Background Information
for the Definition, Theory, Flight Test and Use of the

Minimum Control Speed (V_{MC} or V_{MCA}) of a multi-engine airplane

in US Federal Aviation Regulations and Advisory Circulars,
EASA Certification Specifications, and
USAF Test Pilot School Flying Qualities Textbook

Composed by

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Contents

Use also bookmarks (press Control+B) for table of contents

Introduction

This paper presents some regulatory requirements on engine-out flight, and parts of formal FAA and EASA Flight Test Guides that are to be used by experimental flight test crews to determine the controllability of an engine-out airplane and its $V_{MC(A)}$ as background information to understand the real properties and meaning of $V_{MC(A)}$. It might be of interest to pilots and accident investigators, as still many accidents after engine failure occur (due to the Loss of Control) and accident reports do not conclude on misinterpretation of the Minimum Control Speed in the Air (abbreviated V_{MC} or today more often V_{MCA}) of the airplane that is published in the Airplane Flight Manual.

Regulations require only one $V_{MC(A)}$ to be determined and published in the Airplane Flight Manuals, which is usually the $V_{MC(A)}$ for the takeoff configuration, for straight flight and maximum asymmetrical thrust, because this $V_{MC(A)}$ is used to calculate the takeoff speeds V_R and V_2.

The actual V_{MC} that a pilot will experience in-flight, during climb, cruise, descent and approach, changes with bank angle, thrust level and many more variables that have effect on the lateral and directional equilibrium of forces and moments that act on the engine-out airplane.

Pilots should be made aware that the $V_{MC(A)}$ that is published in their Flight and Training Manuals is for straight flight only when maximum thrust is (to be) set on the remaining engines and a small bank angle of max. 5° is attained away from the inoperative engine(s), if manufacturers used the small bank angle to size the vertical tail and determine $V_{MC(A)}$. The small bank angle decreases both $V_{MC(A)}$ and the sideslip angle. Flight with an inoperative engine is not a coordinated flight, the centripetal force used by pilots to explain turns is not the same as when all engines are operative, because a large sideslip cannot be avoided when banking away from the small favorable bank angle (max. 5°), to either side. When banking more than 5° into the good engine(s), the rudder needs to be reversed to maintain balance of forces and moments. Loss of Control can only be prevented when the airspeed is increased a lot, or the thrust is reduced (temporarily during banking).

Although civil Regulations do not require a V_{MCA2} to be determined and published (anymore), many manufacturers of 4- or more engine airplanes still do. When one engine is inoperative, the V_{MCA} to be observed both in anticipation of a second engine to fail on the same wing and after failure of that engine, is V_{MCA2}. Most graduates of a Test Pilot School do not comprehend why V_{MCA2} does not need to be determined and published, but a Minimum Control Speed with two engines inoperative for approach and Landing (V_{MCL2}) is indeed required. When during an approach less than maximum asymmetrical thrust is required, the actual V_{MCL2} is very low, probably even lower than V_S, but when a go-around becomes necessary and the flaps are selected to takeoff setting or up, V_{MCA2} applies, not V_{MCL2}. Therefore, V_{MCL2} is not required in military regulations, but V_{MCA2} still is.

Not all Regulatory paragraphs pertaining to engine-out flight are included below, but only the paragraphs that require maximum asymmetrical thrust setting – for highest (actual) $V_{MC(A)}$.

For detailed information on most, if not all, aspects of engine-out flight, please refer to the paper *Airplane Control and Analysis of Accidents after Engine Failure,* Download #3 on the Downloads Page of website www.avioconsult.com.

Code of Federal Regulations, Title 14, Part 25 Airworthiness Standards

i.e. the vertical tail may not be that small that V_{MC} exceeds 1.13 V_{SR}.

Is aft cg for shortest rudder moment arm

Should be lowest weight for worst case V_{MC}.

(4) Landing gear (i) retracted and (ii) extended;

(5) Flaps in the most favorable climb position; and

(6) Maximum takeoff weight.

(d) *Lateral control; roll capability.* With the critical engine inoperative, roll response must allow normal maneuvers. Lateral control must be sufficient, at the speeds likely to be used with one engine inoperative, to provide a roll rate necessary for safety without excessive control forces or travel.

(e) *Lateral control; airplanes with four or more engines.* Airplanes with four or more engines must be able to make 20° banked turns, with and against the inoperative engines, from steady flight at a speed equal to 1.3 V_SR1, with maximum continuous power, and with the airplane in the configuration prescribed by paragraph (b) of this section.

(f) *Lateral control; all engines operating.* With the engines operating, roll response must allow normal maneuvers (such as recovery from upsets produced by gusts and the initiation of evasive maneuvers). There must be enough excess lateral control in sideslips (up to sideslip angles that might be required in normal operation), to allow a limited amount of maneuvering and to correct for gusts. Lateral control must be enough at any speed up to V_{FC}/M_{FC} to provide a peak roll rate necessary for safety, without excessive control forces or travel.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25–42, 43 FR 2321, Jan. 16, 1978; Amdt. 25–72, 55 FR 29774, July 20, 1990; Amdt. 25–108, 67 FR 70827, Nov. 26, 2002; Amdt. 25–115, 69 FR 40527, July 2, 2004]

§25.149 Minimum control speed.

(a) In establishing the minimum control speeds required by this section, the method used to simulate critical engine failure must represent the most critical mode of powerplant failure with respect to controllability expected in service.

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

Only one V_{MC} is required, for straight flight while maintaining a small bank angle (for minimum sideslip and lowest V_{MC}.

(c) V_{MC} may not exceed 1.13 V_{SR} with—

(1) Maximum available takeoff power or thrust on the engines;

(2) The most unfavorable center of gravity;

(3) The airplane trimmed for takeoff;

(4) The maximum sea level takeoff weight (or any lesser weight necessary to show V_{MC});

(5) The airplane in the most critical takeoff configuration existing along the flight path after the airplane becomes airborne, except with the landing gear retracted;

(6) The airplane airborne and the ground effect negligible; and

(7) If applicable, the propeller of the inoperative engine—

(i) Windmilling;

(ii) In the most probable position for the specific design of the propeller control; or

(iii) Feathered, if the airplane has an automatic feathering device acceptable for showing compliance with the climb requirements of §25.121.

(d) The rudder forces required to maintain control at V_{MC} may not exceed 150 pounds nor may it be necessary to reduce power or thrust of the operative engines. During recovery, the airplane may not assume any dangerous attitude or require exceptional piloting skill, alertness, or strength to prevent a heading change of more than 20 degrees.

(e) V_{MCG}, the minimum control speed on the ground, is the calibrated airspeed during the takeoff run at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the airplane using the rudder control alone (without the use of nosewheel steering), as limited by 150 pounds of force, and the lateral control to the extent of keeping the wings level to enable the takeoff to be safely continued using normal piloting skill. In the determination of V_{MCG}, assuming that the path of the airplane accelerating with all engines operating is along the centerline of the runway, its path from the point at which the critical engine is made inoperative to the point at which recovery to a direction parallel to the centerline is completed may not deviate more than 30 feet laterally from the centerline at demonstrations should be made rolling the aeroplane in either direction, and the manoeuvres may be unchecked.

Conditions:

(a) En-route: Airspeed. All speeds between the minimum value of the scheduled all-engines-operating climb speed and V_{MO}/M_{MO}.

Wing-flaps. En-route position(s).

Air Brakes. All permitted settings from Retracted to Extended.

Landing Gear. Retracted.

Power. All engines operating at all powers from flight idle up to maximum continuous power.

Trim. The aeroplane should be in trim from straight flight in these conditions, and the trimming controls should not be moved during the manoeuvre.

(b) Approach: Airspeed. Either the speed maintained down to the 15 m (50 ft) height in compliance with CS 25.125(a)(2), or the target threshold speed determined in accordance with CS 25.125(c)(2)(i) as appropriate to the method of landing distance determination used.

Wing-flaps. In each landing position.

Air Brakes. In the maximum permitted extended setting.

Landing Gear. Extended.

Power. All engines operating at the power required to give a gradient of descent of 5·0%.

Trim. The aeroplane should be in trim for straight flight in these conditions, and the trimming controls should not be moved during the manoeuvre.

CS 25.149 Minimum control speed

(See AMC 25.149)

(a) In establishing the minimum control speeds required by this paragraph, the method used to simulate critical engine failure must represent the most critical mode of powerplant failure with respect to controllability expected in service.

(b) V_{MC} is the calibrated airspeed, at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with that engine still inoperative, and maintain straight flight with an angle of bank of not more than 5°.

(c) V_{MC} may not exceed 1·13 V_{SR} with – i.e. the vertical tail may not be that small that V_{MC} exceeds 1.13 V_{SR}.

(1) Maximum available take-off power or thrust on the engines;

(2) The most unfavourable centre of gravity; Is aft cg for shortest rudder moment arm

(3) The aeroplane trimmed for take-off; Should be lowest weight for worst case V_{MC}.

(4) The maximum sea-level take-off weight (or any lesser weight necessary to show V_{MC});

(5) The aeroplane in the most critical take-off configuration existing along the flight path after the aeroplane becomes airborne, except with the landing gear retracted;

Only one V_{MC} is required, for straight flight while maintaining a small bank angle (for minimum sideslip and lowest V_{MC}.

(6) The aeroplane airborne and the ground effect negligible; and

(7) If applicable, the propeller of the inoperative engine –

(i) Windmilling;

(ii) In the most probable position for the specific design of the propeller control; or

(iii) Feathered, if the aeroplane has an automatic feathering device acceptable for showing compliance with the climb requirements of CS 25.121.

(d) The rudder forces required to maintain control at V_{MC} may not exceed 667 N (150 lbf) nor may it be necessary to reduce power or thrust of the operative engines. During recovery, the aeroplane may not assume any dangerous attitude or require exceptional piloting skill, alertness, or strength to prevent a heading change of more than 20°.

(e) V_{MCG}, the minimum control speed on the ground, is the calibrated airspeed during the take-off run at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane using the rudder control alone (without the use of nose-wheel steering), as limited by 667 N of force (150 lbf), and the lateral control to the extent of keeping the wings level to enable the take-off to be safely continued using normal piloting skill. In the determination of V_{MCG}, assuming that the path of the aeroplane accelerating with all engines operating is along the centreline of the runway, its path from the point at which the critical engine is made inoperative to the point at which recovery to a direction parallel to the centreline is completed, may not deviate more than 9.1 m (30 ft) laterally from the centreline at any point. V_{MCG} must be established, with –

(1) The aeroplane in each take-off configuration or, at the option of the applicant, in the most critical take-off configuration;

(2) Maximum available take-off power or thrust on the operating engines;

(3) The most unfavourable centre of gravity;

(4) The aeroplane trimmed for take-off; and

(5) The most unfavourable weight in the range of take-off weights. (See AMC 25.149(e).)

(f) (See AMC 25.149(f)) V_{MCL}, the minimum control speed during approach and landing with all engines operating, is the calibrated airspeed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with that engine still inoperative, and maintain straight flight with an angle of bank of not more than 5°. V^{MCL} must be established with –

(1) The aeroplane in the most critical configuration (or, at the option of the applicant, each configuration) for approach and landing with all engines operating;

(2) The most unfavourable centre of gravity;

(3) The aeroplane trimmed for approach with all engines operating;

(4) The most unfavourable weight, or, at the option of the applicant, as a function of weight;

(5) For propeller aeroplanes, the propeller of the inoperative engine in the position it achieves without pilot action, assuming the engine fails while at the power or thrust necessary to maintain a 3 degree approach path angle; and

(6) Go-around power or thrust setting on the operating engine(s).

(g) (See AMC 25.149(g)) For aeroplanes with three or more engines, V_{MCL-2}, the minimum control speed during approach and landing with one critical engine inoperative, is the calibrated airspeed at which, when a second critical engine is suddenly made inoperative, it is possible to maintain control of the aeroplane with both engines still inoperative, and maintain straight flight with an angle of bank of not more than 5°. V_{MCL-2} must be established with –

(1) The aeroplane in the most critical configuration (or, at the option of the applicant, each configuration) for approach and landing with one critical engine inoperative;

(2) The most unfavourable centre of gravity;

(3) The aeroplane trimmed for approach with one critical engine inoperative;

(4) The most unfavourable weight, or, at the option of the applicant, as a function of weight;

(5) For propeller aeroplanes, the propeller of the more critical engine in the position it achieves without pilot action, assuming the engine fails while at the power or thrust necessary to maintain a 3 degree approach path angle, and the propeller of the other inoperative engine feathered;

(6) The power or thrust on the operating engine(s) necessary to maintain an approach path angle of 3° when one critical engine is inoperative; and

(7) The power or thrust on the operating engine(s) rapidly changed, immediately after the second critical engine is made inoperative, from the power or thrust prescribed in sub-paragraph (g)(6) of this paragraph to –

(i) Minimum power or thrust; and

(ii) Go-around power or thrust setting.

