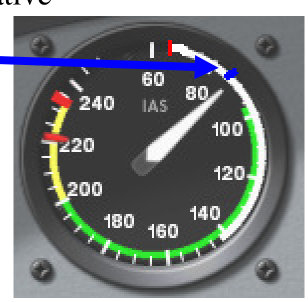
Lesson Plan:	Single-Engine Operations
Objective:	Identify the priorities during SE Operations, understand SE aerodynamics, and understand SE procedures. Also consider planning for and executing actions during engine failure during takeoff.
Equipment:	Marker board, Emergency checklists, FOM
Instructor's Actions:	Orally quiz student to verify material is understood.
Student's Actions:	Demonstrate understanding of the material.
Completion Standards:	Student demonstrates sound understanding of lesson material through oral quizzing.

Losing an engine in-flight presents different priorities, depending on phase of flight:

Phase of Flight	**Primary Concern**	**Procedure**
On Runway During TO	Directional Control	Throttles Idle Regain Directional Control
After Takeoff	Climb / Clear Obstacles	Maximize Thrust Minimize Drag Fix Problem
In Flight	Directional Control / Determine Plan of Action	Maximize Thrust Minimize Drag Fix Problem Decide Where to Go
Landing / Approach	Wheels on Runway	Secure Engine Lower Gear

Stabilizing Airplane

- Directional Control
  - Rudder into operating engine
  - Bank 2-3° into operating engine to establish Zero Sideslip
    - Zero Sideslip is making the relative wind go straight up and down the fuselage again (since engine is trying to make plane yaw)
    - This eliminates drag from body surfaces hitting relative
- Establish Best Single-Engine Rate-of-Climb Airspeed (V_{YSE})



  - We need to try to maintain altitude
    - With sufficient thrust, we can maintain altitude without changing airspeed
      - This is seldom the case!
    - We maintain altitude until we reach V_{YSE}
    - If, at V_{YSE}, we cannot maintain altitude, continue to fly V_{YSE}
      - V_{YSE} will ALWAYS give you the best ROC during SE Ops

Maximizing Thrust

- Mixtures full forward
- Props full forward
- Throttles full forward

Minimizing Drag

- Flaps Up
  - Flaps create more lift but also create more drag
- Gear Up
  - Gear is a huge source of drag, but be careful – on some advanced airplanes, raising the gear makes more drag during retraction process
- Identify
  - "Dead foot, dead engine" means that the foot not doing any work is the engine that's not doing any work
- Verify
  - Move dead engine's throttle to idle
    - Listen for any change in sound
    - Look for change in yaw
  - Purpose is to make sure you don't have the wrong engine identified
- DECIDE
  - With sufficient altitude and time, you can attempt to troubleshoot the problem and a possible restart
  - Without sufficient altitude, eliminate the drag created by windmilling prop immediately
    - Feathering prop changes its blade angle to create minimal drag and stop windmilling

Single-Engine Aerodynamics

An asymmetric thrust situation presents two concerns. It is important to remember that they are independent of each other – and one does not provide the other. They are:

Control **Performance**

V_{MC} – V_{MC} is the ***minimum airspeed*** with the critical engine ***suddenly made inoperative*** where **CONTROL** can be **MAINTAINED** in straight flight with no more than 5° bank into operating engine, and no more than 150 lbs. of pressure exerted on the rudder pedals (full rudder deflection)

I.E. – Go any slower with one engine inoperative, and you will lose control of the aircraft!

What happens at VMC: Uncommanded roll into dead engine!

