SPECIFICATION FOR PILOT'S OPERATING HANDBOOK

GAMA Specification No. 1
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Limited Review

Including recaps of Calibrated and Indicated Airspeeds (Pitot-Static System)
and the Minimum Control Speed

Harry Horlings

Pilot and Flight Test Engineer, ret.

Avio*Consult*
Independent Aircraft Expert and Consultant

– Committed to Improve Aviation Safety –

SPECIFICATION FOR PILOT'S OPERATING HANDBOOK, GAMA Specification No. 1

This review is written by Harry Horlings, Lt-Col RNLAF ret., BSc, graduate Flight Test Engineer of the USAF Test Pilot School, class 85A, former chief experimental flight-test RNLAF, horlings@avioconsult.com. Website https://www.avioconsult.com

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1. Introduction

1.1. During the past 25 years, more than 520 engine failure-related accidents with small and big multi-engine airplanes were reported on the Internet alone, causing more than 4,150 casualties; these numbers are still growing. Airplanes are designed and thoroughly flight-tested to be able to continue to fly safely following the failure of one or two engines, so why do such accidents happen? Avio*Consult* started reviewing Accident Investigation Reports, Airplane Flight Manuals (AFM), Pilot's Operating Handbooks (POH) and multi-engine rating courses 20 years ago. It did not take long to conclude that there is an accident-causing knowledge gap about performance and controllability of multi-engine airplanes while an engine is inoperative between (airline) pilots, including writers of AFM/POH and training manuals and approving authorities on one side, and airplane design engineers of manufacturers, including experimental test pilots – being graduates of a test pilot school − on the other side.
Multi-engine rated pilots learn about the minimum control speed (V_{MC} or V_{MCA}) of their airplane, but are regrettably neither made aware anymore of the real value of the V_{MCA}, that is already used during the design phase of the airplane for sizing the aerodynamic control surfaces rudder and ailerons, and that is published as one of the airspeed limitations in the Airplane Flight Manual (AFM), nor of the associated maneuver limitations that apply for this V_{MCA} to be valid, which must be observed to avoid losing control when one engine is indeed fails or is inoperative and high thrust is set on the remaining engine(s).
The many fatal accidents mentioned above were the consequence of inappropriate guidance in multi-engine rating learning manuals and in AFMs/POHs for preventing the loss of control in an engine-out case. Proper knowledge on this subject obviously got lost or forgotten during the past 50 years.

1.2. While reviewing a *Pilot Operating Handbook and Airplane Flight Manual* of a Viking DHC-6 following a fatal accident in Thailand, the existence of *General Aviation Manufacturers Association (GAMA) Specification No.1*[1] was noticed, revealing the source of improper use of airspeeds and of procedures for flight with an inoperative engine in the reviewed and in other Airplane Flight Manuals and/or Pilot's Operating Handbooks of Beechcraft, Cessna, DHC, Diamond, Piper, and other Part 23 and even Part 25 airplane manufacturers.
The provided guidance on several subjects in GAMA Specification No. 1 is neither in agreement with airplane design methods as taught at universities, nor with Federal Aviation Regulation 14 CFR FAR 23[2] or equivalent, and nor with the FAA Flight Test Guide in Advisory Circular AC 23-8C[3] either, making a critical review of the GAMA Specification No. 1 an indispensable obligation of a flight-test expert who has become aware of improper guidance to manufacturers, as contribution to preventing fatal accidents in the future.

1.3. The author of this limited review is graduate Flight Test Engineer of the USAF Test Pilot School, Edwards AFB, CA (1985). TPSs were founded 80 years ago after experienced pilots crashed during flight-testing prototypes of new airplanes due to the lack of engineering knowledge. The very few Test Pilot Schools around the globe provide the highest level of flight-test training required to conduct experimental flight tests in or with any aircraft. The entrance level was an MSc degree in engineering or a BSc and an entrance exam. Test Pilot Schools teach aircraft performance, flying qualities, airborne systems and flight-test management. During the one-year course, students receive academics and flight training, and conduct some 120 flight hours of flight-testing in 24 different types of curriculum aircraft: fighter jets, single, twin and 4-engine propeller and turbojet transports, helicopters, gliders, and simulators. They must pass 32 exams, write 32 reports, and undergo frequent test rides. Calibrating pitot-static systems, and flying qualities testing of multi-engine airplanes while half of the

[1] GAMA Specification No. 1, Specification for Pilot's Operating Handbook. https://gama.aero/facts-and-statistics/consensus-standards/publications/gama-and-industry-technical-publications-and-specifications/.
[2] Code of Federal Regulations, Title 14, Chapter I, FAR 23, 1−1−10 Edition was used in this review. Link to FAR 23 2017: https://www.ecfr.gov/on/2017-01-03/title-14/chapter-I/subchapter-C/part-23/subpart-B.

number of engines are made inoperative, and determining the Minimum Control Speed in the Air (V_{MC} or V_{MCA}) is part of the curriculum.

The flight-test techniques that test pilots use are also described in FAA Flight Test Guide[3]. The Flying Qualities textbook of the USAF Test Pilot School, which includes the explanation of the controllability of multi-engine airplanes when an engine is inoperative, i.e. when flying on asymmetrical power, can be downloaded in two parts from the USArchives[4].

1.4. To again increase the level of knowledge about flight with an inoperative engine, Avio*Consult* published several reviews and accident analyses, wrote several papers and courses, and published these on the Downloads and Accidents pages of its website[5] and in aviation magazines. A video lecture *"The real Value of V_{MCA}"* with the subtitle *"How to prevent a dead engine from turning into a killing engine"* was uploaded on YouTube[6]. Papers were also presented during seminars of the European Chapter of the Flight Safety Foundation[7], the Safety Forum in Brussels[8], ALPA and other organizations, such as FAA Engine and Propeller Directorate, Luftfahrt Bundes Amt, and Delft University. Letters were written to FAA, NTSB (Dr. Earl F. Weener), ATSB and manufacturers with the recommendation to improve their investigations and Flying Handbooks, but these organizations did not respond, change anything, and obviously did not appreciate the competency of a Test Pilot School graduate either.

Dr. Weener quoted Douglas Adams in a video on the subject loss of control during takeoff and landing: *"Human beings, who are almost unique in having ability to learn from the experience of others, are also remarkable for their apparent disinclination to do so"*.

Most pilots explain the controllability of an airplane with an inoperative engine not correctly, because of unawareness of all the forces and moments acting on an engine-out airplane. Improper and short falling manuals did put the mishap pilots on the wrong foot. Accident investigating organizations do not conclude the real cause of controllability problems which are all reasons why accidents continue to occur; aviation is drifting into failure due to knowledge poverty. Therefore, Avio*Consult* continues its unsolicited work and wrote this review.