(h) In demonstrations of V_{MCL} and V_{MCL-2} –

(1) The rudder force may not exceed 667 N (150 lbf);

(2) The aeroplane may not exhibit hazardous flight characteristics or require exceptional piloting skill, alertness or strength;

(3) Lateral control must be sufficient to roll the aeroplane, from an initial condition of steady straight flight, through an angle of 20° in the direction necessary to initiate a turn away from the inoperative engine(s), in not more than 5 seconds (see AMC 25.149(h)(3)); and

(4) For propeller aeroplanes, hazardous flight characteristics must not be exhibited due to any propeller position achieved when the engine fails or during any likely subsequent movements of the engine or propeller controls (see AMC 25.149(h)(4)).

AMC 25.149 Minimum control speeds

1 The determination of the minimum control speed, V_{MC}, and the variation of V_{MC} with available thrust, may be made primarily by means of 'static' testing, in which the speed of the aeroplane is slowly reduced, with the thrust asymmetry already established, until the speed is reached at which straight flight can no longer be maintained. A small number of 'dynamic' tests, in which sudden failure of the critical engine is simulated, should be made in order to check that the V_{MC}s determined by the static method are valid.

2 When minimum control speed data are expanded for the determination of minimum control speeds (including V_{MC}, V_{MCG} and V_{MCL}) for all ambient conditions, these speeds should be based

on the maximum values of thrust which can reasonably be expected from a production engine in service.

The minimum control speeds should not be based on specification thrust, since this thrust represents the minimum thrust as guaranteed by the manufacturer, and the resulting speeds would be unconservative for most cases.

AMC 25.149(e) Minimum control speed

During determination of V_{MCG}, engine failure recognition should be provided by:

a. The pilot feeling a distinct change in the directional tracking characteristics of the aeroplane, or

b. The pilot seeing a directional divergence of the aeroplane with respect to the view outside the aeroplane.

AMC 25.149(f) Minimum Control Speed during Approach and Landing (V_{MCL})

(a) CS 25.149(f) is intended to ensure that the aeroplane is safely controllable following an engine failure during an all-engines-operating approach and landing. From a controllability standpoint, the most critical case usually consists of an engine failing after the power or thrust has been increased to perform a go-around from an all-engines-operating approach.

(b) To determine V_{MCL}, the flap and trim settings should be appropriate to the approach and landing configurations, the power or thrust on the operating engine(s) should be set to the go-around power or thrust setting, and compliance with all the V_{MCL} requirements of CS 25.149(f) and (h) must be demonstrated.

(c) At the option of the applicant, a one-engine-inoperative landing minimum control speed, $V_{MCL\ (1\ out)}$, may be determined in the conditions appropriate to an approach and landing with one engine having failed before the start of the approach. In this case, only those configurations recommended for use during an approach and landing with one engine inoperative need be considered. The propeller of the inoperative engine, if applicable, may be feathered throughout.

The resulting value of $V_{MCL\ (1\ out)}$ may be used in determining the recommended procedures and speeds for a one-engine-inoperative approach and landing.

[Amdt 25/26]

AMC 25.149(g) Minimum Control Speed with Two Inoperative Engines during Approach and Landing (V_{MCL-2})

(a) For aeroplanes with three or more engines, V_{MCL-2} is the minimum speed for maintaining safe control during the power or thrust changes that are likely to be made following the failure of a second critical engine during an approach initiated with one engine inoperative.

(b) In accordance with CS 25.149(g)(5) for propeller-driven aeroplanes, the propeller of the engine that is inoperative at the beginning of the approach may be in the feathered position. The propeller of the more critical engine must be in the position it automatically assumes following an engine failure.

§ 25.1505 Maximum operating limit speed.

The maximum operating limit speed (V_{MO}/M_{MO} airspeed or Mach Number, whichever is critical at a particular altitude) is a speed that may not be deliberately exceeded in any regime of flight (climb, cruise, or descent), unless a higher speed is authorized for flight test or pilot training operations. V_{MO}/M_{MO} must be established so that it is not greater than the design cruising speed V_C and so that it is sufficiently below V_D/M_D or $V_{DF}/M_{DF,}$ to make it highly improbable that the latter speeds will be inadvertently exceeded in operations. The speed margin between V_{MO}/M_{MO} and V_D/M_D or $V_{DF}M/_{DF}$ may not be less than that determined under § 25.335(b) or found necessary during the flight tests conducted under § 25.253.

[Amdt. 25–23, 35 FR 5680, Apr. 8, 1970]

§ 25.1507 Maneuvering speed.

The maneuvering speed must be established so that it does not exceed the design maneuvering speed V_A determined under § 25.335(c).

§ 25.1511 Flap extended speed.

The established flap extended speed V_{FE} must be established so that it does not exceed the design flap speed V_F chosen under §§ 25.335(e) and 25.345, for the corresponding flap positions and engine powers.

§ 25.1513 Minimum control speed.

The minimum control speed V_{MC} determined under § 25.149 must be established as an operating limitation.

The bank angle used to determine V_{MC} and hence, for which this V_{MC} is valid should have to be published as well. The difference between V_{MC} with the wings level, and V_{MC} while maintaining 5° of bank away from the failed engine can be between 5 kt for a small twin and 30 kt for a 4-engine transport. Think of effect on takeoff speeds!

§ 25.1515 Landing gear speeds.

(a) The established landing gear operating speed or speeds, $V_{LO,}$ may not exceed the speed at which it is safe both to extend and to retract the landing gear, as determined under § 25.729 or by flight characteristics. If the extension speed is not the same as the retraction speed, the two speeds must be designated as $V_{LO(EXT)}$ and $V_{LO(RET),}$ respectively.

(b) The established landing gear extended speed V_{LE} may not exceed the speed at which it is safe to fly with the landing gear secured in the fully extended position, and that determined under § 25.729.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25–38, 41 FR 55468, Dec. 20, 1976]

§ 25.1516 Other speed limitations.

Any other limitation associated with speed must be established.

[Doc. No. 2000–8511, 66 FR 34024, June 26, 2001]

§ 25.1517 Rough air speed, V_{RA}.

(a) A rough air speed, $V_{RA,}$ for use as the recommended turbulence penetration airspeed, and a rough air Mach number, M_{RA}, for use as the recommended turbulence penetration Mach number, must be established. V_{RA}/M_{RA} must be sufficiently less than V_{MO}/M_{MO} to ensure that likely speed variation during rough air encounters will not cause the overspeed warning to operate too frequently.

(b) At altitudes where V_{MO} is not limited by Mach number, in the absence of a rational investigation substantiating the use of other values, V_{RA} must be less than V_{MO} minus 35 KTAS.

(c) At altitudes where V_{MO} is limited by Mach number, M_{RA} may be chosen to provide an optimum margin between low and high speed buffet boundaries.

[Amdt. 25–141, 79 FR 73469, Dec. 11, 2014, as amended by FAA–2022–1355; Amdt. No. 25–148, 87 FR 75710, Dec. 9, 2022; 88 FR 2813, Jan. 18, 2023]

§ 25.1519 Weight, center of gravity, and weight distribution.

The airplane weight, center of gravity, and weight distribution limitations determined under §§ 25.23 through 25.27 must be established as operating limitations.

§ 25.1521 Powerplant limitations.

(a) *General.* The powerplant limitations prescribed in this section must be established so that they do not exceed the corresponding limits for which the engines or propellers are type certificated and do not exceed the values on which compliance with any other requirement of this part is based.

(b) *Reciprocating engine installations.* Operating limitations relating to the following must be established for reciprocating engine installations:

OPERATING LIMITATIONS

CS 25.1503 Airspeed limitations: general

When airspeed limitations are a function of weight, weight distribution, altitude, or Mach number, limitations corresponding to each critical combination of these factors must be established.

V_{MC} is a function of weight and of weight distribution (cg), when bank angle is not zero.

CS 25.1505 Maximum operating limit speed

The maximum operating limit speed (V_{MO}/M_{MO}, airspeed or Mach number, whichever is critical at a particular altitude) is a speed that may not be deliberately exceeded in any regime of flight (climb, cruise, or descent), unless a higher speed is authorised for flight test or pilot training operations. V_{MO}/M_{MO} must be established so that it is not greater than the design cruising speed V_C and so that it is sufficiently below V_D/M_D or V_{DF}/M_{DF}, to make it highly improbable that the latter speeds will be inadvertently exceeded in operations. The speed margin between V_{MO}/M_{MO} and V_D/M_D or V_{DF}/M_{DF} may not be less than that determined under CS 25.335(b) or found necessary during the flight tests conducted under CS 25.253.

CS 25.1507 Manoeuvring speed

The manoeuvring speed must be established so that it does not exceed the design manoeuvring speed V_A determined under CS 25.335(c).

CS 25.1511 Flap extended speed

The established flap extended speed V_{FE} must be established so that it does not exceed the design flap speed V_F chosen under CS 25.335(e) and 25.345, for the corresponding wing-flap positions and engine powers.

CS 25.1513 Minimum control speed

The minimum control speed V_{MC} determined under CS 25.149 must be established as an operating limitation.

The bank angle for which this V_{MC} is valid should be included. See note previous page.

CS 25.1515 Landing gear speeds

(a) The established landing gear operating speed or speeds, V_{LO}, may not exceed the speed at which it is safe both to extend and to retract the landing gear, as determined under CS 25.729 or by the flight characteristics. If the extension speed is not the same as the retraction speed, the two speeds must be designated as $V_{LO(EXT)}$ and $V_{LO(RET)}$, respectively.

(b) The established landing gear extended speed V_{LE} may not exceed the speed at which it is safe to fly with the landing gear secured in the fully extended position, and that determined under CS 25.729.

CS 25.1516 Other speed limitations

Any other limitation associated with speed must be established.

Preface

List of Effective Pages

Page layout, including identification and approval status

m. Units of measure proposed.

n. Amendment system (e.g. temporary revision identification and normal revision identification).

o. Breakdown of the manual (e.g. topics, sequence, dividers).

p. Performance charts layout.

q. Digital performance data proposal, if applicable.

r. References to other information required by the certification basis but not contained in the basic AFM.

The document presented may include more than the proposed amount of information, if deemed necessary.

CS 25.1583 Operating limitations

(See AMC 25.1583)

(a) *Airspeed limitations.* The following airspeed limitations and any other airspeed limitations necessary for safe operation must be furnished.

V_{MC} required in CS 25.1513.

(1) The maximum operating limit speed V_{MO}/M_{MO} and a statement that this speed limit may not be deliberately exceeded in any regime of flight (climb, cruise, or descent) unless a higher speed is authorised for flight test or pilot training.

(2) If an airspeed limitation is based upon compressibility effects, a statement to this effect and information as to any symptoms, the probable behaviour of the aeroplane, and the recommended recovery procedures.

(3) The manoeuvring speed established under CS 25.1507 and statements, as applicable to the particular design, explaining that:

(i) full application of pitch, roll, or yaw controls should be confined to speeds below the manoeuvring speed; and

(ii) rapid and large alternating control inputs, especially in combination with large changes in pitch, roll, or yaw, and full control inputs in more than one axis at the same time, should be avoided as they may result in structural failures at any speed, including below the manoeuvring speed.

(4) The flap extended speeds V_{FE} and the pertinent wing-flap positions and engine powers.

(5) The landing gear operating speed or speeds, and a statement explaining the speeds as defined in CS 25.1515(a).

(6) The landing gear extended speed V_{LE}, if greater than V_{LO}, and a statement that this is the maximum speed at which the aeroplane can be safely flown with the landing gear extended.

(b) *Powerplant limitations*. The following information must be furnished:

(1) Limitations required by CS 25.1521.

show that the lateral control available is the determining factor of a particular V_{MC}.

