Staying Alive with a Dead Engine

How to prevent a dead engine from turning into a killing engine

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Abstract

Throughout the world, accidents following the failure of an engine during takeoff, go-around, approach and during training continue to happen with both small multi-engine airplanes and with airliners, despite the fact that much effort is made to thoroughly flight-test the airplanes in order to explore and publish its limitations as well as to the training of flight-crew. One of the limitations that is of importance after engine failure and during flight with an inoperative engine, and that is published in the airplane flight manual of each multi-engine airplane, is the air minimum control speed (V_{MCA}).

Federal Aviation Regulations (FAR) 23 and 25 and European Aviation Safety Agency/ Certification Specifications (EASA/ CS) 23 and 25 and other equivalent regulations allow the use of a small bank angle (max. 5 degrees) for designing the vertical tail and allow this bank angle also to be used during flight-testing to determine V_{MCA}. The tail design and the flight-test determined V_{MCA} are for maintaining straight flight after engine failure only, not for turning. Experimental test pilots and flight test engineers usually determine V_{MCA} using a 3 – 5 degrees bank angle away from the inoperative engine while maintaining straight flight. Any deviation from this small bank angle will increase *actual* V_{MCA} above the published value. Keeping wings level for instance, increases the *actual* V_{MCA} 10 – 30 knots or more above the published value of V_{MCA}.

V_{MCA} is also one of the factors used to calculate takeoff safety speed V_2. Many airline pilots believe that takeoff safety speed V_2 is always safe, even after engine failure, but if the pilot does not maintain the bank angle used to determine V_{MCA}, then the *actual* V_{MCA} might increase to a value higher than preflight calculated V_2, leading to a complete loss of control from which recovery at low altitude is not possible.

Therefore, the bank angle that was used to design the vertical tail and to determine V_{MCA} is important for the safety of flight while an engine is inoperative. However, the (airline) pilot does not get to know what bank angle was used and should be maintained for either the V_{MCA} that is listed in the flight manual or for V_2 that is calculated before flight, to be valid. There is no requirement (yet) in FAR and EASA/ CS 23 and 25 to present this bank angle (as a limitation) in the airplane flight manual. FAR's as well as EASA/ CS's currently concentrate on the loss of performance after engine failure, not on maintaining control. Accident investigation reports show that the mishap pilots and accident investigators indeed were not aware of the effect of bank angle on the controllability of the airplane. Not maintaining both straight flight and the same bank angle that were used to design the vertical tail and that were also used to determine V_{MCA} and to calculate V_2, might easily turn a dead engine into a killing engine, when maximum thrust is set and the airspeed is low. To the opinion of Avio*Consult*, this is the real cause of many engine failure related accidents during takeoff, go-around and during the approach when thrust was added to maintain the landing pattern or approach path. This paper is one of the papers that was written by Avio*Consult* to increase the awareness of the real meaning of V_{MCA} and therewith for staying alive with a dead engine.

1. Introduction

Accidents due to engine failure are happening not only during normal operations but also during pilot training, despite the fact that manufacturers design and thoroughly test their airplanes and establish operational limitations to ensure the safe continuation of flight after an engine failure in any phase of flight. Manufacturers provide, and aviation authorities approve, flight manuals in which the limitations are listed that are to be observed while operating the airplane. One of the limitations that is always determined of all multi-engine airplanes, is the air minimum control speed V_{MCA}. V_{MCA} is in fact a procedural, a 'software fix' for a hardware 'problem' being a too small vertical tail. In addition, pilots learn the theory of asymmetrical powered flight, receive training in simulators and receive a demo of V_{MCA} in-flight during their training for a multi-engine rating.

Most pilots of Part 23 airplanes consider their (multi-engine) airplane to be controllable as long as the airspeed is at or above V_{MCA} in the event that an engine suddenly fails. V_{MCA} is therefore indicated on the airspeed indicator with a red radial line (in accordance with 23.1545(b)(6)).

Pilots of Part 25 airplanes use takeoff safety speed V_2 and not V_{MCA} anymore. Therefore, pilots (and accident investigators) often incorrectly consider V_{MCA} a useless speed (although V_{MCA} is used to calculate V_2).

The significance of V_{MCA} for the controllability of a multi-engine airplane after engine failure seems well documented in EASA/ CS 23 and 25 (ref. 1), in FAR 23 and 25 (ref. 2) and in flight manuals and textbooks, but – in fact – it is not. If the applicable V_{MCA} and/ or V_2 are readily available to well-trained pilots before every takeoff or go-around, why do engine failures and in-flight simulation or demonstration of engine failures during training still turn into catastrophes so often? Many publications were written to try to answer this question, but most reports and papers discuss the early recognition of engine problems and the remaining performance only.

In an effort to further increase the safety of flight while an engine is inoperative, the author of this paper reviewed many flight manuals, textbooks and FAR's and CS's, accident investigation reports and other documents on the subject of airplane controllability after engine failure and published his findings in the report *Prevention of Airplane Accidents after Engine Failure* (ref. 3). He concluded that most of these publications were imperfect, in many cases even incorrect and deficient on the subject of flight with asymmetrical thrust. From many accident investigation reports it was also learned that pilots allowed their airplane to bank into the dead engine side while the airspeed was low and the thrust setting on the operating engine(s) high. By doing so, a catastrophic accident could not be avoided. This proves that the test methods & conditions as well as the configurations used during experimental flight testing to determine V_{MCA} never made it to be appropriately included as limitation or restriction in Airplane Flight and/ or Operating Manuals, in student pilots textbooks and not even in FAR and EASA/CS 23 and 25. This contributes, to the opinion of the author of this paper, to the real cause of most engine failure related accidents.

In this paper, a few imperfections in flight manuals, training manuals, textbooks and aviation regulations FAR and EASA/CS 23 and 25 are presented, that affect the controllability of an airplane following the failure of an engine in-flight; ref. 3 presents more. Both V_{MCA} and V_2 will be discussed in greater detail.

The objective of this paper is to explain that a very important limitation, essential to staying alive with a dead engine, is required to be included in flight and operating manuals to improve the engine-out handling by flight crews and bring down the engine failure related accident rate. This paper is applicable to all multi-engine airplanes with wing-mounted engines.

2. Air Minimum Control Speed V_{MCA}

Airplane manufacturers, writers of flight manuals and authors of student pilot textbooks, and also pilots and many more aviation personnel use regulatory paragraphs (rules) out of FAR and CS (23 and 25) and copy parts thereof into their own manuals and books. Manufacturers might believe that by doing so, they will avoid approval problems with the certifying aviation authorities. But in reality, this copy-work leads and has led to incorrect text for the purpose of the documents that the parts are copied into, because not all of the regulatory text that is intended for certification purposes is applicable to airline or airplane operations. Many rules and regulations are neither intended, nor good enough to be copied unchanged into pilot manuals. An example follows:

In a flight manual of just a multi-engine airplane, the following definition of V_{MCA} is presented:

> *'V_{MC} is the calibrated air speed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the airplane with that engine still inoperative and (thereafter) maintain straight flight with an angle of bank of not more than 5 degrees.'*

The biggest part of this definition is copied out of FAR or EASA/CS 23.149 or 25.149. Although incomplete, the definition is correct for describing some of the test conditions for determining V_{MCA} by the experimental test pilot of the manufacturer and for certification purposes, but this definition is certainly not suitable to be listed in a flight manual and to be used by the (airline) pilot. There are **four imperfections** in this *flight manual* definition of V_{MCA} and **two** important conditions missing.

