

# Controlling Multi-Engine Airplanes after Engine Failure

Limitations Imposed by the Size of the Vertical Tail

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## Introduction

Engine failures on multi-engine airplanes continue to lead to fatal accidents all around the globe quite frequently, although the airplanes were designed, flight tested and certified to continue to fly safely after engine failure or while an engine is inoperative and the pilots are licensed. After reviewing many accident investigation reports, it was noticed that most instructors, pilots and accident investigators explain and apply the *minimum control speed in the air* ( $V_{MCA}$ ) of the airplane in a different way than airplane design engineers, experimental test pilots and flight test engineers do. This difference in interpretation has, to the opinion of AvioConsult, led to many catastrophic accidents caused by the loss of control and/or performance after engine failure and also to incorrect and incomplete conclusions and recommendations in accident investigation reports.

This article is for all multi-engine rated pilots and accident investigators. Briefly discussed are the design of the vertical tail of a multi-engine airplane, the flight test techniques that are used to determine  $V_{MCA}$  and a factual error in the  $V_{MCA}$  definition in most Airplane Flight Manuals (AFM).

After reading this article, the real value of  $V_{MCA}$  that is listed in the AFM of multi-engine airplanes and the conditions for which this  $V_{MCA}$  is valid will have become much clearer, which is of vital importance for getting home safely after engine failure and for preventing engine failure related accidents. Accident Investigations will also improve.

## Sizing the vertical tail

In Figure 1, the most important forces and moments are shown that act on a multi-engine airplane during steady straight flight when engine #1 is inoperative and the wings are kept level.

As for any body, an airplane is in equilibrium if both the sum of the forces and the sum of the moments that act on the airplane are zero.

A deflected rudder ( $\delta_r$ ) generates a side force ( $Y_{\delta_r}$ ) that causes a yawing moment ( $N_{\delta_r}$ ) to counter the asymmetrical thrust yawing moment ( $N_T$ ).  $Y_{\delta_r}$  also causes acceleration to the dead engine side; a sideslip develops. The acceleration continues and the sideslip increases, until the sum of the side forces is zero.

The aerodynamic side force  $Y_{\delta_r}$  is proportional to the (square of the) airspeed ( $V^2$ ). The

lowest airspeed at which straight flight can just be maintained while either the rudder or the ailerons are maximum deflected, is called  $V_{MCA}$ , but sometimes also incompletely as  $V_{MC}$ .

Sideslip causes drag which reduces the remaining climb performance significantly and should therefore be kept to a minimum. This is impossible without banking (unless the opposite engine is also shut down).

When banking, a component of the weight, leads to a side force due to bank angle ( $W \cdot \sin \phi$  in Figure 2), that can replace the side force  $Y_{\delta_r}$  due to sideslip that was required for balance with the wings level. The small bank angle decreases the sideslip angle to a minimum, decreasing the total drag and, hence, increasing climb performance. Side force  $W \cdot \sin \phi$  acts in the centre of gravity and therefore does not cause any adverse yawing moments.

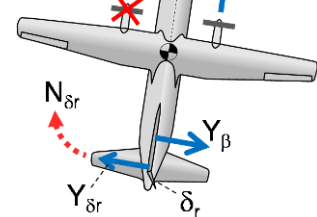


Fig. 1. Forces and moments - wings kept level.

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Because the side force  $Y_{\delta_r}$ , generated by the vertical tail with rudder, no longer has to act against the side force due to sideslip  $Y_{\beta}$ , but only against the thrust yawing moment  $N_T$ , the rudder deflection need not be maximal, the airspeed can be reduced until the deflection is again maximal, or the vertical tail can be dimensioned smaller to save manufacturing cost and weight.

FAR/CS 23.149 and 25.149 allow the engineer designing the

vertical tail to use a bank

angle of maximum 5 degrees.

Reducing the size of the vertical tail increases  $V_{MCA}$  (for a high enough side force  $Y_{\delta_r}$ ).

FAR/CS 23.149, however,

does not allow the vertical tail to be made so small that  $V_{MCA}$  exceeds 1.2 times the stall

speed ( $V_S$ ). Hence, the vertical

tail is made just big

enough to maintain straight

flight while the thrust of the

opposite engine is at the maximum

takeoff setting, the

rudder is maximal deflected

and while maintaining a small

bank angle as opted by the

designer of the vertical tail,

usually between 3 and 5

degrees away from the inoperative

engine for airspeeds down

to  $V_{MCA}$ .