5.4.2.5 For changes to approved designs, the effect of any aerodynamic or propulsive changes on compliance with 25.149 must be assessed per § 21.20. For example, for design changes involving an increase in engine thrust, the effect of the higher thrust on minimum control speeds must be specifically evaluated, and, if found to be not negligible, must be accounted for.

5.4.3 Procedures: Minimum Control Speeds—Air (V_{MCA}).

5.4.3.1 In showing compliance with the V_{MCA} requirements, the following two conditions should be satisfied:

5.4.3.1.1 The stabilized (static) condition where constant heading is maintained without exceeding a 5° bank angle, and

5.4.3.1.2 The dynamic condition in which control is maintained without exceeding a heading change of 20°.

Note: Separate tests are usually conducted to show compliance with these two conditions.

5.4.3.2 **Static Test Procedure and Required Data.**

5.4.3.2.1 To determine V_{MCA}, use the configuration specified in § 25.149, except that V_{MCA} is normally determined at minimum weight in order to minimize the stall speed and because static V_{MCA} decreases with increased weight if a 5° bank angle is used. The requirement of § 25.149(c) that V_{MCA} not exceed 1.13 V_{SR} is based on V_{SR} at maximum sea level takeoff weight. With the critical engine inoperative, the corresponding opposite engine should be adjusted to maximum takeoff power/thrust, and the airspeed decreased until heading can just be maintained with full rudder and no more than a 5° bank into the operating engine. For airplanes with more than two engines, the inboard engine(s) may be set to any power or thrust necessary to assist in developing the desired level of asymmetric power or thrust, or to achieve the desired flight path angle (normally level flight).

5.4.3.2.2 If the maximum asymmetric power or thrust that is permitted by the AFM operating limitations was maintained at the test day V_{MCA}, and the rudder pedal force did not exceed the limit specified in § 25.149(d), the resulting speed may be used as the single value of V_{MCA} for the airplane. If, at the option of the applicant, the AFM value of V_{MCA} is to vary with pressure altitude and temperature, the test day minimum control speed and the corresponding power or thrust should be used to calculate an equivalent yawing moment coefficient (C_N). This C_N value may then be used to calculate V_{MCA} as a function of takeoff power or thrust, thus permitting V_{MCA} to be scheduled as a function of pressure altitude and temperature for takeoff data expansion and presentation in the AFM. (See appendix F of this AC for further discussion of V_{MCA} correction.)

5.4.3.2.3 If maximum allowable takeoff power or thrust could not be developed at the flight test conditions, but maximum rudder deflection was achieved, then the V_{MCA} value corresponding to sea level standard day maximum asymmetric power or thrust may be calculated from the C_N attained at the test value of V_{MCA}. Extrapolation using this constant C_N method should be limited to 5 percent of the test day asymmetric power or thrust, and should only be permitted if the rudder pedal force at the test day V_{MCA} was not more than 95 percent of the limit value specified in § 25.149(d). For extrapolation beyond 5 percent power or thrust, a more rigorous analysis, using all the applicable stability and control terms, should be made. (See appendix F of this AC for further discussion of V_{MCA} correction.)

5.4.3.2.4 If V_{MCA} could not be achieved due to stall buffet, or excessive rudder pedal force, a parametric investigation should be undertaken to determine whether V_{MCA} is limited by stall speed, maximum rudder deflection, or maximum allowable rudder pedal force. (See appendix G of this AC.)

5.4.3.3 **Dynamic Test Procedures and Required Data.**

5.4.3.3.1 After the static V_{MCA} tests have been completed, dynamic engine cuts should be evaluated at a series of decreasing airspeeds to show that sudden engine failure at any speed down to the static V_{MCA} value meets the requirements of § 25.149. The dynamic V_{MCA} test is conducted by applying the maximum approved power/thrust to all outboard engines, stabilizing at the test airspeed, and then cutting fuel to the critical engine. The pilot must be able to recover to a straight flight condition (constant heading) with an angle of bank of not more than 5°.

- Without deviating more than 20 degrees from the original heading,
- While maintaining the test airspeed, without reducing power/thrust on the operating engine(s), and
- Without exceeding the rudder pedal force limit of § 25.149(d).

5.4.3.3.2 In accordance with § 25.149(d), the airplane may not assume any dangerous attitude, nor require exceptional piloting skill, alertness, or strength. The maximum bank angle achieved during the tests may exceed 5° provided the airplane characteristics comply with this qualitative requirement. If the dynamic tests result in a V_{MCA} greater than the static value, the increment between the static and dynamic V_{MCA} at the same altitude should be added to the sea level extrapolated value. If the dynamic value is less than the static value, the static V_{MCA} should be used for the AFM data expansion.

5.4.3.3.3 If static V_{MCA} is near stall speed at the minimum practicable test weight, or if the thrust-to-weight ratio (T/W) results in a trimmed pitch attitude of more than 20°, it is not feasible to attempt to accurately define a quantitative value of V_{MCA} using a sudden engine cut because of the dynamics of the rapid pitch down maneuver required, and the hazard associated with a potential spin entry. Additionally, an extreme nose up attitude followed by an engine cut is not representative of an operational takeoff engine failure. Since § 25.107(e)(1)(ii) requires V_R to be not less than 1.05 V_{MCA}, and there is some additional speed increase prior to lift off, a transport airplane is typically never airborne below approximately 1.08 V_{MCA}. Therefore, instead of using the dynamic method to define V_{MCA} for these aircraft with high T/W or stall speed coincident with V_{MCA}, it is more appropriate for a dynamic engine cut to be evaluated only for acceptable controllability, and at a more representative speed. For these airplanes, a dynamic engine cut should be evaluated at an airspeed of either 1.08 V_{SR} or 1.1 V_{MCA} (static), whichever is greater. During the entry to, and recovery from this maneuver, all the requirements of § 25.149(d) must be met.

To consider: If V_{MCA} was determined with 5° of bank, then the actual V_{MCA} with wings-level is much higher, and V_R needs to be higher as well.

5.4.3.3.4 For airplanes with rudder travel-limited V_{MCA} that have increased power or thrust engines installed, with no changes to the airframe's geometric layout or dimensions, it may not be necessary to conduct dynamic V_{MCA} flight testing if the power or thrust has not increased more than 10 percent above the level at which dynamic V_{MCA} had previously been demonstrated. (See appendix F of this AC.)

5.4.4 Procedures: Minimum Control Speed-Ground (V_{MCG})—§ 25.149(e).

5.4.4.1 It must be demonstrated that, when the critical engine is suddenly made inoperative at V_{MCG} during the takeoff ground roll, the airplane is safely controllable if the takeoff is continued. During the demonstration, the airplane must not deviate more than 30 feet (25 feet prior to amendment 25-42) from the pre-engine-cut projected ground track. The critical engine) for ground minimum control speed testing should be determined during the takeoff ground run using techniques similar to these described in paragraph 5.4.2. If there is a significant difference in left and right rudder deflection, the loss of asymmetric propeller disc loading, due to near zero angle-of-attack during the takeoff roll, could result in the critical engine being on the opposite side of the airplane relative to the airborne minimum control speed tests.

5.4.4.2 Work up tests may be conducted by abruptly retarding the critical engine to idle to determine the airplane asymmetric control characteristics and provide data from which an estimate of V_{MCG} can be made. Due to the engine spindown characteristics with the critical engine retarded to idle, the speed will not, in general, be representative of the V_{MCG} speed that would be obtained with a fuel cut. Therefore, the certification tests for

EASA CS 23 & 25 Certification Specifications

For V_{MC} (and other flight tests, CS-25 refers to FAA Advisory Circular (AC) 25-7D, dated 4 May 2018, being the FAA Flight Test Guide for Certification of Transport Category Airplanes.

CS-23 Flight Test Guide presents V_{MC} test guidance for Part 23 airplanes. The explanation in a number of paragraphs applies also to Part 25 V_{MC} Flight Testing, reason why this is included below.

lateral stability for which it is possible for a single failure in the primary lateral control system to disconnect the aileron rudder interconnect, compliance with CS 23.147(c) must be performed for the most critical case. If compliance with the continued safe flight provisions of CS 23.147(c) can only be demonstrated with flap, speed, power and/or procedures, these procedures should be noted in the Aircraft Flight Manual, in the Emergency Section.

i. Altitude. A low altitude and an altitude near the maximum capability of the aeroplane. The high altitude test is to determine controllability with decreased Dutch roll damping.

ii. Weight. Maximum gross weight for all tests except where otherwise described in subparagraph (3) below.

iii. C.G. For conventional configuration paragraph 23.147(a) the most aft c.g. is critical, if the rudder is used to roll the aeroplane. For unconventional configurations the most critical c.g. must be used.

iv. Lateral Imbalance. The maximum lateral imbalance for which certification is requested must be used when flight testing for compliance with Paragraph 147(c).

v. Configuration, Power and Speed. Lateral controllability must be demonstrated with all practicable configurations and speeds. The maximum flaps used to demonstrate an actual or simulated landing need not be the maximum deflection possible.

48 PARAGRAPH 23.149 MINIMUM CONTROL SPEED

for straight flight

a. Background. Paragraph 23.149 requires the minimum control speed to be determined. Paragraph 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. Paragraph 23.1583(a)(2) requires that V_{MC} be furnished as an airspeed limitation in the AFM. These apply only to twin-engine aeroplanes. A different V_{MC} airspeed will normally result from each approved takeoff flap setting. There are variable factors affecting the minimum control speed. Because of this, V_{MC} should represent the highest minimum airspeed normally expected in service. The variable factors affecting V_{MC} testing include:

and for each bank angle.

(1) Engine Power. V_{MC} will increase as power is increased on the operating engine(s). Engine power characteristics should be known and engine power tolerances should be accounted for.

(2) Propeller of the Inoperative Engine. Windmilling propellers result in a higher VMC than if the propeller is feathered. V_{MC} is normally measured with propeller windmilling unless the propeller is automatically feathered or otherwise driven to a minimum drag position (e.g. NTS-System) without requiring pilot action.

(3) Control Position. The value of V_{MC} is directly related to the control surface travel available. Normally, V_{MC} is based on available rudder travel but may, for some aeroplanes, be based on aileron travel. For these reasons, V_{MC} tests should be conducted with rudder and aileron (if applicable) controls set at minimum travel. In addition, rudder and aileron

control cable tensions should be adjusted to the minimum production tolerances. If during V_{MC} tests, control force limits would be exceeded at full deflection, then a lesser deflection should be used so as not to exceed §23.143 force limits.

(4) Weight and C.G. For rudder limited aeroplanes 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 and 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 minimised. Light weight may be necessary for V_{MC} testing, because the stall speed is reduced.

(5) Lateral Loading. The maximum allowable adverse lateral imbalance (fuel, baggage etc.) should be maintained.

b. Explanation

(1) Controllability. The determination of V_{MC} is closely related to the controllability requirements. It is one of the manoeuvres which generally requires maximum rudder and/or maximum aileron deflection (unless limited by temporary control forces) to maintain aeroplane control. When minimum control speed is determined using maximum rudder deflection, limited aeroplane manoeuvring is still available using the ailerons and elevator. When minimum control speed is determined using maximum aileron deflection, the aeroplane may be incapable of further manoeuvring in the normal sense.

(2) Critical Engine. The regulation 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 VMC speed. This is normally accomplished during static V_{MC} tests.

(3) Straight Flight. Straight flight is maintaining a constant heading. Paragraph 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, with up to 5° of bank toward the operating engine. Normally, 2– 3° of bank allows the aeroplane to attain zero sideslip ~~so that at 5° bank, the beneficial effects of directional stability to counter the yaw produced by asymmetric thrust can be utilised.~~

for the published V_{MCA} to be valid

because the rudder side force to counteract asym. thrust is counteracted by side force W.sin ϕ in the cg. See note p. 8.

(4) Control Forces. The rudder and aileron control force limits may not exceed those specified in 23.143.

(5) Deicer Boots, Antennas and other External Equipment. The installation of deicer boots, antennas, and other external gear could change the V_{MC} speed significantly. Re-evaluation of the V_{MC} speed should be considered when these installations are made. See AC 23.1419–2 if a 'flight into icing' approval is being sought.

(6) Variable V_{MC}. For reciprocating engine-powered aeroplanes of more than 2 722 kg (6 000 lb) maximum weight and for turbine-engine powered aeroplanes, a V_{MC} which varies with altitude and temperature is a permissible condition for use in determining 23.51 takeoff speeds, provided that the AFM does not show a VR below the red radial line speed required by 23.1545(b)(6).

