# Limited Analysis of the Engine Failure Procedure of Boeing 737 - 200/400/500 in the Flight Crew Training Manual

**Harry Horlings**
Avio*Consult*, an independent aircraft expert and consultant
The Netherlands
www.avioconsult.com

## References

1) *Accident Investigation Report 7t-z030306a*. Democratic People's Republic of Algeria, Ministry of Transport, National Commission of Inquiry. Download link: http://89.30.127.14/docspa/2003/7t-z030306a/pdf/7t-z030306a.pdf.

2) Horlings, Harry. Paper *Airplane Control after Engine Failure – Vertical Tail Imposed Limitations*, Avio*Consult*, Sept. 2008; 4 pages pdf, downloadable (for free) from www.avioconsult.com/products.htm.

## Attachment

Boeing 737 Flight Crew Training Manual, Page 2-19, AUG 31/89, One Engine Inoperative Rotation and Initial Climb.

## Author biography

Harry Horlings is a graduate Flight Test Engineer of the USAF Test Pilot School, Edwards Air Force Base, CA, December 1985. Following his Air Force career, which he concluded as Chief Experimental Flight Test, he founded Avio*Consult* and dedicated himself to improve aviation safety using his knowledge of experimental flight-testing. He researched many engine failure related catastrophic accidents that occurred to multi-engine airplanes after engine failure or while an engine was inoperative. He published several papers, reports on the prevention of this kind of accidents, and presented these to the European Aviation Safety Seminar of the Flight Safety Foundation, to the Dutch TSB, the Engine and propeller Directorate of the FAA and to a number of Airlines, Air Force and Navy organizations. He also wrote supplementary analyses of individual catastrophic accidents, of training and airplane flight manuals and of deficiencies in Aviation Regulations FAR, CS 23 and 25 and equivalent, all of which can be downloaded (for free) from the products page of www.avioconsult.com.

## 1. Introduction

1.1. On 6 March 2003, a Boeing 737-200 crashed almost immediately after takeoff from the airport Tamanrasset in Algeria. About 5 seconds after rotation, at 78 ft AGL, the left engine failed and the airplane yawed 12 degrees to the left. According to the accident investigation report, the airplane lost speed progressively, stalled and crashed, killing all but one on board.

1.2. In the Accident Investigation Report (Ref. 1), a copy of page 2-19 of the Boeing 737 Flight Crew Training Manual (FCTM) was included containing the procedures for rotation and initial climb after engine failure. This FCTM page is included as an attachment. Avio*Consult* reviewed the FCTM procedures and concluded that these were neither in accordance with the conditions that engineers normally use to design the vertical tail of a multi-engine airplane, nor with the flight test techniques that are used by experimental flight-test crews during engine inoperative flight-testing to determine the minimum control speed in the air ($V_{MCA}$). $V_{MCA}$ is an important safety speed, because it is used to calculate both the rotation speed ($V_R$) and the minimum takeoff safety speed ($V_{2MIN}$) (FAR/CS 25.107).

1.3. During the research for preventing accidents after engine failure, it became clear that airline flight crews were (and as of today still are) not made aware of the limitations that apply while using $V_{MCA}$, or $V_R$ and $V_2$. These limitations are a consequence of the methods used to design and size the vertical tail of a multi-engine airplane and of the flight test techniques that are used to determine $V_{MCA}$. Just maintaining an airspeed equal to $V_{MCA}$ and/or $V_2$ in-flight is not sufficient to guarantee safety of flight while an engine is inoperative; maneuvering limitations apply as well, but these are regrettably not published anymore in airline flight crew procedures, but are still applied during tail design and experimental flight-testing.

 

1.4. Avio*Consult* recommended Boeing in July 2005 to improve the procedures, but Boeing responded that *'there was no compelling reason to change the procedures'*. This in turn became a compelling reason for Avio*Consult* to closely review the formal Boeing FCTM using experimental flight test knowledge and write this analysis.

1.5. This analysis is limited to FCTM content regarding airplane control after engine failure. A summary of the relevant theory is included in Ref. 2 for the readers as a knowledge basis to be able to understand the analysis presented below. It contains some of the 'forgotten' theory of airplane control after engine failure as is still used to design airplanes and to flight-test them. It is highly recommended to download and read Ref. 2 before proceeding to paragraph 2. A brief introduction to $V_{MCA}$ and $V_2$ is included below.

