Review
and
Recommendations for Improvement

Course Notes

Multi-Engine Safety Review

Bridging the gap between experimental flight-test and flight operations

Avio*Consult*

Harry Horlings
Experimental Flight Test Expert

July 2012

REFERENCES:

1. *Course Notes of Multi-Engine Safety Review*, FAA – Safety Program. Website: https://faasafety.gov/gslac/ALC/course_content.aspx?cID=30&sID=116&preview=true. Direct download: https://www.faasafety.gov/files/gslac/courses/content/30/247/Multi-Engine%20Safety%20Review%20Course%20Notes.pdf.
2. Paper *Control and Performance during Asymmetrical Powered Flight*, by Avio*Consult*, June 2005, downloadable (free) from the downloads page of website www.avioconsult.com, (#2), or direct via: http://www.avioconsult.com/downloads/Control%20and%20Performance%20During%20Asymmetrical%20Powered%20Flight.pdf.
3. Paper *Airplane Control and Accident Investigation after Engine Failure,* Avio*Consult,* downloadable from the downloads page of website www.avioconsult.com, (#3).
4. Advisory Circular 23-8C. *Flight Test Guide*, FAA. Direct download: http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC%2023-8C.pdf.
5. *Engine inop trainer*, University of North Dakota. Direct link: http://media.avit.und.edu/f4_Inop%20Engine%20Trainer/f1_Inop%20Engine/060302/mainmenu.php.

INTRODUCTION

Quite frequently, all around the globe, small and big multi-engine airplanes crash due to the loss of control following a propulsion system malfunction or while an engine is inoperative. These accidents occurred despite the fact that all multi-engine airplanes are thoroughly designed, flight-tested and certified, after which operating limitations are published in airplane flight and performance manuals for pilots to be able to continue to operate safely, including following the malfunction of a propulsion system. After reviewing many accident investigation reports, Avio*Consult*, having a strong experimental flight-test background, noticed that the minimum control speed in the air (V_{MCA}) was not used by airline pilots in a way that was anticipated by the airplane design engineers and the experimental test pilots who conducted the flight-testing to determine V_{MCA}; the conditions that come with V_{MCA} were obviously not known. To explain the real value of V_{MCA}, Avio*Consult* wrote papers on the subject of airplane control after engine failure that were first published in June 2005 (ref.'s 2 and 3).

The real cause of most engine failure related accidents is, to the opinion of Avio*Consult*, the inappropriate crew response to propulsion system malfunction because of the inappropriate understanding of the real value of V_{MCA} by most pilots, instructors, airplane accident investigators and also by aviation rule makers and authorities. Manufacturers and authors of all kinds of (course) books on the controllability and performance of multi-engine airplanes, including the authors of the *Course Notes of Multi-Engine Safety Review*, copied paragraphs/ sections out of FAR 23 (and 25) into their documents, and seemed not to realize that these regulatory paragraphs are for the design and certification of an airplane, not for their operational use. Some of the paragraphs/ sections of FAR 23 and 25 can be used though, but should be modified before including them in airplane flight manuals, student pilot text books, course notes, etc.
In this review, a limited number of imperfections and deficiencies that were found in the *Course Notes* are discussed and recommendations for improvement are presented.

The objective of the FAA Safety Program is: *Promoting aviation safety through education and cooperative efforts*. Avio*Consult* presents this review to bridge the obviously existing knowledge gap between experimental flight-test and operations. Please consider this review, the explanation and recommendations for improvement as a cooperative effort for increasing flight safety.

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

The results of the review of the course notes, including brief explanations, are presented page by page. Please refer to the referenced papers to learn almost all there is to know about the subject, or ask Avio*Consult* by e-mail. If feasible, reference is made to the FAA Flight Test Guide, Advisory Circular 23-8C (ref. 4).

In the paragraphs below, quotes from the course notes are in *Italic* print, quotes from the Flight Test Guide (FTG) in Advisory Circular AC 23-8C are in green print; explanation and recommendations are in normal print.

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Overview

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Safe operation of multi-engine aircraft starts with a solid understanding of how an engine failure affects *control* and *performance*. This course reviews these concepts, but be sure to consult the Pilot's Operating Handbook (POH) or Airplane Flying Manual (AFM) for your specific airplane.

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Multi-Engine Safety Review

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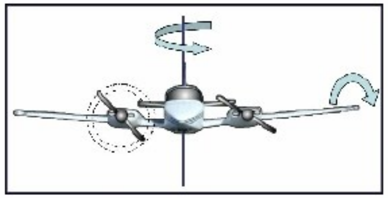
Critical Concepts

Engine Loss and Aircraft Control



In light twin, loss of power on either engine results in:

Yaw. Asymmetric thrust results in yaw toward the failed engine.

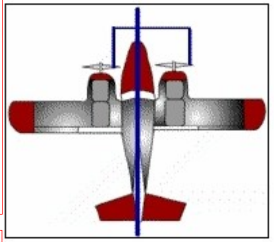
Roll. Loss of airflow causes a roll toward the failed engine.

The dead engine's windmilling prop will also create drag.

The Critical Engine

In a conventional light twin with both engines turning clockwise, the descending blade of the right prop creates asymmetric thrust (*P-factor*) at a greater distance from the airplane's center of gravity than the descending blade on the left prop.

Because the right engine thus produces a greater yawing force, failure of the left engine would have a greater adverse effect on aircraft control and performance. The left is therefore considered to be the ***critical engine***.



(*Note: Twins with a counter-rotating right engine do not have a "critical engine."*)

Quotes out of FTG AC 23-8C (ref. 4) pages 70 and 71:

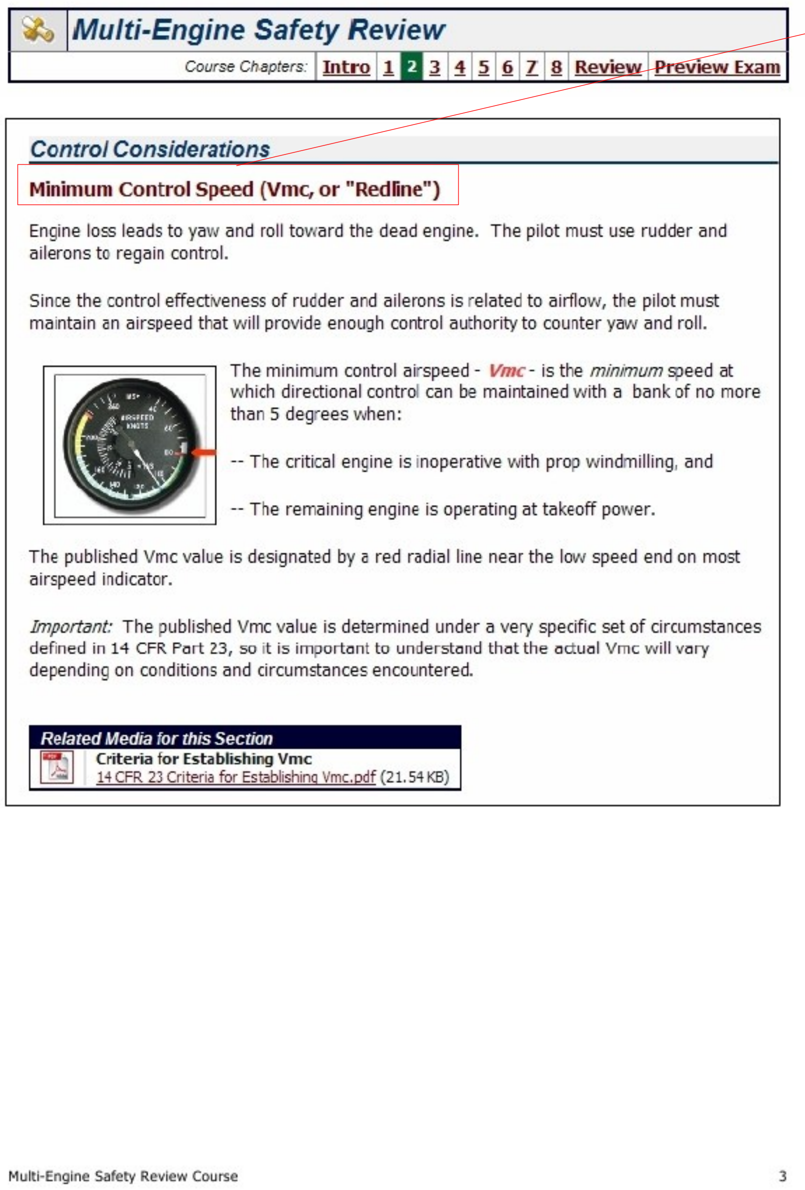
a. *Background*. Section 23.149 requires the minimum control speed to be determined. Section 23.1545(b)(6) requires the airspeed indicator to be marked with a red radial line showing the maximum value of one-engine-inoperative minimum control speed. Section 23.1583(a)(2) requires that V_{MC} be furnished as an airspeed limitation in the AFM. These apply only to multiengine airplanes. A different V_{MC} airspeed will normally result from each approved takeoff flap setting. <u>There are variable factors affecting the minimum control speed.</u> Because of this, V_{MC} should represent the highest minimum airspeed normally expected in service. The variable factors affecting V_{MC} testing include …