These imperfections and the missing conditions will be discussed in greater detail later in this paper. First, the flight test techniques to determine V_{MCA} and the effect of bank angle and weight on V_{MCA} will be explained.

3. Flight-testing V_{MCA}

The required airplane test configuration is described in EASA/CS 23.149 and 25.149 (ref. 1), in FAR 23.149 and 25.149 (ref. 2), in the flight test guide of EASA (included in ref. 1) and in FAA Advisory Circulars AC 23-08B and AC 25-7A (ref. 4 and 5). The author of this paper learned about Stability and Control, including engine-out testing, at the USAF Test Pilot School in 1985 using ref. 7. The flight test techniques for determining V_{MCA} were taught using References 8 and 9.

FAR or EASA/CS 23.149 and 25.149 allow the applicant of a certificate of airworthiness (the manufacturer) to use a maximum of 5° of bank angle to determine V_{MCA}. Experimental test pilots and flight test engineers know that this means a maximum of 5° away from the inoperative engine because the direction and the magnitude of the bank angle have great effect on V_{MCA} and on the sideslip, as will be explained in the next paragraph. Normally a bank angle between 3° and 5° away from the inoperative engine is used to determine V_{MCA}.

The configuration used during flight-tests to determine V_{MCA} is:

- Flaps in takeoff setting, or a setting as required;
- Landing gear as required;
- Propeller, if applicable, feathered if the feathering system is automatic, otherwise windmilling;
- Max. takeoff thrust on the operating engines. On three or more engine airplanes, the thrust of the centerline or symmetrical inboard engines may be reduced to avoid excessive climb. This has no effect on V_{MCA}.

Other test conditions used during flight-testing V_{MCA} represent the worst case of each of the conditions for V_{MCA} testing which will return the highest – the safest – V_{MCA} to be published in the flight manual. These conditions, that will be explained later, are:

- Critical engine off and propeller feathered, if automatic (and applicable);
- Center of gravity most aft and laterally into the inoperative engine, but within the approved envelope;
- Lowest gross weight possible.

Before actual flight-testing begins, a thorough (stability derivative) analysis of the subject airplane is performed to be prepared for any control or airspeed limitations that might occur during the testing. V_{MCA} testing is dangerous, and should not be performed without proper training and taking safety precautions.

Normally, two types of V_{MCA} are determined: static V_{MCA} and the transient effects of an engine failure, also called dynamic V_{MCA}. Dynamic V_{MCA} is of relevance immediately after the sudden failure of an engine; static V_{MCA} is for being able to continue the flight safely while an engine is inoperative. The highest of static V_{MCA} and dynamic V_{MCA} will be listed in the airplane flight manual as the V_{MCA} for the airplane.

The flight test technique used to determine dynamic V_{MCA} is, while at a safe altitude of at least 5,000 ft above ground level, to cut the fuel supply to the critical engine, wait 2 seconds for normal decision making and then recover control. This test is repeated at decreasing airspeed test points. Dynamic V_{MCA} will not be further discussed, because static V_{MCA} is much more relevant for *staying alive with a dead engine*, the objective of this paper. Dynamic V_{MCA} is most often lower than static V_{MCA}. Static V_{MCA} will be referred to as V_{MCA} in the remainder of this paper.

The flight test technique used to determine static V_{MCA} is: at the safe altitude and using the configuration and conditions described above, the airspeed is slowly decreased, while keeping the wings level, until either:

- The heading can no longer be maintained, or
- The rudder is maximum deflected or pedal force is 150 lb (667 N), or
- The ailerons are maximum deflected or roll control force is 25 lb (112 N).

The speed at which this occurs is V_{MCA} with the wings level.

On some airplanes, V_{MCA} cannot be determined because V_{MCA} is lower than V_S: these airplanes are said to be controllable down to the stall which is to be preferred, but there is an important condition to this as will be explained later.

Once V_{MCA} with the wings level is determined, the testing continues by banking the opted 3 to 5 degrees away from the inoperative engine after which the airspeed is further decreased until again one of the limits listed above is reached. The calibrated airspeed at which this occurs is the V_{MCA} for this airplane for the tested configuration. This V_{MCA} will, after extrapolation to sea level and correction for temperature, etc., be listed in the airplane flight manual or – if required – after reduction of the data to other altitudes or temperatures be presented in graphs in the airplane flight manual.

4. Factors that have influence on V_{MCA}

4.1. Effect of Bank Angle on V_{MCA}. FAR and CS 23.149 and 25.149 (ref. 1 and 2) allow a bank angle of maximum 5 degrees to determine V_{MCA}. A manufacturer will, in most cases, opt to use a bank angle between 3 and 5 degrees away from the inoperative bank angle to determine V_{MCA}, as already described above. The reason for the use of this bank angle will be explained in this paragraph.

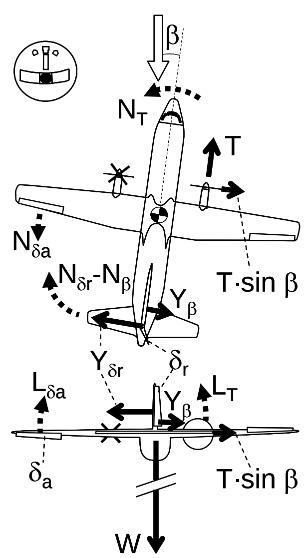

Figure 1. Straight flight – wings level.

After failure of an engine, many forces (solid lines in figures 1 and 2) and moments (dashed lines) act on an airplane; only a few (the biggest ones) are shown and will be discussed. The figures show a sample turboprop airplane during equilibrium – straight flight while an engine is inoperative. It is important to realize that equilibrium (with asymmetrical thrust) can only exist when both forces and moments are balanced.

After failure of engine #1 on the sample multi-engine airplane in figure 1, the asymmetrical thrust T of engine #2 generates a yawing moment N_T about the center of gravity that can be balanced only by a yawing moment $N_{\delta r}$ generated by rudder side force $Y_{\delta r}$ that is caused by rudder deflection δ_r. For equilibrium, this side force needs to be balanced by opposite side forces.

When the wings are kept level as illustrated in figure 1, the only side forces available to achieve a balance of forces are side forces due to sideslip β. Sideslip β generates (in this case) not only a side force Y_β (normally for 'weathercock' stability) opposite of $Y_{\delta r}$ but also a side force $T \cdot \sin\beta$ due to airflow bending caused by the propeller disc (or turbofan inlet), that both add up to equal rudder side force $Y_{\delta r}$ for balance of side forces. This means that when the wings are kept level, a sideslip is required for equilibrium – straight flight. However, side slipping also causes drag that deteriorates the already reduced climb performance. This side slipping and therewith the drag can be reduced, as will be shown next.