1.5. This review presents engineering and experimental flight-tests based facts, not opinions, and is not to apportion personal blame or liability, but is written to alert, make aware, teach, and learn from, which is necessary because proper knowledge obviously just faded away during the past 50 years or so, and fatal accidents with multi-engine airplanes continue to occur every month. To bring a stop to the unnecessary accidents and associated fatalities, explanations as well as some recommendations for improvement are included.

Pilots have the right to know and understand how to prevent a dead engine from turning into a killing engine. They have the right to be provided with excellent AFMs, POHs and training manuals. It is the duty and responsibility of the members of GAMA to provide such manuals. This review is written to stimulate and contribute to improving airplane and training manuals.

2. Preface of GAMA Specification No. 1

2.1. In the preface, the limitation of Specification No. 1 is stated: *"Pilots Operating Handbooks prepared in accordance with "GAMA Specification No. 1", as revised through Revision No. 2,*

[3] FAA Flight Test Guide, Advisory Circular AC 23-8C: http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_23-8C.pdf.

[4] Flying Qualities Textbook, Volume II, Part 1, 1986, https://ia800107.us.archive.org/32/items/DTIC_ADA170959/DTIC_ADA170959.pdf,
Flying Qualities Textbook, Volume II, Part 2, 1986 (Chapter 11, Asymmetrical power), https://ia801001.us.archive.org/17/items/DTIC_ADA170960/DTIC_ADA170960.pdf.

[5] Website Avio*Consult*: https://www.avioconsult.com.

[6] Harry Horlings, video lecture: *"The real value of the minimum control speed"*, https://youtu.be/Wbu6X0hSnBY.

[7] Harry Horlings, *"Staying Alive with a Dead Engine"*. Proceedings – European Aviation Safety Seminar (EASS), Athens, Greece, March 13 – 15, 2006.

[8] Harry Horlings, *"Safety Critical Procedure Development requires high level multi-disciplinary knowledge"*, https://skybrary.aero/sites/default/files/bookshelf/4665.pdf. PPT with working animations: https://www.avioconsult.com/downloads/Safety Forum slides AvioConsult June 2019 - video links.ppsm.

dated October 18, 1996, are appropriate for showing compliance with CAR 3, Paragraph 3.777, and FAR 23, Paragraph 23.1581 on airplanes having a certification basis including FAR 23 through Amendment 23-44 except Commuter Category".

2.1.1. Hence, the Specification applies to small twins with seating configuration of nine or less, the normal and utility categories. The Specification is however also used by manufacturers of SFAR 23 airplanes carrying more than 10 occupants and FAR 23 commuter class airplanes with a seating configuration up to 19 passengers, like the Viking DHC-6 Twin Otter and the Beechcraft 1900. This review therefore includes relevant comments for these airplane categories.

2.2. The Preface continues with: *"This Specification was developed by representatives of member companies of the General Aviation Manufacturers Association for use in preparing Pilot's Operating Handbooks that:*

a. Are of maximum usefulness as an operating reference book for pilots;

b. Meet government regulatory requirements where applicable; and

c. *Meet industry standards for scope of material, arrangement, nomenclature, and definitions."*

2.2.1. This review will show that Specification No.1 is not of maximum usefulness as a guide to operating manuals for pilots, and does not meet government regulatory requirements. The information needed for pilots to operate an airplane in a safe manner is not provided in the Specification. The Specification does not contribute to preventing accidents.

2.3. In the first paragraph on page v of the Preface is stated: *"Calibrated Airspeed (CAS) is to be used only as necessary to comply with any applicable requirements of the certificating authority as the pilot works exclusively with Indicated Airspeed (IAS)"*.

2.3.1. The pilot indeed can only read the Indicated Airspeed (IAS) from the Airspeed Indicator in the cockpit, but must also work with the limiting speeds and performance data in the AFM/POH which are (originally) provided as Calibrated Airspeeds (CAS) as is determined in SFAR 23.5(b) for operations under Part 135 for takeoff speeds and the speeds used to calculate these speeds(§ 5(b)), such as V_S and V_{MC}, as well as in FAR 23.51, and then calculate the corresponding IAS by adding the pitot-static system and instrument errors.
This Preface-statement is incorrect and is not true, is neither in agreement with the way these airspeeds are defined in FAR 23, nor as used by airplane design engineers, nor as used during experimental flight testing, and nor are taught at Test Pilot Schools.
The writers of the Specification and the approving authorities seem to struggle with understanding why these airspeeds exist and what their function and value are. It is obviously necessary to recap and once again explain CAS and IAS. Therefore, a few general remarks on airspeed theory are presented in the § 3 below, prior to further reviewing Specification No. 1. Reference is made to the applicable aviation and other regulations for readers to be able to verify the provided recap. A pilot needs to work with CAS too, as will be explained below.

2.4. In the fourth paragraph on page v: *"The Federal Aviation Administration has reviewed this Specification and has ". . . determined that a handbook that would meet the specification would also meet the intent of the requirements in FAR 23, which is to provide the pilot with all of the information needed to operate his aircraft in a safe manner." The Federal Aviation Administration recognized that compliance with this Specification will result in a high degree of standardization of content and format for all aircraft types and this will lead to a level of safety equal to or higher than is required under FAR 23."*

2.4.1. The first line confirms that *"the FAA has reviewed this Specification"*, etc. After reading the review below, the reader will be able to conclude whether the FAA review was conducted with the required and expected expertise, and find an answer to the question why so many airplanes crashed after engine failure, and still do.

3. Review of Airspeeds Used in GAMA Specification No. 1

3.1. During reviewing this GAMA Specification, the use of Calibrated Air Speeds (CAS) and Indicated Air Speeds (IAS) was found to be neither in compliance with the way these airspeeds are defined and used in 14 CFR FAR 23[2] – Airworthiness Standards: Normal Category and Commuter Class Airplanes, nor as used during airplane design and calibration (flight) testing, and nor as taught at Test Pilot Schools[9]. Therefore, a few general remarks are presented prior to reviewing the Specification to become aware of the real values of the used airspeeds. Misuse of the different airspeeds in AFM/POH led and still leads to fatal accidents, as will become clear in this review. Reference is made to the applicable aviation and other regulations; the source of the remarks below is the *Pitot-Statics and the Standard Atmosphere* course book of the USAF Test Pilot School[9] that is approved for public release. Instructors of this Test Pilot School teach and conduct pitot-static system testing, i.e. airspeed system calibrations, at least 50 times each year to and with the students; they know what they are talking about, and share their knowledge.

