MULTI-ENGINE PERFORMANCE INFORMATION

WHAT IS THE CRITICAL ENGINE?

The critical engine is the engine that if failed will have the most adverse affect on the **CONTROL** and **PERFORMANCE** of the aircraft.

WHICH ENGINE IS THE CRITICAL ENGINE?

In a conventional twin (clockwise prop rotation), the LEFT ENGINE is the critical engine.

In a counter rotating twin, there is no critical engine.

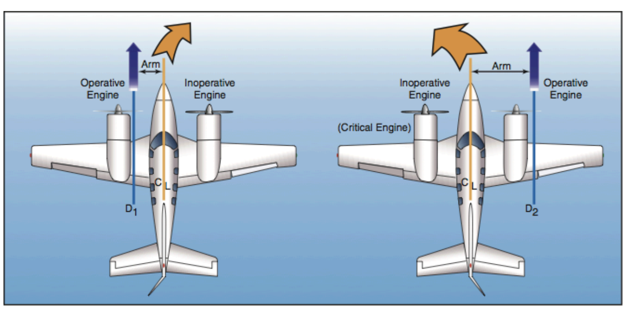
WHY IS THE LEFT ENGINE THE CRITICAL ENGINE?

There are 4 reasons the left engine is the critical engine (remember those 4 forces?):

P-FACTOR -- **A**CCELERATED SLIPSTREAM -- **S**PIRALING SLIPSTREAM -- **T**ORQUE

P-FACTOR:

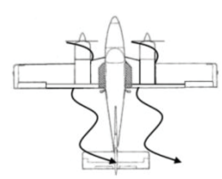
-The descending blade of each propeller produces more thrust than the ascending blade
-Therefore, in a conventional twin, the center of thrust is offset to the right of each engine (see thrust arrows below)
-There is a greater distance (arm) between the center of thrust & the longitudinal axis on the R-engine than on the left
-The greater the distance, or arm, the greater the leverage
-If the R-engine fails the leverage associated with P-Factor is not as great as if the left engine fails
-If the L-engine fails the yaw from P-Factor is most adverse, therefore the L-engine is critical



ACCELERATED SLIPSTREAM:

-Due to P-Factor, there is greater airflow (more lift) over the wings on the right side of each engine (D1 & D2 areas)
-There is a greater distance (arm) between the excess lift and the longitudinal axis on the R-engine than on the L-engine
-The greater the distance, or arm, the greater the leverage
-If the L-engine fails, there is a stronger rolling action than if the R-engine fails, therefore the L-engine is critical

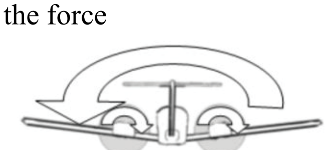
SPIRALING SLIPSTREAM:



-Each prop produces a spiraling slipstream of air behind it (picture)
-The L-engine's slipstream strikes the rudder on the left side creating a left turning tendency
-The R-engine's slipstream has no affect on the aircraft
-If the R-engine fails the L-engine's slipstream will counteract some of the yaw toward the dead engine
-If the L-engine fails the airplane will yaw uninhibited toward the dead engine, therefore the L-engine is critical

TORQUE:

-Torque is based on Newton's 3rd law: For every action there is an equal and opposite reaction-When the props spin clockwise torque will cause the plane to roll counter-clockwise (CCW) (picture)
-If the R-engine fails the plane will roll to the right, but the CCW torque will offset some of the force
-If the L-engine fails the CCW torque will encourage the roll toward the L-engine
-The L-engine is critical since torque most adversely affects control when the L-engine fails