(7) Autofeather Annunciations. If autofeather is installed, there should be annunciations to advise of the status. This will include at least green advisory anytime the system is armed. For some aeroplanes, the autofeather system will be identified as a critical system. This

could be because V_{MC} has been determined with an operative autofeather system or because commuter category takeoff conditions were predicated on an operative autofeather system. For such installations, additional annunciations may be necessary to ensure that the system is armed and that malfunctions are immediately recognised. This could include caution/warning/advisory annunciations as follows:

(i) Caution or warning, if autofeather switch is not armed.

(ii) Caution or advisory if the autofeather is armed, then is subsequently disarmed because of a system malfunction.

All annunciations should be evaluated to verify that they can be easily and quickly recognised. For critical systems, the AFM limitations should require a satisfactory preflight check and that the autofeather be armed for takeoff and landing.

c. Procedures

(1) Configuration. Prior to conducting V_{MC} tests, rudder and aileron control travels should be set to the minimum allowable production travels. Rudder and aileron control cable tensions should be adjusted to the minimum value for use in service. The critical loading for V_{MC} testing is generally minimum weight and maximum aft c.g.; however, each aeroplane design should be evaluated independently to be assured that tests are conducted under the critical loading conditions. Variable aft c.g. limits as a function of weight, tip tanks, etc., can cause the critical loading condition to vary from one aeroplane to another.

(2) Power. An aeroplane with a sea-level engine will normally not be able to produce rated takeoff power at the higher test altitudes. Under these circumstances, VMC should be determined at several power settings and a plot of VMC versus power will allow extrapolation to determine VMC at maximum takeoff power. See sub-paragraph c(6) for a further explanation of extrapolation methods. If tests are conducted at less than approximately 914 m (3 000 ft) density altitude, no corrections to V_{MC} are normally necessary. If tests are conducted above 914 m (3 000 ft) density altitude, then additional tests should be conducted to allow extrapolation to sea level thrust. Because propeller thrust decreases with increasing true airspeed, VMC will increase with decreasing altitude and temperature, even at constant power.

The results of testing are used to predict the VMC for a maximum takeoff power condition at sea level unless, because of turbocharging or other reasons, some higher altitude prevails as the overall highest V_{MC} value.

(3) Propeller Controls. All propeller controls have to stay in the recommended takeoff or approach position as appropriate throughout the whole procedure.

(4) Flap Settings. An applicant may want to specify more than one takeoff or landing flap setting as appropriate which would require V_{MC} investigation at each flap setting. Incl. flaps up?

(5) Stalls. Extreme caution should be exercised during V_{MC} determination due to the necessity of operating with asymmetric power, full rudder and aileron at speeds near the aerodynamic stall. In the event of inadvertent entry into a stall, the pilot should immediately reduce the pitch attitude, reduce power on the operating engine(s) and return rudder and aileron controls to neutral to preclude possible entry into a spin.

(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} manoeuvre by conducting static tests with

first one then the other engine inoperative to discover which produces the higher V_{MC}. Power should be set to the maximum available for the ambient condition. Test weights should be light enough to identify the limits of directional control without stalling or being in prestall buffet.

For each test altitude condition, the following should be accomplished:

(i) Flaps and Gear. For the Take-off conditions, the gear should be retracted and the flaps in the Takeoff position(s). For the landing conditions the gear should be extended and the flaps in the landing position(s).

(ii) Trim. The aeroplane should be trimmed to the settings associated with normal symmetrical power takeoff or approach as appropriate with all engines operating, as indicated.

(iii) Power. Render the one engine inoperative and set take-off power on the other engine. The propeller on the inoperative engine should be windmilling, or in the condition resulting from the availability of automatic feathering or other devices.

(iv) Test Techniques. Gradually reduce airspeed until it is no longer possible to prevent heading changes with maximum use of the directional and/or maximum use of the lateral controls, or the limit control forces have been reached. No changes in lateral or directional trim should be accomplished during the speed reduction. Usually the 5° bank option will be used (see paragraph 48b(3)) to maintain straight flight. A yaw string may be used to assist the test pilot in attaining zero sideslip (or minimum sideslip).

If this option is used, the actual V_{MCA} when the wings are kept level will be higher, 5 - 30 kt depending on type of airplane. So pilots need to know what bank angle was used.

(v) Critical Engine. Repeat steps (i) through (iv) to identify which inoperative engine results in the highest minimum control speed.

(7) Extrapolation to Sea Level. The only VMC test data that can be extrapolated reliably are static V_{MC} data, where most of the variables can be carefully controlled to a constant value. Because V_{MC} data are typically collected in ambient conditions less critical than sea level standard day, extrapolation is nearly always necessary. Therefore, the usual way to establish an AFM V_{MC} is to extrapolate static V_{MC} data. When V_{MC} is determined for an aeroplane with an automatically feathered propeller, special techniques may be required. Appendix 3 shows one method for extrapolating static V_{MC} from test conditions to sea level standard day.

(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 cut-off 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 aeroplane and maintain straight flight without reducing power on the operating engine. During recovery, the aeroplane should not assume any dangerous attitude nor should the heading change more than 20° when a pilot responds to the critical engine failure with normal skill, strength, and alertness. The climb angle with all engines operating is high, and continued control following an engine failure involves the ability to lower the nose quickly and sufficiently to regain the initial stabilised speed. The dynamic V_{MC} demonstration will normally serve as verification that the numbers obtained statically are valid. If, in fact, the dynamic case is more critical, then the extrapolated static V_{MC} value should be increased by that increment. Frequently, the dynamic V_{MC} demonstration will indicate a lower V_{MC} than is obtained from static runs. This may be due to the fact that the inoperative engine, during spooldown, may provide net thrust or

that control force peaks exceed limit values for a short period and go undetected or that due to high yaw and pitch angles and rates, the indicated airspeed values are erroneous. Because of the twin-variable nature of the dynamic V_{MC} demonstration, the AFM V_{MC} value should represent the highest of the static or dynamic V_{MC} test data, corrected to critical conditions. Specially in test conditions with a high thrust/weight ratio, a modified procedure may be applied to avoid extreme pitch attitudes. In this case decelerate to below V_{MC}, all engines, accelerate with 2 x MTOP to a representative climb pitch attitude, cut the critical engine at static V_{MC} (verify before that V_{MC} is acceptably above actual stall speed).

(9) Repeatability. Once determined, and if the dynamic V_{MC} seems to be the critical one, the dynamic V_{MC} should be verified by running a series of tests to determine the speed is repeatable.

(10) AFM Minimum Control Speed Value. V_{MC} is usually observed at several different power settings and/or altitudes. Sufficient test data should be obtained such that the V_{MC} for the highest power and sea level density conditions may be determined. The V_{MC} resulting from this extrapolation to sea level is the one entered into the AFM and marked on the airspeed indicator. If this V_{MC} is determined with an autofeather system, the AFM required equipment list, as well as the Kind of Operation List (KOEL), should list autofeather as a required item and the AFM may state the V_{MC} with the autofeather system inoperative (propeller windmilling) in the abnormal/emergency procedures section. The normal procedures section should also require the autofeather to be armed (if applicable) during takeoff and landing. ?

The bank angle for which this V_{MC} is valid should be stated as well.

(d) Safe, Intentional, One-engine-Inoperative Speed, VSSE (RESERVED).

49 PARAGRAPH 23.151 AEROBATIC MANOEUVRES

a. Explanation. This regulation requires each manoeuvre to be evaluated and safe entry speeds established. Paragraph 23.1567(c), which is associated with this requirement, imposes a requirement for a placard which gives entry airspeeds and approved manoeuvres. If inverted flight is prohibited, the placard should so state.

b. Procedures. The applicant should fly each manoeuvre for which approval is sought. The Agency test pilot should then evaluate those manoeuvres considered most critical.

c. Data Acquisition. A recently calibrated airspeed system, airspeed indicator, accelerometer, and tachometer should be provided by the applicant for the test aeroplane. The following should be recorded:

(1) Load factor.

(2) Entry airspeeds.

(3) Maximum airspeeds.

(4) Maximum r.p.m.

50 PARAGRAPH 23.153 CONTROL DURING LANDINGS

a. Explanation

(1) Purpose. The purpose of this requirement is to ensure that aeroplanes do not encounter excessive control forces when approaching at a speed of 9.3 km/h (5 knots) lower than normal landing approach speed, also, a safe landing is required. Safe is considered to

FIGURE 11.8 LOW DECISION SPEED

11.2.3 Climb Performance

What about the initial climb segment after becoming airborne? The period between lift-off and attaining best engine-out climb speed can be very critical. Major air commands normally specify a minimum authorized rate of climb between 200 and 500 feet per minute for engine-out operations. The level of performance allows little margin for mismanagement of attitude or configuration. Flap retraction should be incremental on a very tight speed schedule to keep sufficient lift for a positive climb gradient without excessive drag. Unexpected characteristics may be encountered in this phase. For example, the additional drag due to opening doors might make it desirable to delay gear retraction until late in the cleanup phase. In another instance, the time available to obtain the clean configuration might be limited by the supply of water injection fluid if dry thrust is insufficient to maintain the climb. Careful flight test exploration of this phase is an obvious requirement.

11.3 THE CONTROL PROBLEM

To maintain control of an aircraft after an engine failure the flight controls must be used to balance the asymmetric moments generated by the operating engine. An aircraft's flight controls should be effective in balancing the inoperative engine throughout its normal operating envelope. Limits may be placed on the aircraft's envelope in the air or on the ground, and caused by a loss of either directional or lateral control. The control problem is evaluated in a steady state and in a dynamic case. The dynamic case is just an extension of the steady state case due to rates and accelerations incurred during pilot reaction time. It will generally dictate the larger control inputs than the steady state case.

Figure 11.9 shows the typical forces and moments during an engine out.

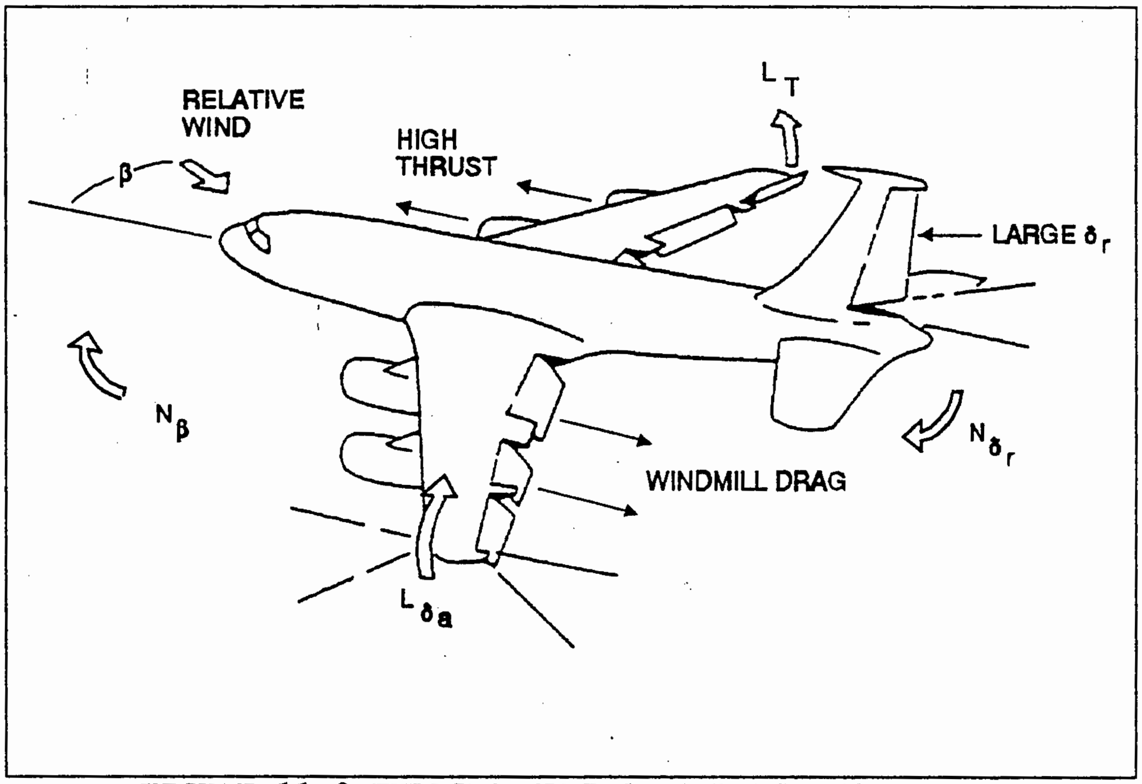

FIGURE 11.9 TYPICAL YAWING MOMENTS ENGINE OUT

Notice that the moment created by asymmetric thrust is opposed by a rudder moment and that the rudder force is opposed by the side force generated by the side slip angle at equilibrium. The yawing moment due to the failed engine is a function of basic engine parameters, temperature and pressure altitude. The other forces and moments are a function of airspeed and bank angle.