Aileron deflection δ_a not only generates a rolling moment $L_{\delta a}$ to counteract the propulsive lift moment L_T, but also an adverse yawing moment $N_{\delta a}$ for which also additional rudder deflection is required to compensate for. On turbofan-equipped airplanes, the deflection of ailerons might be different from the deflection in the figures, because turbofans are mounted below the wings and do not generate propulsive lift.

If, in accordance with regulations, a small bank angle of maximum 5° is used away from the inoperative engine, side force Y_β in of the wings level case in figure 1 can be replaced by side force $W \cdot \sin\phi$ as shown in figure 2. Side force $W \cdot \sin\phi$ acts in the center of gravity and generates no adverse or proverse moments. The rudder does not have to counteract side forces due to sideslip, meaning that the rudder deflection can be smaller, or the airspeed can be lower for maximum deflection as compared to the wings level case. This is the reason that V_{MCA} is lower when a small bank angle is maintained away from the inoperative engine. If V_{MCA} is lower, a takeoff can be performed at a lower speed, which increases the maximum payload (and profit) on the available runway length. A small bank angle reduces the sideslip to (near) zero; hence, the drag is as low as possible which is favorable to the climb performance. These are reasons for using the small bank angle during flight-testing V_{MCA}, and should be the reasons too for using the small bank angle during normal operations following the failure of an engine when the thrust is high and the airspeed low.

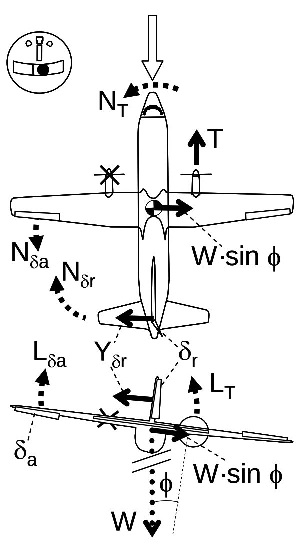

Figure 2. Straight flight – bank angle 5° away from inoperative engine.

Figures 3 and 4 show the effect of bank angle and gross weight on V_{MCA} (through side force $W \cdot \sin\phi$) for a sample 4-engine swept wing airplane with one outboard engine (#1) inoperative during straight (equilibrium), constant heading, 1 g flight and with the remaining engines producing maximum continuous takeoff thrust. The plotted airspeeds are the lowest possible airspeeds in the takeoff configuration for the given bank angles and are calculated using the stability derivatives of this sample airplane while using the maximum of either aileron deflection (maximum 20°), or rudder deflection (maximum 30°) or sideslip (maximum 14° to prevent the vertical tail from stalling), whichever maximum occurs first. The maximum allowed rudder pedal force is not included and might have effect on the data. Experimental test pilots and flight test engineers would normally perform this kind of analysis before V_{MCA} flight-testing. A positive bank angle is in this case a bank angle away from the inoperative engine #1.

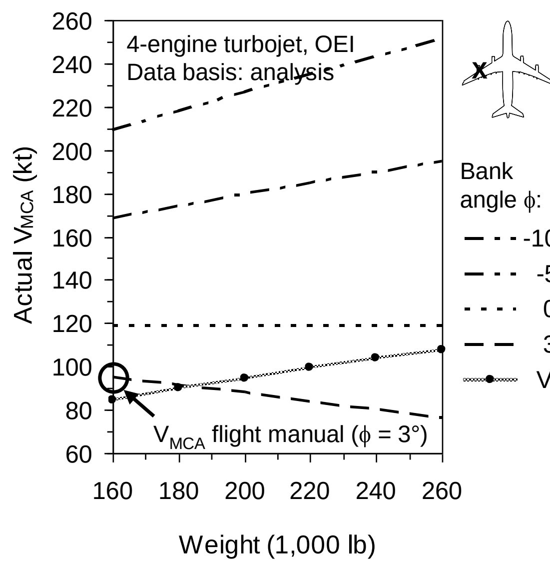

Figure 3. Effect of weight and bank angle on V_{MCA} during straight equilibrium flight.

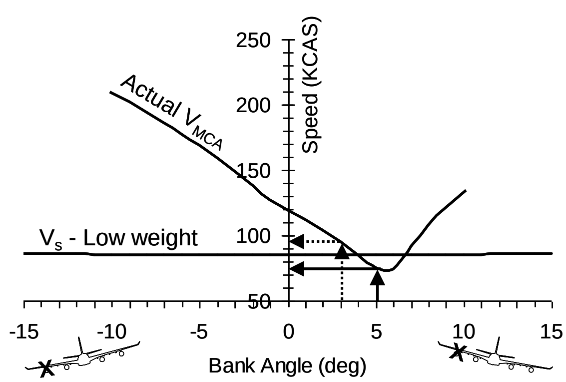

Figure 4. Effect of bank angle on V_{MCA} during straight equilibrium flight.

As can be seen in both figures, V_{MCA} of this sample airplane, as determined by analysis (prediction), is below stall speed if a bank angle of 5° away from the inoperative engine would be used. If the manufacturer had opted for this 5° bank angle and the data would have been confirmed by flight-tests, the airplane flight manual would state that the airplane is controllable down to the stall. This being the case, the V_{MCA} definition might not even be included in the flight manual. As will be shown later, it would be beneficial to the safety to include V_{MCA} anyhow.

If the manufacturer had opted for a bank angle of 3° away from the inoperative engine for determining V_{MCA} (3° line in figure 3), then the V_{MCA} listed in the airplane flight manual for this configuration would be 95 knots calibrated airspeed. The *actual* V_{MCA} would decrease with increasing weight, which is favorable to takeoff safety, until it decreases below V_S.

This decrease is also very common for straight wing turboprop airplanes while banking 5° away from the inoperative engine. V_{MCA} on these airplanes is often higher than V_S for all weights. If highest gross weight would have been chosen to determine V_{MCA}, then the *actual* V_{MCA} for any lower weight is higher and pilots would have to use weight as entry variable to determine the *actual* V_{MCA} before every takeoff and landing to be prepared for engine failure (during go-around). This would require too much data and be too complex.

Lowest gross weight is the worst-case weight for the magnitude of V_{MCA} and is therefore used during flight-testing. Then the resulting V_{MCA} is safe for all gross weights, provided the small bank angle is being maintained.

Things change dramatically for this and other multi-engine airplanes if the bank angle is not maintained away from the inoperative engine. If the wings are kept level, the analysis shows that *actual* V_{MCA} for this sample airplane, in this configuration, at all gross weights ($W \cdot \sin \phi = 0$) will have become 119 kt, 24 kt higher than V_{MCA} with 3° bank away from the inoperative engine and 11 kt higher than the stall speed V_S at high weight. This means that straight flight cannot be maintained at or below an indicated (calibrated) airspeed of 119 kt, following the failure of an outboard engine while the wings are kept level and the opposite engine is at maximum takeoff thrust setting (if all factors that have effect on V_{MCA} are at their worst case values; see § 4.2). The airplane is not controllable down to the stall anymore either.