(2) *Critical Engine*. The regulation [FAR 23] requires that V_{MC} determination be made "when the critical engine is suddenly made inoperative." The intent is to require an investigation to determine which engine is critical from the standpoint of producing a higher V_{MC} speed. This is normally accomplished during static V_{MC} tests.

The criticality of an engine is just one of the variable factors affecting V_{MCA}. However, it is only of relevance to the airplane manufacturer and the certification staff to know and use the criticality of an engine. A pilot should not have to consider the criticality of a failing engine. There is only one engine emergency procedure for failure of either engine, critical or non. The purpose of using the inoperative "critical" engine for manufacturers and certification staff is to determine the highest, the worst case V_{MCA} normally expected in service after failure of either of the engines, which will then be published in the limitations section of flight manuals and redlined on the airspeed indicator.
Bank angle is also a variable affecting V_{MCA}, but is not considered on this Critical Concepts page. Bank angle has a much greater effect on V_{MCA} than the critical engine (refer to the figure on the page 7 below). *Critical engine* does not belong in texts for pilots. Later in this review, more comments on the use of the *critical engine* will be presented.
It is recommended to delete all about *critical engine* out of this Safety Review because *critical engine* is for airplane design engineers and experimental test pilots, not for airline pilots (ref. 2, § 5.1 and 5.2).

Both engines are in this case equally critical for control.

Recommended is to explain that when propellers rotate in the same direction, the yaw rate after a sudden failure of the left engine might be a little higher than after failure of the left engine. The published V_{MCA} applies after failure of either engine, though.



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Control Considerations

Minimum Control Speed (Vmc, or "Redline")

Engine loss leads to yaw and roll toward the dead engine. The pilot must use rudder and ailerons to regain control.

Since the control effectiveness of rudder and ailerons is related to airflow, the pilot must maintain an airspeed that will provide enough control authority to counter yaw and roll.

The minimum control airspeed - *Vmc* - is the *minimum* speed at which directional control can be maintained with a bank of no more than 5 degrees when:

-- The critical engine is inoperative with prop windmilling, and

-- The remaining engine is operating at takeoff power.

The published Vmc value is designated by a red radial line near the low speed end on most airspeed indicator.

Important: The published Vmc value is determined under a very specific set of circumstances defined in 14 CFR Part 23, so it is important to understand that the actual Vmc will vary depending on conditions and circumstances encountered.

Related Media for this Section

Criteria for Establishing Vmc

14 CFR 23 Criteria for Establishing Vmc.pdf (21.54 KB)

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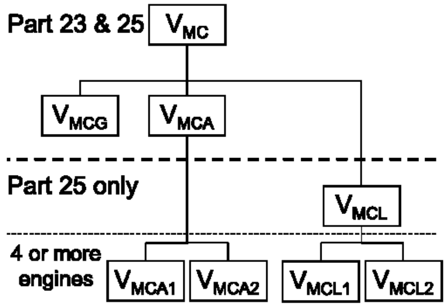
V_{MC} or V_{MCA}? There are seven types of V_{MC} defined in Regulations, as shown in the figure below. There are even two more types of V_{MCA} that are not shown, the dynamic V_{MCA} -- for recovery after a sudden failure -- and a static V_{MCA} that applies following the recovery and during the remainder of the flight, including during the final turn for landing (ref. 2, § 6.1 and quote below). Furthermore, V_{MCA} might change with flap settings. The red line on the airspeed indicator shows the highest V_{MCA} (dynamic or static) normally expected in service, not V_{MCG} or V_{MCL}. Refer to quotes out of the FTG on the previous page. Therefore, it is recommended to change V_{MC} into V_{MCA} in this Review.



Quotes out of FTG AC 23-8C (ref. 4) page 73:

(6) *Static Minimum Control Speed.* The test pilot should select test altitude based on the capability to develop takeoff power and consistent with safe practices. It will be necessary to determine which engine is critical to the V_{MC} maneuver by conducting static tests with first one then the other engine inoperative to discover which one produces the higher V_{MC}. Power should be set to the maximum available for the ambient condition. If possible, test weights should be light enough to identify the limits of directional control without stalling or being in pre-stall buffet…

(8) *Dynamic Minimum Control Speed.* After determining the critical engine static V_{MC}, and at some speed above static V_{MC}, make a series of engine cuts (using the mixture control or idle cutoff control) dynamically while gradually working speed back toward the static speed. While maintaining this speed after a dynamic engine cut, the pilot should be able to control the airplane and maintain straight flight without reducing power on the operating engine. During recovery, the airplane should not assume any dangerous attitude nor should the heading change more than 20 degrees when a pilot responds to the critical engine failure with normal skill, strength, and alertness…

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Related Media for this Section

Criteria for Establishing Vmc

14 CFR 23 Criteria for Establishing Vmc.pdf (21.54 KB)

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Page 3, Continued.

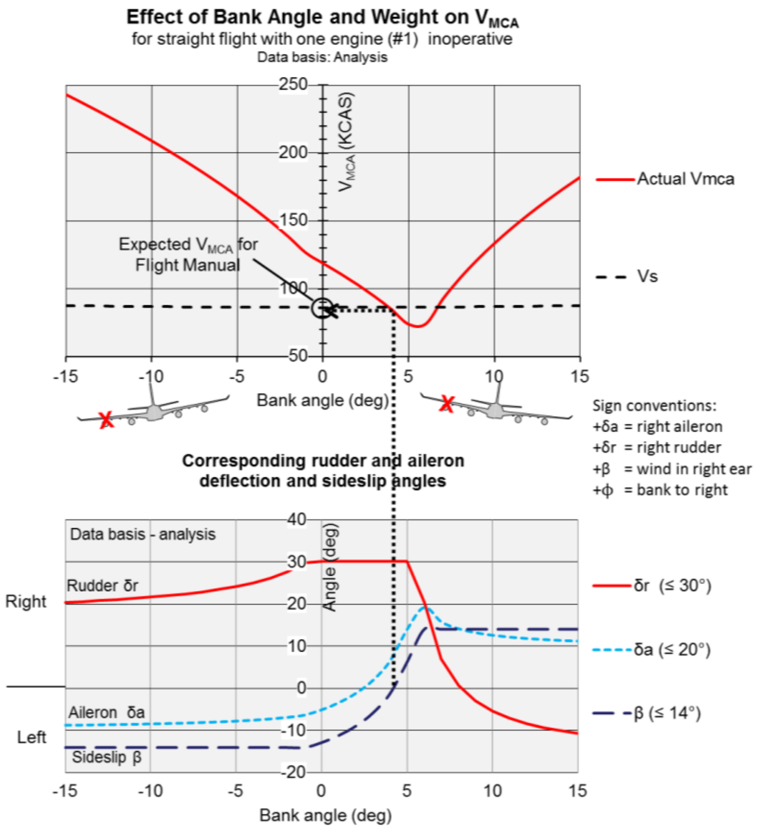
This paragraph is copied from Part 23.149 (a) and can also be found in many Airplane Flight Manuals and learning books. Nevertheless, it contains a life-threatening deficiency: the limitation '*bank angle of no more than 5 degrees'* applies to the design (sizing of the vertical tail) and the certification of an airplane and is definitely not for operational use by airline pilots. The manufacturer, in accordance with FAR 23.149, may use a bank angle away from the inoperative engine of not more than 5 degrees for sizing the vertical tail and/or for which the sideslip (drag) is minimal (figure on the next page). The effect of a small bank angle is that a side force in the c.g. develops that replaces the side force due to sideslip therewith reducing the sideslip to (near) zero (as correctly stated on Review Course page 4), which minimizes the drag and hence, maximizes the remaining climb performance. The legend of many one-engine-inoperative performance diagrams contains a note that the presented data only applies if a small bank angle is being maintained. However, this is not the only effect of a small bank angle. For a thorough explanation, please refer to ref. 2.