11.3.1 Steady State Equations of Motion

The Equations of Motion (EOM) are the starting point for examination of the asymmetric thrust condition. The longitudinal axis not vital when examining engine out control problems. The longitudinal equations are balanced by the usual techniques for stabilized flight. The lateral-directional EOM are of most interest in achieving equilibrium during engine out conditions. From Chapter 4, the lateral-directional EOM for a wings level steady state condition are:

$$\text{"YAWING MOMENT"} \quad N_\beta\beta-\frac{I_{xz}}{I_z}\ddot{\phi}-N_p\dot{\phi}+\dot{r}-N_r r=N_{\delta_a}\delta_\alpha+N_{\delta_r}\delta_r \tag{4.153}$$

$$\text{"SIDE FORCE"} \quad \dot{\beta}-Y_\beta\beta-Y_p\dot{\phi}-Y_\phi\phi+(1-Y_r)\,r=Y_{\delta_a}\delta_\alpha+Y_{\delta_r}\delta_r \tag{4.151}$$

$$\text{"ROLLING MOMENT"} \quad L_\beta\beta+\ddot{\phi}-L_p\dot{\phi}-\frac{Ixz}{Ix}\dot{r}-L_r r=L_{\delta_a}\delta_\alpha+L_{\delta_r}\delta_r \tag{4.152}$$

The term N_T, yawing moment due to asymmetric thrust is introduced. Also the term Y_ϕ ϕ is translated to W sin ϕ, a sideforce from the lateral component of the weight vector due to bank angle. We make the following assumptions to simplify these equations for our investigation:

1. Torque and gyroscopic effects due to rotating engines or propellers are neglected.
2. Sideforce due to aileron deflection, δ_a is neglected.
3. The restriction of steady, unaccelerated flight with all rates equal to zero is imposed.

The three lateral-directional force and moment equations can be now be written as:

$$\text{"YAWING MOMENT"} \quad N_T+N_{\delta_a}\delta_a+N_{\delta_r}\delta_r+N_\beta\beta=0 \tag{11.1}$$

$$\text{"SIDE FORCE"} \quad Y_{\delta_r}\delta_r+Y_\beta\beta + W\sin\phi=0 \tag{11.2}$$

$$\text{"ROLLING MOMENT"} \quad L_{\delta_a}\delta_a+L_{\delta_r}\delta_r+L_\beta\beta=0 \tag{11.3}$$

The yawing moment equation and sideforce equation (11.1 and 11.2) are the primary balancing equations for directional control with an engine inoperative. They are balanced with combinations of yaw control deflection (δ_r), sideslip (β) and bank angle (ϕ). The roll equation (11.3), is balanced by roll control deflection (δ_a). Though usually not critical, roll control power could limit lateral controllability.

The lateral-directional equations with asymmetric thrust suggest there are four variables δ_r, δ_a, ϕ, β, and only three equations. A common way out of this dilemma is to fix one variable and solve for the other three. We will use this technique to investigate the affects of bank angle on equilibrium.

Refer to the Paper *Effect of Bank Angle and Weight on V_{MCA}*. Download #6 on the Downloads Page of website https://www.avioconsult.com. Graphs of V_{MCA} and V_{MCA2} and the control inputs δ_r, δ_a, and the resulting sideslip β are calculated for bank angles between - 15° and + 15° for a sample 4-engine airplane.

11.3.2 Effects of Bank Angle on Equilibrium

To see the effects of bank angle on equilibrium, three cases are of particular interest:

Case 1: $\phi = 0$

Case 2: $\beta = 0$

Case 3: $F_r = 0$

<u>Case 1</u>: $\phi = 0$

Figure 11.10 shows the forces and moments for Case 1, the zero bank angle case, with the left engine inoperative. The aircraft is in equilibrium with no accelerations. The pilot would note this with constant heading, ball centered, turn needle centered, rudder opposing the inoperative engine and aileron opposite the rudder to keep the wings level.

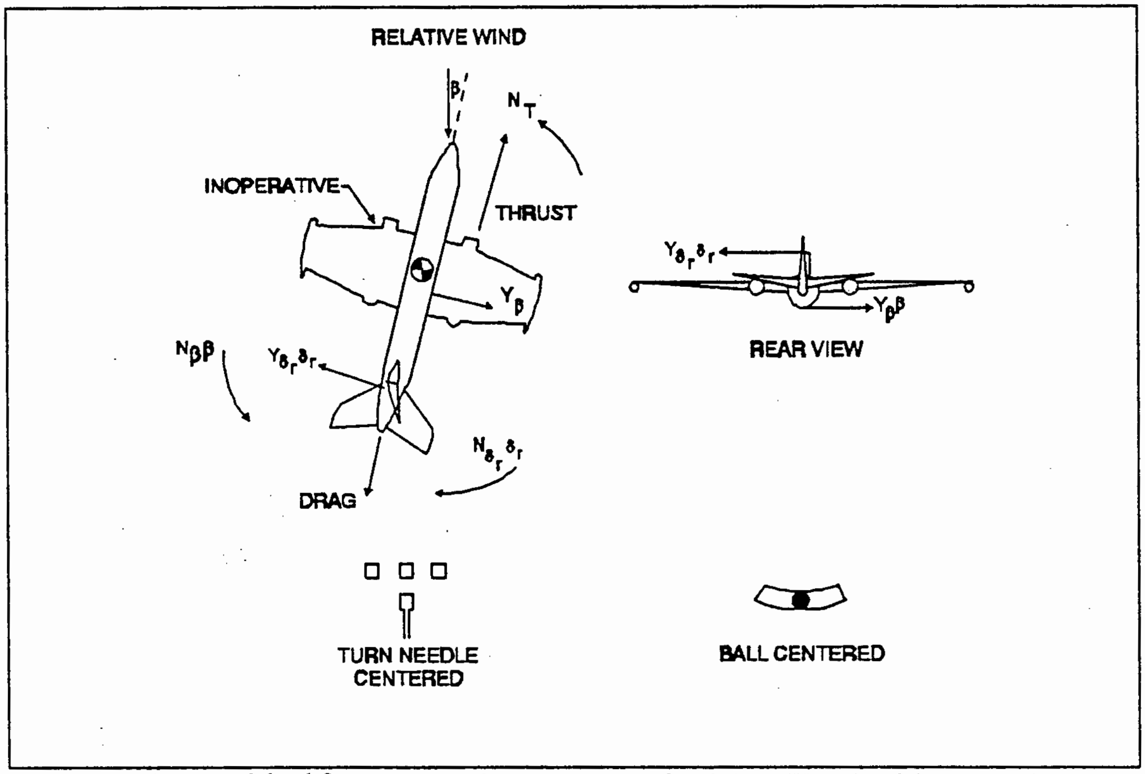

FIGURE 11.10 EQUILIBRIUM FLIGHT WITH WINGS LEVEL

The negative yawing moment generated by the failed engine will be balanced by a positive rudder deflection. The rudder deflection causes a negative sideforce that is balanced by the sideforce due to sideslip. For the zero bank angle case, the yawing and sideforce equations become:

$$N_T + N_{\delta_a}\delta_a + N_{\delta_r}\delta_r + N_\beta \beta = 0 \qquad (11.4)$$

$$Y_{\delta_r}\delta_r + Y_\beta \beta = 0 \qquad (11.5)$$

These equations can be solved simultaneously to determine the control deflections and sideslip required for balanced equilibrium flight. Assuming δ_a produces very little yawing moment:

$$\delta_r = \frac{N_T + N_\beta \beta}{N_{\delta_r}} \qquad (11.6)$$

$$\beta = \frac{N_T Y_{\delta_r}}{N_{\delta_r} Y_\beta - N_\beta Y_{\delta_r}} \qquad (11.7)$$

When the appropriate numbers are substituted for derivatives, for a failed left engine (a negative N_T) β will be negative.

Case 2: $\beta = 0$

Another way to balance the sideforce resulting from rudder deflection is by using the W sin ϕ term in the sideforce equation (11.3). Figure 11.11 shows the forces and moments for the zero sideslip case.

The aircraft is in equilibrium with some bank toward the operating engine, a constant heading and the turn needle centered. The rudder deflection is in the same direction as in the Case 1, however, less δ_r is required. The ball in the turn and slip indicator will be deflected in the direction of the bank angle.

With sideslip equal to zero, the yaw and sideforce equations become:

$$N_T + N_{\delta_r}\delta_r = 0 \qquad (11.8)$$

Regulations allow max. rudder, or a max. control force to determine V_{MC}, so when using a small bank angle, the airspeed can be further reduced until the rudder is again max. The resulting V_{MC} is lower. But you need to tell the pilot, because V_{MC} is used to calculate takeoff speeds, for which the wings are usually kept level, and hence, the actual V_{MC} is higher.

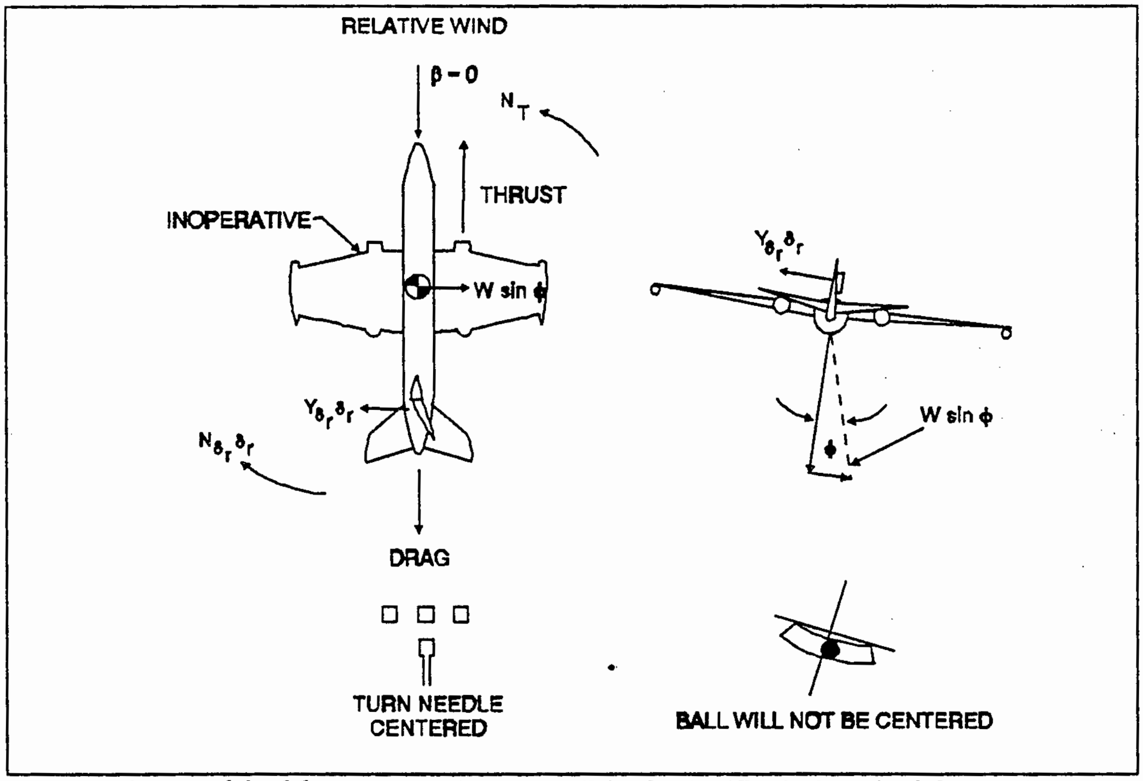

FIGURE 11.11 EQUILIBRIUM FLIGHT WITH ZERO SIDESLIP

$$Y_{\delta_r}\delta_r + W\sin\phi = 0 \tag{11.9}$$

These equations can be solved to determine the amount of bank required to reduce the sideslip to zero:

$$\delta_r = -\frac{N_T}{N_{\delta_r}} \tag{11.10}$$

and

$$W\sin\phi = \frac{Y_{\delta_r}N_T}{N_{\delta_r}} \tag{11.11}$$

therefore:

$$\sin\phi = \frac{Y_{\delta_r} N_T}{W\, N_{\delta_r}} \tag{11.12}$$

Three important conclusions can be made from the previous discussion. First, bank angle can reduce the amount of rudder required to achieve equilibrium. Second, an increase in weight reduces the amount of bank required to reduce the sideslip to zero. Third, this configuration will have the least amount of drag. With $\beta = 0$, no sideforce is generated, and therefore no drag due to sideforce is created. Remaining climb performance is max.