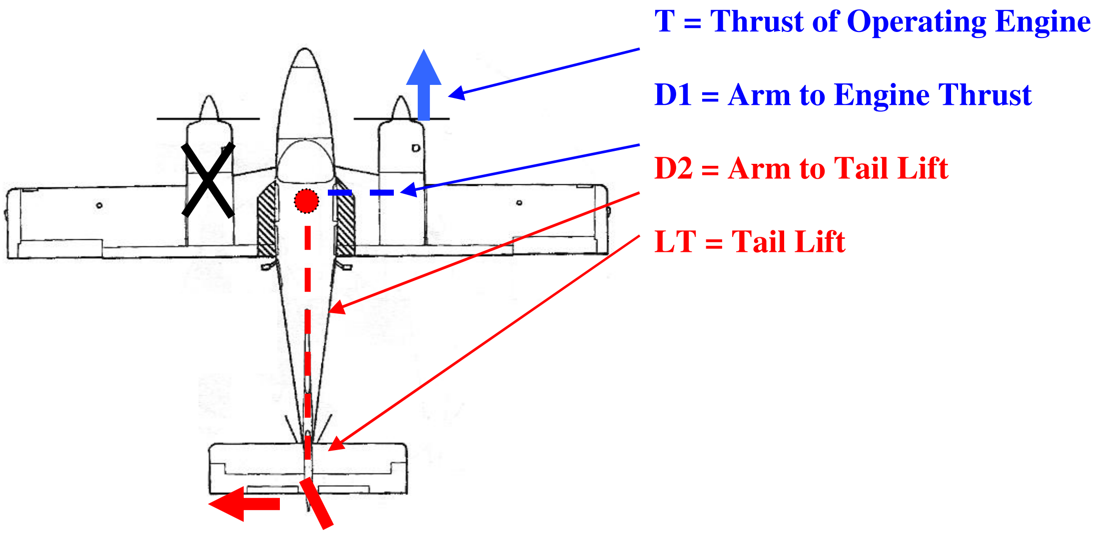
V_{MC} Recovery Technique: Reduce power on operating engine and lower nose to regain airspeed. This reduces the yawing moment of the operating engine's thrust and will increase effectiveness of the rudder by passing more airflow over it.

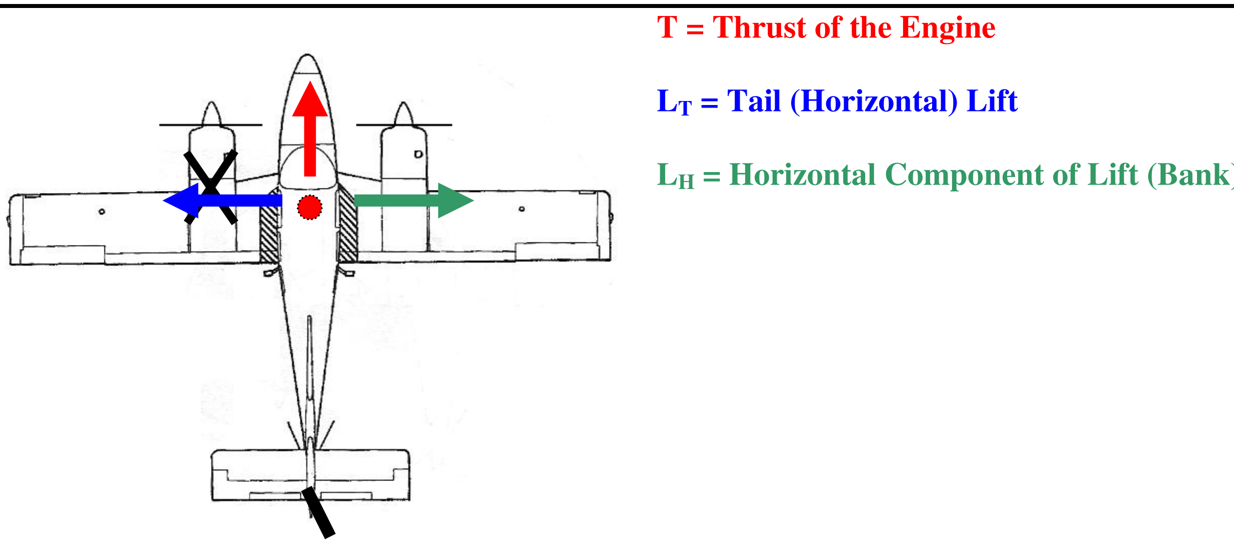
Published V_{MC}

Published V_{MC} is often different than actual V_{MC}, but the conditions used to test for V_{MC} are defined by 14 CFR Part 23.149. They are meant to identify V_{MC} under the worst conditions – just after liftoff on your takeoff run:

- Most unfavorable Weight & CG
- Not in ground effect
- Maximum takeoff power initially
- Trimmed for Takeoff
- Flaps in Takeoff position
- Cowl Flaps in takeoff position
- Landing gear UP
- Propellers in takeoff position
- Critical engine inoperative with propeller windmilling
- Maximum 5° into dead engine
- Maximum 150 lbs. force required on rudder pedals

Forces Affecting V_{MC} Diagram





Coordination in Zero Sideslip

Note that in Zero Sideslip flight, you are NOT coordinated. The Ball appears about ½ a width towards the operating engine.

An extended discussion about Zero Sideslip is later in the lesson.

Factors Affecting VMC

Condition	Trend	V_{MC}
Density Altitude	▲	▼
Weight	▲	▼
Bank into Operating Engine	▲	▼
Gear (Duchess)	▲ (up)	▼
Ground Effect	▲ (out)	▼
Aft CG	▲ (further aft)	▲
Power	▲	▲
Windmilling Prop	▲ (inop windmilling)	▲
Engine Inoperative	Critical	▲

Density Altitude
As density altitude increases, the amount of power the operating engine is able to produce decreases. Because of this, the yawing moment decreases and lowers V_{MC}.

Weight
More weight lowers V_{MC} because the amount of horizontal lift component is increased while banking into the operating engine with increased weight.

Bank into Operating Engine
The more bank you put into the operating engine, the greater the amount of horizontal lift component you create.

Gear
Because the nose gear is located farther AFT when extended, retracting the gear moves the CG of the aircraft slightly forward. This lowers VMC because it creates a slightly greater moment from the tail's lift.

Ground Effect
Operating out of ground effect increases the amount of drag produced by the aircraft's wing. Because of this, the engine thrust is effectively creating more "excess thrust." Operating in ground effect increases ground effect; operating OUT of ground effect LOWERS VMC.

Aft CG
The more the CG is moved aft, the less moment the tail's lift creates. Because the tail's lift is counteracting the yawing moment of the operating engine, an aft CG raises VMC.

Power
Obviously, the more power created by the engine increases the yawing moment it creates. This raises VMC.

Windmilling Prop
A windmilling prop on the inoperative engine presents a large amount of drag. Because the moment of this drag is in the opposite direction and opposite side of the operating engine, it increases VMC.

Engine Inoperative
Making the critical engine inoperative raises V_{MC} due to the greater thrust moment created by the operating engine. See the section below on critical engines.

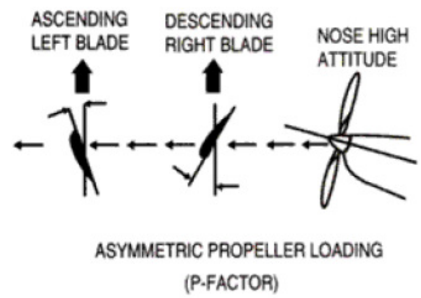
Factors Affecting Performance

Condition	Trend	Performance
Density Altitude	▲	▼
Weight	▲	▼
Bank into Operating Engine	▲	▼
Gear (Duchess)	▲ (up)	▲
Ground Effect	▲ (out)	▼
Aft CG	▲ (further aft)	▲
Power	▲	▲
Windmilling Prop	▲ (inop windmilling)	▼