There are many more factors that have influence on the side

forces and yawing moments that act on an airplane while an

engine is inoperative and therewith affect  $V_{MCA}$ , including

propeller feathering. The design engineer will use the worst

case of each of these factors to design a vertical tail that is just

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big enough to meet the requirements under all circumstances, but in-flight, the pilot controls the bank angle.

Therefore, the effect of bank angle ( $\phi$ ) and weight ( $W \cdot \sin \phi$ ) on  $V_{MCA}$  is worth studying.

### Effect of bank angle and weight

When, during the design phase of the airplane, the size of the vertical tail is either known or assumed, graphs can be calculated using the stability derivatives of the airplane that show the effect of bank angle and weight on  $V_{MCA}$  during straight equilibrium flight while both the asymmetrical thrust and the rudder deflection are maximal. The graphs presented in Figures 3 and 4 below are calculated using B707/DC-8 type airplane data. The shape of the plots is valid for all multi-engine airplane types, though.

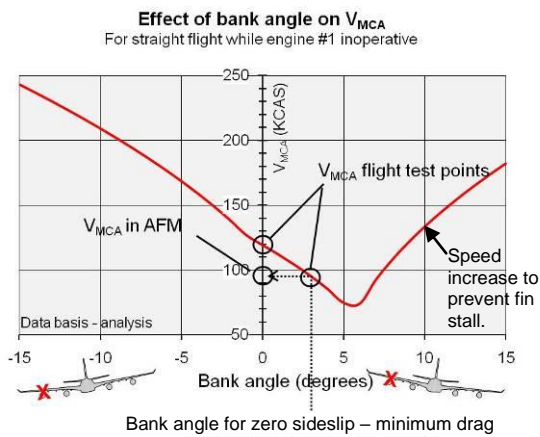


Fig. 3. Effect of bank angle on  $V_{MCA}$

The manufacturer of this sample airplane has calculated that the sideslip angle is near zero, i.e. the drag is minimal, if the bank angle is 3 degrees away from the inoperative engine. For that reason, this bank angle is often included as a condition in the legend of engine inoperative performance diagrams for the presented data to be valid.

Bank angle however, not only has effect on sideslip and drag.

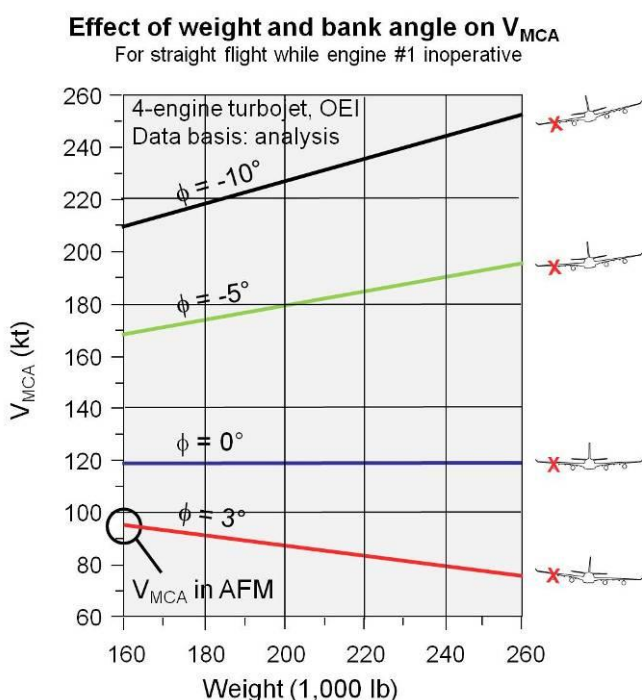


Fig. 4. Effect of weight  $W$  and bank angle  $\phi$  on  $V_{MCA}$ .

Weight ( $W$ ) and bank angle ( $\phi$ ) both have great influence on the *actual*  $V_{MCA}$  of the airplane via side force  $W \cdot \sin \phi$ , as is illustrated in Figure 4. Lockheed C-130 Hercules pilots will recognize Figure 4 from their manuals (SMP777, page 3-18). The *standardized*  $V_{MCA}$  that is listed in the AFM will in this case be 95 kt.

As shown in Figures 3 and 4, the *actual*  $V_{MCA}$  of this sample airplane increases to 120 kt if the wings are kept level. In addition, keeping the wings level or turning to either side leads to a sideslip for the balance of side forces (Figure 1). This increases the drag and hence, reduces the climb performance or leaves no positive climb performance at all.