3.2. Calibrated and Indicated Air Speeds of an Airplane

3.2.1. Two speeds in aviation give information about the distance travelled in a period. These are the True Air Speed (TAS), being the speed of an airplane through the air mass with an ambient pressure and temperature which is not (yet) disturbed by the airplane, and the Ground Speed (GS), which is the speed of the airplane relative to the ground, which is TAS plus or minus a tail-, or headwind component. Both are used by pilots for navigation, for instance to calculate the time at which the destination is reached.
TAS however, is not useful for the piloting task, i.e. for control and performance, because TAS is influenced by ambient temperature and altitude (density). The use of TAS would require computing different speeds for each combination of weight, ambient temperature, and altitude (density). In addition, it is quite complicated to build an accurate mechanical TAS indicator to account for temperature and altitude effects, which was the reason to introduce the Calibrated Air Speed (CAS), which makes the flying task and the use of performance data easier. At sea level *in a standard atmosphere*, TAS is equal to CAS. TAS is, besides for navigation, also used for propeller thrust, turn calculations, etc., i.e. mainly for engineering (design) purposes and flight-test.

3.2.2. CAS is *'the mother'* of all airspeeds and is measured by a calibrated pitot-static system. CAS has the same significance on all days; CAS on one day is CAS on another day, CAS does not depend on temperature and altitude (density). Therefore, the takeoff, stall, cruise, minimum control, and landing speeds are proportional to the CAS for a given gross weight. CAS is of direct use to the pilot, which is the reason why these important piloting speeds are (to be) published as CAS in the AFM/POH.

3.2.3. P_T and P_S are measured with a pitot-static system and their difference $P_T - P_S$ is indicated by an Air Speed Indicator (ASI), which is simple in design and construction, accurate and easy to calibrate. However, neither a pitot-static system, nor an ASI is regrettably without errors due to the positioning of the sensors on the airplane (in disturbed air), and due to manufacturing of the ASI. Hence, the airspeed that the pilot reads on the ASI is not the CAS anymore, but is called the Indicated Air Speed (IAS), which is the CAS minus the pitot-static *system errors* and minus the *instrument errors* of the Air Speed Indicator (ASI). The airspeed measuring system is illustrated in Figure 1 below. The airspeed ahead of the tip of the pitot-tube in the undisturbed airstream is the CAS of the airplane; the ASI indicates the IAS to the pilot. The errors will be discussed further below.

[9] *Pitot-Statics and the Standard Atmosphere*, 4th edition (July 2020), Russell E. Erb, USAF Test Pilot School, https://apps.dtic.mil/sti/pdfs/AD1115005.pdf.

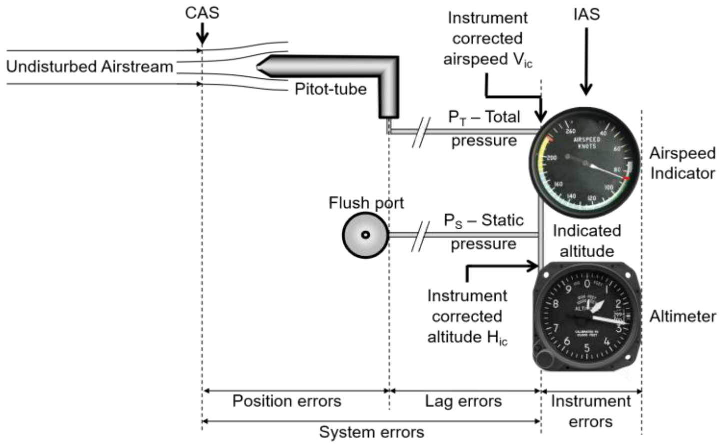

Figure 1. A common Pitot-static system and its errors; from Calibrated Airspeed (CAS) in undisturbed airstream to Indicated Airspeed (IAS) on the Airspeed Indicator (ASI).

3.2.4. ***Position Error***. The position error is the error caused by locating the pitot-tube and flush ports on the fuselage, rather than in the undisturbed airstream in front of the airplane. The pitot-static system is calibrated during flight-testing during which its *position error* is determined over a range of airspeeds, for several flap and landing gear configurations, and weights. FAR 23.1323 (b) "*defines the pitot-static system error, excluding the ASI calibration error, to not exceed the maximum of 3% of CAS or 5 kt*". The position error does not cause difference between the IAS indicated on separate ASIs in the same cockpit that are connected to the same pitot-static system; then a single position error chart applies to any of the ASIs.

3.2.5. ***Lag errors.*** The pressure lag errors for airspeed and altitude are caused by the length of the tubing causing a small delay and are considered not to have influence except when changing airspeed or altitude. These errors will not be used below.

3.2.6. ***Instrument Errors***. The expansion of the aneroid (diaphragm or bellows) within a mechanical ASI due to the difference between P_T and P_S is transferred by mechanical parts such as levers, pinion, and springs to the pointer of the ASI which rotates above an airspeed scale indicating the IAS. The ASI is mechanically designed and constructed to indicate the airspeed with respect to the standard atmospheric pressure and temperature (ISA) at sea level.
The errors between the air pressures P_T and P_S at the entrance of the ASI and the eyes of the pilot(s), caused by the mechanical parts within the ASI, such as manufacturing discrepancies, magnetic fields, hysteresis or friction, altitude, temperature changes, vibration, inertia of moving parts, and the parallax, contribute to the instrument error. The instrument error of each individual ASI over a range of airspeeds is determined in an instrument laboratory during calibration, as required by FAR 23.1323(a).

3.2.7. Hence, each individual ASI has its own (total) *instrument error*. In a cockpit with two or three different ASIs for pilot, copilot and an alternate, the airspeed indication of each IAS usually differs because the instrument errors of each of the ASIs differ, while the CASs, calculated after adding the known instrument correction of each ASI and the (common) position error correction of the pitot-static system, are equal.

3.2.8. SAE AS 8019 presents detailed ASI specifications, but this document is not available for free. The free FAA Standard ETSO-C46a[10] is for maximum allowable airspeed indicator systems which indicate continuously both indicated airspeed and maximum allowable airspeed (FAR 23.1303(g)(1)). Although this standard may not apply to regular ASIs, the tolerance numbers will not differ very much, and are partly presented for low airspeeds in Figure 2.

[10] Technical Standard Order ETSO-C46a, Maximum Allowable Airspeed Indicator Systems Performance Requirements, https://www.easa.europa.eu/download/etso/ETSO-C46a_CS-ETSO_0.pdf.