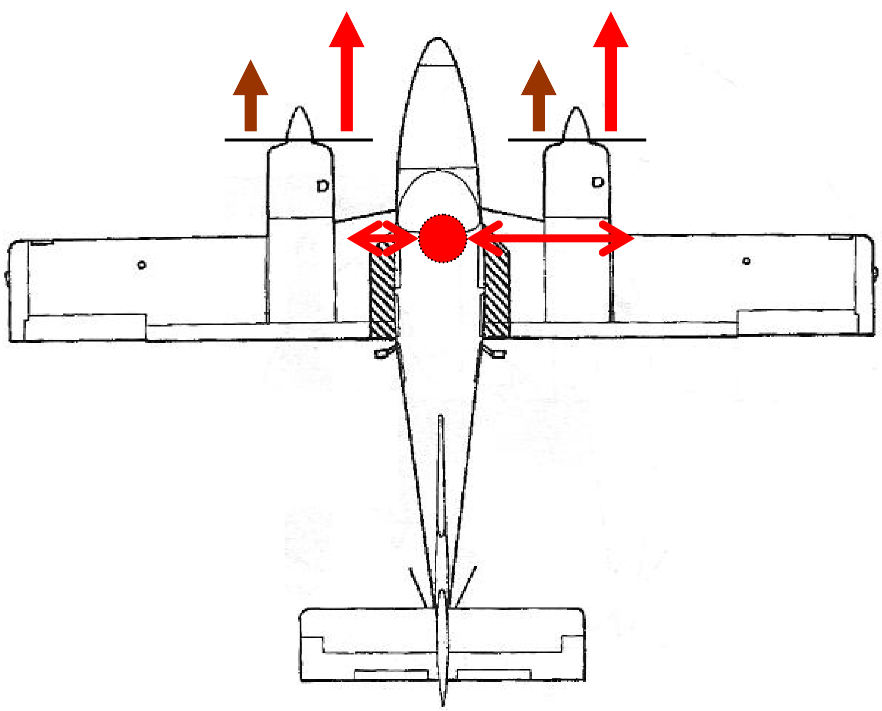
What Makes an Engine "Critical"

A multi-engine aircraft's "critical" engine is determined by the VMC speed it produces when the engine is failed. Simply – when an engine failed on one side produces a higher VMC than the other side, it is considered the critical engine.

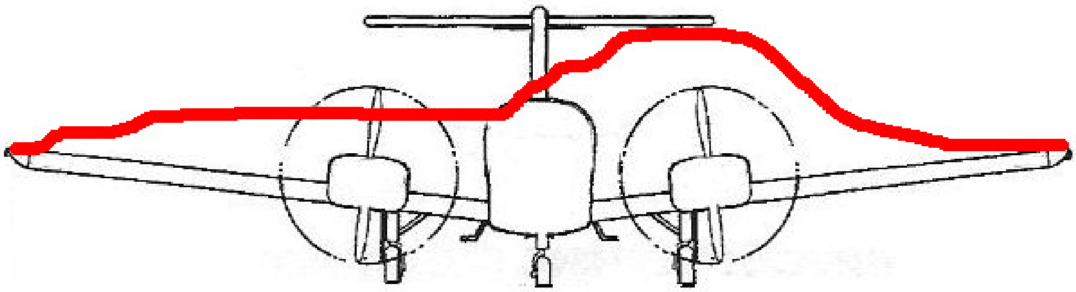
On conventional North American twins, both props rotate clockwise when viewed from the pilot's seat. Recall that in a positive angle of attack situation (such as maintaining V_{YSE}), the ascending blade on a clockwise-rotating prop produces slightly more lift due to a higher angle-of-attack with the relative wind.