Not *directional control* can be maintained when the airspeed is as low as V_{MCA}, but only **straight flight** (FTG quote below). V_{MCA} is for maintaining straight flight only. If a small bank angle is not being maintained (see next page), then straight flight (heading) cannot be maintained when the airspeed is V_{MCA} , the thrust is maximum and the other factors that have influence on V_{MCA} happen to be at their worst-case values (for V_{MCA}) as well. The vertical tail with rudder is not designed large enough to maintain directional control if the bank angle at V_{MCA} is not the favorable bank angle, which in most cases is 5 degrees away from the inoperative engine.

Quote out of FTG AC 23-8C (ref. 4) page 71:

> (3) *Straight Flight*. Straight flight is maintaining a constant heading. Section 23.149(a) requires the pilot to maintain straight flight (constant heading). This can be accomplished either with wings level or, at the option of the applicant [of the certificate of airworthiness], with up to five degrees of bank toward the operating engine. Normally, 2-3 degrees of bank allows the airplane to attain zero sideslip so that at five degrees of bank, the beneficial effects of directional stability to counter the yaw produced by asymmetric thrust can be utilized.

Remark: The higher the airspeed, the smaller the bank angle can be for zero sideslip.



Page 3, Continued.

Bank angle has great influence on the value of V_{MCA} as shown in the adjacent figure in which data of a 4-engine turbojet is used. Data for a two-engine airplane will not be very different, except for the weight and V_{MCA} numbers. The figure is copied from my paper (ref. 2) and is also used in the paper '*Staying Alive with a Dead Engine*' that was presented to the European Aviation Safety Seminar of the Flight Safety Foundation in March 2006.

The Figure illustrates that if the manufacturer designed the vertical tail by using a three degrees bank angle away from the inoperative engine (sideslip zero – lowest drag), V_{MCA} would be 95 kt. When keeping the wings level, the actual V_{MCA} will be up to 24 knots higher (119 kt) than the published V_{MCA} (95 kt), provided the other conditions and factors that have influence on V_{MCA} are at their worst case value, as they were during the flight-testing to determine V_{MCA}.

The V_{MCA} increase above the published V_{MCA} for small twin-engine airplanes, when the wings are kept level, will be around 8 – 10 knots, and therefore definitely a factor to consider. This increase is greater than the difference in actual V_{MCA} between the critical and not-critical engine. The effect of bank angle (and weight) on V_{MCA} is often forgotten, or not known at all, except to experimental test pilots and flight-test engineers who are trained at Test Pilot Schools. They notice this effect each time a V_{MCA} is determined.

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-- The remaining engine is operating at takeoff power.

The published Vmc value is designated by a red radial line near the low speed end on most airspeed indicator.

Important: The published Vmc value is determined under a very specific set of circumstances defined in 14 CFR Part 23, so it is important to understand that the actual Vmc will vary depending on conditions and circumstances encountered.

Related Media for this Section

Criteria for Establishing Vmc

14 CFR 23 Criteria for Establishing Vmc.pdf (21.54 KB)

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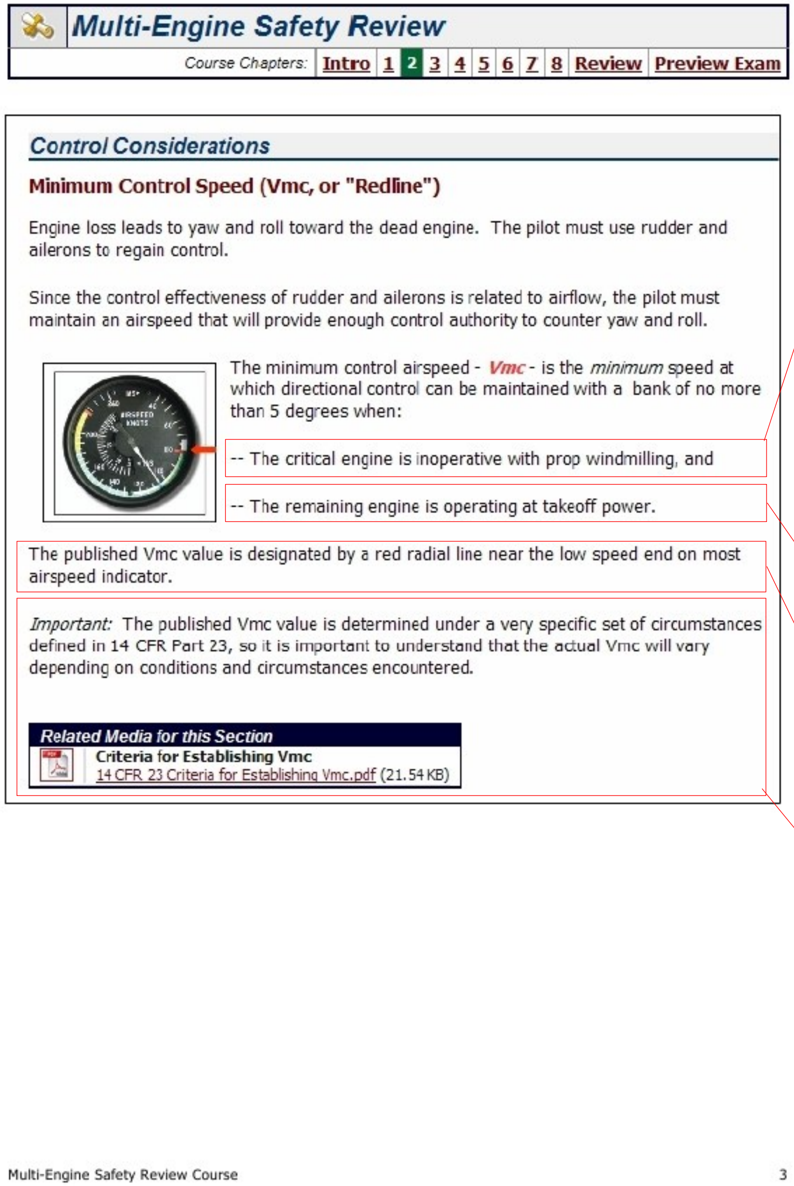
Page 3, Continued.

It is recommended to replace *"with a bank angle of no more than 5 degrees"* by either "with a bank angle of 5 degrees away from the inoperative engine ", or – even better – by "with a bank angle of X degrees away from the inoperative engine", where X is the bank angle used by the manufacturer to design the vertical tail and/ or to determine (flight-test) V_{MCA}.

It is recommended to amend FAR 23 and 25 with the requirement to publish the bank angle used to determine V_{MCA} with V_{MCA} data in the manuals as well as on the required V_{MCA} placard in Part 23 airplanes. Many more suggestions for improving FAR 23 and 25 are presented in a paper available on the downloads page of my website.



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Related Media for this Section

Criteria for Establishing Vmc

14 CFR 23 Criteria for Establishing Vmc.pdf (21.54 KB)

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Page 3, Continued.

