# Aerodynamics of the glide

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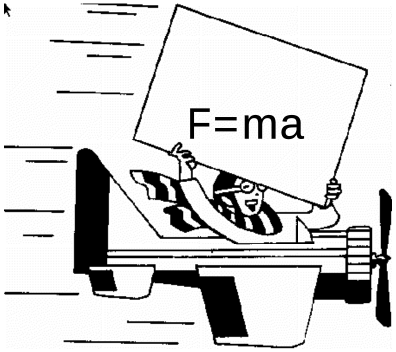
presented at SMXGIG '99, Santa Maria Ca

# Only **two** forces act on an airplane!




(1) *Weight* - vertically downward

(2) Air pressure forces:

Static (buoyancy) - negligible for airplanes!

Dynamic forces

*Thrust* - air motion from prop or jet.

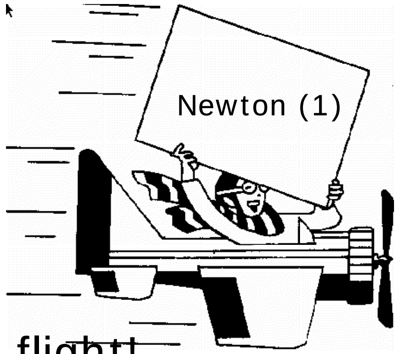
Lift/drag - from relative motion of airplane through the air.

*Lift* is the component of the aerodynamic force *perpendicular* to the flight path.
*Drag* is the component of the aerodynamic force *parallel* to the flight path.

For convenience, we often say there are *four* forces:

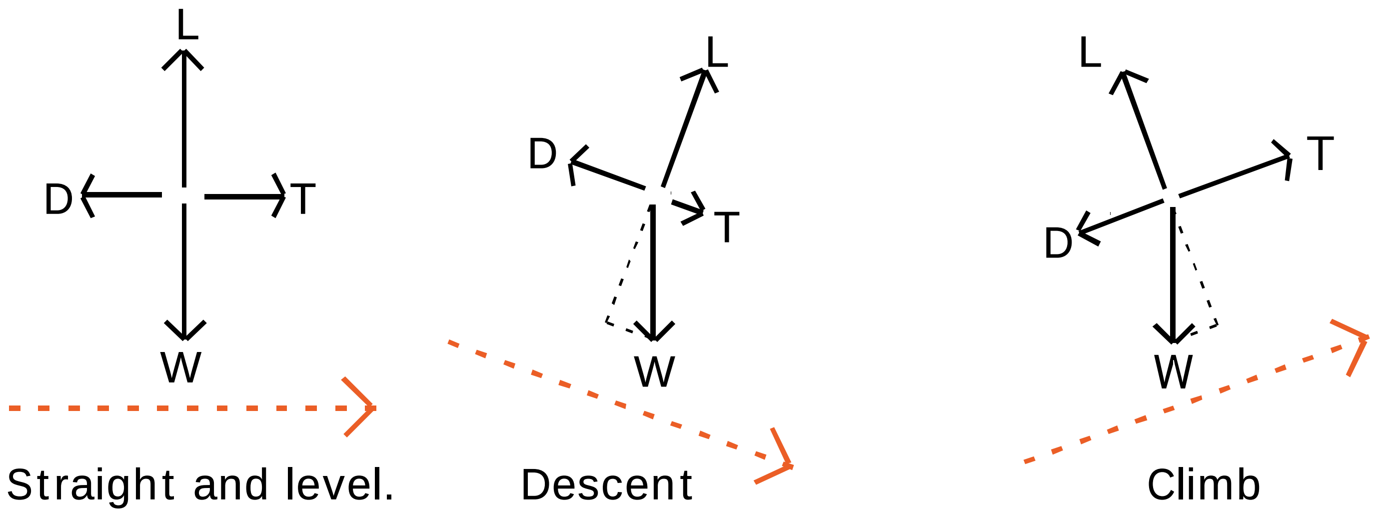
*Lift, weight, thrust and drag*

# *Steady* flight implies *balanced* forces




Not just straight and level- any straight line, constant velocity flight!
e.g. Steady climbs and descents.

Throttle or elevator changes unbalances the forces, changing the flight path or airspeed.




In climbs/descents you have excess thrust/drag and *less* lift. Force components balance.