Case 3: $F_r = 0$

The last case to be examined is with zero rudder force. With a irreversible flight control system, δ_r will also be zero. With a reversible system , some rudder deflection will result because of sideslip being produced, however for the purposes of our discussion δ_r will be considered equal to zero.

Figure 11.12 shows the forces and moments for Case 3. The aircraft is in equilibrium with rudder force equal to zero, constant heading, turn needle centered. The bank angle required to achieve this steady state condition is considerable more than required in Case 2. Also note the ball in the turn and slip will be deflected slightly more in the direction of the bank.

With rudder force and δ_r equal to zero, the yaw and sideforce equations become:

$$N_T + N_\beta \beta = 0 \tag{11.13}$$

This also means that when banking more than 5° into the good engines, the rudder requirement reverses for maintaining equilibrium flight. See the paper mentioned on pdf page 21.

$$Y_\beta \beta + W\sin\phi = 0 \tag{11.14}$$

These equations can be solved to determine the amount of bank required to achieve equilibrium with $F_r = 0$.

$$\beta = -\frac{N_T}{N_\beta} \tag{11.15}$$

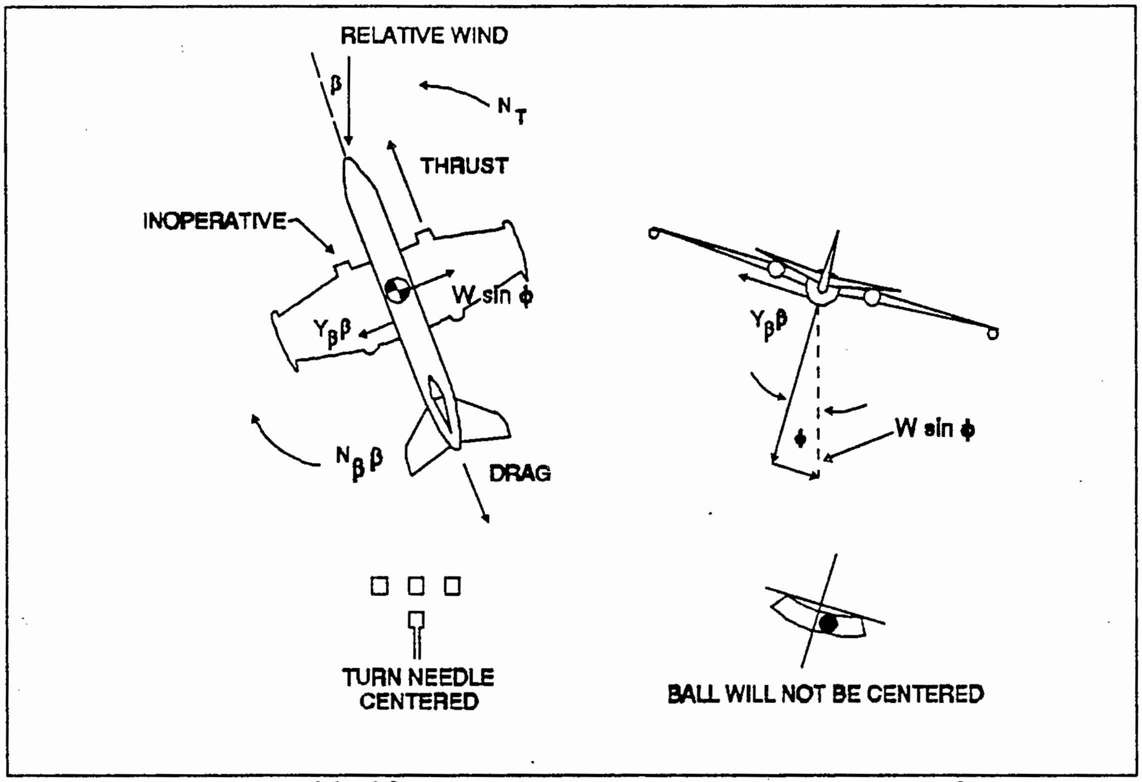

FIGURE 11.12 EQUILIBRIUM FLIGHT WITH F_r=0

$$\sin \phi = \frac{Y_\beta \, N_r}{W \, N_\beta} \tag{11.16}$$

This applies when banking for a turn at max. asymmetrical thrust. A rudder reversal by the pilot will be required. When banking into the dead engine(s) no reversal is required.

From the above equations it can be seen that for a failed left engine (negative N_T) β must be positive to balance the equation. The amount of sideslip developed in this case is considerably more than in Case 1 (φ = 0). Also to balance the sideforce equation the bank angle must be positive. The amount of bank required to achieve F_r = 0 is also more than required to achieve β = 0. Given these two points, it should be recognized that this is the highest drag condition of the three cases discussed. Another thing to consider is the possibility of fin stall and loss of directional control due to the high sideslip and bank angles produced during this case.

It is important to note that for any asymmetric thrust condition there are numerous combinations of rudder deflection and bank angle that will balance the equations of motion. However, for a given bank angle there is only one rudder deflection that will result in equilibrium (steady state) flight.

Such as during a turn

11.3.3 Air Minimum Control Speed (V_{mca})

MIL-STD-1797A borrows this definition of air minimum control speed from FAR part 25:

"The calibrated airspeed, at which, when the critical engine is suddenly made inoperative, it is possible to recover control of the airplane with that engine still inoperative, and maintain straight flight with zero yaw, or at the option of the applicant, with an angle of bank of not more than five degrees".

Note that "recover" and "maintain" are used in the definition of air minimum control speed referring to a dynamic and static case. For a given set of asymmetric thrust conditions, V_{mca} is the speed below which aerodynamic controls are insufficient to maintain equilibrium. Figure 11.13 is a typical plot that shows the yawing moments due to asymmetric thrust and maximum rudder deflection as a function of airspeed.

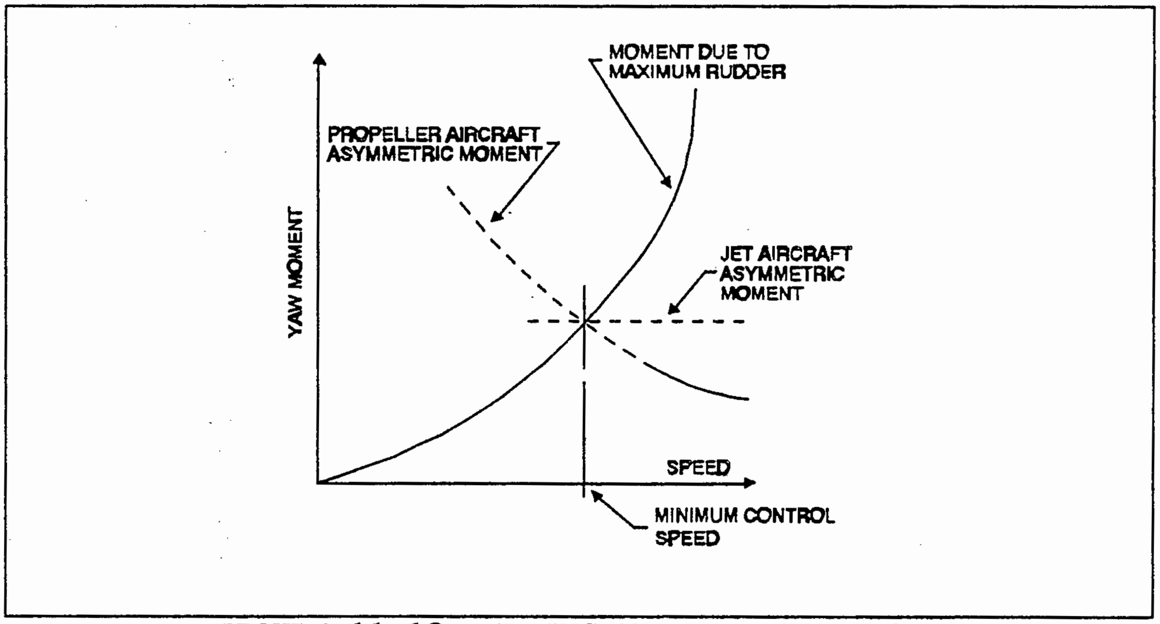

FIGURE 11.13 YAWING MOMENTS IN-FLIGHT

11.3.3.1 Critical Engine

The critical engine for a jet aircraft is most always an outboard engine. The only exception might be when the failure of an inboard engine also fails the sole hydraulic boost to a rudder system. In addition, for propeller driven aircraft the critical engine is defined by the direction of propeller rotation. "P-Factor" is the unequal thrust distance from centerline due to rotation. For clockwise rotating propellers the most critical engine would be the left outboard.

11.3.3.2 Aircraft Design

The aircraft's design dictates whether the air minimum control speed will be defined by loss of directional control or lateral control. Directional controllability is the normal concern of aircraft with conventional airfoil and engine configurations such as the KC-10 or C-141. These aircraft reach a limit to directional control (yaw control power) with adequate lateral control remaining.

Lateral controllability is more of a concern in an aircraft with a blown wing or powered lift such as the C-130 or the C-17. Loss of an engine on these aircraft directly affects the lift generated by that wing. Large asymmetric rolling moments caused by an inoperative engine can lead to loss of lateral control (insufficient roll control power) at airspeeds significantly higher than normal approach speed.

The effects of bank angle in determining the lowest possible air minimum control speed also differ between these designs. The following paragraphs contrast the controls and bank required for the lowest air minimum control speed.

11.3.3.3 Directional Control Limits

The air minimum control speed for an aircraft which is limited by yaw power is achieved by maximum useable rudder deflection and bank into the operative engine(s). Assume that airspeed is allowed to decrease below the minimum control speed for the wings level configuration in Figure 11.14.

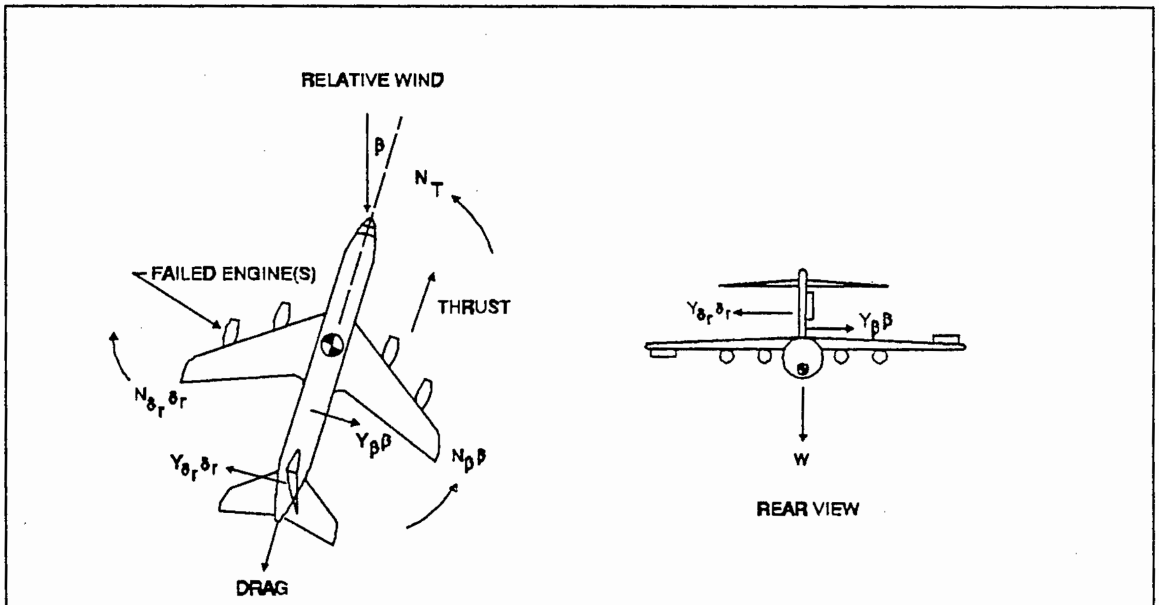

FIGURE 11.14 DIRECTIONAL MINIMUM CONTROL SPEED WINGS LEVEL

With the left engine failed as shown, the aircraft will now begin to yaw left since no additional rudder power is available to balance the yawing moment generated by the operative engines. Recalling Case 2 ($\beta = 0$), equilibrium is regained by using the banked component of weight to reduce the sideslip. This reduces the moment due to sideslip and therefore allows the reduced rudder yawing moment to reestablish equilibrium. Minimum directional control speed is defined when the bank angle reaches 5 degrees into the good engines. This normally results in a small sideslip into the good engines as shown in Figure 11.15.