This line, in a Safety Review that is intended for pilots, suggests that V_{MCA} does not apply when the non-critical engine is inoperative, which would be a dangerously wrong interpretation. V_{MCA} with the critical engine inoperative is indeed a bit higher than V_{MCA} after failure of the other engine. However, the V_{MCA} published in the AFM (for pilots), is the highest of the static V_{MCA}, the dynamic V_{MCA}, the V_{MCA} with the critical engine inoperative and the V_{MCA} with the non-critical engine inoperative. The criticality of an engine is important for designing the vertical tail and for certification, which is the objective of FAR 23, not for airline pilots and should therefore not be mentioned in airplane operating procedures. One V_{MCA} applies after failure of either engine, as the engine emergency procedure applies after failure of either engine.

If the propellers are equipped with an automatic feathering system, this system is used to determine V_{MCA}, not a windmilling propeller. Therefore it is strongly recommended to change this line to:

-- An engine fails or is inoperative with the propeller in the position it achieves without pilot intervention, and

V_{MCA} is determined while the remaining engine is operating at the maximum thrust/ power level that can be set from the throttle quadrant (throttles fully forward), not takeoff power (which might be reduced to save engine life).

It is strongly recommended to add the bank angle for which the redlined V_{MCA} is valid on a placard, or on the placard that is required to be in direct view of the pilot of Part 23 airplanes > 6,000 lb (FAR 23.1563).

Discussed on the next page.

14 CFR 23 Criteria for Establishing Vmc

Under 14 CFR Part 23 small airplane certification rules, the specific set of circumstances required to determine Vmc are as follows:

- Maximum available takeoff power
- Propeller windmilling in takeoff pitch (or feathered, if equipped with autofeather)
- Most unfavorable (aft-most) center of gravity and maximum takeoff weight (or any lesser weight necessary to show Vmc)
- Landing gear retracted
- Wing and cowl flaps in the takeoff position
- Trimmed for takeoff
- Airborne, out of ground effect.

Under these conditions, the flight test pilot must be able to:

1. Stop the turn that results when the critical engine is suddenly made inoperative within 20 degrees of the original heading, using maximum rudder deflection and a maximum of five degrees angle of bank into the operative engine; and

2. Thereafter, maintain straight flight with not more than a five degree angle of bank.

Page 3, Continued.

Page 3 presents a link to the *14 CFR 23 Criteria for Establishing V_{MC},* shown left. The list of the specific set of circumstances required to determine V_{MCA} is correct, though not complete, except for the takeoff weight. Currently, 23.149 (b) calls for the most unfavorable weight, not for "*maximum takeoff weight (or any lesser weight necessary to show Vmc)".* The regulatory paragraph requires that V_{MC} for takeoff must not exceed 1.2 V_{S1}, where **V_{S1} and not V_{MC}** is determined at the maximum takeoff weight. I will briefly explain why the weight should be low for determining V_{MCA}, see also ref. 2 and ref. 3.

The flight test pilot determines two types of V_{MCA}: Dynamic V_{MCA} and Static V_{MCA}, refer to the FTG quotes on page 5 above.

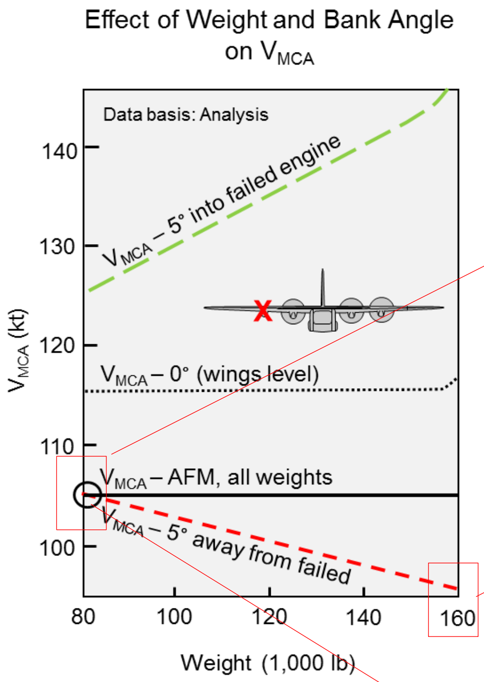
1. This paragraph is about the dynamic V_{MCA}, which is determined by suddenly shutting down the critical engine. The resulting motion following the sudden failure of an engine is not a *turn*, but a yawing and rolling motion due to sudden asymmetrical thrust from the operating engine and loss of propulsive lift from the wing section behind the inoperative engine. The pilot should be able to regain control after the sudden failure of an engine while the heading change does not exceed 20 degrees, the bank angle does not exceed 45 degrees, no dangerous flight attitudes develop and no exceptional pilot skill is required. Therefore the sentence: *maximum of five degrees angle of bank into the operative engine* does not belong here, but in the next paragraph.

Quote FTG AC 23-8C (ref. 4) page 69:

> At no time should the bank angle exceed 45 degrees or excessive yaw be developed.

2. The manufacturer may opt for a bank angle of not more than 5 degrees to determine the static V_{MCA} (as used to size the vertical tail and/ or for minimum drag). The experimental flight test pilot will use this opted bank angle, which is then not a "not more than a five degree angle of bank" anymore, but a <u>**fixed, constant bank angle**</u> used to determine V_{MCA}. It would be better to write: "Thereafter maintain straight flight while maintaining a bank angle as determined by the manufacturer". A pilot might interpret the line as it is right now as "maintain the wings level to within 5 degrees either side". However, this might turn out to be a very dangerous interpretation that results (and resulted) in a catastrophe, because of the increase of actual V_{MCA} as is illustrated in the figure on page 7 above.
The highest of static and dynamic V_{MCA} will be published in a Flight Manual as the V_{MCA} of the airplane, but a static V_{MCA} applies during the remainder of the flight as well.

Refer to the *straight flight* quote out of FTG AC 23-8C on page 7 above.



Quote out of FTG AC 23-8C (ref. 4), page 71:

(4) *Weight and C.G.* For rudder limited airplanes with constant aft c.g. limits, the critical loading for V_{MC} testing is most aft c.g. and minimum weight. Aft c.g. provides the shortest moment arm relative to the rudder thus the least restoring moments with regard to maintaining directional control. V_{MC} should be determined at the most adverse weight. Minimum practical test weight is usually the most critical because the beneficial effect of banking into the operating engine is minimized. Light weight is also desirable for V_{MC} testing because the stall speed is reduced.

Page 3, Continued.

The adjacent figure (ref. 2, ref. 3) illustrates the effect of weight on V_{MCA}. V_{MCA} at low weight is higher than V_{MCA} at high weight while maintaining a small bank angle away from the inoperative engine. If V_{MCA} would be determined at high weight, as the course notes mention, the actual V_{MCA} at low weight would be higher; V_{MCA} would have to be calculated before every takeoff (and landing in anticipation of a go-around). A redlined V_{MCA} on airspeed indicators would not be possible. V_{MCA} is determined while all of the variables that have influence on V_{MCA} are at their worst-case value, resulting in the highest V_{MCA} (for those variables). The actual V_{MCA} will always be lower, which is safer, provided a small bank angle is being maintained away from the inoperative engine as the figure illustrates.

The figure shows that maximum *takeoff weight* does not provide the worst case (the highest) V_{MCA}, if the favorable bank angle is being maintained, but low weight does. Therefore, flight-testing to determine V_{MCA} is always performed while the airplane is at the lowest possible, the most unfavorable weight, because then the resulting V_{MCA} that is published in Flight Manuals is safe for any weight, provided the small bank angle is away from the inoperative engine. If, after engine failure, an equilibrium is established while the wings are level, or even with the wings banking into the dead engine, actual V_{MCA} increases considerably, as the figure illustrates. Hence, turns into the dead-engine side should be avoided at speeds as low as V_{MCA} when the asymmetrical thrust is high. Turns into the good engine should also be avoided because of the increase of sideslip that might lead to a fin stall.
Not mentioned in the criteria is the lateral cg, which should be at the worst case value too, i.e. into the dead engine, for measuring V_{MCA}. Hence, actual V_{MCA} can be decreased by transferring fuel to the good engine side! Please refer to my papers (ref.'s 2 and 3) for the other variables/ conditions that are used to determine V_{MCA}.