Actual V_{MCA} will be even higher if the bank angle is only 5 degrees into the 'wrong' side, which is into the failed or inoperative engine. The 10° bank angle V_{MCA} data are presented too and speak for themselves. The increase of *actual* V_{MCA} on straight wing airplanes will be smaller, but still a factor to consider.

The powerful effect of side force $W \cdot \sin \phi$ can be observed in figures 3 and 4. Of course, V_{MCA} is the minimum speed for maintaining a straight flight equilibrium only, which an intentional turn is not, but the rudder and/ or ailerons might be maximum deflected, leaving no control power to be able to end the turn and return to straight flight once the airplane is allowed to bank away from the favorable 3° – 5° degrees, simply because the remaining aileron control power at V_{MCA} is not an objective of V_{MCA} testing. Pilots may therefore not count on any aileron control power left other than for maintaining the opted 3° – 5° away from the inoperative engine if the airspeed is V_{MCA}. Figure 3 will be used again in § 9, while discussing the takeoff safety speed V_2.

The V_{MCA} that is listed in flight manuals is always determined using the lowest possible gross weight **and** a bank angle of 3° to 5° (as opted by the applicant) away from the inoperative engine, which provides a safe V_{MCA} whatever the actual airplane gross weight is. This also implies that the V_{MCA} listed in flight manuals is only valid on the condition that the bank angle is the opted (3 to 5) degrees away from the inoperative engine. This small bank angle also keeps sideslip angle β (near) zero, which keeps the drag low.

Although the flight manual of this sample airplane might state that the airplane is controllable down to the stall, this will only be the case as long as the bank angle is the same as used to determine V_{MCA}. As can be observed from figure 4, *actual* V_{MCA} (for low gross weight) is expected to be higher than V_S if the bank angle is less than 4° or greater than 6° (during equilibrium).

Maintaining the opted (3° to 5°) bank angle away from the inoperative engine is essential for safety during takeoff or go-around following the failure of an engine and during flight while an engine is inoperative, for this airplane and most probably for all multi-engine airplanes. This very small bank angle will prevent a dead engine from turning into a killing engine.

4.2. Other factors that have influence on V_{MCA}. *Actual* V_{MCA}, that is the V_{MCA} that the pilot would experience in flight given the actual configuration and actual conditions instead of the worst cases used during V_{MCA} testing, depends on many variable factors:

- *Thrust: flexible, less than maximum.* The lower the thrust, the lower the asymmetrical thrust moment and the less rudder deflection or airspeed is required to counteract the asymmetrical thrust moment: *actual* V_{MCA} decreases – is safer. V_{MCA} needs to be determined using the highest thrust level that is settable by the pilot from the cockpit.

- *Position of the center of gravity (cg).* During testing for V_{MCA}, an aft cg is used. This is the worst case cg because then the moment arm from cg to rudder is shortest and hence, rudder control power is lowest. Any more forward cg position lengthens the moment arm to the rudder, leading to less required rudder deflection or a lower speed which results in a lower – safer – *actual* V_{MCA}. A cg laterally displaced away from the inoperative engine (for instance by transferring fuel) shortens the moment arm of the asymmetrical thrust; *actual* V_{MCA} is lower, safer.

- *Criticality of an engine.* V_{MCA} is determined while the critical engine is inoperative. The reason will be explained in § 5.2.
- *Number of inoperative engines.* If two engines on the same wing fail or are inoperative, V_{MCA} increases considerable. But FAR 25 and CS 25 do not require this V_{MCA2} to be determined, but only V_{MCL2}, which applies with the flaps in landing position, but not anymore for continuing the takeoff or for a go-around when the flaps are selected to takeoff (see also § 7). Military Specifications (ref. 6) require V_{MCA2} to be determined for 4 or more engine airplanes with two engines inoperative on the same wing. Before initiating a go-around if one engine is already inoperative, the airplane should be accelerated first to V_{MCA2} (down the glide slope or by symmetrical thrust), in anticipation of another engine to fail.
- *Propeller system – feathered or not.* If the automatic feathering system does not function as advertised, the unfeathered propeller causes higher drag which leads to a higher asymmetrical yawing moment requiring more rudder deflection or a higher speed to counteract. *Actual* V_{MCA} is higher.
- *Rudder boosting.* If the rudder is hydraulically boosted, more rudder deflection is available for the same foot pressure. But if the landing gear for instance is selected up, boost pressure might temporarily drop during the gear transitioning, and rudder deflection might decrease, leading to a temporarily higher *actual* V_{MCA} and control problems.
- *Configuration changes.* Any configuration change that affects lateral or longitudinal balance (cg position) or asymmetrical drag, has influence on the yawing moments that act on the airplane and therefore will have effect on (*actual*) V_{MCA}.

In addition to this list, anything else that affects the thrust or drag symmetry will have effect on (*actual*) V_{MCA}.

The factors mentioned in the list above are not factors used to calculate V_{MCA} or V_2 during preflight. To reduce the otherwise huge amount of data, only the worst cases of these factors are used to determine V_{MCA} during flight-test, so the flight manual listed V_{MCA} is always safe, whatever the values of the variable factors are.

V_{MCA} is the minimum speed for maintaining straight (equilibrium) flight if an engine is inoperative (while banking the opted number of degrees away from the inoperative engine). If one or more of the variable factors that have influence on V_{MCA} are not at the worst-case value, *actual* V_{MCA} might be lower – safer – than the published V_{MCA} and not be as excessively high after banking away from the favorable bank angle as illustrated in the previous paragraph. This might be the reason that on many occurrences of engine failure, control could be maintained while the wings were kept level following the failure of an engine or during a training session with an inoperative engine. Nevertheless, quite a few accidents have also learned that after initiating a turn, it was impossible to end the turn and return to the original heading because of insufficient rudder and/or aileron control power, because the airspeed was below *actual* V_{MCA}. V_{MCA} is definitely determined for a reason on Part 23 as well as on Part 25 airplanes.

5. V_{MCA} definition in flight manuals

Now that the flight test techniques and the effect of bank angle on V_{MCA} are explained, the four imperfections in the V_{MCA} definition that were presented in § 2 and are repeated here, will be explained. The definition of V_{MCA} in many flight and other manuals is, again:

> *'V_{MC} is the calibrated air speed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the airplane with that engine still inoperative and (thereafter) maintain straight flight with an angle of bank of not more than 5 degrees.'*

The imperfections in this flight manual definition of V_{MCA} are, in order of importance:

1. angle of bank of not more than 5 degrees;
2. critical engine;
3. suddenly made;
4. V_{MC}.