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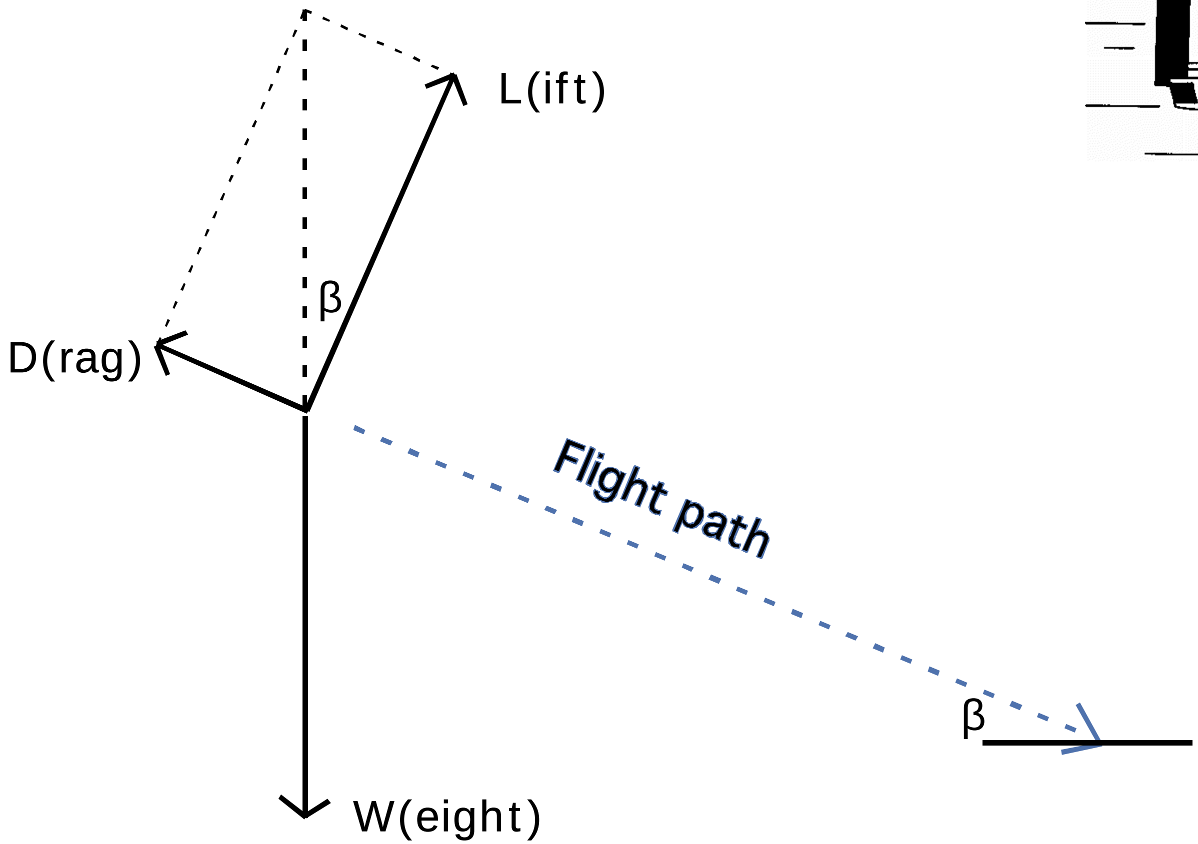
# Let's focus on power-off glides


Glide angle, β, is the angle the total aerodynamic force makes with the lift.

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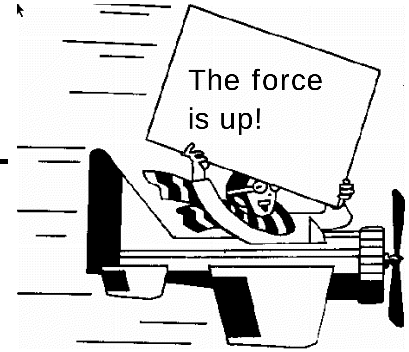
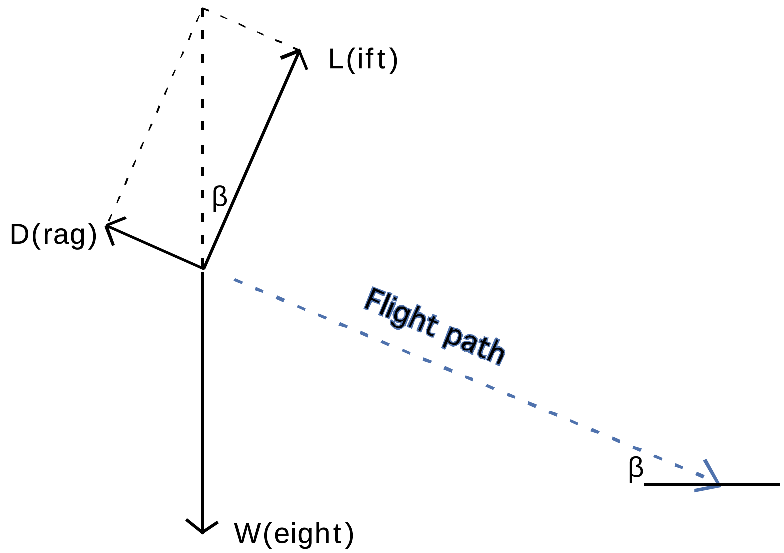
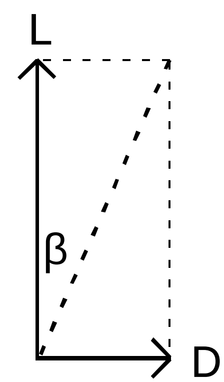
# The glide angle, β, is determined by L/D




Total aerodynamic force (L & D) balance the weight, W.

The glide angle is determined by L/D, in fact tan(β)=D/L.

The optimum (shallowest) glide obtains when L/D is a maximum, or equivalently, D/L is a minimum.

For a given airplane configuration, this ratio only depends on the angle of attack.

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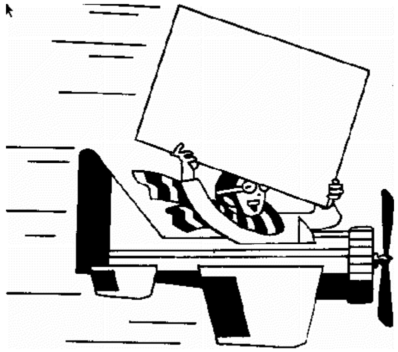
## The aero forces, lift and drag depend on:



(1) True airspeed, proportional to $v^2$
(2) Air density, proportional to $\rho$
(3) Scale size, proprtional to area S
(4) Shape of the body and the airflow direction
(5) Other factors, which often can be ignored (eg viscosity)

In summary:

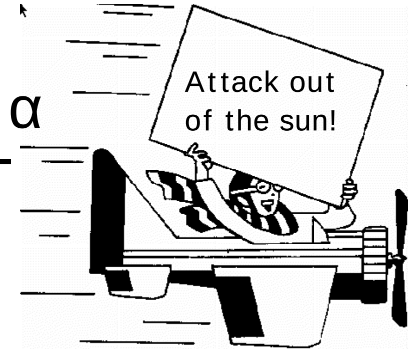
$$L = c_L(\alpha)\, \rho\, v^2\, S/2$$

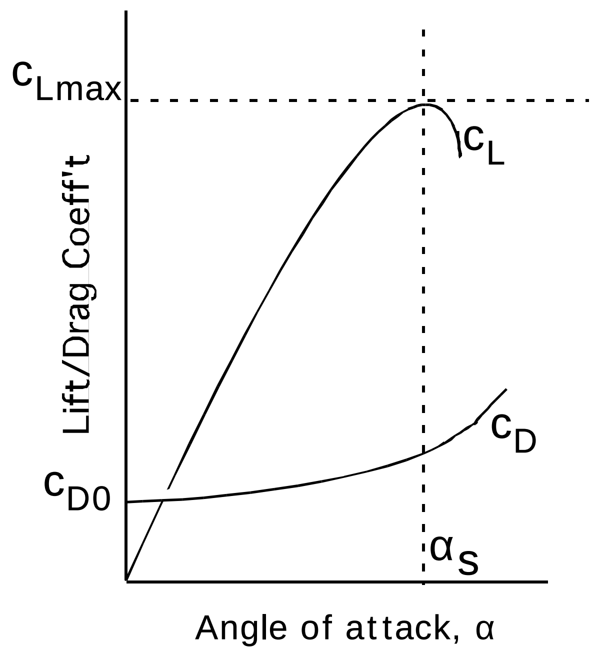
$$D = c_D(\alpha)\, \rho\, v^2\, S/2$$

All the geometrical information is buried in the lift/drag coefficients $c_L$ and $c_D$. $\alpha$ is the angle of attack. Aerodynamicists define $\alpha$ relative to the zero-lift line. Others often use the chord line.

Note that $L/D = c_L(\alpha) / c_D(\alpha)$ is determined by angle of attack.

# Lift and drag vary strongly with angle of attack, α

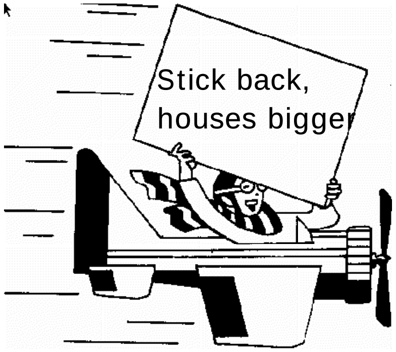


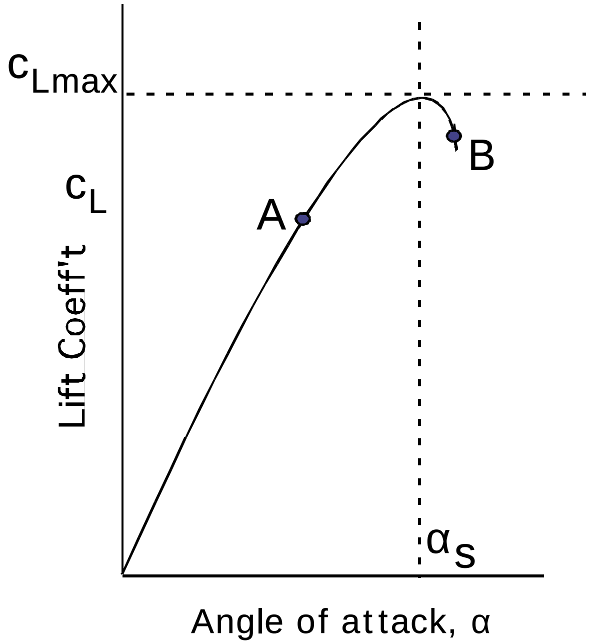




$c_L(\alpha)$ has a maximum, $c_{Lmax}$, when $\alpha=\alpha_S$ after which lift decreases with increasing angle of attack. We'll see that this is the stalling α.

The drag coefficient $c_D(\alpha)$ is minimum at zero α and increases with α. $c_{D0}$ is the parasite drag coefficient. The increase in $c_D$ over $c_{D0}$ with α is termed induced drag.

# The wing stalls at its max lift coeff't




At A: Momentary increase in AOA -> increase in lift -> climb -> decrease in AOA. Stable!

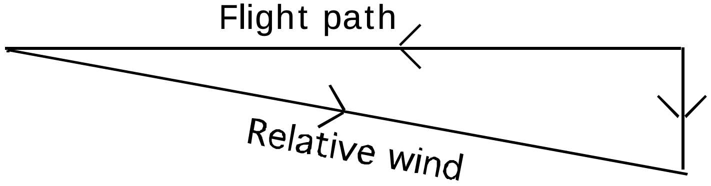
At B: Momentary increase in AOA -> decrease in lift -> descent -> further increase in AOA. Unstable!

There is lift beyond the stalling angle of attack, but no stable flight.

# "Induced" drag is induced by lift.

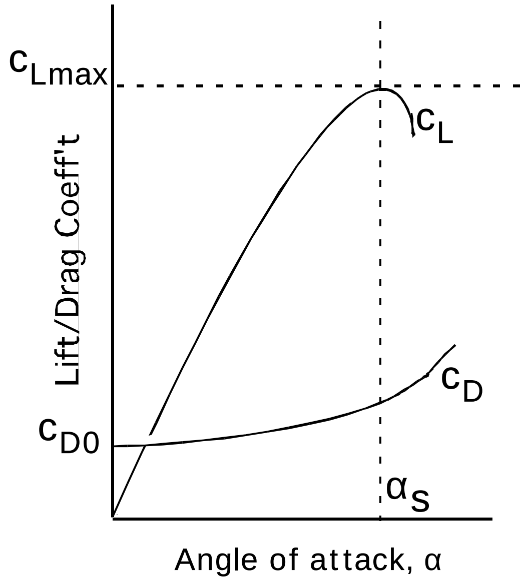

Parasite drag is independent of lift-  frictional and form drag.
Passage of the airplane heats the air and creates a wake. This costs energy.

