Hard copy of website page: www.avioconsult.com/products.htm 6 September 2010

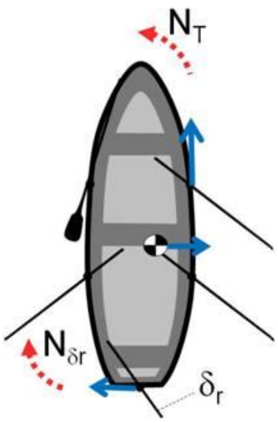
Prevention of Airplane Accidents after Engine Failure

Introduction. Five years after the beginning of aviation, Orville Wright and passenger Lt. Thomas Selfridge took off to conduct a test flight in a new aircraft. In a tight turn, at a height of approximately 150 ft, one of the propellers broke and Orville lost control; the plane plunged to the ground. Lt Selfridge was killed and Orville Wright himself was seriously injured. Aviation claimed its first victim, the cause being the loss of control due to asymmetrical thrust. The Wright bothers' aircraft had one engine, driving two propellers and were therefore to be considered multi-engine airplanes. Orville did not know yet how to control an airplane after the failure of one of the propellers.

Today, 100 years later, engine failures of multi-engine airplanes continue to take their toll. All across the globe, accidents with both small and big multi-engine airplanes continue to happen quite frequently following the failure of an engine during takeoff, go-around, approach for landing and during training, despite the fact that all airplane types are thoroughly flight-tested and operational limitations are published in the airplane flight manuals. The question how accidents after engine failure can be prevented is therefore actual since the beginning of aviation.
Below, this question will be answered. A rowboat will serve as an example to begin with.

Similarity between the controllability of a rowboat and an airplane after 'engine' failure

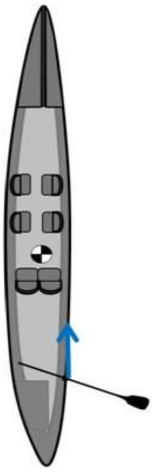
If you are in a rowboat and one of the side-by-side sitting oarsmen quits rowing while the remaining oarsmen continue at maximum effort, the propulsion has become asymmetrical causing the rowboat to start turning (yawing). The helmsman will deflect the rudder to avoid the yawing, but the rudder is effective only down to the speed at which the maximum rudder deflection is reached. This speed is called the minimum control speed (Vmc) of this rowboat.



To reduce the yawing moment due to the asymmetrical propulsion (N_T) and therewith achieve the lowest possible Vmc, the helmsman could ask the oarsman who quit to move a little to the side of the oarsman next to him, to shift the center of gravity of the boat towards the attaching points of the working oar, therewith reducing N_T a bit. The boat will tip over a little into the working oarsman. While at the same speed, the yawing moment generated by the rudder (N_{dr}) can be smaller, so the rudder needs not be fully deflected anymore. Hence, the speed could be further decreased until the rudder is again maximum deflected for maintaining a straight course; the minimum control speed is lower for the same rudder size, by just tipping over the boat a bit (shifting the center of gravity) away from the 'failed' oarsman.

Changing the longitudinal center of gravity affects the rudder generated yawing moment (N_{dr}) as well, because the moment arm, the distance from cg to rudder, changes. Moving the center of gravity aft decreases the rudder moment arm, making the rudder les effective, so a higher speed is required to maintain a straight course; Vmc becomes higher. An aft cg is therefore the worst case.
While the boat is tipping over a few degrees away from the failed oarsman, a side component of the weight develops in a direction opposite of the rudder generated side

force, reducing the sideslip (drift) and therewith the drag to a minimum. For multi-engine airplanes, this similar characteristic is used for designing and sizing the vertical tail.



The gondolas in Venice, Italy are built and operated similarly. The hull is not symmetrical, for a purpose. The heaviest passengers, or if an odd number of people enter the gondola, every 3rd and 5th passenger, are positioned on the right hand side, because gondolas are propelled by only a single oar which attaches to the right-hand side of the stern. This asymmetrical loading displaces the center of gravity to the right hand side and reduces the asymmetrical propulsion moment, which in turn reduces the yawing tendency of the gondola which makes it easier to maintain a straight course.
In addition, the left hand side of the gondola is designed to displace more water, providing more 'lift' which is required because the gondolier always stands on the left hand side of the gondola. Without this hull asymmetry, the gondola would turn to the left all the time. Clever design!

The size of the rudder, the magnitude of the thrust asymmetry, the tipping angle and the location of the center of gravity play an important role for the magnitude of Vmc of a rowboat. On a multi-engine airplane this is not different, although the loss of directional control leads to an uncontrolled descend, while a boat remains afloat. Tipping over into the good engine in an airplane can be easily achieved by banking using the ailerons, rather than shifting weight laterally, like in a rowboat; airplane passengers have their seatbelts fastened. Hence, the bank angle is an important variable as well. This will be further explained in the next paper.