The missing conditions for which the defined V_{MC} applies are in this sample definition:

- airplane configuration
- thrust setting

5.1. 'angle of bank of not more than 5 degrees'. The airline pilot reading this sentence might get the idea that it is required to maintain the wings level or, in any case, keep the bank angle to within ± 5° left or right in order to maintain straight flight after engine failure. However, the pilot who indeed does keep the wings level is, without realizing, jeopardizing not only his/ her safety, but also that of the passengers, because a life saving addition to V_{MCA} is not made in most flight manuals.

Bank angle affects actual V_{MCA} and is under direct control of the pilot. As was explained in § 3, V_{MCA} is determined with a bank angle of 3° to 5° away from the inoperative engine. Any other bank angle results in a higher – less safe – actual V_{MCA}.

As was shown in figures 3 and 4, the *actual* V_{MCA} might increase to more than 60 knots above the flight manual listed V_{MCA} if the wings are kept level, or if the airplane is banked only a few degrees into the inoperative engine (to the wrong side, for instance to avoid obstacles or terrain). Then the airplane cannot be controlled anymore; a catastrophe is unavoidable.

Many engine failure related accidents happened because the pilot did not maintain the 3° to 5° bank angle away from the inoperative engine but started to turn to either side at too low an airspeed, which led to an increase of the *actual* minimum control speed above the indicated airspeed, rendering the airplane uncontrollable. After allowing the airplane to bank away from the favorable bank angle, the rudder and/ or ailerons might not have the control power anymore to return to the original heading. This kind of loss of control is often referred to as a stall, but it certainly is not: the airspeed is below (*actual*) V_{MCA}, control has become impossible. The V_{MCA} definition as is does not contribute to the prevention of these kinds of accidents.

As was explained before, side force $W \cdot \sin \phi$ replaces the side forces due to sideslip to be able to maintain straight flight while only a small bank angle away from the inoperative engine is used. The sideslip will be near zero, the total drag is lower and hence the remaining climb performance is higher. Therefore, some manufacturers include this small 3° – 5° bank angle requirement in the legend of their one-engine inoperative performance graphs. However, performance should not be the first concern after engine failure; maintaining control is much more vital to survival than the remaining performance.

Some engine emergency checklists require a small bank angle, but often too late and aimed at minimizing the loss of performance during the climb with an inoperative engine. The small bank angle however is urgently needed as soon as the thrust asymmetry develops and as long as the thrust asymmetry exists to be able to maintain control of the airplane. The letter C in V_{MCA} is for control, not for performance.

As was explained before, the V_{MCA} that is listed in flight manuals is not valid without applying the same bank angle that was used to determine it (even if the bank angle used was zero). There is no (FAR/ CS) requirement to list this bank angle with V_{MCA} and consequently most manufacturers do not list the bank angle, but define V_{MCA} to be for *'an angle of bank of not more than 5 degrees'*. Fact is also that V_{MCA} is the minimum speed to barely maintain straight flight, thanks to a small bank angle. Turning, or even allowing the airplane to bank away from this small bank angle is dangerous; this in not elaborated on in flight manuals either.

Regulatory authorities do not require listing the bank angle that validates V_{MCA}, but manufacturers have their own responsibility for the safety of flight with their airplanes, and should provide all of the information necessary to operate the airplane safely, including flight with an inoperative engine and the required bank angle to use for the V_{MCA} to be valid. Not stating the required bank angle for the listed V_{MCA} to be valid might be the cause of many accidents, because pilots are not reminded of the fact that the listed V_{MCA} is valid for one specific bank angle only. They are not kept aware of the huge influence of bank angle on V_{MCA}. They therefore do not hesitate to turn their airplane while an engine is inoperative (and the airspeed is low and thrust setting is high) and are surprised by a sudden loss of control (that is often reported on as a stall).

V_{MCA} is not a minimum speed to fly, but to stay away from, just like the stall speed V_S of an airplane. V_{MCA} really is a sneaky killer because is varies (unnoticed) a lot with bank angle (while V_S changes only slightly with bank angle).

The sentence **'angle of bank of not more than 5 degrees'** in the V_{MCA} definition contains a condition for the certification of the airplane and certainly not a bank angle limit for airline operations. The words 'not more than' need to be deleted in this flight manual definition. The number (5°) needs to be replaced with the number of degrees that the manufacturer used to determine V_{MCA}, even if this is zero.

5.2. 'critical engine'. An airline pilot might, after reading the definition in his flight manual, think that V_{MCA} is not applicable if another engine than the critical engine is inoperative, but that is a misinterpretation. V_{MCA} applies after failure of any one of the engines, inboard or outboard, left or right. This is why:

At low airspeed, or as the airspeed in flight decreases, the angle of attack of the wings has to be increased to maintain altitude or to climb. However, the relative wind not only hits the wings under the increased angle of attack, but also the propeller blades. This affects the resulting thrust of each blade while passing its near horizontal position. The angle of attack of the down going blade increases and the angle of attack of the up-going blade decreases. The down going blade produces more thrust than the up going blade, causing the thrust vector of whole propeller to shift in the direction of the descending propeller blade. This asymmetrical loading of the propeller disc is also called P-factor, see figure 5. If the propellers both rotate clockwise, then the yawing moment arm of the propeller thrust on the left wing (T_1) decreases and the yawing moment arm of the propeller thrust on the right wing (T_2) increases with increasing angle of attack. Then the yawing moment of engine #2 ($T_2 \times$ arm T_2) is bigger than the yawing moment of engine #1 ($T_1 \times$ arm T_1). This

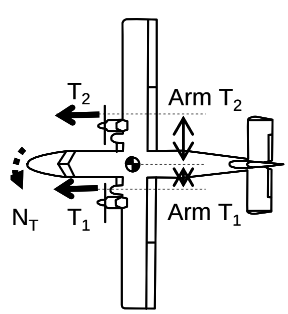

Figure 5. P-factor

effect is also noticeable during normal operations at low speed (as the angle of attack is high), when a rudder input will also be required to counteract the difference in thrust yawing moments and maintain straight flight.

If engine #1 fails, the total remaining thrust moment N_T (in this case generated by engine #2) is bigger than the remaining thrust moment if engine #2 would fail. A bigger asymmetrical thrust moment N_T requires more rudder deflection to counteract this N_T or – if the rudder is at its limit – a higher airspeed. Hence, V_{MCA} after failure of engine #1 will be higher than V_{MCA} after failure of engine #2.

The engine that, after failure, leads to a higher V_{MCA} is called the critical engine. If the propellers rotate clockwise, the (most) left engine #1 is the critical engine.

If the airplane is equipped with counter-rotating propellers or with *turbofans*, there is no change of the total thrust moments with increasing angle of attack and therewith no difference in N_T after failure of a left- or right-hand engine, provided the gyroscopic effects of rotating engines and propellers are negligible. In this case, the opposite engines are equally critical. N_T and hence *actual* V_{MCA} differ for inboard and outboard inoperative engines though.

The failure of the centerline engine on a tri-jet has no influence on the yawing moments and hence not on V_{MCA}, only on the pitching moment requiring a change of elevator input.