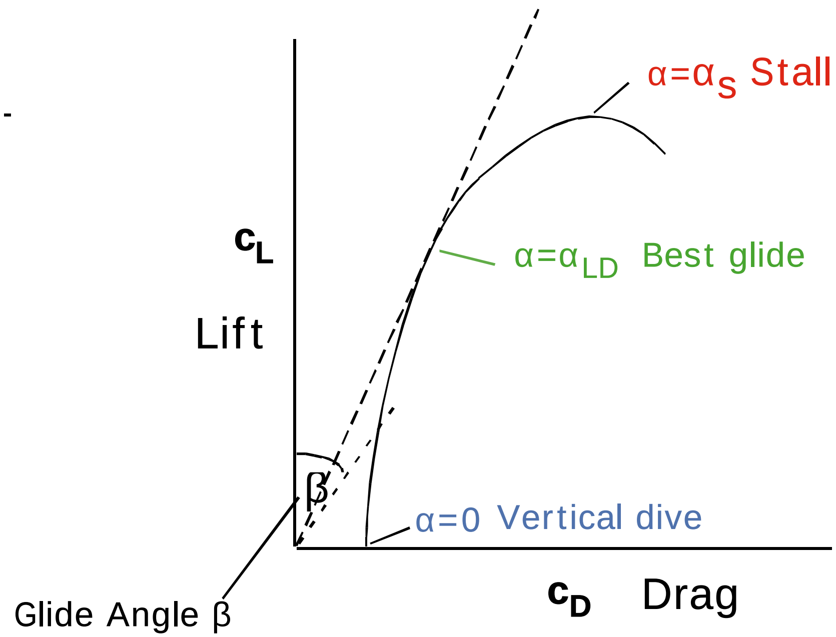
Induced drag is a consequence of the tip vortices present when the wings create lift.  The wings are flying in a self-induced downdraft.




"Lift" perpendicular to the relative wind is tilted back with respect to the flight path.  Larger aspect ratio -> less induced drag.

# Combining Cl and Cd gives us the glide angle.





The (no-wind) glide angle β is determined by the angle of attack α.

The optimum glide occurs at $\alpha_{LD}$, tangent to the "drag polar".

Here induced drag ~ parasite drag.

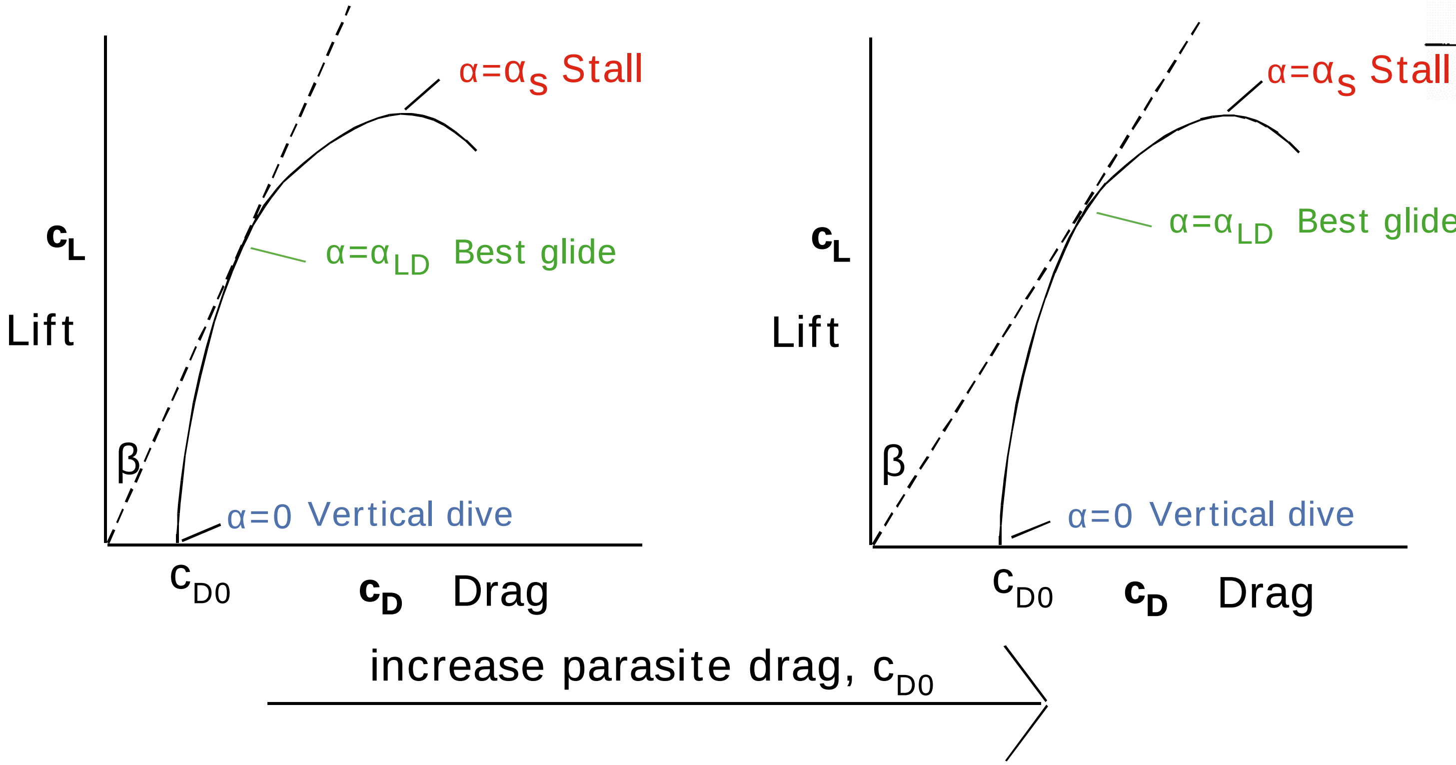
At a given weight, each AOA α corresponds to a definite IAS.