1.6. **About $V_{MCA}$ and $V_R$.** The minimum control speed of a multi-engine airplane is the lowest airspeed at which straight flight can be maintained, while the thrust on the operating engine is set at the maximum takeoff setting and a bank angle between 3 and 5 degrees (as opted by the manufacturer) is maintained away from the inoperative engine. FAR 25.149 allow the engineers who design the vertical tail of a multi-engine airplane to use a maximum bank angle of 5 degrees, away from the inoperative engine. This small bank angle reduces the required size of the tail and hence, saves weight. The magnitude of $V_{MCA}$ depends not only on the bank angle and the size of the vertical tail, but on many more factors, like the location of the center of gravity, the airplane weight, etc. of which the worst-cases are used to determine the – standardized – $V_{MCA}$ that is listed in the Flight Manuals. During flight, a pilot has control over the *actual* $V_{MCA}$[1] by using the throttle of the engine opposite of the inoperative engine and with rudder and ailerons.

1.7. At the instant an airplane lifts off the runway, an *actual* $V_{MCA}$ has come into effect. As was mentioned before, the magnitude of the *actual* $V_{MCA}$ depends highly on the bank angle and thrust setting. If the pilot keeps the wings level, then the *actual* $V_{MCA}$ is at least 10 kt to may be 20 kt higher than the AFM-listed $V_{MCA}$. The exact number is not known for the Boeing 737, but for a small twin, the increase is 8 knots and for a B707/DC-8 type airplane, the actual wings level $V_{MCA}$ is 30 kt (!) higher than $V_{MCA}$ while maintaining a small bank angle away from the inoperative engine.

1.8. This (mostly unknown) increase of the *actual* $V_{MCA}$ over the standardized AFM listed $V_{MCA}$ has great influence on the safety of the airplane immediately after lift-off. The airspeed at this time is still about $V_R$ or a bit higher, depending on the thrust that the remaining engine is set to produce. If the many factors that have influence on the magnitude of $V_{MCA}$ all happen to be at their worst-case value, then the *actual* $V_{MCA}$ is highest (Ref. 2).

1.9. The AFM-listed $V_{MCA}$ is one of the factors for calculating $V_R$. $V_R$ is to be at least $1.05 \times V_{MCA}$ (FAR/CS 25.107). Hence, $V_R$ might be only 5% higher than the AFM-listed $V_{MCA}$ that is determined while maintaining a small bank angle away from the inoperative engine. Given that this 5% safety margin of $V_R$ above (the pre-determined and standardized) $V_{MCA}$ is this small, the pilot should keep the *actual* $V_{MCA}$ as low as possible to ensure safety for all possible airplane configurations. As explained in Ref. 2, the pilot can accomplish this only by maintaining a small bank angle (3 – 5 degrees) away from the failing engine.

1.10. In the paragraphs below, the original text of the FCTM (attachment), if applicable and where needed, is included in *Italic print*.

## 2. Air Algeria Boeing 737 FCTM – Engine failure takeoff procedure

2.1. **Rotation**. The FCTM procedure (see attachment, left column) is as follows:

*If an engine fails between V1 and lift-off, maintain directional control by smoothly applying rudder proportionate with thrust decay to maintain the desired heading or track.*

*Rotate normally at VR, using the required amount of control column and control wheel if necessary, to hold the wings level.*

Comments to the last line: *..., to hold the wings level.*

2.1.1. When the rotation is initiated, the airspeed is $V_R$ and the rudder is still deflected as was required to maintain the desired heading or track on the runway after engine failure. Hence, the vertical tail already generates a side force to the side of the operating engine. Immediately after lift-off, if the wings are held level, this side force causes the airplane to accelerate in a sideward motion into the dead engine until the side force generated by the resulting sideslip is big enough to balance the rudder-generated side force, after which a new equilibrium exists. The resulting asymmetrical sideslip however, causes drag, which reduces the climb performance or even leaves no performance at all to climb away, whereupon the airplane slides in a slow motion to the ground. Loss of performance however, is not the only adverse effect of holding the wings level.