V_{MCA} is highest after failure of the critical engine. V_{MCA} after failure of the opposite (or another) engine will be (a few knots) lower. Therefore, the critical engine is inoperative during flight-testing V_{MCA}; this leads to the highest – worst case – V_{MCA} of any engine to fail.

If one engine powers a critical system for airplane control (for instance hydraulic rudder boost), that engine would be called critical.

V_{MCA} listed in flight manuals applies after failure of any of the engines, critical or non-critical. The pilot does not have to start analyzing the remaining thrust distribution on the airplane and make decisions on the criticality of a failing engine; there is also only one emergency procedure for any failed engine.

Therefore, the word **'critical'** does not belong in the V_{MCA} definition in a flight manual, but only in flight-test and certification procedures. Any failed engine has to be treated alike by the airline pilot. If the *critical engine* is mentioned in the V_{MCA} definition, then other factors that affect V_{MCA} even more, like bank angle and weight (§ 4.1), center of gravity (§ 4.2), etc. should have been mentioned in the definition as well.

5.3. 'suddenly made': During flight-testing to determine V_{MCA}, in addition to the static V_{MCA} described above, also the dynamic (sudden failure) V_{MCA} is determined as was described in § 3. Dynamic V_{MCA} is of importance for maintaining or regaining control immediately after the engine failure occurs; static V_{MCA} is of relevance for the safe continuation of the flight while an engine is inoperative. The higher of the two is usually listed in the flight manual as the V_{MCA} for this airplane (for the tested configuration). Therefore, it is completely irrelevant to an airline pilot whether the listed V_{MCA} is for a sudden failure or for flight with an inoperative engine; only a single V_{MCA} applies. The presented V_{MCA} applies as soon as and as long as one of the engines is inoperative, whether following the sudden failure or during the remainder of the flight while an engine is inoperative, while returning to the airport. This is of relevance too, because many accidents happen while flying with an inoperative engine (at too low a speed) after turning into the dead engine with high thrust setting.

The words **'suddenly made'** are for the flight-test methods & conditions to determine the transient effects of a sudden engine failure, i.e. to determine the dynamic V_{MCA} only, and do not belong in a flight manual definition of V_{MCA} to confuse airline pilots.

5.4. Configuration is not addressed in the sample V_{MCA} definition at all. A different V_{MCA} can be determined though for different airplane configurations, for different flap settings (takeoff, cruise, landing), landing gear up and down, in or out of ground effect, etc. Some manufacturers (of big airplanes) present V_{MCA} graphs in their flight manuals in which altitude, temperature and ground effect are the entry variables to find the applicable V_{MCA} for takeoff or go-around. Leaving out the configuration for which the listed V_{MCA} is valid might also be the cause of many accidents because pilots are not made aware of the differences.

Thrust setting also affects *actual* V_{MCA} and is – like bank angle – under direct control of the pilot. V_{MCA} is determined using maximum thrust for the tested configuration. This provides the highest V_{MCA}. A lower thrust setting, like a reduced (assumed temperature) setting, results in a lower – safer – *actual* V_{MCA}. However, if, after engine failure, the thrust on the remaining engines is increased, the listed V_{MCA} applies again.

Both the configuration for which the listed V_{MCA} is valid and the thrust setting should be included in the V_{MCA} definition.

5.5. Improved V_{MCA} definition for flight manuals. Using the explanation presented above, an improved definition of V_{MCA} for use in flight manuals and in student pilot text books would be:

> 'V_{MCA} is the lowest (calibrated) airspeed at which only straight flight can be maintained while an engine is inoperative and the other engine(s) provide maximum takeoff thrust, given the specified configuration and provided the given bank angle is being applied.'

In the limitations section of the flight manual where V_{MCA} is presented, V_{MCA} itself <u>and</u> the bank angle for which the V_{MCA} is valid should be presented (as a limitation).

6. Consequences for Aviation Regulations

The discussed V_{MCA} definition is just one example of incorrect use of FAR and CS 23 and 25 sections by a flight manual writer; nevertheless, the aviation authorities inappropriately approved this flight manual. The V_{MCA} definition that was copied out of FAR or CS should have been changed to an appropriate version for use in the flight manual for operational use by airline pilots before approving the manual of the airplane. On the other hand, it would be recommendable to make aviation regulations absolutely unambiguous: they should be good for certification as well as be unmistakable to the readers who are not certifying staff, like authors of flight manuals, of student pilot text books, (amateur) test pilots or just interested pilot instructors, etc. During the research for writing the report (ref. 3), many inappropriate regulatory paragraphs were found.

In order to prevent engine failure related accidents in the future, it is strongly recommended to start a regulation improvement process. To get this process going, a number of inappropriate regulatory paragraphs are discussed in the report (ref. 3) and in this paper.

7. Minimum Control Speed for Landing V_{MCL}, V_{MCL2} and V_{MCA2}

Civil aviation regulations require V_{MCL} and V_{MCL2} to be determined on 2- and on 3 and more engine airplanes respectively. However, V_{MCL} is only useful during the approach when maximum thrust is required for maintaining the approach path and – following the decision to go-around – in the short period between setting full thrust (while an engine is inoperative) and the flaps arriving in the takeoff setting. Military 4- or more engine airplanes neither use V_{MCL} nor V_{MCL2}, but do use the much more important V_{MCA2} (ref. 6).

V_{MCA2} applies as minimum control speed as soon as one engine is inoperative. V_{MCA2} is the minimum speed to accelerate to before continuing a two-engine inoperative takeoff or to accelerate to before commencing a go-around if one engine is inoperative in anticipation of a second engine to fail. V_{MCA2} is also the minimum control speed during the remainder of the flight while two engines are inoperative. The effect of bank angle on V_{MCA}, as presented in § 4.1, also applies to flight with two engines inoperative, but V_{MCA2} is much higher than $V_{MCA(1)}$.

8. Stall Speed V_S and Air Minimum Control Speed V_{MCA}

Some multi-engine airplanes with the engines mounted close to the fuselage or with counter-rotating propellers have a V_{MCA} that is lower than stall speed V_S, in which case the flight manual either lists no V_{MCA} at all, or states that 'the airplane is controllable down to the stall', which is of course the preferable and most safe situation. However, this will only be the case if the pilot (after engine failure) actually maintains the bank angle that was used to determine V_{MCA}, in most cases 5° away from the inoperative engine as was illustrated in figures 3 and 4 in § 4.1. If the bank angle differs from this favorable bank angle, the *actual* V_{MCA} might increase to a value higher than V_S and a controllability problem might arise despite of the statement in the flight manual.

9. Takeoff Safety Speed V_2

Takeoff safety speed V_2 is one of the procedural speeds used for planning and performing a takeoff with FAR/ CS Part 25 airplanes. As the name implies, V_2 is supposed to be a safe speed during takeoff, especially if an engine fails after passing decision speed V_1. In the analysis below, airspeed data of the sample 4-engine turbojet airplane presented before in this paper will be used to show that there is a very important condition to indeed make V_2 a safe takeoff speed. Figure 6 below is similar to figure 3, but with V_2 data added.