The POH will list $v_{LD}$ at max gross.

At other weights, $v_{LD}=v_{LDmaxgross}(W/W_{maxgross})^{1/2}$

# Increasing drag lowers $V_{LD}$





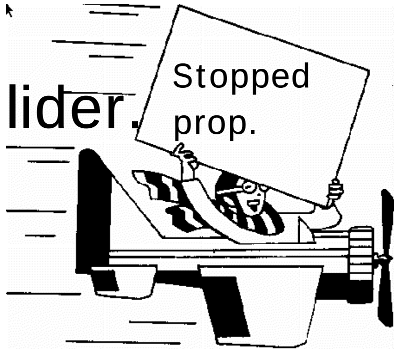


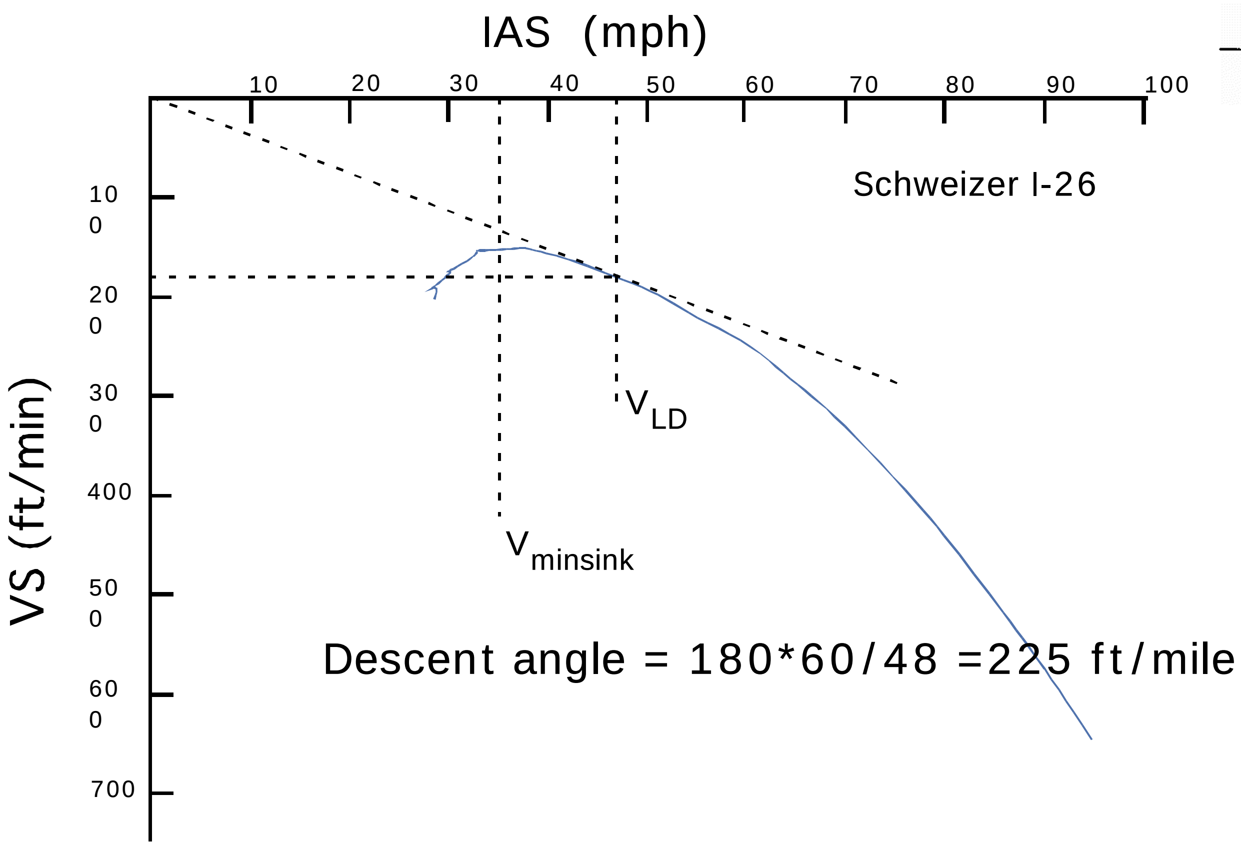
Retractables (gear up!) typically have higher best glide speeds than fixed gear. Lowering the gear reduces the best glide speed.

A36 Bonanza - 110 kts

Cessna 182 - 70 kts.