2.2. If the wings are held level, the rudder not only needs to overcome the asymmetrical thrust yawing moment, but also the increasing side force due to the sideslip. A balance can only be achieved, i.e. control can only be maintained, if the (indicated) airspeed is high enough to generate the required aerodynamic rudder side force. If the rudder is maximum deflected, this higher airspeed is the *actual* $V_{MCA}$ with wings level and can be 10 to 20 kt higher than the AFM listed $V_{MCA}$

[1] *Actual* $V_{MCA}$ means the minimum control speed that a pilot will experience in-flight, while an engine is inoperative, with an actual thrust setting, actual bank angle, actual center of gravity, actual control inputs and actual values of the other factors that affect $V_{MCA}$.

and might be higher than $V_R$. If the current (indicated) airspeed is below the *actual* $V_{MCA}$, control might be lost immediately following rotation. (Ref. 2)

2.2.1. It is therefore of utmost importance to reduce the drag and reduce the *actual* $V_{MCA}$ to the lowest possible value from the instant the airplane is airborne. This can only be achieved by banking a few (3 – 5) degrees away from the inoperative engine. Therefore, if an engine fails between $V_1$ and lift-off, the wings should definitely not be held level, but at the same bank angle that Boeing used to both design the vertical tail and determine $V_{MCA}$ as soon as possible, in this case already during the rotation. Only then, *actual* $V_{MCA}$ is as low as possible and controllability after engine failure can be guaranteed. A complicating factor is roll control on the 737. This will be discussed in the next paragraphs.

2.3. *If the engine failure occurs at or after liftoff, apply aileron to momentarily establish wings level. Add rudder to center the control wheel. To center the control wheel, rudder will be required in the direction that the control wheel is displaced. This approximates a minimum drag configuration.*

Comments to this procedure, line by line:

*If the engine failure occurs at or after liftoff, apply aileron to momentarily establish wings level.*

2.3.1. As presented before, keeping the wings level increases the *actual* $V_{MCA}$ at least 10 kt above the AFM-listed $V_{MCA}$, which is determined while maintaining a small 3 – 5 degree bank angle away from the inoperative engine. *Actual* $V_{MCA}$ varies with many factors, including the location of the cg. If the cg is forward, the actual $V_{MCA}$ is lower, which is safer, and control might not be lost while the wings are level. However, if Boeing presents a procedure that is valid for all configurations, it must indeed cover all configurations and be valid, even for the worst-case configuration (low weight, aft cg, etc.). In addition, the procedure must be in agreement with the criteria used to design the vertical tail. The tail of a multi-engine airplane is usually not designed and sized for maintaining control of the airplane while keeping the wings level if an engine is inoperative, but for maintaining control under the condition that a small bank angle is maintained away from the inoperative engine. $V_R$ in fact is, like $V_{MCA}$, only valid if a small bank angle is being maintained away from the inoperative engine (refer to Ref. 2 or college books by Dr. Jan Roskam, University of Kansas).

2.3.2. Applying aileron to establish wings level with a control wheel input exceeding seven degrees causes the roll control spoiler(s) to deflect. Spoiler deflection enhances the roll control power, but adds additional asymmetrical drag, which is not favorable to the remaining climb performance with a failed engine. In addition, the deflected spoiler(s) affect the yawing moments and consequently, the *actual* $V_{MCA}$.

2.3.3. Establishing wings level increases the drag and increases the actual $V_{MCA}$, as was explained above. In this case, also a small 3 – 5 degree bank angle should be established as soon as possible, rather than wings level.

2.4. *Add rudder to center the control wheel.*

2.4.1. The thrust asymmetry after engine failure is about the yaw axis; yawing is therefore the first motion that occurs after engine failure. The yawing motion in turn causes a roll due to yaw rate ($C_{\ell r}$) and a sideslip ($\beta$) that increases the roll rate (dihedral, $C_{\ell\beta}$). Sideslip ($\beta$) also means drag, which reduces the climb performance; sideslip should be kept to a minimum. The yawing motion therefore should be the first to be detected and countered by the only yaw axis control available to the pilot, the rudder, as soon as possible. Full rudder might be required to maintain the equilibrium of side forces and yawing moments if the thrust is high and the airspeed is still low.