V_2 as defined in FAR/ CS 25.107 (c) must provide at least a (certain) positive one engine inoperative gradient of climb and may not be less than:

- minimum V_2 (V_{2MIN});
- V_R plus the speed increment attained before reaching 35 ft above the runway level.

V_{2MIN} may not be less than $1.10 \times V_{MCA}$ for all airplanes. In addition, a requirement exists for V_{2MIN} to be at least 1.08 or $1.13 \times V_{SR}$, dependant on the number of engines and provisions for power-on stall speed reduction. V_{SR} is the reference stall speed, which is normally the leading factor for calculating V_{2MIN} at higher airplane weights, when V_S is higher than V_{MCA} (if the correct bank angle is used); refer to figure 6 below. Since the exact increment above rotation speed V_R, which is attained before reaching 35 ft above the runway level, is unknown for this sample airplane, the V_2 data shown in figure 6 is V_{2MIN}.

The data used in § 4.1 to explain the effect of bank angle on V_{MCA} will be used again. As was explained in § 3, a 3° – 5° bank angle away from the inoperative engine is used to determine V_{MCA}. Other standardized variables for determining V_{MCA} are the lowest gross weight possible and the most aft center of gravity in the approved envelope as well as the worst cases of other variables that have influence on V_{MCA} (§ 4.2).

Figure 6 below shows the effect of bank angle and weight on V_2. Assumed is that the manufacturer did opt to determine V_{MCA} while using a bank angle of 3° away from the inoperative engine. If opted for 5°, the V_2 line would be a straight line all the way (at $1.13 \times V_S$, in accordance with FAR/ CS 25.107).

As shown in figure 6 below, V_2 for takeoff gross weights below 190,000 lb would have to be 104 kt ($=1.1 \times V_{MCA}$), increasing to $1.13 \times V_S$ for gross weights above 190,000 lb. At 260,000 lb, V_2 would be 122 kt.

If, in this example, the pilot does not bank away 3° from the inoperative engine, but keeps the wings level following the failure of an engine, then the *actual* V_{MCA} will be 119 kt (figure 6 below) and is higher than the preflight calculated V_2, except when the airplane gross weight is above 250,000 lb. At the maximum takeoff gross weight, the preflight calculated V_2 (122 kt) is just 3 kt above the *actual* V_{MCA} with wings level (119 kt). The 10% safety margin that V_2 is supposed to provide over V_{MCA} ($1.1 \times V_{MCA}$, FAR/ CS 25.107) is almost completely vanished; takeoff safety is at stake if the pilot keeps the wings level and the other factors that have effect on V_{MCA} are at their worst case values (§ 4.2).

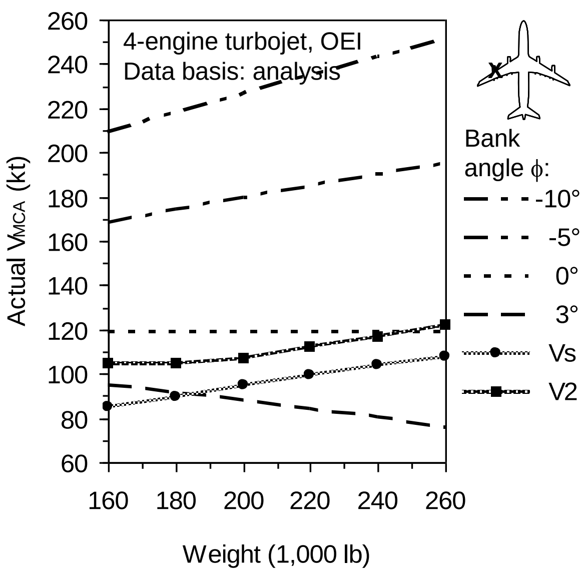

Figure 6. Effect of weight and bank angle on takeoff safety speed V_2.

Instrument flying and departure procedures are simpler with bank angle zero. Therefore, some manufacturers list in their engine failure procedures or guidance to keep the wings level while maintaining V_2. The consequence of this wings level attitude is that, if an engine is inoperative, the *actual* V_{MCA} is higher than while maintaining a small bank angle. To achieve the 10% safety margin above V_{MCA} as intended by FAR/ CS 25.107, the value of V_2 should be increased to $1.1 \times$ *actual* $V_{MCA} = 1.1 \times 119 = 131$ kt. Therefore, if during flight with an inoperative engine the bank angle is not maintained that was used to determine V_{MCA}, the *actual* V_{MCA} might increase above the preflight calculated V_2 and airplane control might be lost. In addition, if a (procedural) bank angle is to be used shortly after liftoff that differs from the bank angle used to determine V_{MCA} it is evident that (*actual*) V_2 needs to be revised as well, to be able to maintain the safety margin and ensure the procedural bank angle to be safe.

Since the airspeed during takeoff or go-around will be V_2 after engine failure at or below 400 ft, the consequences of banking away from the favorable bank angle (3° to 5° away from the inoperative engine) will be that the airplane will start drifting away from the extended runway centerline and that control will be lost already as soon as the wings turn through wings level attitude (if the gross weight happens to be low and/ or the center of gravity is aft). The airplane might continue to roll into the dead-engine-side until the flight ends in calamity. These uncommanded yawing and rolling motions can only be counteracted by immediately decreasing the *actual* V_{MCA}, which – in this situation – can only be achieved by reducing the asymmetrical thrust temporarily, which instantaneously decreases *actual* V_{MCA} to a more safe value below the indicated airspeed. If altitude is available to be exchanged for speed, that is an option too, but this might take too much time.

In order to prevent takeoff accidents after engine failure, it is certainly required for this sample airplane – and most probably for all multi-engine airplanes – to bank 5°, or the specified number of degrees away from a failing engine immediately, which will keep the *actual* V_{MCA} below the preflight calculated takeoff safety speed V_2.

V_2 is supposed to add at least a 10% safety margin on top of the minimum control speed V_{MCA}, but that is obviously not the case if the bank angle is less than the bank angle used to determine V_{MCA}. The pilot assumes to be safe while maintaining V_2 on the airspeed indicator after engine failure, but the *actual* V_2 he should be maintaining after banking away from the favorable bank angle is many knots higher. Not maintaining the favorable bank angle reduces the safety margin required by FAR/ CS 25.107 considerably or even nulls it.

Often it is stated that V_{MCA} is the leading factor for calculating V_2 at low takeoff weights; V_S would be the leading factor for calculating V_2 for high takeoff weights and for airplanes that are said to be controllable down to the stall. V_S increases with weight and only slightly with small bank angles around wings level (by a factor of $1/\sqrt{\cos \phi}$). Referring to the analysis above, it will be clear that V_{MCA} is not only the leading factor for calculating V_2 for low takeoff weights, but also for high takeoff weights and for airplanes that are controllable down to the stall, if the bank angle is deviating from the bank angle used to determine V_{MCA}, even if this is just a few degrees. This however, is never stated in the graphs or tables that present V_2 or with the display of V_2.