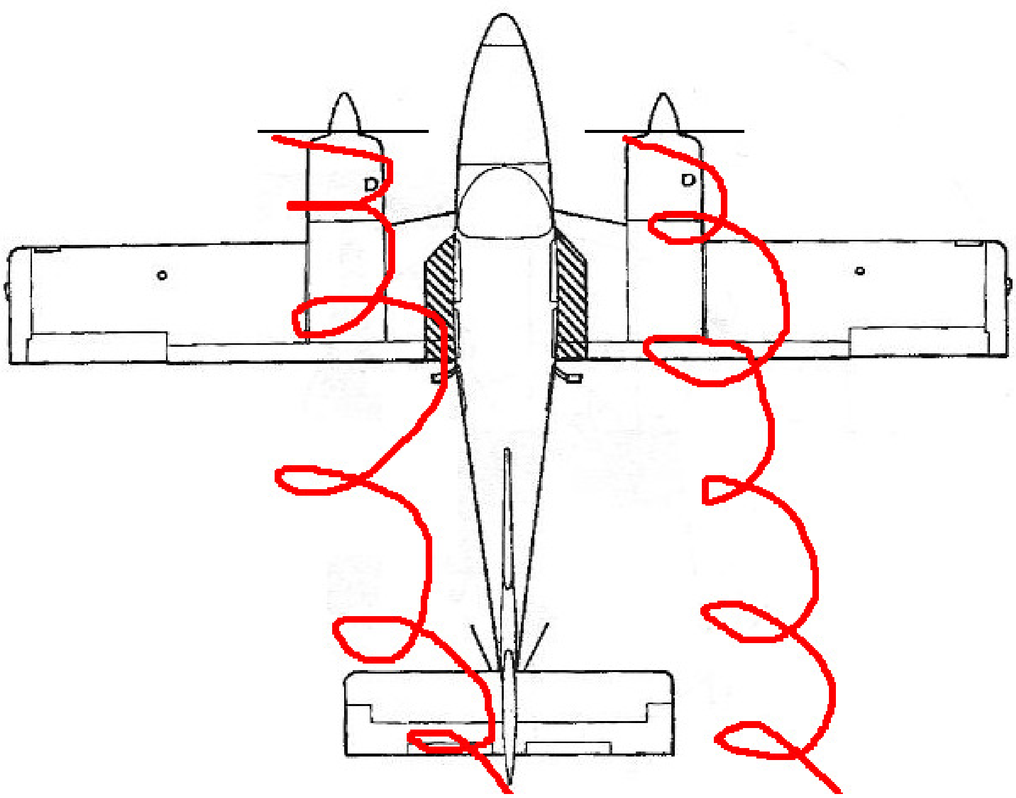
Now consider how far away the greater thrust of the RIGHT blade is from the aircraft's CG for both engines. Notice that the LEFT engine has a shorter distance to the CG.



Because there would be a greater **MOMENT** created by the **DOWNWARD BLADE** on the **RIGHT** engine if the **LEFT** engine were to **FAIL**, the **LEFT** engine is considered **CRITICAL**.



Also, because of this P-factor condition – a greater accelerated slipstream is created farther outboard on the right wing when the engine fails. This creates a greater rolling tendency when the left engine fails.



Tail effectiveness in the event of an engine failure is also affected by the left engine. If the left engine fails, we lose a certain amount of spiraling slipstream hitting the tail. Losing the right side does not affect the amount of air hitting the tail.

Counter-Rotating Propellers

On aircraft equipped with counter-rotating props, the same thrust moment is produced by either engine failing. Because of this, these aircraft **DO NOT** have a **CRITICAL** engine.

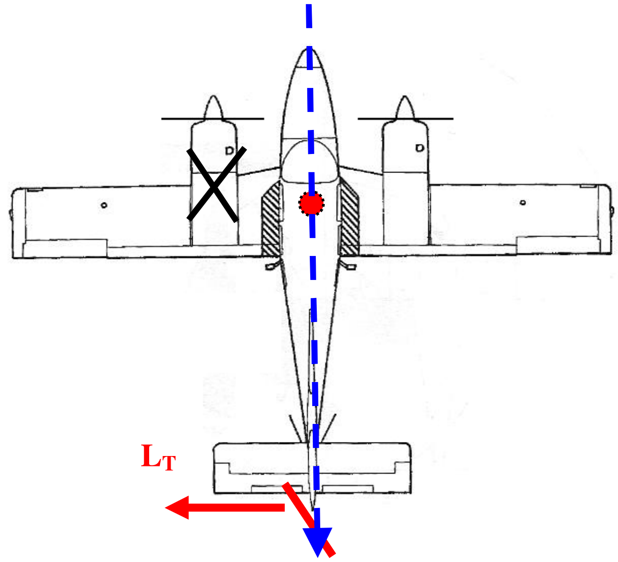
The Importance of Maintaining Zero Sideslip

Establishing "Zero Sideslip" offers two advantages: a lower V_{MC}, and the best performance in terms of minimizing drag. It is done by first using rudder to counteract the yawing moment of the operating engine, then using a 2-3° bank into the operating engine to counteract the horizontal component of lift created by the tail.