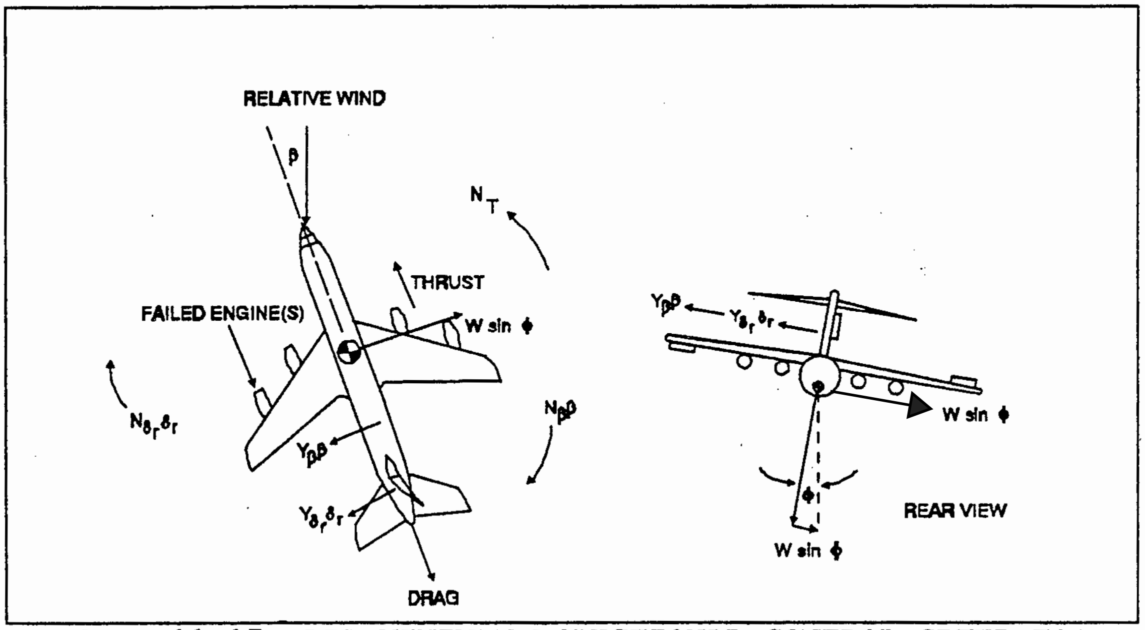

FIGURE 11.15 AIR MINIMUM DIRECTIONAL CONTROL SPEED FOR WINGS BANKED 5 DEGREES

11.3.3.4 Lateral Control Limits

The air minimum control speed for an aircraft which is limited by roll power is achieved by maximum useable lateral control deflection and bank into the inoperative engine(s). The situation for lateral minimum control speed is illustrated in Figure 11.16. This situation is the same as illustrated in Figure 11.14 for the directional control speed case except that now, minimum control speed is defined when the maximum allowable lateral control deflection is reached. The propulsive rolling moment, L_T shown in Figure 11.16 is that generated by propulsive lift and must be balanced by the lateral control deflection and also the rolling moment due to sideslip.

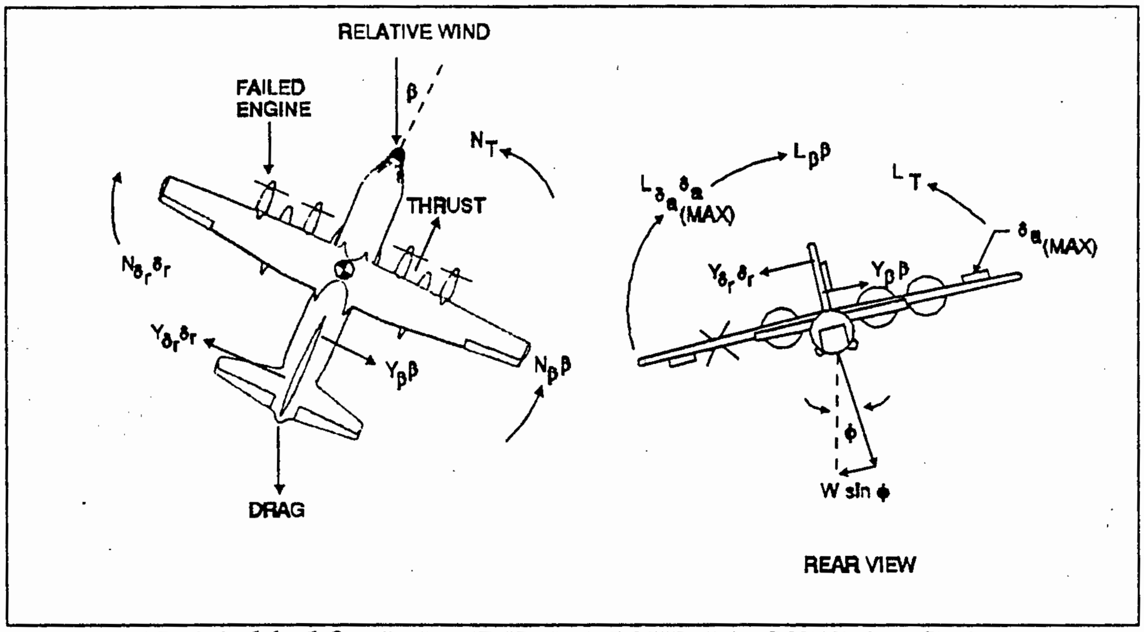

FIGURE 11.16 AIR MINIMUM LATERAL CONTROL SPEED

Assume that airspeed is allowed to decrease below the minimum lateral control speed for the wings-level configuration and that additional rudder power is available. With the left engine(s) failed as shown, the aircraft will now begin to roll left since no more lateral control is allowable to balance the propulsive rolling moment. The aircraft will begin to roll and yaw left. As right rudder is added to stop the yaw, sideslip will increase into the inoperative engine(s). The additional rolling moment due to sideslip, L_β acts to bring the aircraft back into lateral equilibrium. Minimum lateral control speed is defined when the bank angle reaches 5 degrees away from the good engines. This normally results in a strong sideslip into the bad engines as shown in Figure 11.16.

11.3.3.5 Factors Affecting Air Minimum Control Speed

We have previously discussed the effects of bank angle on V_{mca}. This speed will also vary based on weight, altitude, the number of asymmetric engines inoperative, and maximum useable control deflection. Decreasing the aircraft's weight has the same affect as decreasing the bank angle. W sin ϕ, the banked component of weight is less effective in reducing the sideslip. The moment due to sideslip increases and a higher airspeed is required for the rudder yawing moment to maintain equilibrium. As aircraft weight goes down, V_{mca} airspeed goes up.

Decreasing altitude increases the thrust available on the operating engines, increasing the yawing moment to be overcome. As aircraft altitude goes down, V_{mca} airspeed goes up.

Similarly, the loss of a second asymmetric engine on a four engine transport will increase the yawing moment to overcome by rudder. As the thrust asymmetry goes up, V_{mca} airspeed goes up.

Rudder pedal or aileron force limits (rudder or aileron hinge moment limits on irreversible flight control systems) might limit the useable control deflection that can be used to balance the yawing or lateral moment. As usable control deflection goes down, V_{mca} airspeed goes up. Also applies when pilot did not properly adjust his seat and/or pedals.

Figure 11.17 depicts a typical aircraft V_{mca} chart. It shows for a given bank angle and altitude, V_{mca} is a function of the engine thrust moment and gross weight. Note the area of the chart where V_{mca} is not applicable and the aircraft is controllable to stall speed.

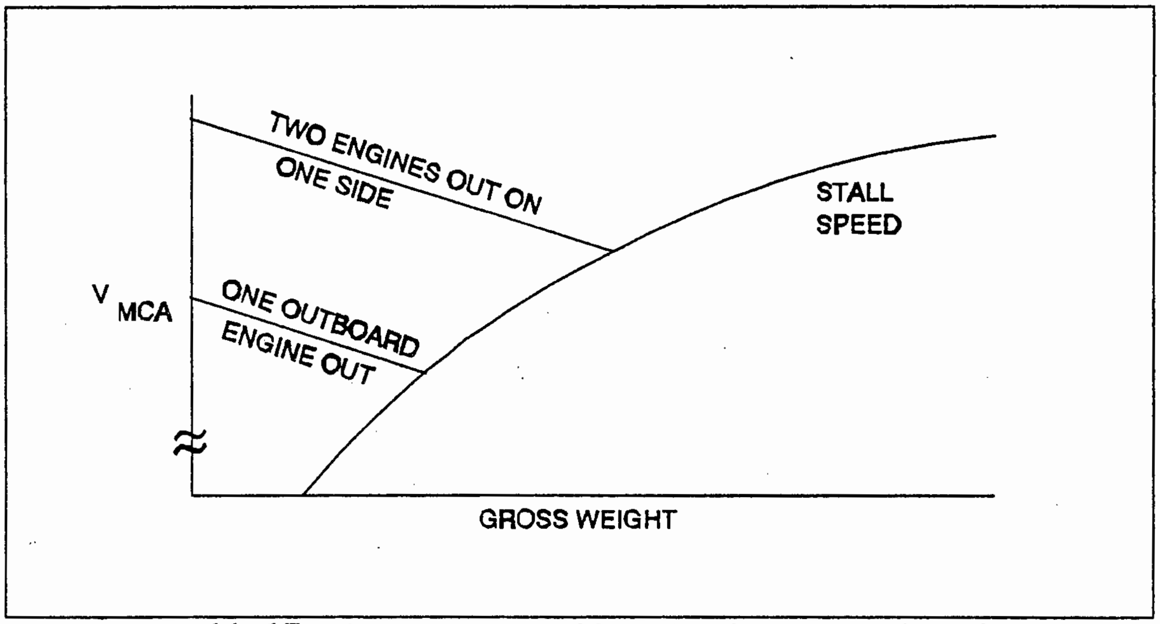

FIGURE 11.17 AIR MINIMUM CONTROL SPEED VERSUS GROSS WEIGHT

The bottom line:

The AFM-published V_{MCA} is an "admin." value, used for takeoff. The actual V_{MCA} that a pilot will experience in-flight varies with many variables, among which bank angle and asymmetrical thrust level, and because a pilot might not apply maximum rudder and/or aileron to stop the yaw and/or roll.

If the airplane continues to yaw and/or roll, despite maximum opposite rudder and/or aileron, control can only be re-established by reducing the thrust yawing moment by closing the throttle of the good engine a bit or, on a 4-engine airplane, by reducing the thrust of the outboard engine a bit, both temporarily until straight flight with a small favorable bank angle is again being maintained.

Never ever increase the (asymmetrical) thrust during a turn.

11.3.4 Dynamic Engine Failure

As stated earlier, the dynamic case is an extension of the steady state case due to rates and accelerations incurred during pilot reaction time. Before an aircraft can achieve equilibrium, the pilot must first overcome these rates and accelerations. The dynamic case usually requires more control authority and may require the use of a higher V_{mca} speed than the steady state case.

One of the most important and controversial variables when considering the dynamic engine failure is the response time. Response time might not be critical with an engine failure at cruise but, is far more crucial when the failure occurs during takeoff or go-around. The following discussion and guidance is excerpted from MIL-STD-1797A, paragraph 4.1.11.4, "Failures". Total response time to a failure is the sum of aircraft response time and pilot response time intervals. The minimum total response time for evaluations should be 1 second. Table 11.2 is reproduced from MIL-STD-1797A.