10. Imperfections in FAR/ EASA CS

The V_{MCA} definition presented before was copied from FAR/ CS 23.149 or 25.149. Although incomplete, this definition is OK for designing the vertical tail and for flight-testing V_{MCA}. However, many authors copy the V_{MCA} definition out of these regulations into their manuals or textbooks without amending them to suit the purpose of their publication. This in itself is not an imperfection in the regulations because these are for certification purposes, but regulations should be unambiguous to any reader; they are not only used for certification but also as reference document to many authors of flight manuals, textbooks, etc. Regulations should be improved to rule out these kinds of mistakes, and improve aviation safety.

Another example of an imperfect regulation is FAR/ CS 23.1545 that requires '*the airspeed indicator to be provided with a red radial line showing the maximum value of the one engine inoperative minimum control speed V_{MCA}*'. Besides the fact that there is no maximum value of V_{MCA} (there is only one V_{MCA}, unless different configurations are tested), there is no requirement in the regulations to include the bank angle that was used to determine V_{MCA}. The red line speed, if used as V_{MCA}, may therefore lead to a calamity if the *actual* bank angle differs from the bank angle used to determine V_{MCA} and the other conditions happen to be at their worst case values. In ref. 3, many more regulatory imperfections are discussed.

11. Conclusions

Many papers and reports, including accident investigation reports, were written on the subject of airplane control after engine failure, but accidents continue to happen. This was reason for Avio*Consult* to review accident reports, formal multi-engine airplane flight manuals, textbooks and aviation regulations on the subject of controllability while flying with asymmetrical thrust. As a result, many imperfections and even deficiencies were found and presented in a report by Avio*Consult* (ref. 3). Consequently, by reading (only) these imperfect documents, pilots, instructors, tutors, writers, etc. receive an incomplete and hence incorrect comprehension of V_{MCA}, which definitely must have contributed to many engine failure related accidents in the past.

In any case, if *actual* V_{MCA} increases above the indicated (calibrated) airspeed due to a change of bank angle away from the favorable bank angle, it might not be possible to maintain heading; control will be lost. The facts about the effect of bank angle and weight on V_{MCA} presented above are not elaborated in most flight, training and operating manuals, nor in many textbooks on asymmetrical flight, nor in FAR's and CS's. This might very well also be the cause of many engine failure related accidents (§ 4).

The pilot has control over *actual* V_{MCA} via bank angle and (opposite) throttle and should maintain a (favorable) bank angle 3° – 5° away from the failed or inoperative engine while the thrust setting is high, which means that he should not maneuver as long as the airspeed is close to V_{MCA}. This bank angle was also used to design the vertical tail of the airplane.

V_{MCA} should apply as minimum flying speed at all times in anticipation of an engine failure, but applies in any case as long as the thrust is asymmetrical, not only during takeoff and during go-around, but also during the remainder of the flight while an engine is inoperative. If at any time the heading cannot be maintained, the airspeed is below the *actual* V_{MCA}. The only way to regain control is either to increase the airspeed or to reduce the throttle of the opposite engine a little, temporarily.

The standardized V_{MCA} that is listed in flight manuals is the lowest possible speed at which straight flight can just be maintained using the worst case of many variable factors that have influence on V_{MCA} (§ 4.2) **and** a small 3° to 5° bank angle away from the inoperative engine, at the option of the applicant (the manufacturer) (§ 4.1 and § 3). *Actual* V_{MCA} might increase more than 60 knots if the bank angle is not maintained at the opted number of degrees away from the inoperative engine, which might lead to an uncontrollable airplane and consequently to a calamity. The effect of bank angle on V_{MCA} is not made clear in flight manuals (may be except for a very few), in aviation regulations, in most textbooks, etc. (§ 4).

The most important conclusion is that the value of $\mathbf{V_{MCA}}$ that is listed in flight manuals and that is used by pilots of multi-engine airplanes **is in reality not a constant number** as the manuals might suggest and pilots assume it is, but that *actual* V_{MCA} varies considerably with bank angle.

The V_{MCA} listed in flight manuals is a minimum control speed for maintaining straight flight, certainly not for maneuvering and is only valid as long as the same small bank angle is applied that was used to determine V_{MCA}.

Takeoff safety speed $\mathbf{V_2}$ is used on Part 25 airplanes. It is supposed to provide safety during takeoff, even after engine failure. V_2 is calculated during preflight (or by the on-board computers) using V_{MCA} and stall speed V_S. V_2 is only a safe takeoff speed as long as the thrust distribution on the airplane is symmetrical and, following the failure of an engine, only as long as a bank angle of 5 degrees (or a number of degrees as opted by the applicant and used to determine V_{MCA}) is maintained away from the inoperative engine (§ 9). 'Unfortunately', a requirement does not exist to list this required bank angle with V_2 (same as with V_{MCA}) in flight manuals or other operational manuals. On the contrary, some flight manuals even allow – and some departure procedures require – a dangerous 15 degrees of bank to either side while the airspeed is as low as V_2.

Appropriate crew response to propulsion system malfunction remains of utmost importance for takeoff and go-around accident prevention. The use of takeoff safety speed V_2 alone warrants no safety if an engine fails during initial climb.

12. Recommendations

For staying alive with a dead engine and to prevent a dead engine from turning into a killing engine, the recommendations listed below can be made. These recommendations are presented in full detail and ready to copy in the report '*Prevention of Airplane Accidents after Engine Failure*', ref. 3. The recommendations, in order of importance, are:

- Improve engine emergency procedures;

- Improve the definition and conditions of V_{MCA} in flight manuals;
- Improve training and demonstration of V_{MCA};
- Improve Federal, European and equivalent Aviation Regulations;
- Include continuously computed *actual* V_{MCA} and/ or *actual* V_2 as well as the safe bank angle range, if available, in alerting systems and on displays.

Ready-to-copy suggestions for these recommendations are presented in reference 3.

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About the Author

Harry Horlings is a graduate flight-test engineer of the USAF Test Pilot School (Class 85A) and served the Royal Netherlands Air Force for a total of 38 years, 15 of which in experimental flight-testing, including 5 years as Chief Experimental Flight Test. He concluded his Air Force career as lead auditor in an operational quality assignment. Following retirement in 2003, he founded aviation consultancy Avio*Consult*, committed himself to increase aviation safety, wrote several critiques on accident investigation reports and acted as an expert witness. In 2005, he wrote the report *Prevention of Airplane Accidents after Engine Failure* with many recommendations to improve aviation regulations, Flight Manuals and student pilot textbooks on the subject of engine failure. Although his main interest is engineering, he has logged a few thousand hours as a pilot and as cockpit crewmember/ test director and performed experimental flight test activities for and on board of over 40 different types of airplanes and helicopters. He is a member of the Netherlands Society of Aeronautical Engineers, was founding member of the European Chapter of the Society of Flight Test Engineers and holds a Dutch engineering degree.

About Avio*Consult*

Avio*Consult* is an independent aircraft expert and consultant and offers aircraft expertise and consulting on operational aspects like performance, flying qualities and airborne systems to aircraft buyers and owners, aviation and simulator companies and accident investigators.

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