It will be clear that the requirement for maintaining a small bank angle must be made known to the pilots of multi-engine airplanes; the saved weight and manufacturing cost of a smaller vertical tail needs to be replaced by a quite 'heavy' condition/ warning in AFMs for maintaining the mandatory small bank angle while an engine is inoperative, the airspeed is low and the power setting is high. This condition is regrettably not presented anymore in AFMs, with the exception of Lockheed manuals.

### Experimental flight-testing $V_{MCA}$

During the flight-test for determining  $V_{MCA}$ , the airplane is in the same configuration that was used to design the vertical tail, of which the most important factors are the *lowest* weight possible (smallest side force  $W \cdot \sin \phi$ ), an aft centre of gravity (smallest rudder moment arm), maximum takeoff power setting on the engine opposite of the inoperative (critical) engine (max. thrust yawing moment) and a feathered propeller, if automatic. This configuration leads to the 'worst case'  $V_{MCA}$ . Two types of  $V_{MCA}$  are determined, first the static  $V_{MCA}$  and then the dynamic  $V_{MCA}$ .

The *static*  $V_{MCA}$  is of vital importance for continuing the flight safely while an engine is inoperative. The airspeed is slowly reduced (with the wings level) until the heading can no longer be maintained using maximum rudder or aileron deflection, or up to the FAR/ CS defined maximum control force limits (150 lb for rudder pedal, 25 lb for roll control). This first test point is the wings-level  $V_{MCA}$  (Figure 3). Then, while applying the same bank angle that was used to design the vertical tail (3 to 5 degrees away from the inoperative engine), the speed is (and can be) further decreased until again the heading can no longer be maintained. This speed is the static  $V_{MCA}$ . This  $V_{MCA}$  is usually between 8 (small twin) and 25 knots (B707) lower than the wings-level  $V_{MCA}$ .

Static  $V_{MCA}$  applies during the entire flight while an engine is inoperative and is obviously only valid during straight flight as long as the small bank angle is being maintained, and definitely not during turns (at high power setting).

The *dynamic*  $V_{MCA}$  is important for regaining control immediately following the sudden failure of an engine during the resulting dynamics. The dynamic  $V_{MCA}$  is determined by cutting the fuel flow to the critical engine at several speed points down to the speed at which the heading change is maximum 20 degrees, the bank angle does not exceed 45 degrees and no dangerous attitudes occur.

The static  $V_{MCA}$  is usually higher than the dynamic  $V_{MCA}$ . The highest of static and dynamic  $V_{MCA}$  will be published as the  $V_{MCA}$  of the airplane in the AFM, but the static  $V_{MCA}$  applies always too. Testing (and demo) of  $V_{MCA}$  is not without danger; therefore the test data are acquired at a safe altitude.

## Takeoff speeds of big airplanes

The AFM-listed  $V_{MCA}$  is one of the factors used for calculating the rotation speed  $V_R$  and the minimum takeoff safety speed  $V_{2MIN}$  of big Part 25 airplanes. Since  $V_{MCA}$  is valid only while maintaining a bank angle of 3 to 5 degrees away from the inoperative engine, both the calculated  $V_R$  and  $V_{2MIN}$  are also valid only when maintaining a small(er) bank angle.

### Definition of $V_{MCA}$

The  $V_{MCA(A)}$  definition in an AFM is often:

*"Minimum control speed is the minimum flight speed at which the airplane is controllable with a bank angle of not more than 5 degrees when the critical engine suddenly becomes inoperative and the remaining engine is operating at takeoff power".*

This line is copied inappropriately out of an aviation regulation (FAR/CS 23/25.149) that is intended to be used by airplane design engineers for designing airplanes (including sizing the vertical tail) and for the certification of the airplane. Once the airplane is in operational use, for which the AFM applies, pilots should definitely not keep the wings level to within 5 degrees of bank, left or right, as the definition suggests. On the contrary, in order to ensure that control of their airplane after engine failure can be maintained, whatever the configuration is, and that the remaining climb performance is positive, pilots need to maintain the same bank angle that was used to design the vertical tail and that was also used to determine the AFM listed  $V_{MCA}$  during flight testing, which is usually between 3 and 5 degrees away from the inoperative engine. Any other bank angle, or a bank angle to the other side, will disturb the balance of side forces and yawing moments and will lead to lateral accelerations and yawing moments that cannot guaranteed be balanced by the aerodynamic controls, simply because the vertical tail with rudder (and the ailerons) were not sized big enough to do so. *Critical engine* is for certification, not for pilots: only one  $V_{MCA}$  is published, the highest after failure of any engine. Actual  $V_{MCA}$  after failure of a non-critical engine is a little lower – safer. The word *suddenly* in the  $V_{MCA}$  definition in an AFM does not make sense at all, is misleading;  $V_{MCA}$  applies always, even during the approach when an engine already failed during takeoff or en-route. The above quoted AFM definition of  $V_{MCA}$  is definitely deficient and should be improved.