# Rate of descent vs. IAS for the Schweitzer I-26 glider.



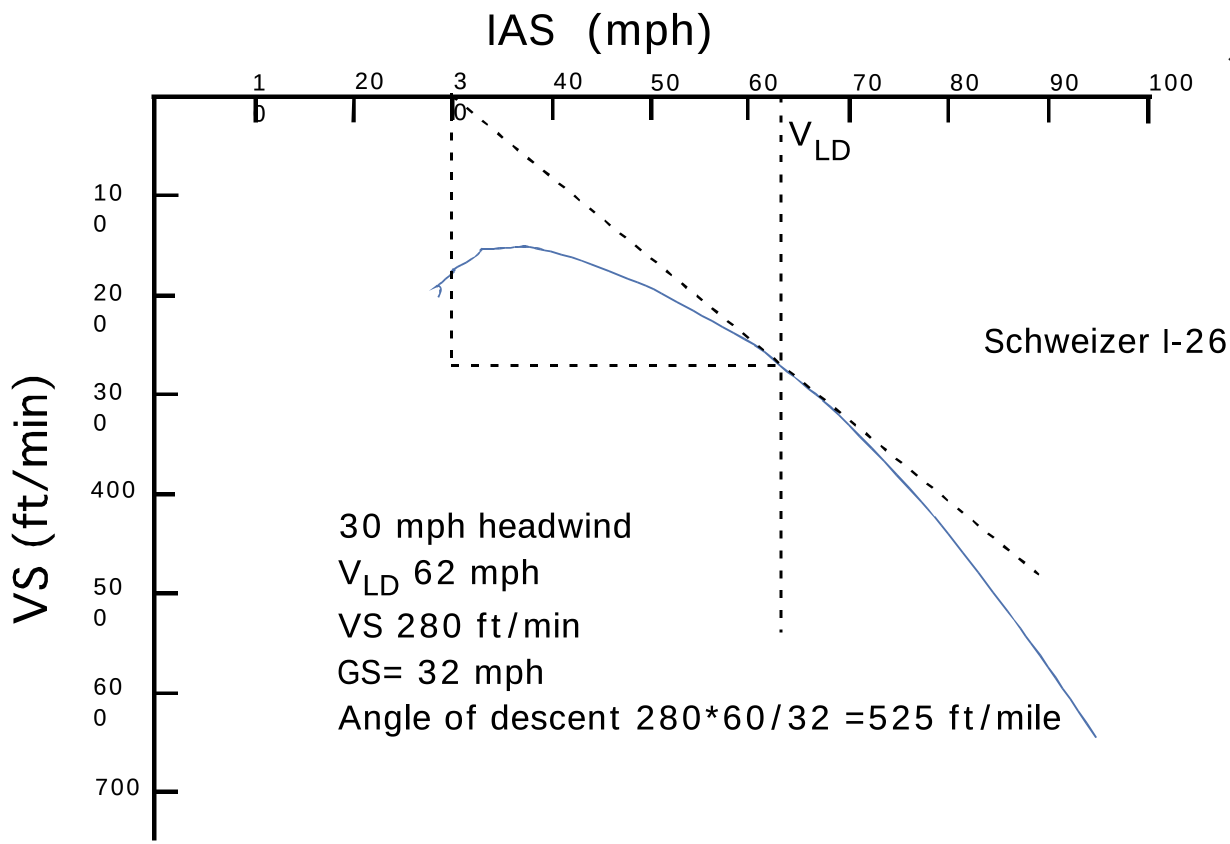




Should really be forward speed - nearly the same as airspeed for shallow angles.

$V_{minsink}$ (35 mph) gives the slowest descent rate.

$V_{LD}$ (48 mph) gives the shallowest still-air glide.

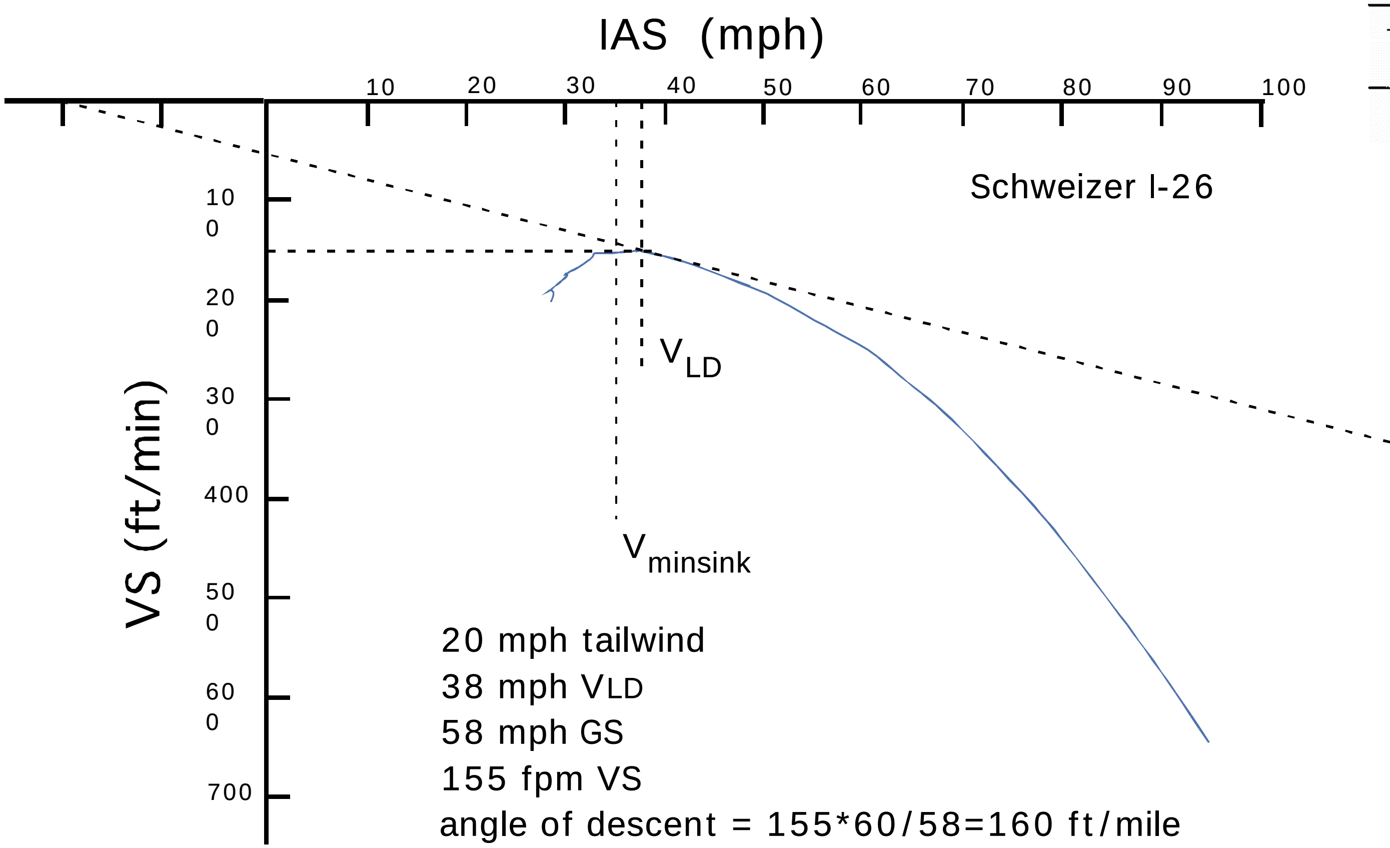
# In a headwind $V_{LD}$ increases!