11.3.4.1 Aircraft Response Time

This is the time period between the failure occurring and the pilot being alerted by a suitable cue. The cue may take the form of an adequate tactile, audio or visual warning. The eye should not be relied upon to detect unusual instrument indications. In the absence of adequate cues listed, the pilot can be considered alerted when the aircraft meets or exceeds the responses listed in Table 11.2.

11.3.4.2 Pilot Response Time

Pilot response time is especially critical in defining a reasonable minimum pilot intervention time (delay time) to a failure. The status of the pilot in the overall task of controlling the aircraft can be described as active or attended operation, divided attention operation (both hands on and hands off the controls), or unattended operation such as autopilot mode (both hands on and hands off the controls).

As an example, if a pilot is flying the final approach to landing, he is performing attended operation with his hands on the controls. If he engages an autopilot mode during the approach, he is now performing unattended operation. Should a failure occur during this operation, the pilot response time for a corrective control input would be quite small because his hands would be on or in close proximity to the controls. It would be reasonable to assume a pilot response time of 1/2 second. However, if the failure occurred at cruise on a cross country leg, this unattended operation would assume that the pilots hands are not in close proximity to the controls. In this case, a pilot response time of 2 1/2 seconds is more reasonable. Table 11.2 provides suggested values of pilot response times to failures for various phases of flight.

Table 11.2 Summary of Minimum Allowable Intervention Times

PHASE OF FLIGHT	AIRCRAFT RESPONSE t_1-t_0	PILOT RESPONSE t_2-t_1	MINIMUM ALLOWABLE INTERVENTION DELAY TIME AND METHOD OF TEST
Attend Operation	Time for aircraft to achieve change of rate about any axis of 3 deg/sec OR The time to reach a change of "G" in any axis of 0.2 OR For an attention getter to function	1/2 sec	System failures will be injected without warning to the pilot. His ability to recover as rapidly as possible without a dangerous situation developing will be used to assess system failure mode acceptability.
Divided Attention Operations Hands On	Time for aircraft to achieve change of rate about any axis of 3 deg/sec OR The time to reach a change of "G" in any axis of 0.2 OR For an attention getter to function	1-1/2 sec (Decision 1 plus reaction 1/2)	The pilot will be warned of the system failure. Demonstration of compliance must show that an intervention delay time equal to 1 1/2 sec + (t_1 - t_0) can be tolerated
Divided Attention Operation Hands On		2-1/2 sec (Decision 1-1/2 plus reaction 1)	As above but intervention delay time 2 1/2 seconds + (t_1 - t_0)
Unattended Operation Hands On	As above but the threshold rates and "G" values are 5 deg/sec and 0.25 respectively	2-1/2 sec (Decision 2 plus reaction 1/2)	As above.
Unattended Operation Hands Off		4 sec (Decision 3 plus reaction 1)	As above but intervention delay time 4 sec + (t_1 - t_0)

11.3.5 Ground Minimum Control Speed (V_{mcg})

Ground minimum control theory is more complicated. The rudder moment and asymmetric thrust moments are related the same as the in-flight case, but nose wheel steering can help oppose the asymmetric thrust moment, landing gear opposes side force, and crosswind can greatly affect the rudder moment available.

If the crosswind is in the direction of the failed engine, less rudder deflection is available to counteract the moment from the engine loss because some rudder is being used to correct the weathercock tendency caused by the crosswind component. Figure 11.18 depicts the major yawing moments encountered on the ground.

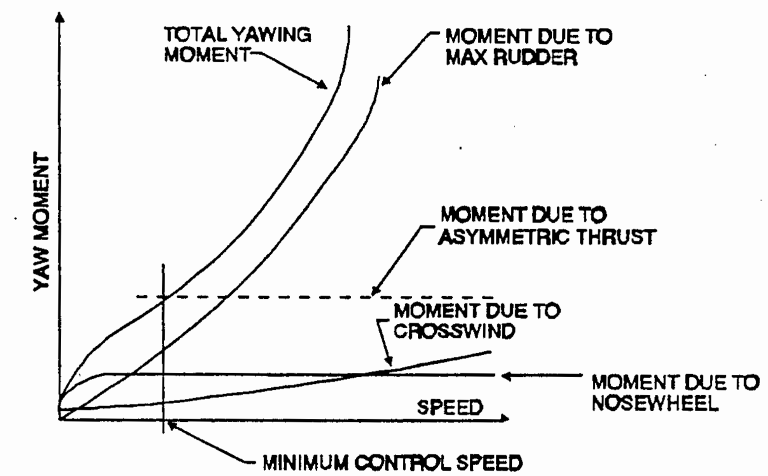

FIGURE 11.18 YAWING MOMENTS ON THE GROUND

11.4 ENGINE OUT MILITARY STANDARDS

MIL-STD-1797A places limits on control forces and deflections useable in controlling an aircraft with an inoperative engine. Useable rudder deflection is limited by a maximum allowable rudder force of 180 pounds. Useable lateral control is restricted to 75% of roll control power available, with a maximum lateral force of 20 pounds allowed. In the case of aircraft with irreversible control systems, the maximum control forces can be evaluated before flight. Pertinent MIL-STD-1797A guidance for engine out evaluations are contained in Table 11.3.

Table 11.3 Engine Out Guidance MIL-STD-1797A

4.1.11.4	Failures
4.1.13.5	Trim for Asymmetric Thrust
4.5.8.4	Roll Axis Control Power for Asymmetric Thrust
4.5.9.5.5	Roll Axis Control Force Limits for Asymmetric Thrust
4.6.5.1	Yaw Axis Response to Asymmetric Thrust
4.6.6.2	Yaw Axis Control Power for Asymmetric Thrust
4.6.7.8	Yaw Axis Control Power for Asymmetric Thrust During Takeoff
4.8.4.2.4	One Engine Out Stalls

11.5 ENGINE OUT FLIGHT TESTING

Military aircraft are usually designed with relatively low safety margins in order to obtain optimum performance. In fact, during war emergency operation the gross weight may be so high that engine out operation is not possible at all. Flight tests of these critical phases, on or near the ground, require a high level of crew skill and proficiency. Each test point must be carefully planned and flown. Such tests are an important part of the developmental testing of a new aircraft. They play a vital role in the side by side evaluation of assault or V/STOL transports where the ability to carry a useful load into and out of a landing area in frequently limited by engine out performance. Individual evaluations to determine if an aircraft meets the contractors guarantees may also hinge on this area of operation.

11.5.1 In-flight Performance

Some flight test programs may require demonstration of an engine out takeoff capability. Critical after takeoff climb gradients should be evaluated by an aircraft performance modeling program before a decision for demonstration of that climb gradient is made. Sawtooth climbs are often used to gather data in areas of low predicted climb performance. Normal performance flight test methods may be used to determine range and endurance with an engine(s) inoperative.

11.5.2 Stall Evaluation

An evaluation of the engine out stall characteristics should be made prior to V_{mca} testing. Evaluation should be made using standard flight test methods for stall but with low to moderate thrust set on the operative engine. Stall should be approached cautiously, noting differences in control forces, deflections and effectiveness from the all engines operating case. Note any departure tendencies and recovery techniques required.

11.5.3 Landing Performance

Restricted reversing capability, and higher approach speeds required to maintain minimum safe speeds will affect landing performance. Normal flight test methods are valid, but caution must be exercised in go-around situations, especially at light gross weights.

11.5.4 Air Minimum Control Speed

Flight test is required to ensure an aircraft's compliance with the specification and to verify contractor data from wind tunnel or flight test. Static V_{mca} should be evaluated first. Once the test team is satisfied it has accurately predicted static V_{mca} they can move to an evaluation of dynamic V_{mca}.

As we have seen, it is possible for a multiengined aircraft to have no air minimum control speed because that aircraft can be controlled down to aerodynamic stall. This is the desired situation, however it is important in this case not to report the aerodynamic stall speed as the minimum control speed. V_{MC} increases with bank angle!

Prior to flight test, consideration must be given to the hazards associated with shutting down engines in flight. On a twin engine aircraft, these hazards may be such that it should not be shutdown. Careful analysis should allow for the simulation of engine shutdown by idle thrust.

Consideration should be given to performing these tests at a variety of gross weights and altitudes. If the aircraft has a rudder power assist system or yaw augmentation, the profile should be repeated with these systems "off".

Once again, MIL-STD-1797A borrows the following additional guidance from FAR part 25 for the most appropriate configuration for flight test of air minimum control speed:

a) Most unfavorable center of gravity (normally an aft c.g); Smallest rudder yawing moment.

b) The airplane trimmed for takeoff;

c) In the most critical configuration in takeoff flight path except gear may be retracted.

d) If applicable, the propeller of the inoperative engine:

(1) Windmilling;

(2) The most probable position for the specific engine design; or

(3) Feathered, if the aircraft has an automatic feathering system.

As with the engine-out stall evaluation, flight test of V_{mca} should be approached cautiously. In most cases the aircraft is very close to stall with full rudder deflection. Plan and discuss control, trim and throttle movements during and at the completion of the test points. Review all stall and departure recovery techniques prior to flight.

11.5.4.1 Static Air Minimum Control Speed

It has been shown that an aircraft with an engine inoperative can be stabilized in straight unaccelerated flight using various combinations of bank angle and rudder deflections. Data taken from these stabilized point can be "normalized" and plotted to predict V_{mca} airspeeds for all combinations of bank, gross weight, altitude, and engines inoperative. There are several methods of collecting engine-out data. Experience, the type of control system (reversible or irreversible) or instrumentation installed may dictate what method to use. The following two methods are based on traditional engine-out FTTs. They are the "varying airspeed" and the "constant airspeed" techniques.

11.5.4.1.1 Varying Airspeed Technique

At an airspeed well above predicted V_{mca}, maximum asymmetric thrust is established by shutting down, or simulating the shutdown of the most critical engine(s) and setting the other symmetric engines to maximum thrust for the test condition. With the aircraft in the specified configuration a series of stabilized wings level points are flown decreasing to the airspeed at which maximum rudder deflection (or aileron deflection limit) occurs. Once the wings level point has been recorded, continue the deceleration by banking into the operative engine(s). Use stall speed or 5 degrees of bank to define as the limit.

11.5.4.1.2 Constant Airspeed Technique

The airspeed is stabilized at 1.1 V_{stall} in the specified configuration with thrust set for level flight. A small asymmetric thrust differential is established from the trim setting. Slowly apply maximum rudder deflection and bank the aircraft to reestablish a steady heading. The bank may be initially into the failed engines. Once data is recorded, incrementally increase the thrust differential and once again establish a steady heading. Terminate the test when maximum asymmetric thrust or 10 degrees of bank is reached.

11.5.4.1.3 Data Recorded

Data recorded at each stable point should include:

a) engine parameters
b) rudder force and deflection
c) aileron force and deflection
d) pressure altitude
e) temperature

f) gross weight

g) bank angle

11.5.4.2 Dynamic Air Minimum Control Speed

The objectives of flight test are to anticipate operational problems, duplicate realistic time delays, and arrive at an air minimum control speed and recovery technique that provides the average pilot a safe margin. The only realistic way to evaluate dynamic engine failure is to flight test it.

MIL-STD-1797A requires that a pilot be able to avoid dangerous conditions that might result from sudden loss of an engine during flight. The method of test compliance is to stabilize at an airspeed approximately 20 knots above static V_{mca} with symmetric power and suddenly fail the most critical engine. After observing a realistic time delay for realization and diagnosis, the pilot arrests the aircraft motion and achieves engine out equilibrium.

The test team must consider the <u>average pilot's</u> ability to arrest the motion and return the aircraft to equilibrium. The minimum airspeed at which the test team believes adequate control power is available in the dynamic situation should be considered in the final determination of air minimum control speed. The test should be repeated at an incrementally reduced speed until a minimum airspeed or static V_{mca} is reached.

If static V_{mca} was determined to be below stall speed a dynamic V_{mca} evaluation should still be performed. The aircraft should be stabilized at 1.1 V_s and the above method used to evaluate control power available.

11.5.5 Ground Minimum Control Speed

V_{mcg} will vary from the flight value because of :

a) The inability to use sideslip or bank angle.

b) Crosswind components.

c) The additional yaw moment produced by the landing gear.

This varies with landing gear configuration, the amount of steering used, the vertical load on the gear, and the runway condition. There are three basic methods for V_{mcg} testing:

a) Acceleration method

b) Deceleration method

c) Throttle chop method