TABLE I

Speed knots	Impact pressure (qc) inches Hg at 25° C	Tolerance knots
50	0.1198	±4.0
*60	.1727	2.0
80	.3075	2.0
*100	.4814	2.0
120	.6950	2.0
*150	1.091	2.5
180	1.580	3.0
*200	1.959	3.0
230	2.610	3.0
*250	3.100	3.0
280	3.924	3.5
*300	4.534	[illegible]
320	[illegible]	

Figure 2. ETSO-C46a, Part of Table I. Minimum performance standards for pitot-static type airspeed indicator sys-

3.2.9. ETSO-C46a Appendix 1, § 2.3(c)(1) states: "*The indicated airspeed pointer must indicate airspeed in accordance with the values contained in Table I*". In this ETSO Table I (Figure 2), the approved tolerance at a range of airspeeds is defined.
Another error source is friction on the pointer: *"The friction on the pointer must not produce an error exceeding 3 kt"* at each point indicated by an asterix in Table I.
Hence, the instrument error of an ASI indicating V_S, V_{MCA}, V_{REF}, or takeoff speeds in the range 60 – 120 kt is allowed to be ±2 kt (Figure 2). The approved tolerance at 50 kt (≈V_{MCG}) is ±4 kt. During increasing or decreasing airspeeds, the instrument error might increase with 3 kt (*friction).
In a worst-case situation, the difference between the IAS indicated on two ASIs in the same cockpit is allowed to be up to 4 kt (if one error happens to be −2 kt and the other +2 kt).

3.2.10. The pressure difference P_T minus P_S at the entrance of the ASI is a measure of the IAS plus the instrument error, and is also called the *instrument corrected airspeed* Vic (Figure 1), which should be the entry variable for the position error chart that is published in the AFM.

3.2.11. Modern air data systems don't have a mechanical ASI anymore (except for a backup/ alternate); pressure transducers in the air data system convert the air pressures into digital numbers for further processing and display. Such a system however, still has the errors as shown in Figure 1. In some cases, an air data system allows entry of calibration correction to compensate for position and lag errors, and possibly also for (its own) instrument errors so that CAS can be displayed on the speed tape in the cockpit. In most cases, the pilot still must deal with both the position and instrument errors though, and hence with both CAS and IAS.

3.2.12. ***Total airspeed error***. The maximum regulations-approved airspeed error, being the sum of the approved instrument and position errors, is in a worst case allowed to be as high as (2 + 5 =) 7 kt (ETSO-C46a and FAR 23.1323(b)). This number could be increased by the allowed 3 kt friction error during acceleration or deceleration. These are numbers that a pilot needs to be made aware of for being able to plan and conduct the takeoff, approach and landing safely, and for handling the airplane in case an engine fails.

3.2.13. Test Pilot Schools also teach Equivalent Airspeed, but the difference with Calibrated Airspeed is small and within acceptable tolerances, and will not be discussed here. Refer to the (free) book *Pitot-Statics and the Standard Atmosphere* in footnote 9 for a complete course on pitot-statics.

3.2.14. ***Summary***. The three most used airspeeds in the AFM will be briefly summarized.

3.2.15. A proper definition of Calibrated Airspeed (CAS) would be:

CAS is the airspeed in undisturbed air with respect to the standard atmospheric pressure and temperature at sea level

CAS is the airspeed of the airplane in undisturbed air, i.e. in the free airstream in front of the bow wave of the airplane. The errors caused by the disturbed air, the placement of the pitot-tube in disturbed air, and the pitot-static system are determined during **calibration** over a range of airspeeds (and altitudes) and furnished as position error in the POH/AFM. CAS is important for the piloting task; the AFM-published speed limitations such as V_S, V_{MCA}, and V_{MO},

and operational speeds such as V_1, V_R, V_2 and V_{REF}, and handling characteristics, are proportional to CAS for a given gross weight. CAS is also used to present performance data in an AFM. CAS has the same significance on all days, whatever the pressure and temperature are. CAS cannot be displayed in the cockpit by a simple mechanical instrument, but must be calculated by the pilot by adding the position error correction and the instrument error correction to the airspeed indicated by the Airspeed Indicator (ASI). The errors can be positive, zero or negative. The CAS of two airplanes flying in formation should be equal, while their IAS are most probably not.
The use of CAS allows the manufacturer or operator to use (copies of) the same AFM/POH for a series of airplanes of the same type. CAS is often inappropriately explained as being the abbreviation of Computed Air Speed, even by accident investigators.

3.2.16. A proper definition of Indicated Airspeed (IAS) would be:

IAS is the airspeed indicated by an Airspeed Indicator

IAS is equal to the CAS plus both the position and instrument errors. The position error of the pitot-static system over a range of airspeeds is presented in the AFM; the instrument error of each individual ASI must be furnished to the pilot separately.
The errors can be positive or negative. The pilot must calculate limiting speeds provided in the AFM/POH from CAS to IAS for use in the cockpit, and calculate CAS from IAS for using appropriate performance data in the AFM/POH.

3.2.17. A proper definition of True Airspeed (TAS) would be:

TAS is the true airspeed of an airplane with respect to the ambient pressure and temperature

TAS is the airspeed to be used for the navigation task, for calculating the speed and time en-route. TAS is calculated from CAS using the actual ambient pressure altitude and outside air temperature, using an E6-B flight computer or by on-board computers.

3.3. Calibrated and Indicated Air Speeds in Regulations

3.3.1. FAR 23.1581(d) requires: *"All Airplane Flight Manual operational airspeeds, unless otherwise specified, must be presented as indicated airspeeds"*. All operational airspeeds in a type-generic AFM (V_S, $V_{MC(A)}$, takeoff speeds, etc.) are determined, calculated, and usually specified to be presented in CAS for reasons described in the paragraphs above and in § 3.4 below. CAS cannot be presented on an instrument in a cockpit because of the errors in the pitot-static system, and in airspeed indicators that vary with airspeed and hence, varies between airplanes. An instrument indicating CAS would be too complicated to make, and would have many errors. Now or in the future, computers might be able to compensate for the pitot-static system and their own (“instrument”) errors and display the important CAS rather than IAS. Until then, pilots must calculate all AFM operational airspeeds from CAS by adding instrument and position errors to the IAS, and vice-versa (even if the errors seem small, as will become clear in § 3.4.4 below).
This FAR requirement can only be met if, besides the position error, also the instrument errors of each individual ASI in all airplanes of the same type for which the AFM applies are known to the AFM-writer, including the errors of a second or third (alternate) ASI in the same cockpit. This would lead to a large data table, the use of which would be prone to errors. A maintenance replacement of a defective ASI would lead to an amendment of the AFM, and approval by authorities taking quite some time during which the airplane is grounded, unless the instrument error of the new ASI is the same as of the replaced ASI.
In addition to the amendment of the AFM of the specific tail number, the required red radial line indicating V_{MC} on the ASI (FAR 23.1545(b)(6)), or for airplanes >6000 lb and turbine engine-powered airplanes the placard in the cockpit (FAR 23.1563(c)) with airspeed limitations also needs to be amended and/or replaced.

This cannot be the intention of this FAR requirement; it is obviously unworkable, and must be in error (or is misunderstood). The quoted FAR 23.1581(d) could also mean that all operational airspeeds must be presented by an ASI which is accompanied by an instrument correction table for a range of airspeeds on the instrument panel, for the pilot to be able to calculate the real indicated airspeed. When the author of this review started flying Part 23 airplanes in the early seventies, such a table could still be found on the instrument panel.