At the no-wind $V_{LD}$ of 48 mph, angle of descent would have been 180*60/18=600ft/mile - even steeper.

As a rule of thumb, add one half your headwind to your still air $V_{LD}$

# In a tailwind $V_{LD}$ decreases a little.

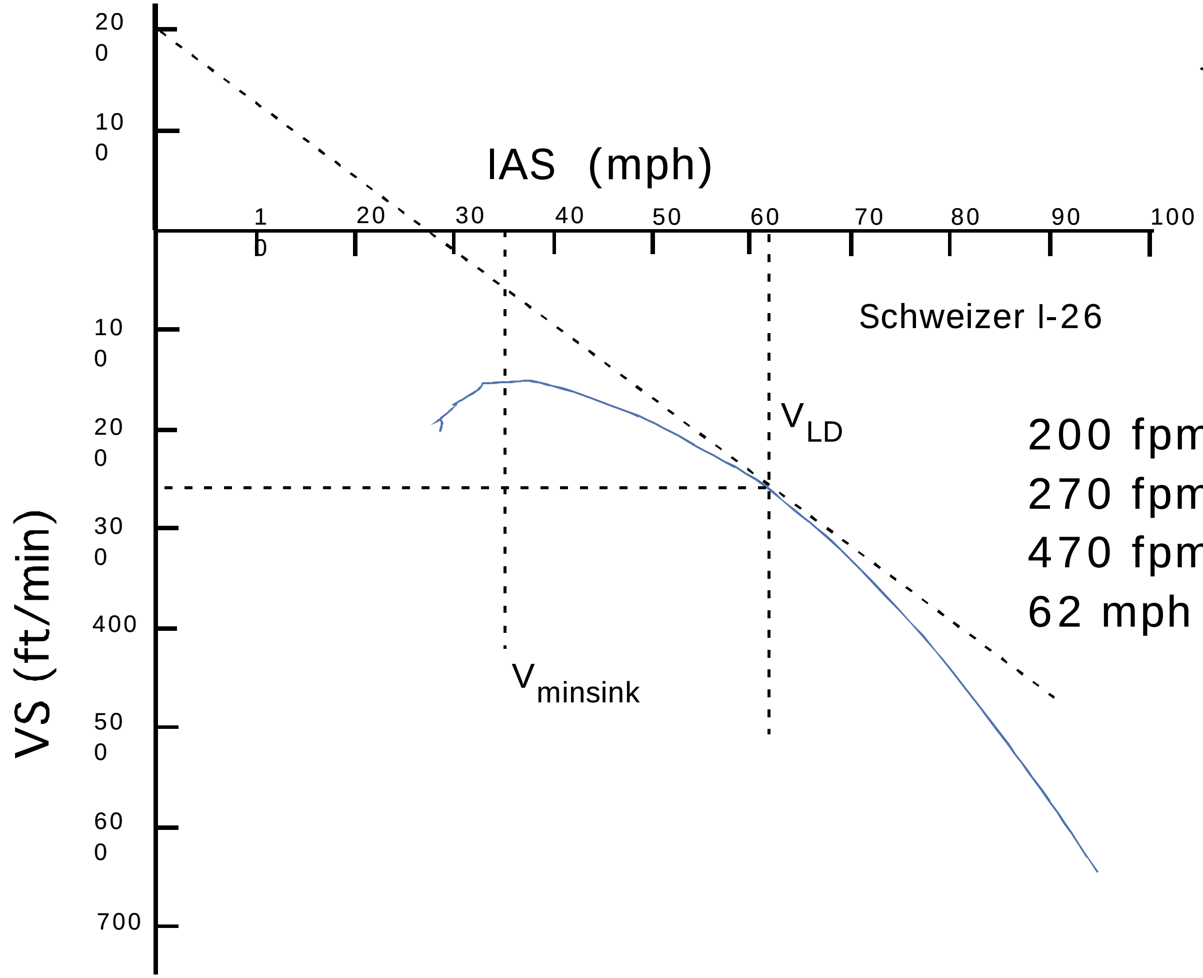




It never pays to fly slower than $V_{minsink}$

The recommended rule is to subtract only one quarter of the tailwind from your still air $V_{LD}$

It is better to err by being too fast rather than too slow.