0° Bank, Rudder Into Operating Engine, Turning Flight

Offers: Moderate Drag, Moderate V_{MC}

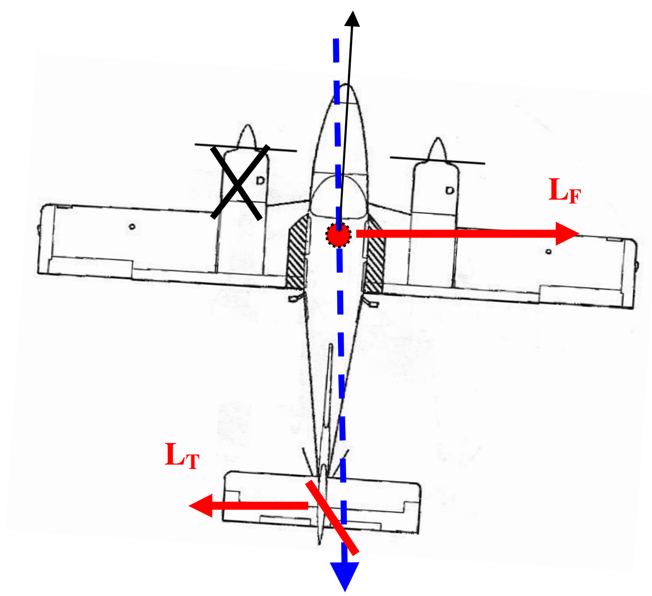
If we simply use rudder to counteract the yawing moment created by the engine, we maintain heading but fail to do two things: align the relative wind with the fuselage, and counteract the tail's lift to prevent a turn. The tail's lift, L_T, acts as a centripetal force making the aircraft turn.



0° Bank, Rudder Into Operating Engine

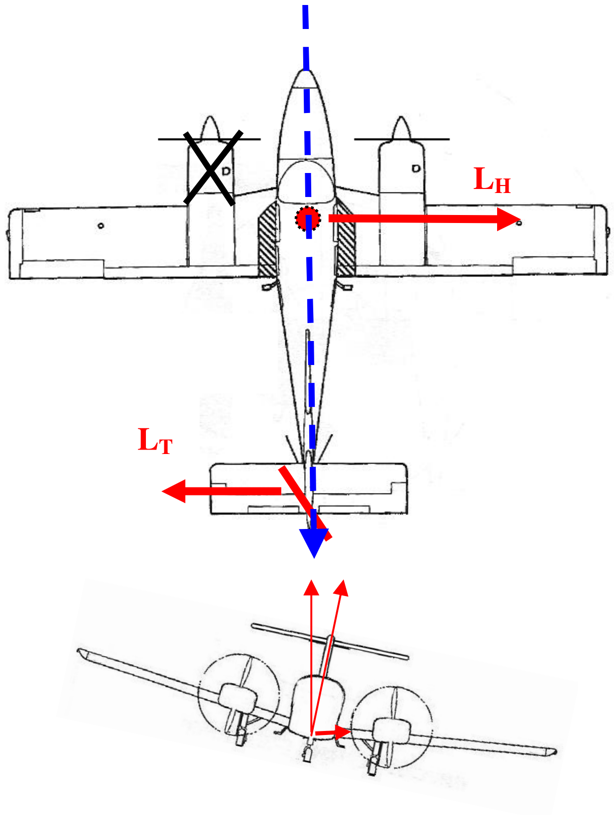
Offers: Moderate Drag, Higher V_{MC}

If we add more rudder to counteract the above mentioned turn, we maintain heading and stop the turn, but fail to do two things: align the relative wind with the fuselage, and produce a greater angle of attack on the tail to lower V_{MC}. Because the fuselage is not aligned directly with the relative wind, it produces a lift force (deflection) and we call that L_F. This creates greater drag and increases V_{MC} because the tail's angle of attack with the relative wind is less.



