LESSON 2 - REVIEW OF "FOUR-FORCE PHYSICS"
Knowing a little aerodynamics really can help you win the fight.

Reading:
Shaw **pp. 387-417**
Bretana pp. 6-7
Problems/Questions:
Work on Problem Set 1
Objectives:
2-1 Understand why maneuvering is needed in aerial combat.
2-2 Know the four primary forces of aerodynamics.
2-3 Understand how lift, drag, thrust and weight are used for maneuvering in combat.
2-4 Know the definition of "G's" and how they affect aircraft performance.
2-5 Know how to read a V-n diagram.

Last time: Introductions, Course Philosophy

Today: Review of Basic Aero
- Four forces of Flight
- Drag
- Sustained Turns
- Lift
- V-n diagrams

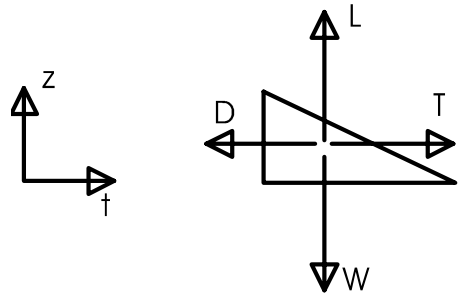
Equations:
- $n=L/W$
- $L = (\rho S C_l/2)\, V_t^2$
- $n\uparrow$ => L (?) => D_i (?) => ΣF_T(?) => a_T(?) => V_T(?) => L(?)

Why maneuver?
- Meeting/Defeating weapons parameters is the point of all maneuvering
- Shoot!
- Avoid being shot!

You maneuver because
- you screwed up earlier
- ROE or conscience force you to (no BVR)
- System malfunction

According to Shaw, maneuver = accelerate (changing speed or direction)
Accelerate => Newton => $\Sigma\mathbf{F}=m\mathbf{a}$ => Free body diagrams

Review: only three things on the FBD – the object, the forces, and the coordinate system



=> Aero = 4 force physics

Simple Case: Level flight, constant airspeed

Show that L = W, T = D

Over the course of an engagement, of the four forces, which do we control?

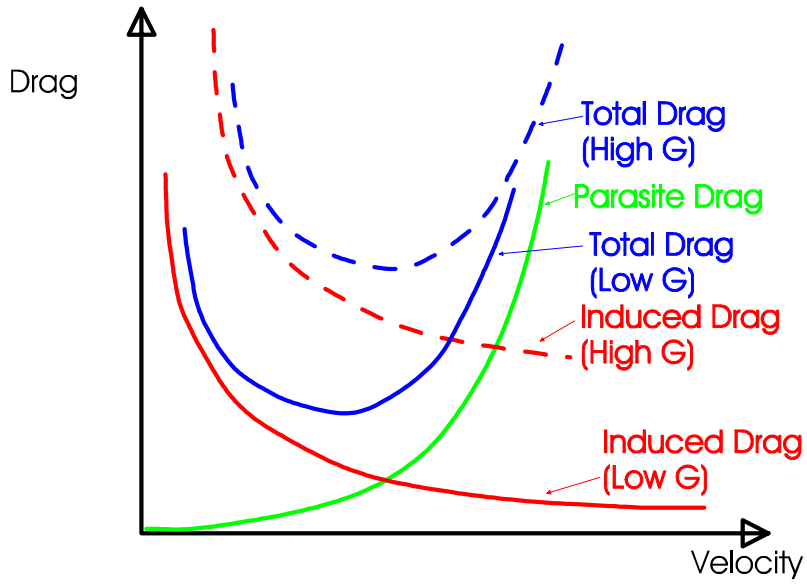
- Weight is approximately constant
- thrust = left hand (throttle)
- Lift = right hand (stick)
- Drag = ???