3.3.2. Pt. 23, SFAR No. 23, § 13(a) and FAR 23.1323(a) require: *"Each airspeed indicating instrument must be calibrated to indicate true airspeed (at sea level with a standard atmosphere) with a minimum practicable instrument calibration error when the corresponding pitot and static pressures are applied".* Although TAS is equal to CAS at sea level, an ASI cannot indicate TAS, which would require to apply pressure altitude and OAT to the instrument as well, as explained above. Each ASI is calibrated in a laboratory to determine only its instrument error, being the error between the applied pressures to the entrance ports of the ASI (P_T and P_S), which are equivalent to the CAS plus the position error (Vic in Figure 1), and the airspeed indicated on the ASI. An ASI can also be calibrated in the airplane (on the ground) by applying P_T to the pitot tube, and P_S to the flush ports for a range of airspeeds. This way, the position error of the pitot-static system is avoided.
FAR 23.1581 (d) (§ 3.3.1 above) requires operational airspeeds to be presented as indicated airspeeds, while FAR 23.1323(a) requires that each airspeed indicating instrument must be calibrated to indicate True Air Speed. FAR 23 seems to need a review as well.

3.3.3. FAR 23.1323 (b) requires: *"Each airspeed system must be calibrated in flight to determine the system error. The system error, including position error, but excluding the airspeed indicator instrument calibration error, may not exceed three percent of the calibrated airspeed or five knots, whichever is greater, throughout the following speed ranges:"*
A similar requirement is in Part 23, SFAR No. 23, § 13: "*The airspeed indicating system must be calibrated to determine the system error, i.e., the relation between IAS and CAS, in flight and during the accelerate takeoff ground run*", and in § 13(d): "*information showing the relationship between IAS and CAS must be shown in the Airplane Flight Manual*". FAR 23.1587(d)(10) requires for commuter category airplanes: *"The relationship between IAS and CAS determined in accordance with §23.1323 (b) and (c)"*.
The system error is the position error plus the lag error (Figure 1 above), but not including the instrument error. The relationship between IAS and CAS is the sum of the instrument error of the ASI and the position error of the pitot-static system: CAS = IAS + instrument error + position error. The instrument error cannot be presented in an AFM, as explained above, only the position error is provided in a chart or table. In this SFAR paragraph, the instrument error is obviously assumed to be zero, which cannot be the case due to the manufacturing process of Airspeed Indicators. The pilot must read the airspeed instrument correction from an instrument error correction table and add this to the IAS to calculate the instrument corrected airspeed (Vic) which is then used to enter the position error chart to read the position error or CAS. An IAS to Vic conversion table is to be made for each individual ASI (for each serial number).

3.3.4. FAR 23.1323 requires both the pitot-static system and the airspeed indicator instrument to be calibrated separately. The calibration data of both should be made available to the pilot to be able to calculate the CAS from the IAS during flight, and to calculate pre-flight determined performance data and takeoff speeds from CAS in the AFM to IAS for use in the cockpit. The GAMA Specification No. 1 seems not to mention the instrument calibration error and therefore does not comply with FAR 23. It should not have been approved by the aviation authority.

3.3.5. In FAR 23.1587(d): *"In addition to paragraph (a) of this section, for commuter category airplanes, the following information must be furnished— (10): The relationship between IAS and CAS determined in accordance with §23.1323 (b) and (c)"*.

The relationship between IAS and CAS is the sum of the position error (≤ 5 kt) and the instrument error (≤ 4 kt), i.e. between 0 and 9 kt, depending on the airspeed, and can be 3 kt higher due to the approved friction error when the airspeed decreases or increases. This FAR paragraph requires both the position error and the instrument error to be furnished. The position error is usually published in a chart in the AFM, but the instrument error seems forgotten, while it can be larger than the position error. Not furnishing instrument errors is not in compliance with this FAR paragraph.

3.4. Calibrated and Indicated Air Speeds in an AFM

3.4.1. The takeoff, stall, minimum control, cruise, approach and landing speeds, and the handling qualities of the airplane were determined during experimental test flights with a calibrated test system, and were reported as CAS for a given gross weight (mass). These, for flight operations important speeds are usually also published as CAS in an AFM because then they are valid for all airplanes of the same type, with a similar pitot-static system. As also mentioned above, another reason for publishing airspeeds as CAS is that the AFM-writer does neither know the position error of the airplane, nor the instrument error of each individual ASI installed in any production airplane (at any one time, now or in the future). The position error of the pitot-static system must be published In a chart in the AFM, an airspeed instrument correction table in the cockpit of each airplane should show the airspeed correction for each individual installed ASI, except for a few categories of airplanes, unless the errors are compensated for in a computerized air data system (§ 3.2.11 above). The airspeed instrument correction table should be mentioned in the AFM/POH, like all required placards are. With this table, and with the position error chart in the AFM, the pilot can determine the Indicated Airspeed to maintain a desired Calibrated Airspeed (that is published in the AFM as limitation, procedural, or performance speed).

3.4.2. GAMA Specification No. 1 requires airspeeds to be published as IAS, because *"the pilot exclusively works with IAS"* (Preface). In addition, publishing airspeeds as both IAS and CAS is recommended. This might cause confusion, and certainly also errors because the instrument errors are not included, only the position error. Limiting airspeeds presented as IAS might be higher than intended/determined as CAS + position error + instrument error, which might lead to controllability problems, while the pilot believes to be safe when reading the ASI.

3.4.3. *An example*: The minimum control speed, determined during flight-tests is 66 KCAS. The position error CAS to IAS = −2 kt, and suppose the instrument error is the maximum approved +2 kt, but is not provided. Then the minimum control speed would be 66 KCAS − 2 + 2 = 66 KIAS. The red line on the ASI, or on the placard in the cockpit however, tells the pilot that V_{MCA} is 64 KIAS. So, if maintaining 64 KIAS, the pilot believes to be safe, but this airspeed is 2 kt, the instrument error, below the published V_{MCA} (in IAS), and he will lose control when an engine fails and the other is set at maximum thrust and he doesn't maintain the small favorable bank angle. The takeoff speeds (in IAS), which are calculated using V_{MCA}, will also be too low. CAS and both errors are required to indicate a safe V_{MCA} to the pilot.

3.4.4. Readers, like the writers of the GAMA Specification No. 1 and the reviewers of the FAA, might believe 1 or 2 kt is not that big of an (instrument) error, so why all the fuzz. But it is not about the few knots, it's all about physics, about the forces and moments generated by the aerodynamic control surfaces that are required to maintain the equilibrium of forces and moments, i.e. to maintain control, which are proportional to V^2 (lift equation: Lift = $C_L \frac{1}{2}\rho V^2 S$). A few knots have a very large influence on the generated control forces, and can make the difference between life and death. For instance, a difference of 2 kt on the generated aerodynamic force at an airspeed V = 80 kt is $80^2 - (80 - 2)^2 = 316$ units of force, and not just 2^2. The pilot might consider to be safe, but his controls do not function as expected; control might be lost. Rule makers require airspeeds to be provided accurately; rules were made many years ago with competence and should not be amended or neglected by ignorance, because physics

has no mercy.
Pilots have the right to be made aware of the errors in the pitot-static systems for them to be able to apply the correct speed corrections and hence, correct limitations (in CAS), and to conduct a flight and return home safely.