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Basic Performance

Best Single Engine Rate of Climb (Vyse, or "Blueline")

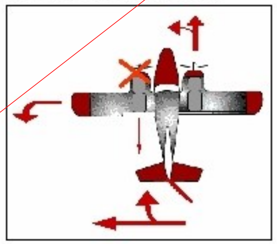
The published Vmc value is established under very specific conditions (*see previous section*), so actual Vmc can vary.

When operating on only one engine, your target airspeed should be ***Vyse***, which is the speed for "best rate of climb with a single engine." Vyse is designated on the airspeed indicator with a blue radial line and often referred to as "blueline."

Vyse *theoretically* provides the greatest altitude gain when only one engine is working, but it does not guarantee that you will be able to climb on one engine. In general, the best you can realistically expect from Vyse is level flight, or smallest rate of descent.

Zero Sideslip

The pilot uses rudder to counteract yaw from a failed engine, but the operating engine still produces forward thrust, and the deflected rudder produces "sideways lift." Together, these two forces create a sideslip in the direction of the failed engine. Sideslip significantly increases drag, which is bad for both aircraft control and aircraft performance.



To achieve zero sideslip, "raise the dead" engine by banking approximately 2 degrees into the good engine. Because of asymmetric thrust, the inclinometer -- "ball" -- will be deflected toward the good engine by about one-half of its diameter in a zero sideslip condition.

Related Media for this Section

Multi-Engine Aerodynamics Interactive (Flash) for Windows
ME Interactive.exe (810.71 KB)

Multi-Engine Aerodynamics Interactive (Flash) for MacIntosh
ME Interactive.hqx (1.41 MB)

Multi-Engine Safety Review Course 4

Actual V_{MCA} can vary, but is never higher than the published V_{MC} value, unless the pilot does not maintain the small bank angle, or uses less than maximum rudder deflection while the asymmetrical thrust/ power is maximal. It is recommended to add: "Actual V_{MCA} will be lower, safer, if the asymmetrical thrust is decreased (temporarily), but actual V_{MCA} will be higher than the redlined V_{MCA} if the rudder is not deflected for maintaining straight flight (heading) and a small bank angle (to be specified by the manufacturer) is not maintained away from the inoperative engine."

Bank angle is not only required for maintaining control, but also for decreasing the sideslip angle, hence drag (figure on page 7 above). The required number of degrees of the favorable bank angle depends on the airspeed. At V_{MCA}, the bank angle for zero sideslip might have to be 5 degrees; the bank angle at the higher climb speed V_{YSE} might have to be only 2 – 3 degrees, which number should be, and in some cases is, listed in the legend of engine-out performance data in the flight manual.
At V_{MCA}, the ball is ½-ball width toward the good engine when the bank angle is 5 degrees toward the good engine, but less than ½ if the airspeed is higher than V_{MCA}. The ball does not indicate sideslip under asymmetrical thrust conditions.

An important condition is that the rudder is deflected as to maintain the heading, no more, no less. Less rudder deflection than maximum and a greater bank angle to maintain the heading will increase actual V_{MCA} and sideslip (fin stall) and hence decrease performance.

It is also recommended to add the link to the on-line Engine Inoperative Trainer of the University of North Dakota. This link is provided in the list of references on page 2, ref. 5.

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Twin Takeoff Performance

General

Takeoff planning is essential for any airplane you fly, but there are special considerations for flying a light twin.

For normal takeoff, use the manufacturer's recommended rotation speed (Vr). If Vr is not published, add at least 5 knots to the published Vmc.

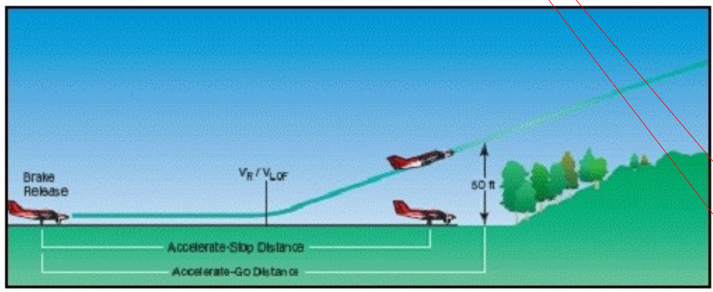
Never try to fly before reaching Vmc. If an engine fails below that speed, the rudder will not be effective enough to counteract the yaw resulting from asymmetric thrust, and you will not be able to control the airplane.

Always review emergency procedures in case you lose an engine on liftoff. Download the takeoff briefing guide below for items to review.

Related Media for this Section
Multi-Engine Takeoff Briefing Checklist
Twin Takeoff Briefing Checklist v2.pdf (27.18 KB)

Accelerate-Stop Distance

Accelerate-Stop Distance is the runway required to accelerate to Vr and bring the aircraft to a complete stop, assuming that you experience an engine failure right at Vr.



Accelerate-stop distance charts are in the POH or AFM for your aircraft. These charts were developed under specific conditions (e.g., paved, level, dry runway) and power settings, and different conditions will not produce the same results.

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As explained above, the consequence of keeping the wings level during liftoff or go-around at an airspeed that is only 5 knots above the published V_{MCA} is that control will be lost as soon as the airplane gets airborne or immediately after the power lever is advanced to maximum takeoff setting (during approach or go-around), if the variables that have influence on V_{MCA} happen to be at their worst-case value. For safety reasons the worst-case values have, of course, to be used for a takeoff speed recommendation, hence V_{MCA} + 5 is not safe and should be V_{MCA}+10+5, in this example for small twins. Loss of control means that a maximum rudder input, maximum aileron input and / or a pedal force of 150 lb, whichever occurs first, cannot maintain the heading. The airplane will continue to yaw and/ or roll into the dead engine side. The resulting sideslip into the dead engine side decreases the performance; the weathercock stability and loss of speed will start pointing the nose of the airplane down. A catastrophe cannot be avoided if the altitude is low, unless the actual V_{MCA} is quickly reduced to below the indicated airspeed by reducing the thrust of the operating engine just a little, until the controls are effective again. There is not much time to do this though, so it should be standard procedure to attain and maintain 5 degrees (or the number of degrees that the manufacturer used for designing the vertical tail and/ or to measure V_{MCA} in-flight) away from the inoperative engine for as long as the power setting is high and the altitude and airspeed are both low. Thrust and bank angle are the only two variables that are under direct control of the pilot; both have great effect on the value of the actual V_{MCA} (ref. 2).

It is recommended to add 10 kt (increase of actual V_{MCA} for wings level of a small twin) plus a 5 kt safety margin, a total of 15 kt to the published V_{MCA} for rotation, unless the published V_{MCA} is the wings-level V_{MCA}; then adding 5 kt is adequate.

It is recommended to say "never try to fly before reaching V_{MCA} plus (10+5)", because a wings level attitude might increase actual V_{MCA} up to 10 knots above published V_{MCA} on small airplanes, if the other factors that have influence on V_{MCA} happen to be at their worst case value. Worst-case is what has to be taken into account – always. It is recommended to add: "Immediately after getting airborne with a failed engine, bank the specified angle away from the inoperative engine to reduce the actual V_{MCA} for maintaining control and to reduce the sideslip". Never turn if you cannot afford losing altitude.

Refer to the next page.

Should V_R not be V_1, the decision speed?

Light Twin Takeoff
Control & Performance Briefing

Density altitude =			
Runway length =		Vmc =	
Takeoff wt =		Vr =	
Takeoff dist =		Vyse =	
Accel-stop dist =		Vy =	
SE climb rate =			
SE svc ceiling =			

- If an engine fails below ____ (Vmc) or ____ (Vr), I will retard the throttles and abort the takeoff.
- If an engine fails after liftoff and the landing gear is down, I will close both throttles and land straight ahead.
- If an engine fails after liftoff (at/above Vxse) and the landing gear is retracted, I will follow the Airplane Flight Manual procedures to:
  - Control (pitch & power for Vyse)
  - Configure (flaps, gear, prop)
  - Climb (maintain Vyse; zero sideslip)
  - Checklist (upon reaching 400 AGL)

Page 5 of the Review Course presents a link to this Multi-Engine Takeoff Briefing Checklist.