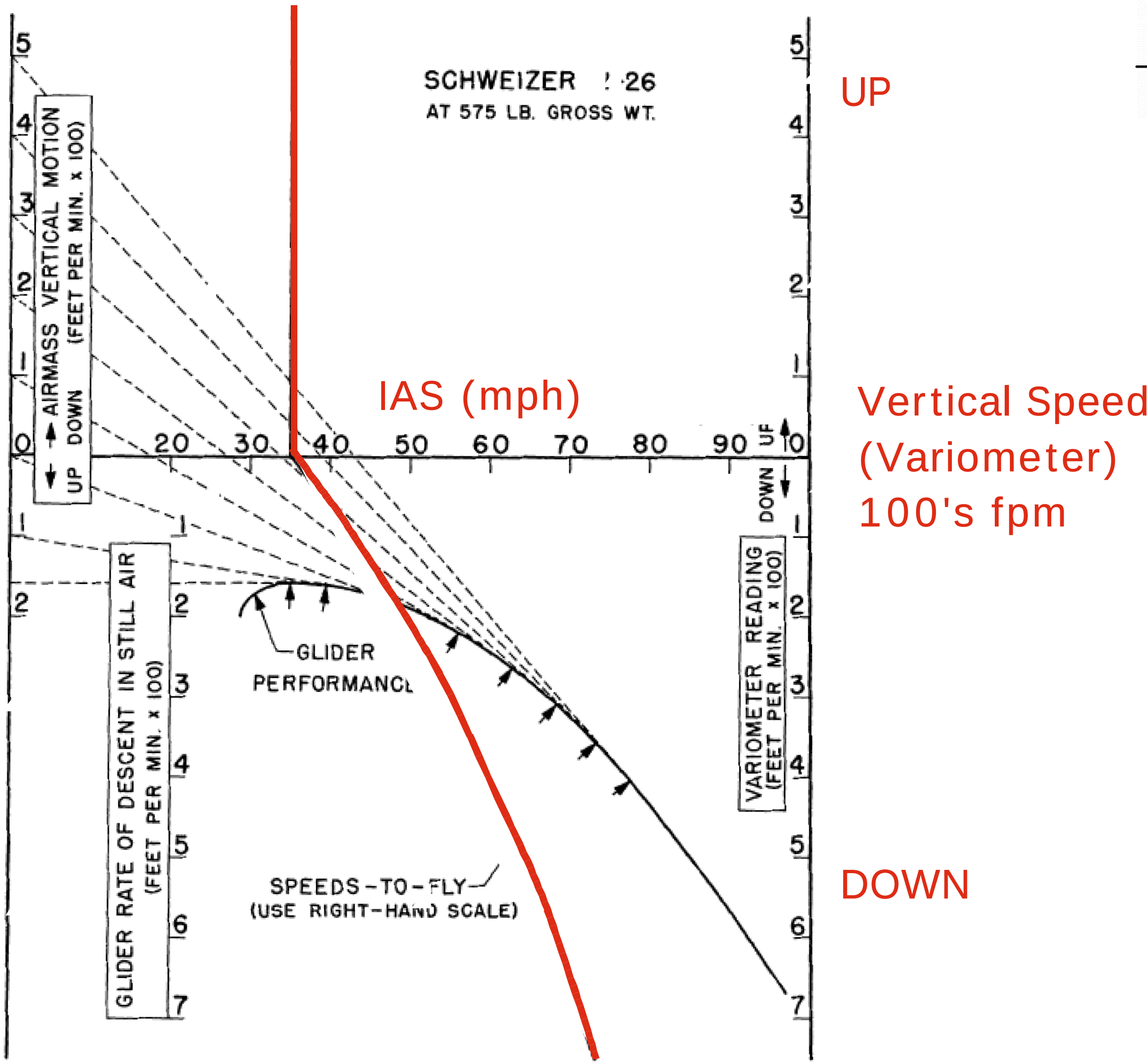
# Up- and down- drafts affect $V_{LD}$

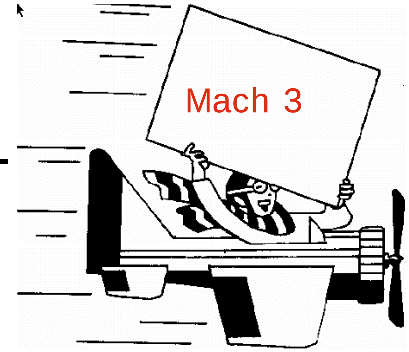




200 fpm downdraft
270 fpm VS -airmass
470 fpm VS - ground
62 mph $V_{LD}$

Speed up in downdrafts, slow up in updrafts.
In an airplane add 4-5 knots per 100fpm sink, slow 2-3 knots per 100fpm rise. Never slow below $V_{minsink}$

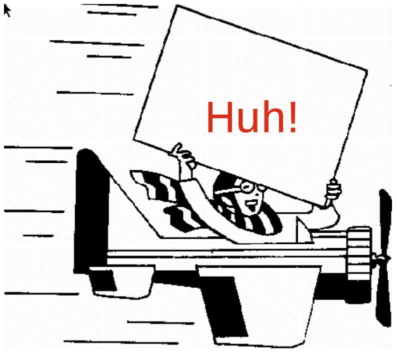
# Glider pilots chart "Speed to Fly"




Red curve gives airspeed to fly given (total) vertical speed

# What have we learned about $L/D_{max}$?




Lift/Drag is a maximum at a specific angle of attack, where
still air glide is shallowest
the angle of glide is the tilt of the lift vector.

This angle of attack corresponds to an IAS which (like other purely aerodynamic speeds) varies as the square root of the gross weight.

In downdrafts and headwinds the optimum glide speed increases.
Increase glide speed by half the headwind or 4-5 knots per 100 fpm sink.
In updrafts and tailwinds the optimum glide speed decreases.
Decrease glide speed by one quarter of the tailwind or 2-3 knots per 100 fpm rise, BUT not below minimum sink speed.

Know what it is for your airplane!