2.4.2. However, because of the limited yaw rate detection and display in today's cockpits, the yawing might not be the first motion that is detected by the pilot flying after an engine failure occurs. Boeing in fact tells the pilots to wait for the airplane to bank when the thrust has become asymmetrical (this is easier to be observed on the ADI or FD) and only then take action by returning the wings to a level attitude first and add rudder until the control wheel is centered. However, just before adding rudder in this case, the sideslip (and the drag) will have increased considerably, and the controllability of the airplane is at stake because the *actual* $V_{MCA}$ has increased (bank angle change into the failing engine). The rudder was not designed to provide adequate yaw control power while the wings are kept level and might not have the control power anymore to center the control wheel if the airspeed is too low.

2.4.3. An early rudder deflection is important for maintaining control and for maximizing climb performance because this keeps the sideslip angle (i.e. the drag) from increasing too much and limits both the roll due to sideslip as well as the yaw rate. The control wheel should then be used to maintain a small bank angle away from the inoperative engine. The Boeing airplane design engineers will have used these tail design criteria for sizing the vertical tail (as taught by aviation colleges around the globe).

2.4.4. Except if Boeing used wings level to determine $V_{MCA}$, adding rudder to center the control wheel is definitely incorrect. The correct order of applying controls is to smoothly add rudder proportional with the thrust decay, to maintain the desired heading or track (which is the Boeing procedure for failure between $V_1$ and liftoff), and simultaneously apply ailerons to establish a small bank angle of 3 – 5 degrees (as opted by Boeing for designing the vertical tail) away from the inoperative engine (a half ball-width).

2.4.5. Maintaining a bank angle of 3 to 5 degrees away from the inoperative engine for achieving both the lowest possible *actual* $V_{MCA}$ and drag might require the control wheel to be rotated more than seven degrees away from the center. This will cause the roll assisting spoilers to deflect for increasing the roll control power, if the flaps are still down. To prevent the spoilers from deflecting and hence to keep the drag low at a critical point in-flight, Boeing cannot but recommend centering the control wheel, therewith accepting a potential control problem and higher drag. Not known is what bank angle the Boeing test pilots used to determine $V_{MCA}$ and whether the flaps were up or in takeoff. In any case, the presented procedure seems to assume that $V_{MCA}$ is determined with the wings level, otherwise the safety margins that the Rulemakers (the public) required when prescribing FAR/CS 25.107 cannot be met.

2.4.6. The real purpose of adding rudder to center the control wheel is getting rid of the drag that the roll assisting spoilers produce as long as the control wheel deflection is in excess of 7 degrees. Currently, the Boeing procedure seems intended for increasing performance, not for maintaining control.

2.5. *... momentarily ...*

2.5.1. The adverb *momentarily* has two different meanings: 'for only an instant or moment', and 'very soon' and should not be used in an emergency procedure; it should be left out.

2.6. *This approximates a minimum drag configuration.*

2.6.1. A level control wheel will not necessarily result in a wings level attitude, or in a bank angle of 3 degrees at which the drag is normally minimal, while the thrust is asymmetrically. The airplane will settle in a new equilibrium under the current thrust and control settings. The sideslip that develops as a result of the asymmetrical thrust cannot be reduced for sure by keeping the control wheel level or by keeping the wings level; a small bank angle is definitely required to achieve this (Ref. 2). Maintaining the control wheel level might approximate the drag to be ***a*** minimum, but not **the** minimum drag configuration. The drag is only minimal if the sideslip is zero and the sideslip is only zero while the wings are banked approximately 3 degrees away from the inoperative engine, which is most certainly not the case when the control wheel is centered.
The *actual* $V_{MCA}$ with a centered control wheel is not as low as possible either, which might jeopardize the controllability just after liftoff (Figure in Ref. 2).

2.6.2. Minimum drag and controllability can only be guaranteed and achieved while maintaining a small bank angle away from the inoperative engine, as long as the thrust of the operating engine is high.

2.7. **Initial climb**. The FCTM procedure (see Attachment) for initial climb is as follows:

*..., the initial climb attitude should be immediately adjusted to maintain a minimum of $V_2$ and a positive climb. If an engine fails at an airspeed between $V_2$ and $V_2$ + 25, climb at the airspeed at which the failure occurred. If an engine fails at an airspeed above $V_2$ + 25, increase pitch attitude in order to reduce airspeed to $V_2$ + 25 and maintain airspeed until flap retraction altitude.*

*Retract the landing gear after attaining a positive rate of climb. Hold a minimum of $V_2$ and takeoff flap setting to flap retraction attitude.*

2.7.1. This procedure is again on performance only; controllability was not in the mind of the procedure writer, but is still a factor to consider here too, as might become clear in the next paragraphs. Please also refer to Ref. 2.