Recommended is to add the bank angle for which this V_{MCA} is valid.

It is recommended to add the bank angle for which this climb rate is applicable. It can be found in the one-engine inoperative performance data in the flight manual and is usually smaller than the bank angle for V_{MCA} to be valid.

This step is OK if the runway is long enough; nevertheless, V_{MCA} is determined and published to be able to continue to fly safely if an engine fails or is inoperative.
This needs to be in accordance with the AFM. Some airplanes have rudder boosting; retracting the landing gear (at low altitude) might reduce the rudder boosting level and therewith increase the actual V_{MCA} above the published level.

What if the airspeed is between V_R and V_{XSE}? Recommended is to delete this and the landing gear part. This is in the AFM procedures.

It is strongly recommended to add as first bullet:

- Immediately bank 5 degrees away from the failed engine and maintain straight flight until reaching a (t.b.d.) safe altitude.

The safe altitude is not recommended to be 400 ft, but much higher. When a turn is initiated at 400 ft, while the airspeed is V_{YSE}, control might be lost and no altitude will be available for recovery; disaster is imminent.

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Accelerate-stop distance charts are in the POH or AFM for your aircraft. These charts were developed under specific conditions (e.g., paved, level, dry runway) and power settings, and different conditions will not produce the same results.

Accelerate-Go Distance

Accelerate-Go Distance is the runway required to accelerate to Vr and, assuming an engine failure at that instant, continue on the remaining engine and climb to a height of 50 feet.

Add: "length"

Not all manufacturers specify an accelerate-go distance. Even if your POH/AFM does include it, always remember that these figures were determined under ideal flight test circumstances, and not under the kind of real world conditions that you might face.

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Twin Climb Performance

Altitude and Airspeed

After takeoff, altitude gain is more important than achieving an enroute climb airspeed. Accelerate in a shallow climb to Vy, and maintain Vy until you reach a safe single engine maneuvering altitude (typically at least 400 feet AGL).

Follow the specific recommendations in your POH or AFM, but in general, retract the landing gear after you establish a positive rate of climb and you can no longer land safely on the runway remaining.

Single Engine Climb

Climb performance depends on an excess of thrust (power) over what is required for level flight. Losing one engine represents a 50 percent loss of thrust, but it often results in an 80 to 90 percent loss of climb performance - sometimes even more.

As noted, ***Vyse*** ("blueline") does not guarantee a climb or even level flight with only one engine working, but it is the best performance speed for operation with one engine inoperative (OEI).

Best single engine angle of climb speed (***Vxse***) is used only to clear obstructions during initial OEI climbout. It is invariably a slower speed than Vyse, and may be just a very few knots above Vmc.

Related Media for this Section

Climb Performance Requirements
Climb Performance Requirements.pdf (13.2 KB)

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400 ft is definitely not a safe single engine maneuvering altitude! The reason is that actual V_{MCA} can easily increase above V_{YSE} or V_{XSE} if the same bank angle is not being maintained that was used to design the vertical tail and determine V_{MCA}, as shown in the figures on pages 7 and 11. Remember, V_{MCA} is a safe minimum control speed for maintaining straight flight only while a small bank angle is being maintained away from the inoperative engine; V_{MCA} is definitely not a minimum speed for maneuvering safely while the thrust is maximum asymmetrical, not even above 400 ft AGL! Accident statistics prove that this is not understood by most multi-engine rated pilots, but it simply is the way V_{MCA} is determined and, hence, is to be used when the thrust is asymmetrical, not only during takeoff and go-around, but also during approach and landing, because an increase of thrust up to the (max.) setting used to determine V_{MCA} might be required to maintain the glide slope. Actual V_{MCA} increases with the thrust increase.

Before maneuvering at any altitude, the airspeed should be increased (above the increased actual V_{MCA} during banking) or the asymmetrical thrust should be reduced (temporarily a little to reduce actual V_{MCA}). During maneuvering some altitude will be lost because the sideslip and therewith the drag increase. Following maneuvering, the lost altitude can be regained during straight flight while maintaining the small favorable bank angle.

The loss of performance can be minimized by banking the specified bank angle (mostly between 3 and 5 degrees) away from the inoperative engine because then, as was already stated, the sideslip and hence, the drag are minimum. The bank angle at Vyse could be a little smaller, because V_{YSE} is higher than V_{MCA}, provided it is away from the inoperative engine.

It is recommended to add: Provided a small bank angle is being maintained away from the inoperative engine. Performance data in flight manuals should list both V_{YSE} and the required bank angle.

Very few knots, alright, but only if a small bank angle is being maintained. If not, actual V_{MCA} will increase above Vxse instead and cause control problems; the obstruction might not be cleared at all. Performance data in flight manuals should list both V_{XSE} and the required bank angle for maximum climb performance.

Discussed on the next page.

Page 7 of the Review Course presents a link to these Climb Performance Requirements.

Climb Performance Requirements

The current 14 CFR Part 23 single engine climb performance requirements for reciprocating engine twins are as follows:

More than 6,000 pounds maximum certificated takeoff weight and/or Vs0 more than 61 knots:

The single engine rate of climb in feet per minute at 5,000 MSL must be equal to at least .027 Vso squared. For twins type-certificated on February 4, 1991 or thereafter, the single engine climb requirement is expressed in terms of a climb gradient, 1.5 percent.

6,000 pounds or less maximum certificated takeoff weight and Vso 61 knots or less:

The single engine rate of climb or climb gradient at 5,000 MSL must simply be determined. The rate of climb could be a negative number. There is no requirement for a positive single engine rate of climb at 5,000 feet or any other altitude.

Rate of climb is the altitude gain per unit of time, while climb gradient is the actual measure of altitude gained per 100 feet of horizontal travel, expressed as a percentage. An altitude gain of 1.5 feet per 100 feet of horizontal travel is a climb gradient of 1.5 percent.

With regard to climb performance, the light twin with one engine inoperative will perform marginally at best, and may not be capable of climbing at all under existing conditions. There is no requirement that a light twin in the takeoff or landing configuration be able to maintain altitude, even at sea level, with one engine inoperative.

It is recommended to add a recommendation that operators of these climb-limited airplanes could limit the takeoff weight to ensure some remaining climb performance after engine failure.
In addition, it is recommended to add that climb performance while an engine is inoperative can be maximized by maintaining straight flight with the small favorable bank angle away from the inoperative engine while climbing to a safe altitude before turning.

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Cruise Performance Considerations

Service Ceiling

Losing an engine in cruise may allow time to establish control and troubleshoot, but one critical cruise consideration is service ceiling.

- The single engine *absolute* ceiling is where the rate of climb is zero.
- The single engine *service* ceiling is the altitude at which a twin-engine aircraft with one engine feathered can no longer climb at 50 feet per minute in smooth air.

Service ceiling is important for terrain and obstacle avoidance. If you lose an engine at an altitude above the single engine service ceiling, you can expect to drift down to that altitude. Plan the flight so that you will still be able to maintain minimum IFR or VFR altitudes and remain clear of terrain/obstacles if you lose an engine. Bear in mind that a 50 fpm climb rate is very small. In some conditions (e.g., turbulence), it may only be enough to maintain level flight.

It is recommended to repeat here too to keep in mind that a small favorable bank angle is required to climb or to maintain altitude at airspeeds V_{YSE} or V_{YSE}. Check the single engine performance data in the AFM.