So, we directly control at least two of these forces

Let's talk about the only ??? – Drag

Three types of drag (Draw on board on plot of Drag vs. V)

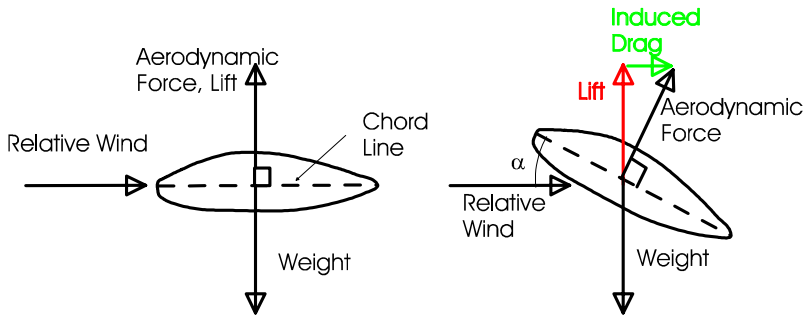
- *Parasite* (friction w/air; goes as V^2)
- *Wave* (air compressibility; goes as a complicated function, but worse as you approach Mach)
- *Induced* (due to AOA/Lift; goes as 1/V for a constant L)



For fighter maneuvering, we'll just look at induced drag because

- you can't change V very fast
- You don't fight near Mach (V big = turn radius big and turn rate small)
- We CAN change lift quickly, so we need to investigate the drag that depends on lift
- We've got direct control of the relative amount of induced drag in our right hand!

The easiest way to explain D_i is by showing that with any angle of attack other than zero, there is a component of lift in the same direction as drag.



Remember, lift is defined for our purposes as being *perpendicular to the velocity vector*, or, equivalently, to the relative wind.

Other explanations (vortices, etc) give the same result: at a constant AOA, as lift increases, induced drag increases.

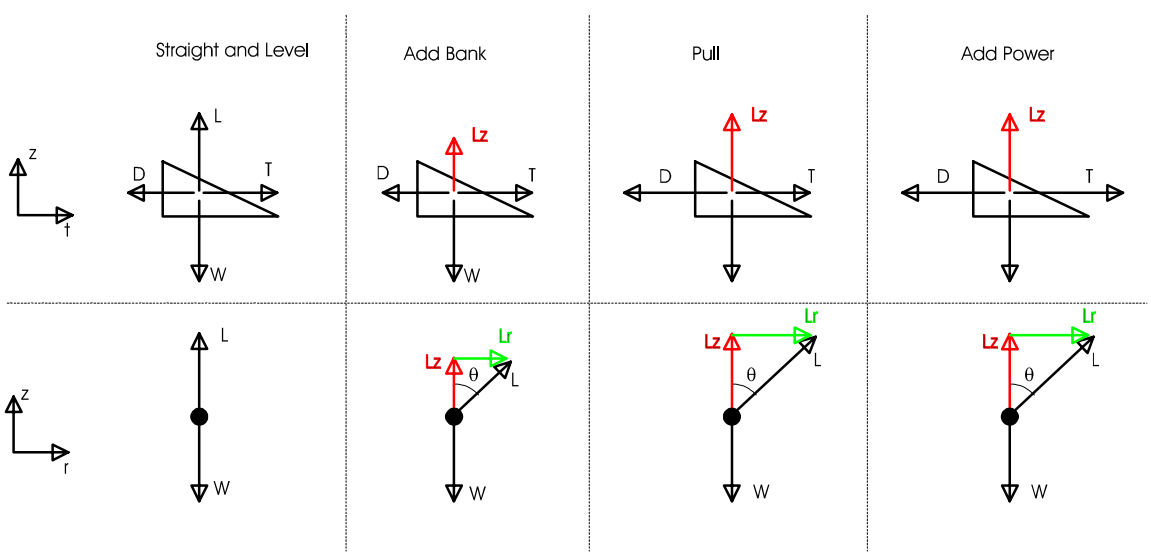
Bottom line: Pulling on the pole controls lift directly and drag indirectly

We now control *three* of the forces of flight during an engagement.