2.7.2. The minimum takeoff safety speed $V_{2MIN}$ is, like $V_R$, calculated using $V_{MCA}$, but for $V_{2MIN}$, $V_S$ is also a factor. $V_{2MIN}$ = the higher of 1.1 × $V_{MCA}$ and 1.13 × $V_S$ (FAR /CS 25.107). It is not known what the difference is between $V_2$ and $V_{2MIN}$ for the Boeing 737-200. If the bank angle is not maintained to the same value that was used to determine $V_{MCA}$, then the *actual* $V_{MCA}$ might increase to a value higher than the (pre-flight) calculated $V_2$ after which control might be lost. The increase of actual $V_{MCA}$ above $V_2$ can be considerable, as is illustrated in the Report *Airplane Control after Engine Failure*, see endnote [1]).

2.7.3. Boeing recommends the takeoff speed to be between $V_2$ and $V_2$ + 25 and the control wheel centered, i.e. the ailerons are not deflected. If in this case the wings are level and the thrust setting on the remaining engine is max. takeoff, the *actual* $V_{MCA}$ might be dangerously close to $V_2$.

2.7.4. The reader is reminded of the fact that the vertical tail is sized just big enough to only maintain straight flight, while banking 3 to 5 degrees away from the inoperative engine. The vertical tail was not designed and is not big enough for wings level flight with high asymmetrical thrust settings and airspeeds as low as $V_{MCA}$ in all configurations. The test pilots will have used this same bank angle to determine $V_{MCA}$. This $V_{MCA}$ is used to calculate $V_R$ and $V_2$ (Ref. 2).

*2.8. Obstacle clearance or departure clearance may require a turn shortly after takeoff. Climb performance is slightly reduced while turning but is accounted for in the airport procedure.*

2.8.1. $V_{MCA}$ and therefore also $V_{2MIN}$ are valid only when maintaining straight flight and while banking 3 – 5 degrees (as opted by the manufacturer) away from the inoperative engine. In accordance with FAR 25.107 (c), a $V_2$ has to be selected by the manufacturer to provide a minimum gradient of climb but may not be less than $V_{2MIN}$ and a speed that provides certain maneuvering capabilities (25.143 (g)). The thrust setting required for these maneuver capabilities is as required to produce the minimum required climb gradient and hence, is not necessarily maximum thrust. If however the thrust setting shortly after takeoff is selected maximum, then turning away from the favorable 3 – 5 degree bank angle will still increase the *actual* $V_{MCA}$ to a value that can easily increase above $V_2$, rendering the airplane uncontrollable. Turning at low speed and maximum thrust setting should be avoided. Again, the vertical tail of the airplane is not designed (is not big enough) to maintain control of the airplane if the bank angle is not maintained to the same value that was used during the design for any approved configuration.

2.8.2. Not maintaining straight flight, but turning while the airspeed is $V_{2MIN}$ will not always lead to control problems, because the cg might be forward of the cg that was used to design the tail and to determine $V_{MCA}$, or the thrust is not at the maximum takeoff setting, both of which decrease the *actual* $V_{MCA}$. Nevertheless, $V_{MCA}$ is a predetermined and $V_{2MIN}$ is a preflight calculated minimum speed and are lower speed limits for ensuring the safety for all airplane configurations in case an engine fails. The condition for which these airspeed limits are valid, i.e. a bank angle of a few degrees away from the inoperative engine and hence maintaining straight flight, should therefore be listed with the $V_{MCA}$ and/ or $V_2$ data in the engine failure takeoff and climb procedures. This requirement for safety should be observed at all times and not be violated. Airport procedures for obstacle or departure clearance at low altitude while an engine is inoperative most probably do not take this into account yet; these procedures might only concern the remaining performance and not the controllability of the airplane after engine failure.

2.8.3. If obstacle or departure clearance requires a turn shortly after takeoff, the sideslip increases and the climb performance will reduce. Not maintaining the 'safe' bank angle while the thrust is high increases the *actual* $V_{MCA}$ to a speed that might exceed the indicated airspeed after which control will be lost (Ref. 2).