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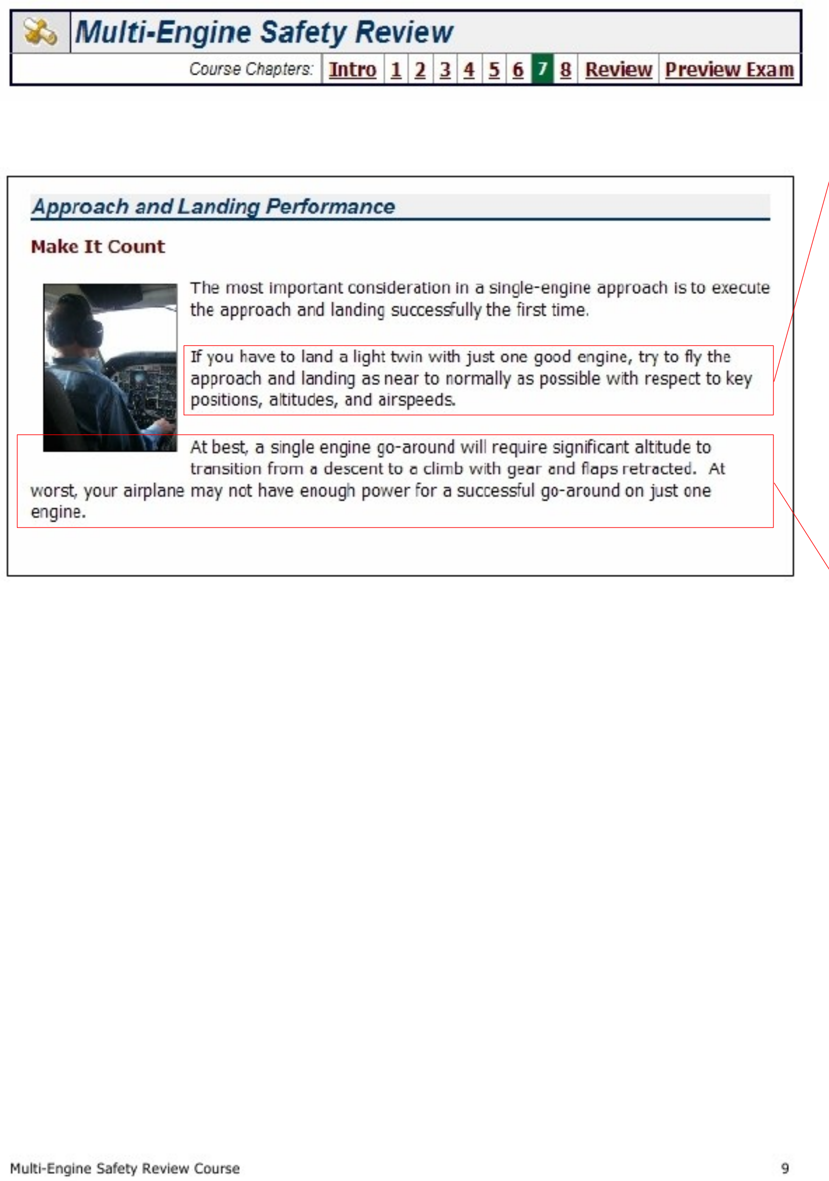
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Approach and Landing Performance

Make It Count

The most important consideration in a single-engine approach is to execute the approach and landing successfully the first time.

If you have to land a light twin with just one good engine, try to fly the approach and landing as near to normally as possible with respect to key positions, altitudes, and airspeeds.

At best, a single engine go-around will require significant altitude to transition from a descent to a climb with gear and flaps retracted. At worst, your airplane may not have enough power for a successful go-around on just one engine.

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Accident statistics show that pilots always seem to be in a hurry to get back to the runway as soon as possible after having experienced an engine failure. They turn to the downwind leg at too low an altitude or increase thrust to maximum during the final turn for landing and lose control because of the increase of actual V_{MCA} due to not maintaining the small bank angle and straight flight, which are conditions for the validity of V_{MCA}, as was explained above and in ref. 2.
During a turn while one engine is inoperative and the other engine at high thrust, rudder is required to counteract the yawing. The rudder generated side force increases the sideslip, hence the drag. Climb performance is lost; the airplane descends in a sideward uncontrollable motion because the rudder is already maximum deflected. Mostly the ailerons also lose their control power because of high propulsive lift of the energized airflow on only one of the wings and the low airspeed.

Therefore, it is strongly recommended to conduct a long straight climb-out after engine failure and/or a long straight-in approach if an engine is inoperative, rather than conducting an *approach and landing as near to normally as possible*, as is recommended on this page. The vertical tail of the airplane is not sized large enough to fly *normally* after engine failure! *Near to normally* is definitely not safe as accidents statistics show!

If a go-around might become necessary, whether an engine is already inoperative or in anticipation of an engine to fail, accelerate down the glide path while gradually increasing both power and bank angle to the specified bank angle (usually between 3 and 5 degrees) away from the inoperative engine, until V_{YSE} is reached and only then transition to the climb.

If near maximum rudder deflection is required to maintain the heading, the airspeed is very close to the actual V_{MCA}. Then control problems are nearby, even while maintaining the 5-degree favorable bank angle.

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Light Twin Training and Proficiency

Safety and Training Tips

Safe operation of light twin aircraft requires three separate, but related, sets of skills: stick-and-rudder (aircraft control), systems knowledge (operation of avionics, hydraulics), and aeronautical decision-making. Good decision-making involves good preparation, including the following actions:

1. Know the key airspeeds for your airplane and when to fly them.

2. Become thoroughly familiar with the AFM/POH recommended procedures and the checklist, particularly the memory items.

3. Know the AFM/POH performance capabilities for your airplane under the proposed flight conditions, and factor in significant margins to adjust for real-world performance. Before every flight, carefully review:

- *Accelerate-stop distance*
- *Accelerate-go distance*
- *Single engine service ceiling*
- *Expected single engine rate of climb*
- *Obstacles or terrain in the flight path.*

4. Know the basic OEI emergency procedures common to all conventional light twins:

- ***Control*** . Maintain directional control with rudder and aileron. Assume the pitch attitude for Vyse.
- ***Configure*** . Execute the memory items from the "Engine Failure After Takeoff" checklist.
- ***Climb*** . Assume the bank angle and ball position for zero sideslip and maintain the best climb rate at Vyse.
- ***Checklist*** . Review and accomplish any remaining checklist items appropriate to the situation.

Regular training and practice with a qualified instructor is essential for proficiency in any airplane, but it is especially important in light twins. As you train, however, be sure to:

- Thoroughly brief simulated engine failures in advance.
- Maintain a safe altitude when practicing OEI maneuvers.
- Accomplish all simulated engine failures below 3,000 AGL by smoothly retarding the throttle - never with mixture!

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The requirement for banking is not mentioned here (for *control* of the airplane), but only under the bullet for *Climb* (for performance). However, for the safety it is definitely required to increase the bank angle away from the inoperative engine proportional with increasing the (asymmetrical) power up to the specified value (which is less than or equal to five degrees away from the inoperative engine). In some emergency procedures, attaining the bank angle is a step in the engine emergency procedure, but is most often considered only for maximizing climb performance, not for maintaining control. The bank angle step therefore is always executed too late. In addition, straight flight is not being maintained. As was mentioned a number of times before, the published V_{MCA} is only valid during straight flight while maintaining a small favorable bank angle.
The bank angle ties engine-out control and performance together.

Engine-out training should be performed at a safe altitude of 5,000 ft AGL or above; V_{MCA} demos are dangerous, especially following a sudden failure as might be meant here. Smoothly retarding a throttle will not show the dynamics that might be the objective of the training.
It is far safer to demo the static V_{MCA} by reducing the speed at a rate of 1 knot per second from the safe intentional one engine inoperative speed V_{SSE} until either one of the control limits is reached or the heading cannot be maintained with maximum rudder. It is recommended to set the propeller of the 'inoperative' engine to the zero drag setting (is presented in the AFM), rather than shutting the engine down. The effect for demonstrating static V_{MCA} is the same.

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Course Review, Notes, Resources

Course Review

Chapter 1 - Critical Concepts

In a light twin, loss of power on one engine results in:

Yaw toward the failed engine (from asymmetric thrust).
Roll toward the failed engine (from loss of airflow over the wing).
Drag on the failed engine side.