TURNS: Level (for today) at a constant airspeed
Think of flying the motorgliders you've all flown in.

Start out level with constant A/S (L=W, T=D)

Bank to desired angle. Now, $\Sigma F_z \neq 0$, so you start to sink. How do you fix this? Pull until $L_z = W$. Look at the free body diagrams…

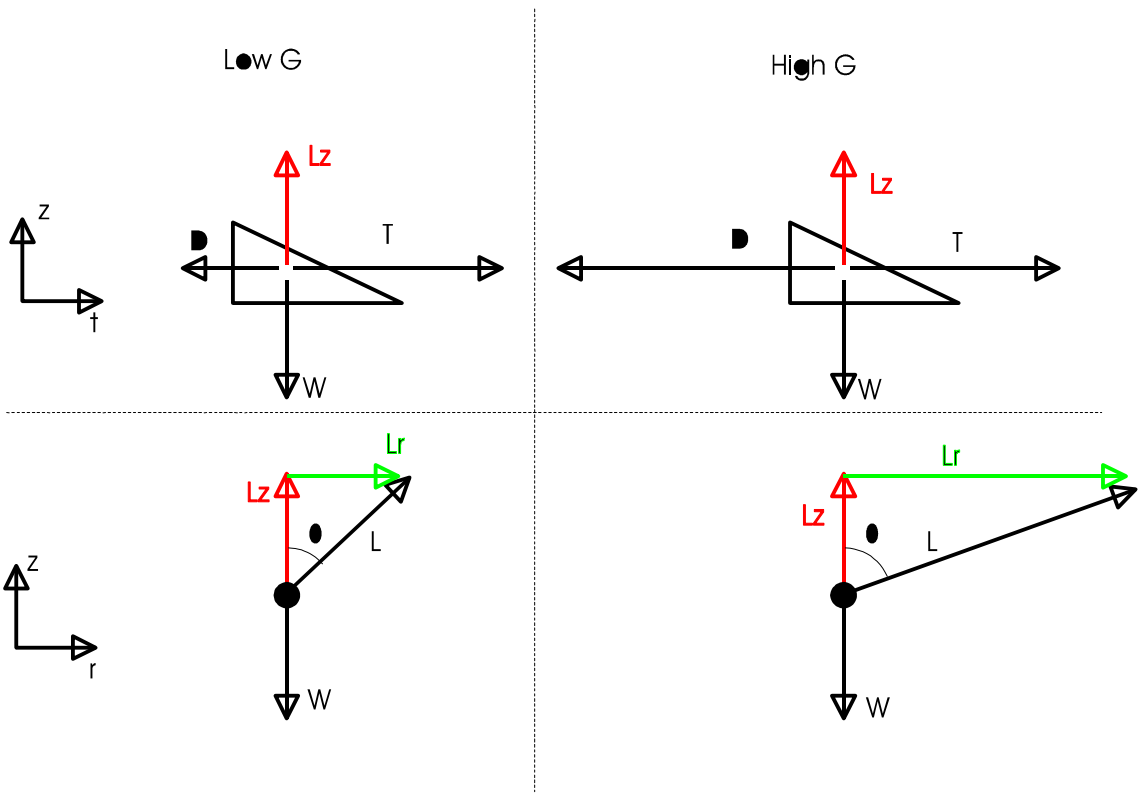


Now, $\Sigma F_z = 0$ and $\Sigma F_t = 0$ but $\Sigma F_r \neq 0$ From Newton II, $L_r = ma_r = mv^2/r$ => $r = mv^2/L_r$ => at a constant airspeed, as lift increases, turn radius decreases

In combat, changing power to speed up/slow down is usually not an option. Power is almost always in max A/B. This means we're down to controlling two of the forces of flight.

Let's look at two situations. In the first, in straight and level flight with thrust greater than drag, $a_z = a_r = 0$, but $a_t > 0$.

In the second, we bank hard and pull on the pole hard. Now, we're in a level turn with thrust less than drag and a_z is still 0, but $a_t < 0$ and $a_r > 0$.