3.4.5. An AFM is designated by number in the Type Certificate Data Sheet of the airplane, and is mandatory for the airplane to be operated airworthy. In the Specification many more statements are found that are not in agreement with FAR 23 and FAA Flight Test Guides. The writers of the GAMA Specification No. 1 obviously had a disappointing understanding of airplane speeds, performance, and control, and of FAR 23, and did not contribute to preventing the fatal accidents referred to in § 1.1 above.
So far, the airspeed theory. In the next chapters, GAMA Specification No. 1 will be reviewed.

4. Section 1. General

4.1. **§ 1.15 Propeller(s)**. Recommended is to add the direction of rotation of the propellers, to be able to determine which engine is the critical engine, being the engine that was made inoperative during measuring the AFM-published V_{MCA}. The actual V_{MCA} when the other engine fails is usually a few knots lower, which is less critical. In case of counterrotating propellers, both engines are equally critical.

4.2. **§ 1.31 (a) General Airspeed Terminology and Symbols**. In the following paragraphs, the *"terminology and symbols"* in § 1.31 (a) are reviewed.

4.3. **CAS.** "*Calibrated Airspeed means the indicated speed of an aircraft, corrected for position and instrument error. Calibrated airspeed is equal to true airspeed in standard atmosphere at sea level".*

4.3.1. CAS is more than 'defined' in the first sentence, which only says how to calculate CAS. But what is CAS? CAS is measured by a calibrated pitot-static system (§ 3.2.2 above), and is the airspeed for the piloting task. Flight limitations and performance data are measured or calculated, then published in knots CAS (KCAS) in graphs, charts, and tables in the AFM/POH. CAS on one day is CAS on other days. CAS in one airplane is equal to CAS in another airplane of the same type/series (with identical pitot-static systems).
The definition should be: '**CAS is the airspeed with respect to the standard atmospheric pressure and temperature at sea level**'. CAS is the source of other airspeeds. Compare this definition with the TAS definition below.

4.3.2. CAS cannot be indicated accurately in the cockpit due to the errors in the pitot-static system and in the airspeed indicator. FAR 23.1323 requires the calibration of both the pitot-static system and the airspeed indicator to be conducted separately to determine the position errors of the pitot-static system over a range of speeds, which are to be published in the AFM/POH, and to determine the instrument errors of the airspeed indicators, which are to be furnished to the pilot. The instrument error is usually not furnished in an AFM, because the instrument error varies for each individual airspeed indicator. Both errors between CAS and IAS, called 'relationship' in FAR 23 (§ 3.3.5 above), are to be used by pilots to either calculate the CAS from the IAS for looking up performance data in the AFM for a given IAS, or to calculate limiting and/or performance speeds given in CAS in the AFM to the IAS that is indicated in the cockpit.

4.3.3. The second sentence *"Calibrated airspeed is equal to true airspeed in standard atmosphere at sea level"* belongs not yet here, but in the TAS definition, and written the other way around; TAS is derived from CAS and calculated by the pilot using pressure altitude and ambient temperature, with an E6-B flight computer or by on-board computers. At sea level and in standard temperature, TAS = CAS, see § 4.6 below.

4.4. **GS**. Ground Speed is the speed of an airplane relative to the ground.

4.4.1. In other speed definitions, the relation with another speed is mentioned. It is recommended to add: 'The Ground Speed of the airplane is equal to the TAS minus the headwind or plus the tailwind component'.

4.5. **IAS**. *"Indicated Airspeed is the speed of an aircraft as shown in the airspeed indicator when corrected for instrument error. IAS values published in this Handbook assume zero instrument error".*

4.5.1. What is meant with *"speed"* in the first sentence? *"The speed of an aircraft as shown by the airspeed indicator when corrected for instrument error"* is the instrument corrected airspeed Vic, certainly not the IAS (§ 3.2.10 above). Indicated Airspeed is no more than the airspeed of an aircraft as shown in the airspeed indicator. Vic is to be used to enter the position error chart in the AFM/POH.

4.5.2. Assuming *"zero Instrument error"* in the definition of an ASI in an AFM/POH is acting against the Regulation FAR 23, rendering the airplane not airworthy. Authorities should neither have approved such an advice in the GAMA Specification No. 1, nor an AFM/POH that applies zero instrument errors for all ASIs in the cockpit. Refer to § 3.4.4 above for the impact of a relatively small 2 kt instrument error on the forces and moments acting on the airplane.

4.5.3. The IAS definition should be: '**IAS is the airspeed indicated by an Airspeed Indicator'.** IAS is equal to the CAS plus both the pitot-static system position error and airspeed indicator instrument error. These errors can be positive or negative and are unavoidable due to manufacturing and other reasons. The pitot static system of a type/series of airplanes is calibrated and the position error published in the type-specific AFM/POH. In addition, each individual ASI is calibrated separately, as required by FAR 23.1323; the instrument errors of each ASI are to be furnished as well, for use by pilots. The errors can be used both ways: IAS + instrument error + pitot-static system position error = CAS, and vice versa. IAS in one airplane is not equal to IAS in another airplane of the same type (except if the instrument errors happen to be equal).

4.5.4. IAS might differ between ASIs in the same cockpit, and will change after replacing a malfunctioning ASI. Instrument errors of ASIs are not constant, but vary with temperature, speed, and other parameters (§ 3.2.7 above).

4.6. **TAS.** *"True Airspeed is the airspeed of an airplane relative to undisturbed air which is the CAS corrected for altitude, temperature, and compressibility".*

4.6.1. A correct definition is: '**TAS is the airspeed of an airplane with respect to the ambient pressure and temperature'**. TAS is used by pilots for the navigation task. TAS is the CAS corrected for pressure altitude and outside air temperature, not for compressibility (refer to an E6-B flight computer which can be used to calculate TAS in-flight, or to the book in footnote 9, page 37). TAS is equal to CAS in a standard atmosphere at sea level.

4.7. **V_{MCA}.** "*Air Minimum Control Speed is the minimum <u>flight speed</u> at which the airplane is directionally and laterally <u>controllable</u>, determined in accordance with the Federal Aviation Regulations. Airplane certification conditions include one engine <u>becoming</u> inoperative and windmilling (or, in airplanes with autofeathering devices, feathered), <u>not more than</u> a 5" bank toward the operative engine, takeoff power on the operative engine, landing gear up, <u>flaps in the takeoff position</u>, and <u>the most critical C.G</u>".*

4.7.1. There are a few errors and imperfections in this definition (underlined), which might be the cause of many, if not all accidents after engine failure. There is a lot to say and explain, which is the reason for a longer text below.