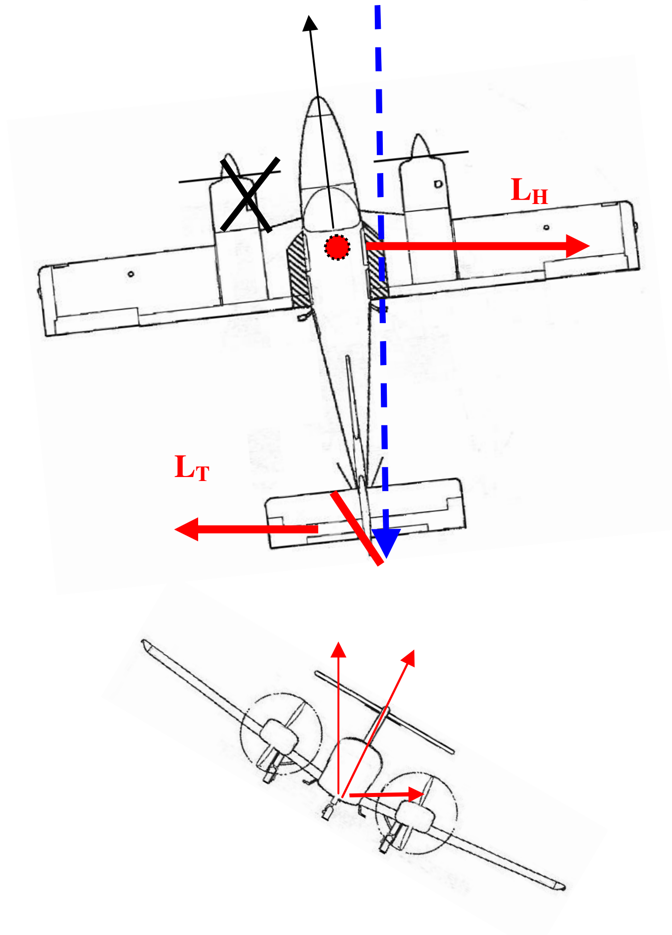
2° Bank, Rudder Into Operating Engine
Offers: Minimum Drag, Moderate V_{MC}

Now if we establish a small bank into the operating engine *instead of* adding more rudder to counteract the turn, accomplish two things. We again align the relative wind with the fuselage, eliminating drag created by presenting part of the fuselage to the relative wind. We also create a horizontal component of lift (L_H) that counteracts the turning tendency of the aircraft. Also, because the tail again has a larger angle of attack, V_{MC} is lowered because the tail can continue to produce lift at a slower airspeed.



5° Bank, Rudder Into Operating Engine
Offers: Higher Drag, Low V_{MC}

Now if we choose to bank even more into the operating engine, we do several things. Because we would initially start a turn to the right, the angle of attack on the tail would increase, and we would need to take out some rudder to counteract this effect. This effectively lowers V_{MC} because a greater amount of available tail lift is available to us to a slower airspeed. But since the relative wind is no longer flowing straight over the fuselage, we once again increase drag.



Planning for Engine Failure During Takeoff

You should plan and be ready for an engine failure during your takeoff run. Your takeoff phases should be split into three phases: Engine Failure before Liftoff, Engine Failure after Liftoff with Runway Remaining, Engine Failure after Liftoff with No Runway Remaining.

An important consideration for takeoff planning is anticipated single-engine climb performance after liftoff and single-engine service ceiling. Using these figures, you will know whether or not you can expect your aircraft to climb after liftoff if an engine fails. **Remember:** Most light twins do not have the performance necessary to climb on one engine even in the best of conditions.

If you encounter an engine failure before liftoff, simply close the throttles quickly, maintain directional control, and stop on the runway (if able).

After you lift off, you should keep your gear DOWN until there is not enough runway remaining in the event of an engine failure. If you encounter an engine failure after liftoff with enough runway remaining to stop (and presumably with your gear down), close both throttles and land straight ahead.

If you encounter an engine failure after takeoff with NO runway remaining, your gear should be up or in transit. At this point, you have to options:

1. **If your airplane CAN climb** – immediately minimize drag and maximize performance. Maintain SPEED and CONTROL and return for an immediate landing.
2. **If your airplane CANNOT climb** – you are now searching for a clearing to put your plane down in. Essentially, you're making a forced landing like you would in a single-engine airplane except that you may have more time to pick a site.