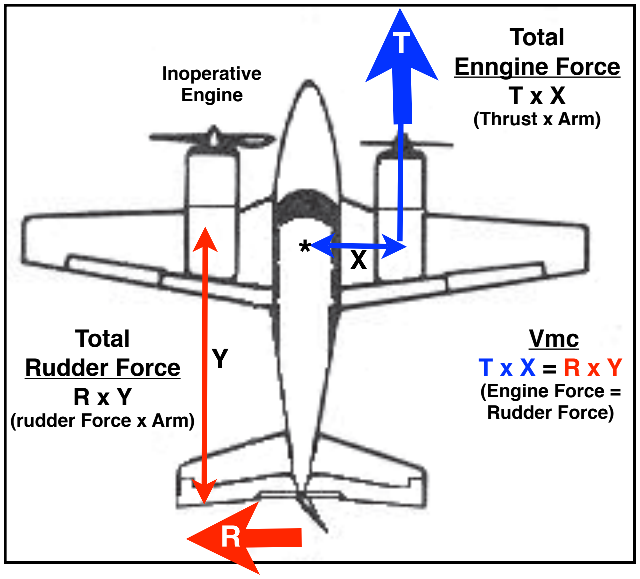


WHAT IS V m c (MINIMUM CONTROLLABLE AIRSPEED)?

-Vmc is the speed at which the rudder no longer has the authority to overcome the yaw caused by the critical engine being inoperative, under specific criteria mandated by the FAA.
-The lower Vmc is, the safer the aircraft is. It makes sense that the slower an aircraft can go while still maintaining control with an engine failed, the better.

*Vmc strictly deals with maintaining directional control, irrespective of climb performance.

WHAT CAUSES A MINIMUM CONTROLLABLE AIRSPEED?



-With an engine failed, the operating engine (assume full power) will produce a yawing force toward the dead engine (T x X)
-The rudder is used to counteract the yaw and keep the aircraft straight
-The rudder's force (R x Y) is based on airspeed
    -The slower the aircraft, the less airflow over the rudder, and therefore the less force (faster means more force)
-As an aircraft slows and the rudder's force decreases, the force of yaw generated by the engine remains constant
-Therefore, there will be an airspeed where the rudder's force is equal to the engine's force (this is Vmc, the Minimum Controllable Airspeed)
-If the aircraft slows beyond this speed, the rudder will produce less force than the engine and the airplane will yaw uncontrollably to the dead engine

Say, for example, an operating engine at max thrust produces 1,000 lbs of yaw (T x X) toward the dead engine. This force will remain consistent regardless of airspeed. Now, assume that at 150 kts the rudder can produce 2,000 lbs of force (R x Y). As airspeed is reduced, so is the rudder's force. At 100 kts, this rudder can generate 1,400 lbs of force, more than enough to control the 1,000 lbs from the failed engine. But, as airspeed continues to bleed the rudder will reach a point, say 70 knots, at which it can produce exactly 1,000 lbs (the same as the yaw from the engine). This is the minimum controllable airspeed. As soon as the aircraft decelerates below 70 kts the rudder's force drops below 1,000 lbs. At this point, the rudder is unable to overcome the yaw caused by the engine being inoperative and the aircraft begins an uncontrollable yaw toward the dead engine. If the airspeed is increased, or thrust is reduced on the operating engine, the rudder can regain control.

HOW IS V CERTIFIED?

The FAA sets forth criteria for aircraft manufacturers to follow in order to establish Vmc for an aircraft. The criteria is as follows:

-Maximum Takeoff Power
-Critical Engine Inoperative
-Inoperative Engine Windmilling
-Sea Level Conditions
-Most Adverse Legal Weight
-Most Adverse Legal C of G
-5° of Bank into the Operative Engine
-Gear Up
-Flaps in the Takeoff Position
-Cowl Flaps Open
-Out of Ground Effect

HOW DOES THIS CRITERIA AFFECT Vmc ?

-Vmc is not a fixed airspeed. It is only fixed for the specific set of circumstances under which it was tested for certification.
-We want to maintain control at the slowest possible speed, so A LOWER Vmc IS GOOD and A HIGHER Vmc IS BAD.
-Anything increasing the force to the dead engine will increase Vmc, and vice versa. .
-Anything increasing the amount of force the rudder can produce will decrease Vmc, and vice versa.

MAXIMUM TAKEOFF POWER - BAD for Vmc

The more power on the operating engine, the greater the force pulling toward the dead engine. The greater the force, theearlier the rudder will lose control. The minimum controllable airspeed will be higher with greater power.

CRITICAL ENGINE INOPERATIVE - BAD for Vmc

The critical engine is the engine that has the most adverse affect on control of the plane. By failing this engine, the rudder has more force to overcome than if the R-engine was failed, therefore Vmc will be higher.