4.7.2. V_{MC} is defined in FAR 23.149(a) as follows: *"V_{MC} is the <u>calibrated airspeed</u> at which, when the critical engine <u>is suddenly made</u> inoperative, it is <u>possible to maintain control</u> of the* *airplane with that engine still inoperative, and thereafter maintain straight flight at the same speed with an angle of bank of not more than 5 degrees"*.

4.7.3. FAR 23 is for the certification of airplanes, so V_{MC} is already used by the tail design engineer for sizing the vertical tail and ailerons, because these control surfaces need to be able to generate the control forces and moments "*to maintain control*" and recover following a sudden failure, and "*thereafter maintain straight flight*". This is confirmed/measured during flight-testing at airspeeds down to V_{MC} in compliance with the FAA Flight Test Guide in Advisory Circular AC 23-8C[3], page 83. A dynamic V_{MC} is determined, being the V_{MC} at which it is possible to maintain control and recover when *"the critical engine is suddenly made inoperative"*, but also a static V_{MC} is measured at which it is possible to *"thereafter maintain straight flight"* while the thrust is maximum asymmetric. The critical engine is made inoperative during flight-testing because then V_{MC} is a few knots higher than with the other engine inoperative, which is the worst case (§ 4.1 above). Pilots don't have to analyze whether the failing engine is the critical engine; there is only one engine emergency procedure.

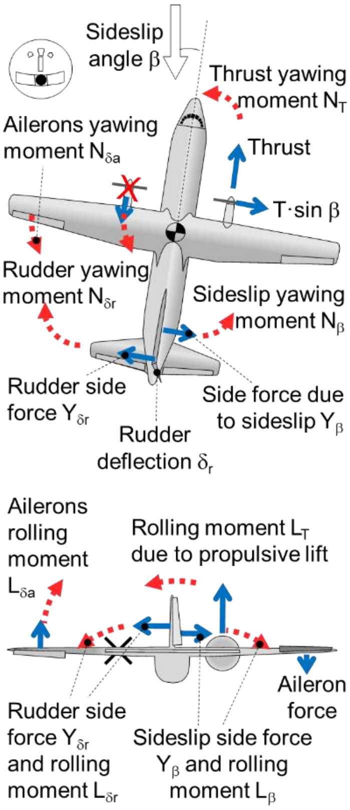

Figure 3 Lat-Dir forces and moments in body axis coordinate system, OEI, wings level, straight flight. Forces are not to scale.

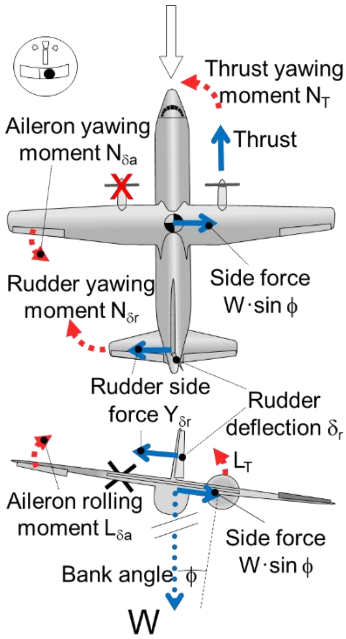

Figure 4. Lat-Dir forces and moments in body axis coordinate system, OEI, bank angle 5° into good engine, straight flight.

NOTE. In the analysis of Lateral-Directional forces and moments, the body axis coordinate system is used. Lift has no lateral component in this system, but Weight (gravity) has, even at large bank angles.

4.7.4. The static V_{MC} is first determined with the wings level, by slowly reducing the airspeed until the heading can no longer be maintained with full rudder (Figure 3), and then again with a small bank angle away from the inoperative engine. A small bank angle does not initiate a turn, because the thrust is asymmetrical and hence, the flight not coordinated; the pilot does not pull the elevator control either. The manufacturer determines the bank angle to be used to determine the static V_{MC}, which must be smaller than or equal to 5° away from the inoperative engine (FAR 23.149). The small bank angle generates a side force (W·sin ϕ) in the center of gravity (cg − Figure 4) that replaces the side force due to sideslip and therewith reduces the sideslip angle caused by the rudder deflection which is required to counteract the remaining asymmetrical thrust after engine failure, and hence, reduces the drag to a minimum for maximum remaining climb performance. Since the rudder does not have to overcome the sideslip side force when maintaining the small bank angle, the small bank angle also decreases the required rudder deflection and hence, allows decreasing the airspeed further until the rudder is again maximum, which results in a lower V_{MC}, but only as long as straight flight is being maintained. This characteristic is also used by the manufacturer to reduce the size of the vertical tail with rudder and still comply with the Regulation. The vertical tail with rudder may not be sized that small though, that V_{MC} increases above 1.2 V_{S1} (FAR 23.149(b)). This limit is often misinterpreted by pilots as 'V_{MC} will always be lower than 1.2 V_S', but this limitation applies, just like V_{MC}, for straight flight only. The forces and moments are thoroughly explained in the paper *Airplane Control and Analysis of Accidents after Engine Failure*[11].

The highest of dynamic or static V_{MC} during straight flight, which usually is the static V_{MC}, will be published as the V_{MC} of the airplane in the AFM. Determining a V_{MC} during turns while One Engine is Inoperative (OEI) is not required by FAR 23, but this V_{MC} is much higher than the AFM-published V_{MC} for straight flight. The theory and flight-test of V_{MC} is also explained in paper[11].

A conclusion of the V_{MC} flight-test techniques described above is that V_{MC} varies with bank angle. Manufacturers are regrettably not required to publish the bank angle that was used to determine V_{MC} in the V_{MC} definition or with V_{MC} data in the AFM, while some manufacturers do publish the bank angle for minimum drag and lowest actual V_{MC} in One Engine Inoperative performance diagrams, for instance Lockheed in C-130 Performance Manual SMP777, and Piper in the PA-44 POH.

The symbol V_{MC} is used in regulations, but in other publications, such as this AFM, V_{MCA} for V_{MC} in the Air is also used, which means the same. The use of both V_{MCA} and V_{MC} in an AFM/POH might be found confusing; better would be to choose one.