Obviously, there will be some intermediate state where both a_z and a_t will be zero (T = D), but ar ≠ 0. This is called a sustained, level turn.

Show sustained turn chart

So, how, without changing power, can we change our speed?

- Pull more or pull less!

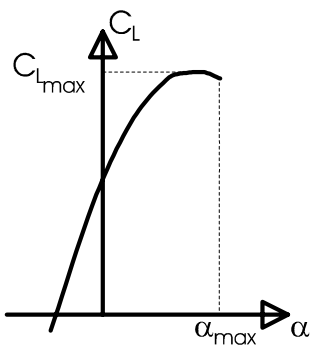
This means the stick controls all aspects of combat maneuvering – changing both the magnitude and direction of the velocity vector!!

In the next lesson, we'll see how pulling on the pole relates to ENERGY, but now…

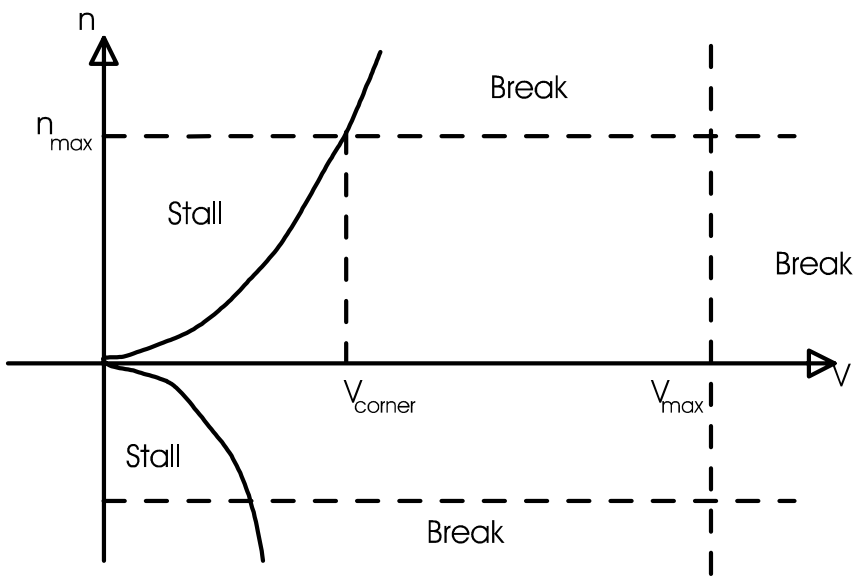
Just how much lift can we generate? Can we measure it?

Sure!! The G-meter gives an indirect indication of lift.

Since the load factor, or # of G's pulled, is defined as $n = L/W$ (demo for 1 G) and $L = \rho S V^2 C_l/2$, $n = \rho S V^2 C_l/2W$ where $\rho = f(\text{altitude})$, $S = \text{constant}$, $C_l = f(\alpha)$, $W = \text{constant}$. This means that $n = f(\text{altitude}, \alpha, V^2)$. At a given speed and altitude, n_{max} goes as $\alpha_{max} = \text{constant}$.



Thus, at a given altitude, n_{max} goes as V^2.



Discuss $n_{max(structural)}$ and $v_{max(structural)}$ on V-n diagram

Show F-4 V-n diagram

What is the difference between this chart and the sustained chart we saw earlier? V-n gives max instantaneous numbers at max power, while sustained gives long-term numbers at max power.

Summary:

$n = L/W$ $\quad$ $L = \rho V_t^2 S C_l/2$

$D_i \approx (\text{const})L$ (NOT rigorous) $\quad$ $V_T = a_T t$

Be able to discuss:

$n\uparrow \Rightarrow L\uparrow \Rightarrow D_i\uparrow \Rightarrow \Sigma F_T\downarrow \Rightarrow a_T\downarrow \Rightarrow V_T\downarrow \Rightarrow L\downarrow \Rightarrow$ pull harder