INOPERATIVE ENGINE WINDMILLING - BAD for Vmc

Increased drag on the inoperative engine will create a stronger yaw toward the dead engine. A windmilling prop creates more drag than a feathered prop. Therefore, the rudder has to overcome more force, raising Vmc.

SEA LEVEL CONDITIONS - BAD for Vmc

At sea level the dense air allows the operating engine and prop to produce maximum thrust. Since there is more thrust, there is a greater force toward the dead engine for the rudder to overcome, therefore Vmc is higher.

MOST UNFAVORABLE LEGAL WEIGHT (LIGHTEST WEIGHT) - BAD for Vmc

Vmc increases as weight is reduced so the lightest legal weight is most unfavorable. The lightest weight provides the aircraft the least momentum. The heavier the aircraft, the more likely its inertia will carry it forward and help prevent the yaw and roll associated with a failed engine.

MOST UNFAVORABLE LEGAL CENTER OF GRAVITY (AFT C of G) - BAD for Vmc

Vmc increases as the C of G is moved aft. The further aft the C of G, the shorter the rudder's arm is. The shorter the arm, the less effective the rudder. Vmc will be higher since the rudder produces less force at any speed than if the C of G was forward.

OUT OF GROUND EFFECT - BAD for Vmc

Vmc decreases in ground effect. As the aircraft yaws and rolls toward the dead engine the dead engine's wing would dip further into ground effect, reducing its drag as it became more efficient, and reducing the yaw toward the dead engine.

GEAR RETRACTED - BAD for Vmc

When the gear is down it acts as a keel (like on a boat) which aids directional stability and decreases Vmc. With the gear up the keel effect is removed and it cannot help keep the aircraft straight.

COWL FLAPS OPEN - GOOD for Vmc

With the cowl flaps open the operating engine's prop will push air into the cowl flaps resulting in increased drag. Increased drag on the operating engine decreases Vmc since it assists in counteracting the yaw toward the dead engine.

5º OF BANK INTO THE OPERATING ENGINE - GOOD for Vmc

The horizontal component of lift generated by bank assists the rudder in counteracting the yaw from the inoperative engine. Vmc is reduced considerably with bank angle so the FAA limits the bank during testing to 5o.

FLAPS IN THE TAKEOFF POSITION - Could go either way

Most twins takeoff without flaps, therefore there will be no effect. But, with many different sizes, types, and settings, having the flaps down could help or hurt Vmc. Having the flaps down could produce more drag on the operating engine (reducing the yaw), but it could also create more lift on the operating engine's wing (increasing roll toward the dead engine).

Terminology

CRITICAL ENGINE
The engine that if failed will have the most adverse affect on the control and performance of the aircraft.

Vmc
The speed at which the rudder no longer has the authority to overcome the yaw caused by the critical engine being inoperative, under specific criteria.

ACCELERATE STOP DISTANCE
The distance required to accelerate to rotation speed, and assuming an engine failure at rotation, bring the aircraft to a stop. This is the maximum runway required for an aborted takeoff since an engine failure after rotation will be handled airborne.

ACCELERATE GO DISTANCE
The distance required to accelerate to rotation speed, and assuming an engine failure at rotation, climb to 35' above the departure end.

SERVICE CEILING
The density altitude which will produce a 100 foot per minute climb when flying in a clean configuration, at the best rate of climb airspeed with both engines at maximum continuous power.

SINGLE ENGINE SERVICE CEILING
The density altitude which will produce a 50 foot per minute climb when flying in a clean configuration, at the best rate of climb airspeed with one engine at maximum continuous power and the other engine feathered.

ABSOLUTE CEILING
The highest altitude at which an airplane can sustain level flight with both engines operating (this altitude will never be reached in flight except during flight testing).

SINGLE ENGINE ABSOLUTE CEILING
The highest altitude at which an airplane can sustain level flight with one engine operating. This altitude will only be reached if flying above the single engine absolute ceiling when the engine is lost and the aircraft drifts down to the SE absolute ceiling.

CRITICAL ALTITUDE
The maximum altitude under standard atmospheric conditions at which a turbocharged engine can produce its rated horsepower. Above this altitude, the engine's performance will begin to decrease.

Vyse
The best rate of climb airspeed during single engine operations.

Vsse
The safe single engine speed. It is unsafe to intentionally fail an engine below this airspeed.