## 3. Conclusions

3.1. Boeing recommends pilots to wait with control inputs to counter the asymmetrical thrust until after the wings start banking, may be because the airplane systems and cockpit instruments do not detect or show the uncommanded yaw rate into the failing engine at all, or in an inadequate way. Banking however, causes the *actual* $V_{MCA}$ to increase instantaneously after which it might not be possible at all to yaw and roll the airplane back, because the vertical tail is not big enough to achieve this. This might have happened during this accident (Ref. 1).

3.2. The Boeing engine failure procedures for rotation and initial climb after engine failure, as published in the Boeing FCTM, are neither in accordance with the criteria that are normally used to design vertical tails of multi-engine airplanes, nor with the flight test techniques used to determine $V_{MCA}$. The procedure does neither reduce the drag to the minimum possible value for maximizing the climb performance of the airplane, nor provides the safety margin as required by the Regulations between minimum control speed $V_{MCA}$, and the rotation speed $V_R$ as well as the minimum takeoff safety speed ($V_{2MIN}$) for all configurations. $V_{MCA}$, and therewith $V_R$ and $V_{2MIN}$, that were calculated using $V_{MCA}$, apply to straight flight only, while maintaining a small bank angle away from the inoperative engine, not for any other bank angle.

3.3. The Boeing engine failure procedures seem not aimed at maintaining control, but at preventing the spoilers (that assist the ailerons for roll control) to deflect, which can only be achieved by maintaining the control wheel to within seven degrees from the center. However, for maintaining both minimum drag and maximum safety margins (i.e. minimum *actual* $V_{MCA}$), a control wheel deflection in excess of 7 degrees might be required for any given airplane configuration. A centered control wheel might be good for *approximating a minimum drag configuration* (spoilers not deflected), but is in most cases not adequate for maintaining control of the airplane while an engine is inoperative and the power setting is high. The design criteria used for scheduling the deflection of the roll assisting spoilers might have resulted in a controllability problem that might have contributed to the catastrophe with the Algerian Boeing 737.

3.4. The Boeing procedure seems concerning the remaining performance only, not maintaining control following the failure of an engine. The listed procedures and the pilot training and possible indoctrination for using these procedures could have led to inappropriate airplane handling that caused the catastrophic accident.

## 4. Recommendations

4.1. To ensure that control can be maintained following the failure of an engine and while the airspeed is low and engine thrust high, as will be the case just after liftoff, it is of utmost importance to not only *add rudder*, but to deflect the rudder as soon as possible while the thrust decays, as to maintain (runway) heading and add aileron to establish a bank angle of 3 to 5 degrees (as opted by Boeing for designing the vertical tail) away from the inoperative engine. Only then, both the *actual* $V_{MCA}$ and the drag are as low as possible and control can be guaranteed for all airplane configurations. The aileron control wheel, as required for this straight flight equilibrium, will most probably not be centered.

4.2. The FCTM procedure should be changed to be in agreement with the criteria used to design the vertical tail and to determine the minimum control speed: If an engine failure occurs, apply rudder as to maintain heading first and apply aileron to establish and maintain a small bank angle away from the inoperative engine.

4.3. Improve roll control without spoilers, prevent spoiler deflection under asymmetrical thrust and/or delay spoiler deflection to a t.b.d. control wheel deflection, i.e. beyond the deflection required to maintain straight flight after liftoff while banking 3 – 5 degrees away from the failed engine (as opted by Boeing). To prevent the spoilers from deflecting while using the control wheel for regaining control after engine failure, a redesign of the spoiler control system might have to be considered.

4.4. The bank angle used to design the vertical tail and to determine $V_{MCA}$ during flight-testing and to calculate $V_2$ should be listed with the $V_{MCA}$ and $V_2$ data in the Airplane Flight Manual and in the engine failure procedures as a condition for maintaining control while an engine is inoperative. $V_R$ should be calculated with the wings-level $V_{MCA}$, rather than with the standardized $V_{MCA}$.

4.5. Improve yaw rate detection, indication and alerting to enable appropriate directional control as soon as possible after engine failure.

4.6. Final recommendation to Boeing is to have the tail design engineers review the engine failure takeoff emergency procedures to verify whether the assumptions that they made during designing the vertical tail are included appropriately in the flight crew emergency procedures.