Asymmetric thrust is a key consideration in flying light twins, because loss of an engine results in yaw toward the dead engine. In a conventional light twin (both engines turning clockwise), P-factor on the right engine is a major factor. Because the right engine's greatest thrusting moment is to the right of the airplane's center of gravity, it produces significant yaw toward the left if the left engine fails. The left engine is thus considered the *critical engine* because its failure has a greater adverse impact on aircraft control and performance.

Chapter 2 - Control Considerations

The effectiveness of the rudder and ailerons is related to airflow – the greater the airflow, the more effective they are. Airflow depends on airspeed, so it is necessary to establish and maintain an airspeed that will provide enough control authority to counter yaw and roll after engine failure. The published minimum control airspeed – Vmc -- is designated by a red radial line near the low speed end on most airspeed indicator.

Chapter 3 - Basic Performance

Vmc varies, and many light twins will not maintain level flight near Vmc with one engine inoperative. Establish and maintain a higher speed – Vyse ("best rate of climb with a single engine"). Vyse is designated on the airspeed indicator with a blue radial line and generally known as "blueline." Vyse does not guarantee ability to climb with one engine inoperative.

Sideslip significantly increases drag, which is bad for both aircraft control and performance. To achieve zero sideslip with one engine inoperative, the pilot must use rudder and ailerons to bank toward the good engine. The inclinometer will be deflected toward the good engine by about one-half of its diameter.

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It is recommended to add:
'Drag if the favorable bank angle is not maintained'.
'Increase of actual V_{MCA} if the favorable bank angle is not maintained'.

As explained above, not maintaining straight flight while banking the small favorable bank angle away from the inoperative engine has a much greater effect on controllability and performance than the difference between the failure of the critical and the other engine. Critical engine should not be mentioned here, the small bank angle and straight flight should be mentioned instead.

This line under *Control Considerations* suggests that the airplane is controllable at V_{MCA}, which is definitely not the case. It is strongly recommended to add to this sentence: ', but is valid only while maintaining straight flight while banking the favorable bank angle away from the inoperative engine. Turning requires a higher airspeed or reduced asymmetrical thrust. Be aware that altitude is lost during turning or while banking away from the favorable bank angle'.

Varying V_{MCA}, as presented here, is not relevant for performance; delete. Add to the first sentence: 'at higher gross weights and/ or when not maintaining the favorable bank angle'.

It is recommended to add to this paragraph: 'To achieve the best rate of climb, a small favorable bank angle away from the inoperative engine is required. This bank angle is usually presented in the legend of the one engine inoperative climb performance data in the AFM.'

Add to *rudder*: 'to stop yawing'.

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Chapter 4 - Takeoff Performance

Takeoff planning is essential. *Never* try to fly before reaching Vmc, since an engine failure below that speed would leave you without enough rudder effectiveness to control the airplane. Review emergency procedures, so you will be fully prepared to act promptly (and correctly) if you lose an engine on liftoff, or just after takeoff.

Accelerate-Stop Distance is the runway required to accelerate to Vr and bring the aircraft to a complete stop if you experience an engine failure right at Vr.

Accelerate-Go Distance is the runway required to accelerate to either Vr and, assuming an engine failure at that instant, continue the takeoff on the remaining engine and climb to a height of 50 feet. Not all manufacturers specify an accelerate-go distance.

Chapter 5 - Climb Performance

Climb performance depends on an excess of thrust (power) over what is required for level flight. Losing power on one engine represents a 50 percent loss of thrust, but it often results in an 80 to 90 percent loss of climb performance - sometimes even more.

Chapter 6 - Cruise Performance

The *single engine service ceiling* is the altitude at which a twin-engine aircraft can no longer climb at 50 feet per minute in smooth air, with one engine feathered, at maximum certificated takeoff weight.

If you lose an engine at an altitude above single engine service ceiling, you can expect to drift down to the single engine service ceiling. Review the single engine service ceiling before each flight to determine if the airplane can maintain appropriate minimum altitudes and remain clear of terrain and obstacles.

Chapter 7 - Approach and Landing Performance

If you have to land a light twin with just one good engine, fly the approach and landing as near to normally as possible. Execute the approach and landing successfully the first time; your airplane may lack the power to make a successful go-around on just one engine.

Chapter 8 - Light Twin Training and Proficiency

Know key airspeeds and be thoroughly familiar with the AFM/POH recommended procedures. Know the basic one-engine-inoperative (OEI) emergency procedures common to all conventional light twins:

- ***Control***. Maintain directional control with rudder and aileron. Assume the pitch attitude for Vyse.
- ***Configure***. Execute the memory items from the "Engine Failure After Takeoff" checklist.
- ***Climb***. Assume the bank angle and ball position for zero sideslip and maintain the best climb rate at Vyse.
- ***Checklist***. Review and accomplish any remaining checklist items appropriate to the situation.

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Recommended: V_{MCA} + 15 kt.

Regrettably, the really correct promptly act (attain the favorable bank angle) is not included in most emergency procedures, or only as very last step (that will never be executed because the airplane already crashed).

It is recommended to add: 'Maximize climb performance by attaining and maintaining straight flight while banking the favorable bank angle for the given speed away from the inoperative engine.'

It is recommended to add: 'Maintaining a small favorable bank angle might be required to reduce drag and maintain altitude at V_{XSE} or V_{YSE}.'

Refer to the comments on page 20. A *normal* approach might turn into a catastrophe.

Refer to page 21 above.

CONCLUSION

The course notes begin with: *"Safe operation of multi-engine aircraft starts with a solid understanding of how an engine failure affects **control** and **performance**. This course reviews these concepts, but be sure to consult the Pilot's Operating Handbook (POH) or Airplane Flying Manual (AFM) for your specific airplane."*

The most important 'concept' for the safe operation of airplanes (***control***) that originates at the drawing board of the tail design engineer is – regrettably – neither included in this course, nor in most airplane flight manuals, student pilot text books, training programs, etc. Manufacturers and writers only seem concerned with the remaining climb performance after engine failure and not with airplane control, while the loss of control is the real cause of most engine failure related accidents. Loss of control while the thrust is asymmetrical is often not recognized as such and is confused with a stall in many accident investigation reports. This might have been caused by copying the definition of V_{MCA} out of FAR 23.149, which is applicable to the design and certification of an airplane, unchanged into books and manuals that are applicable to the operation of the airplane. That is, to the opinion of Avio*Consult,* where the safety- and life-threatening misinterpretation of V_{MCA} starts.

The most important and life-saving concept for maintaining both control and performance after engine failure is attaining and maintaining a small bank angle away from the inoperative engine for as long as the asymmetrical thrust is high and the airspeed low. The vertical tail with rudder is not large enough to maintain directional control without banking a few degrees away from the inoperative engine at airspeeds near or as low as V_{MCA} (and V_{YSE}). The manufacturer should be required to specify the required bank angle with V_{MCA} and V_{YSE} data in the flight manual of their airplanes.
Bank angle ties engine-out control and performance together.

Regrettably neither this course, nor most, if not all, *Pilot's Operating Handbooks (POH)* and *Airplane Flight Manuals (AFM)* are in agreement with control and performance after engine failure as taught at aeronautical universities by for instance Dr. Jan Roskam, University of Kansas, and with the engine-out flight test techniques that are presented in the FAA Flight Test Guide (FTG, ref. 4) and that are taught at formal Test Pilot Schools.
This applies not only to Part 23 airplanes, but also to Part 25 airplanes!

RECOMMENDATIONS

The objective of this paper is to bridge the obviously existing gap between the worlds of experimental flight test and flight operations. A safer aviation could be achieved by using the recommendations for improvement of the Multi-Engine Safety Review as presented throughout this paper.
It is also strongly recommended to review my free paper *Control and Performance during Asymmetrical Powered Flight* (ref. 2), or the more complete paper *Airplane Control and Accident Investigation after Engine Failure* (ref. 3) in which almost all there is to learn about V_{MCA} is explained.
In addition, the accidents page of the website of Avio*Consult* (www.avioconsult.com), presents reviews and supplementary analyses of a number of engine failure related accidents.

Please feel free to contact Avio*Consult* via e-mail (info@avioconsult.com) for assistance.

Committed to improve aviation safety