Cylinder & Airfoil)

- ***Now let us examine how the fluid flow is disturbed when we immerse some objects in this flow field.***
  - **First we see how a cylinder changes the flow field:**

    https://youtu.be/TOUylg7Eyec?t=24s

  - **Now let' see how an airfoil changes the flow field:**

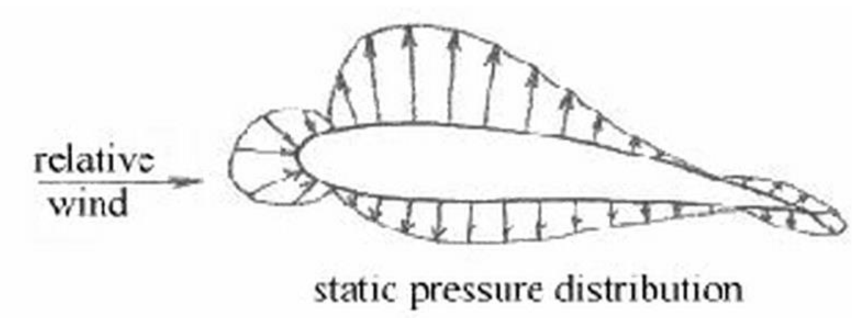
    https://youtu.be/6UlsArvbTeo?t=5s

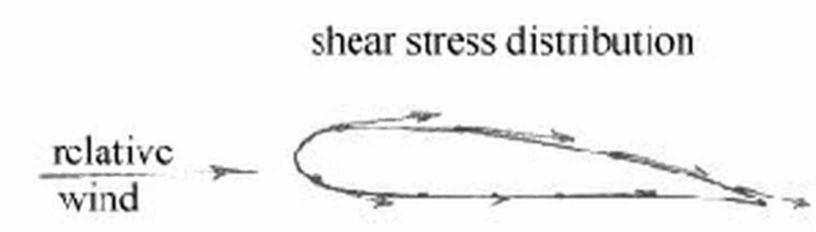
- ***The change of flow velocity above and below the airfoil is the mechanism of how lift is produced. We are going to study how we explain this in terms of pressure later in this course!***

Fluid Velocity Fields Around Bodies

(Forces due to Pressure & Shear)

• ***If we consider only the two dimensions of an airfoil, we can identify two distinct, orthogonal*** (acting at right angles to one another) ***forces acting on the airfoil:***





➢ **Forces due to pressure:**

- Caused by changes in flow velocity (+ or -) from the free undisturbed flow ahead of airfoil.
- Always normal to airfoil surface!
- Primarily causes a net lift.
- Can contribute to drag (pressure drag).
- Can provide small amounts of thrust!

➢ **Forces due to shear stress:**

- Caused by friction between the fluid molecules and the airfoil surface.
- Always tangent to the airfoil surface!
- Primary source of drag (skin friction drag).
- Focus of study in early parts of ARO 202.

Ideal Gas Law (Equation of State)

Deriving Preferred Aerodynamics Version

• ***The common form of the ideal gas law most often taught in high school physics curriculum looks like this:***

$$P*V = n*\mathcal{R}*T$$

NOTE: $\mathcal{R}$ is the <u>universal</u> gas constant! It is the same for all fluids.

• ***In aerodynamics, we typically are always flying within a known, common fluid (air!), and therefore it is more useful to employ the <u>specific gas constant</u>, which we denote with a normal "R." This changes the equation above as follows:***

$$P*V = m*R*T$$

• ***If we recognize that the definition of fluid density is mass divided by volume, we can re-arrange and substitute as follows:***

$$P = \rho*R*T$$

• ***This yields an equation that relates 3 important aerodynamic fluid properties*** (Pressure, Density, & Temperature) ***to each other <u>at any single point</u> within a fluid mass!***

Ideal Gas Law (Equation of State)

Units & Values for "R" and how NOT to use this equation!

- ***If we solve the ideal gas law for "R" we can then perform a dimensional analysis on it to determine what the proper units for "R" must be:***

$$P = \rho * R * T \xrightarrow{\text{Solving For R}} R = \frac{P}{\rho * T}$$

UNITS

$$\frac{[F][L^3]}{[L^2][M][\theta]} \text{ or } \frac{[M][L^4]}{[L^2][M][\theta][T^2]}$$

SIMPLIFIED

$$\frac{[L^2]}{[\theta][T^2]}$$

R (British) = 1716 ft*lb/(slug*°R)

Reduce the units shown in both variants of R to prove to yourself they match the simplified units shown above!

R (SI) = 287 J/(kg*°K)

- $P_2 = \rho_2 * R * T_2$
- $P_1 = \rho_1 * R * T_1$

√ Correct Usage!

- ρ_2
- T_1

X ~~$P_? = \rho_2 * R * T_1$~~ X

X Incorrect Usage!