### How do I get home safely after engine failure?

As was explained above, the vertical tail of a multi-engine airplane is just big enough to maintain straight flight after engine failure down to the AFM-listed  $V_{MCA}$ , provided a small bank angle between 3 and 5 degrees (as opted by the manufacturer) is maintained away from the inoperative engine when the power setting of the opposite engine is high. Only then,

the manufacturer guarantees that directional control can be maintained under all conditions.

This does not mean that an airplane, while an engine is inoperative, never can safely execute a turn at airspeeds as low as  $V_{MCA}$  and at high thrust settings. If one or more of the factors that have influence on  $V_{MCA}$  are not at their worst case value, as used during the design of the vertical tail and during  $V_{MCA}$  flight testing, then a turn might be possible. But you may never count on this.

If an engine fails on takeoff, input rudder as required to maintain heading (dead leg – dead engine) and continue straight ahead while banking 3 to 5 degrees away from the inoperative engine. Do not turn until reaching a safe altitude and an airspeed well above  $V_{MCA}$ .

En-route, the airspeed will usually be high enough for the tail to provide a big enough side force. Rudder will not be maximal.

### Warning

*If near full rudder is required for maintaining the heading, then the airspeed is near (actual)  $V_{MCA}$ . Do not turn!*

In case the airplane does not respond appropriately to control inputs, then the airspeed is below the *actual*  $V_{MCA}$ , the airplane is out of control, but you are not yet lost. Just reduce the engine yawing moment by reducing the thrust a little (the *actual*  $V_{MCA}$  decreases) and select maximum thrust again after reaching the small bank angle. If at very low altitude, the only option that might be left is closing the throttles and land wings-level, which is more survivable than hitting the ground with a wing tip first.

*The bottom line:* If an engine is inoperative and high asymmetrical thrust becomes necessary while the airspeed is low, first bank a few degrees (between 3 and 5, as the manufacturer should have specified with the

$V_{MCA}$  definition in the AFM) away from the inoperative engine before pushing the throttles forward. Increase rudder with increasing thrust for maintaining straight flight and maintain the small bank angle, as long as the thrust is maximum (and climb to a safe altitude).

*$V_{MCA}$  is definitely not a minimum safe speed for turning!*

Plan an engine inoperative landing well ahead, make sure you will not be needing maximum thrust during the final turn for landing; a long straight-in approach is a lot safer.

After reading and understanding this article, you should be able to make it home safely when an engine fails.

On website [www.avioconsult.com](http://www.avioconsult.com), lots of information can be found on this subject, including free suggestions for improvement of training, regulations, manuals, etc. Need help or questions? Please do not hesitate to ask. Fly safely.



On the airspeed indicator of Part 23 airplanes, a red radial line, here at 80 kt, indicates the standardized  $V_{MCA}$ . However, neither a placard nor a note or warning in the AFM tells the pilot that this  $V_{MCA}$  is valid if and only if a bank angle of 3 to 5 degrees (to be specified by the manufacturer) is maintained away from the inoperative engine while the power on the opposite engine is high. Any other bank angle can lead to a much higher *actual*  $V_{MCA}$  and to an unexpected loss of control or to the lack of climb performance after which an accident cannot be avoided.

If the pointer is at or near the red line and a high thrust setting is needed, first bank 3 to 5 degrees away from the inoperative engine. If a turn is needed, decrease asymmetrical thrust first (a little). It might be required to gain altitude first during straight (banked) flight before turning.

### Author biography

Harry Horlings is a retired Lt-Col of the Royal Netherlands Air Force and graduate Flight Test Engineer of the USAF Test Pilot School, Edwards Air Force Base, California, USA (1985). Following a career of 15 years in flight testing, of which the last 5 years as chief flight test, he founded AvioConsult and dedicated himself to improving the safety of aviation using his knowledge of experimental flight testing.