It is recommended to read this 3-page paper first:

Controlling Airplanes after Engine Failure

Tail Design Imposed Limitations

Airplanes are designed, flight tested and certified to continue to fly safely after engine failure or while an engine is inoperative. After reviewing many accident investigation reports using the knowledge gained at the USAF Test Pilot School, it was noticed that most pilots and accident investigators explain and use the minimum control speed V_{MC} in a different way than airplane tail design engineers, experimental test pilots and flight test engineers do. This difference in interpretation has, to the opinion of Avio*Consult*, often led to catastrophic accidents caused by the loss of control and/or performance after engine failure and also to incorrect and incomplete conclusions and recommendations in accident investigation reports.

The objective of this paper is to prevent accidents following the failure of an engine. To achieve this, a few aspects of the design of the vertical tail of a multi-engine airplane and of the flight test techniques that are used to determine the minimum control speed V_{MCA} (Vmc in the Air, or Airborne) are discussed for the readers to become aware of the real value of V_{MCA} that is listed in Airplane Flight Manuals (AFM) and to learn about the conditions for which V_{MCA} is valid and about the V_{MCA} related deficiencies that exist in AFM's, training manuals and engine emergency procedures.

Conclusions of the paper: The vertical tail of multi-engine airplanes is designed and sized only for maintaining straight flight after engine failure down to the AFM listed minimum control speed V_{MCA}, while maintaining a bank angle of 3 - 5 degrees (as opted by the manufacturer for sizing the vertical tail) away from the inoperative engine and while the power setting of the opposite engine is max. takeoff. However, this essential and life-saving condition for the AFM listed V_{MCA} to be valid is regrettably not included anymore in

the operational limitations and engine emergency procedures of most multi-engine airplanes and not in training books either. In addition, the definitions of V_{MCA} in AFM's and training manuals are usually not i.a.w. the tail design criteria and V_{MCA} flight test techniques. Pilots, unaware of these conditions, perform maneuvers, while the airspeed is at or above the AFM-listed V_{MCA} when an engine is inoperative, that the airplane was not designed to do, which has led and will lead again to catastrophic accidents, unless improvements are made.
While maintaining the small 3 to 5 degree bank angle **away from the inoperative engine** (not just max. 5 degrees without specifying the direction, as listed in most flight manuals), not only the actual V_{MCA} is lowest, but also the sideslip angle is smallest, so the drag is lowest possible, leaving maximum available climb performance while an engine is inoperative. Refer to the paper presented below for many suggestions to improve airplane control after engine failure, including regulations, manuals, procedures and training for flight with an inoperative engine.

The Dutch magazine Piloot en Vliegtuig (Pilot and Airplane) published this article in their December 2008 issue.

To download this paper: click here.

A few examples:

V_{MC}. On the airspeed indicator of **Part 23** twin-engine airplanes, the standardized AFM-listed V_{MCA} is indicated by a red radial line, in this example at 80 kt. However, neither a placard on the instrument panel nor a note or warning in the AFM tells the pilot that this V_{MCA} is valid only if a bank angle of 3 to 5 degrees (to be specified by the manufacturer) is maintained away from the inoperative engine. Any other bank angle can lead to a much higher actual V_{MCA} and to loss of control after which an accident cannot be avoided.
If the pointer is at or near the red line and the thrust on the remaining engine(s) is maximum, only straight flight should be maintained while maintaining a bank angle of 3 to 5 degrees away from the inoperative engine, in all phases of flight.

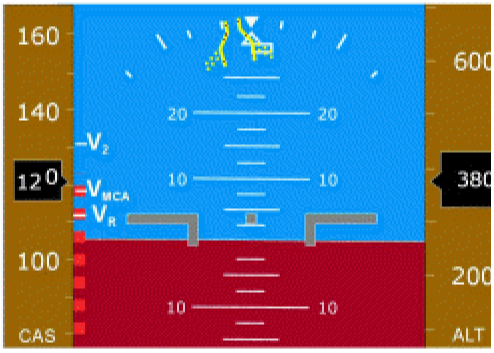
NOTE

2° to 3° BANK TOWARD OPERATING ENGINE

This note is included in the legend of the Climb Performance Chart - One Engine Operating in the Piper PA-44 Pilot's Information Manual. It is included, because not maintaining this bank angle renders the presented performance data invalid; the airplane might not even be able to maintain altitude. Keeping the wings level or turning means loss of performance. Altitude cannot be maintained on most multi-engine airplanes if this NOTE is neglected.

ONE ENGINE INOPERATIVE
AIR MINIMUM CONTROL SPEED 56 KIAS

This placard is installed in full view of the pilot of the PA-44 to comply with Aviation Regulations (23.1563). The required small bank angle for the listed V_{MCA} to be valid is regrettably not included on the placard, because this is not required by the Aviation Regulations. Not maintaining the small bank angle at airspeeds as low as V_{MCA} while the power setting of the remaining engine is high is the real cause of most engine failure related accidents.