4.7. These recommendations and many more are detailed in the report *'Airplane control after engine failure'*, see the endnote below. ■

**Endnote**

[1]) Both the referenced paper (Ref. 2) and the report *Airplane Control after Engine Failure* can be downloaded from the products page of website www.avioconsult.com. This report explains almost all there is to know about $V_{MCA}$ (and $V_2$) and presents many recommendations to improve the safety after engine failure, including recommendations to improve Aviation Regulations (FAR and CS) and engine-out training. A shorter version, the paper *Staying Alive with a Dead Engine*, which was aimed at errors in Airplane Flight Manuals, was presented to the European Aviation Safety Seminar of the Flight Safety Foundation in March 2006.
In addition, a number of analyses of other accidents and of airplane manuals can be downloaded from the website.

**Attachment**

Boeing 737 Flight Crew Training Manual, One Engine Inoperative Procedures.

 

**Attachment**

Page out of the Boeing 737 Flight Crew Training Manual, as copied out of Accident Investigation Report *7t-z030306a* ( Ref. 1).



- (737-200) FLAP 1, 2, 5, 10, 15, OR 25 AND 75,000 LB/34,020 KG TO 128,000 LB/58,060 KG GROSS WEIGHT
- (737-300) FLAP 1, 5, OR 15 AND 95,000 LB/43,092 KG TO 135,000 LB/61,236 KG GROSS WEIGHT
- (737-400) FLAP 5 OR 15 AND 95,000 LB/43,092 KG TO 150,000 LB/68,039 KG GROSS WEIGHT
- BASIC TAKEOFF SPEED SCHEDULE

| | ROTATION TIMES - SECONDS | |
|---|---|---|
| CONDITION | 737-200 | 737-300/400 |
| ALL ENGINES OPERATING | 5 TO 6 | 6 TO 7 |
| ONE ENGINE INOPERATIVE | 6 TO 9 | 8 TO 12 |

TABLE 2-2 TAKEOFF ROTATION TIMES VR TO 35 FEET

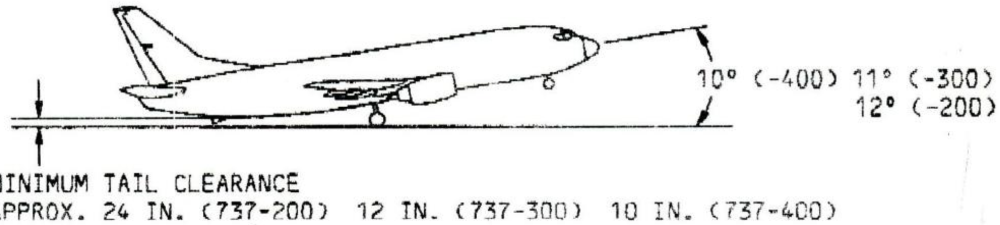


Figure 2-14 LIFTOFF BODY ATTITUDE - ONE ENGINE INOPERATIVE

**Rotation**

If an engine fails between V1 and lift-off, maintain directional control by smoothly applying rudder proportionate with thrust decay to maintain the desired heading or track.

Rotate normally at VR, using the required amount of control column and control wheel if necessary, to hold the wings level.

The rotation should be executed smoothly with one continuous motion. Do not rotate early or rapidly. The rate of rotation should be no faster than for a normal takeoff.

If the engine failure occurs at or after liftoff, apply aileron to momentarily establish wings level. Add rudder to center the control wheel. To center the control wheel, rudder will be required in the direction that the control wheel is displaced. This approximates a minimum drag configuration.

**Initial Climb**

Indicated airspeed and vertical speed are the primary instruments for pitch control after the initial target pitch attitude has been established, consequently, the initial climb attitude should be immediately adjusted to maintain a minimum of V2 and a positive climb. If an engine fails at an airspeed between V2 and V2 + 25, climb at the airspeed at which the failure occurred. If engine failure occurs above V2 + 25, increase pitch attitude in order to reduce airspeed to V2 + 25 and maintain airspeed until flap retraction altitude.

Retract the landing gear after attaining a positive rate of climb. Hold a minimum of V2 and takeoff flap setting to flap retraction altitude.

Obstacle clearance or departure clearance may require a turn shortly after takeoff. Climb performance is slightly reduced while turning but is accounted for in the airport procedure.