V_R and V_{2MIN}. The standardized, AFM-listed V_{MCA} is one of the factors for calculating the rotation speed V_R and the minimum takeoff safety speed V_{2MIN} of big **Part 25** airplanes. Since this V_{MCA} is valid only while maintaining a bank angle of 3 to 5 degrees, as to be specified by the manufacturer, away from the inoperative engine, both the calculated V_R and V_{2MIN} are also valid only when maintaining the same bank angle (when the thrust setting is maximum takeoff).

This figure, a safety improving suggestion out of the paper presented below, shows that the actual V_{MCA} in this example has become higher than V_R because the wings are kept level. Bank angle and rudder advisories are presented to decrease the actual V_{MCA} to a safe level to prevent the loss of airplane control. The bank angle advisory widens up as airspeed increases.

Airplane Control after Engine Failure

This paper, first called '*Prevention of Airplane Accidents after Engine Failure*', presents almost all there is to know about flight with an inoperative engine and was prepared using the knowledge that formally trained experimental test pilots and flight-test engineers have on the subject and on the proper flight test techniques to determine V_{MCA} and is intended for pilots, instructors, teachers, aviation authorities, accident investigators, etc.

The paper (28 pages, 25 figures) includes all of the following subjects:

- airplane control after engine failure;
- variable factors that influence minimum control speed V_{MCA};
- flight-testing V_{MCA} and the airplane configuration used;
- the apparent safety of takeoff safety speed V_2;
- imperfections and deficiencies in flight manuals and text books on the subject engine failure and flight with an inoperative engine.

Included in the paper are many ready-to-copy recommendations to improve:

- engine emergency procedures;
- flight manuals;
- student pilot textbooks;
- engine-out training;
- primary flight display.

Avio*Consult* believes this paper was necessary because too many unnecessary accidents are happening following the failure of an engine.
This paper is available for download, click here.

In case you are interested, a two to four hour **lecture** on the subject of *Airplane Control After Engine Failure* is available, please contact Avio*Consult.*

Besides to the European Aviation Safety Seminar (EASS) of the Flight Safety Foundation, a lecture was recently presented to the airplane accident investigators of the Dutch Transportation Safety Board. An earlier, less extensive version was presented in a meeting with the Engine and Propeller Directorate of the FAA and ALPA, to the Flight Safety Committee of the Dutch Airline Pilot Association, to the Netherlands Association of Aeronautical Engineers, the Air Forces Flight Safety Committee Europe and to Air Force and Navy.
Please refer to the accidents page for a number of accident descriptions.

The Effect of Bank Angle and Weight on V_{MCA}

In the paper presented above, graphs showing the effect of bank angle and weight on V_{MCA} and on takeoff safety speed V_2 are included. These graphs were calculated using a prediction method that is also used by experimental test pilots and flight test engineers before beginning the flight-tests to determine V_{MCA} in order to learn about limitations, etc. that might be encountered during the test. This paper presents the prediction method and includes a few data figures. This method can be used for all multi-engine airplanes, provided the required stability derivative data are available.

This paper is available for download, click here

Staying Alive with a Dead Engine

A paper by Avio*Consult*, presented at the European Aviation Safety Seminar (EASS) of the Flight Safety Foundation (FSF) on 14 March 2006 in Athens, Greece.

Abstract: During flight-testing multi-engine airplanes while an engine is inoperative, the manufacturer may opt to use a small bank angle (max. 5 degrees away from the inoperative engine) to determine the minimum control speed V_{MCA} that is to be listed in flight manuals as an operational limitation and that is used to calculate takeoff safety speed V_2.

However, any deviation from this bank angle increases the actual V_{MCA}. Keeping wings level increases V_{MCA} already by some 8 kt; banking into the dead engine increases V_{MCA} much more. But the airline pilot does not get to know which bank angle was used and should be maintained for the listed V_{MCA} to be valid, because there is no requirement in FAR's 23 and 25 to present this bank angle in the Airplane Flight Manual. Manuals currently concentrate on the loss of performance after engine failure, not on maintaining control.
Many pilots also believe that takeoff safety speed V_2 is a safe speed after engine failure. V_2 however, is calculated using V_{MCA} (and V_S). If the pilot does not maintain the bank angle that was used to determine V_{MCA}, then the actual V_{MCA} might increase to a value higher than V_2: control will be lost.
Not maintaining the bank angle used to determine V_{MCA} after engine failure during takeoff or go-around can make the difference between life and death.
This paper is a much abbreviated version of the paper presented above and can be downloaded here.

Imperfections in FAA and EASA Regulations

A paper by Avio*Consult* that resulted from the research for the papers presented above. It presents and explains many errors found in aviation regulations and includes ready-to-copy suggestions for improvement. Please contact Avio*Consult.*

Support

In case you are interested in having Avio*Consult* verify and/ or improve your Flight Manuals, engine emergency procedures, textbooks, accident investigation reports, etc. on the subject, please contact Avio*Consult*.

Downloads

Comments and downloads on several accident investigation reports and training material, can be found on the accidents page of the website. The comments were written using the knowledge from the papers presented above. To proceed to the downloads page, click here.

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