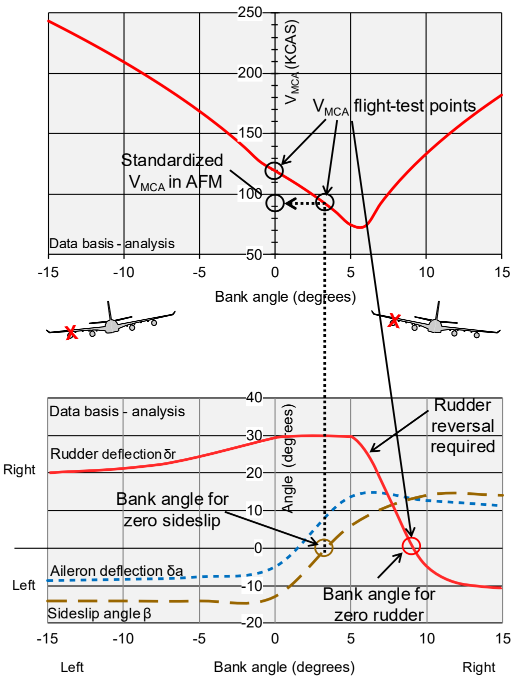

Figure 5. Effect of bank angle on V_{MCA} and on rudder, aileron, and sideslip angles during equilibrium flight at maximum thrust, of a sample airplane.

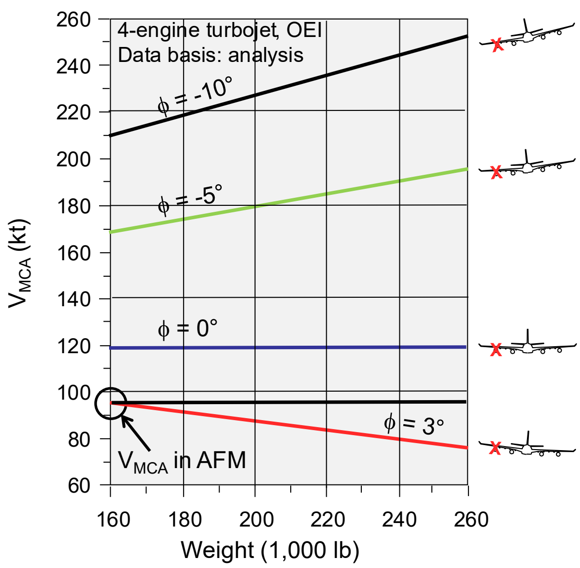

Figure 6. Effect of Weight and Bank Angle on V_{MCA}.

NOTE. C-130 pilots know this figure, because it is like the Weight and Bank Angle figure in the C-130 Performance Manual SMP-777.

[11] AvioConsult – Harry Horlings, *Airplane Control and Analysis of Accidents after Engine Failure*, https://www.avioconsult.com/downloads/Airplane Control and Analysis of Accidents after Engine Failure.pdf.

4.7.5. As already mentioned above, V_{MC} while maintaining a small up to 5° bank angle into the good engine decreases V_{MC} as is also shown in Figure 5 which is, like Figure 6, calculated in paper *The Effect of Bank Angle and Weight on V_{MCA}*[12] using the lateral-directional equations of motion for steady flight. This lower, standardized, V_{MC} is published in the AFM. When the wings are kept level though (bank angle 0°), the actual V_{MC} is higher than the published V_{MC}; the difference for other airplane types will be different. For a DHC-6-100 Twin Otter, for instance, the wings-level V_{MC} is approximately 6 kt higher than the AFM-published V_{MC}[13]. When banking away from the small favorable bank angle to either side, the actual V_{MC}, i.e. the V_{MC} which the pilot will experience in-flight, as well as the sideslip angle, will increase considerable while an engine is inoperative. Figure 6 shows the effect of weight and bank angle into the inoperative engine. When maximum asymmetrical thrust is maintained or attained during a shallow turn, a 20 – 30 kt (or more) higher airspeed will be required for a DHC-6-100 to maintain the equilibrium of forces and moments acting on the airplane, i.e. to maintain control during a turn. This increase will be much larger for airplanes with more powerful engines; the thrust yawing moment is much higher and a higher airspeed will be required for the rudder to be able to counteract the thrust yawing moment. The figures above are thoroughly explained in the paper referred to in footnote 11.
Control, i.e. the equilibrium of forces and moments, can be maintained during a turn when the airspeed is high enough, or by reducing the asymmetrical thrust a little, temporarily (following a straight climb to a safe altitude). This asymmetrical thrust reduction reduces the thrust yawing moment and therewith the required counteracting rudder (and aileron) deflection, leaving room for increased deflection during turns.

4.7.6. V_{MC} is also used for calculating the takeoff speeds V_R and V_2, and is therefore often considered to be applicable during takeoff only, and to be always as low as the red radial line on the ASI or as placarded. But a V_{MC} applies during the whole flight (V_{MCA} – V_{MC} in the Air), with takeoff flaps or flaps up, which might be the reason that V_{MCA} is used in most publications rather than V_{MC}, including in the GAMA Specification No. 1.

4.7.7. As shown above, the actual V_{MC} with the wings level is higher than when maintaining the small favorable bank angle. GAMA should recommend which V_{MC} to use for calculating V_R and V_2 (when the wings are kept level).

4.7.8. V_{MCA} is the lowest speed at which the control surfaces generate just large enough forces and moments to maintain the equilibrium of forces and moments, i.e. to maintain control. The yawing moment generated by the rudder is the rudder side force times its arm to the cg. The shortest arm, i.e. an aft cg called *"the most critical C.G."* above, is the worst case for V_{MCA} and is used during flight testing to determine V_{MCA}. Pilots don't have to analyze the effect of cg on controllability; they don't have to know about the criticality of the cg; its effect is included in V_{MCA}.

4.7.9. *An improved definition of V_{MC}* would be: **'$V_{MC(A)}$ is the minimum speed for maintaining straight flight when an engine fails or is inoperative and the opposite engine is set to provide maximum thrust, provided a constant bank angle is being maintained of 3° – 5° (exact number to be provided by the manufacturer) away from the inoperative engine'**.

4.7.10. Pilots must be made aware of the bank angle for which the AFM-published V_{MC} applies, and of the large increase of V_{MC} when straight flight is not being maintained, i.e. when the bank angle is not the small, favorable (5°) bank angle away from the inoperative engine, such as during intentional turns, or when the pilot after engine failure allows the bank angle

[12] AvioConsult - Harry Horlings, *The Effect of Bank Angle and Weight on V_{MCA},* https://www.avioconsult.com/downloads/Effect of Bank Angle and Weight on Vmca.pdf
[13] Experience of the author from V_{MCA} testing a UV-18 (DHC-6-100) during curriculum flight test training at the USAF Test Pilot School.

to increase. The AFM/POH should remind pilots with: **'Published V_{MCA} is valid for straight flight only; V_{MCA} increases during turns'**, and with: **'The pilot controls the actual V_{MCA} with bank angle and (asymmetrical) thrust'**.

4.7.11. Copies of the applicable Regulations, flight test guide and course manuals are brought together in one *Background Info* pdf file[14] for the reader to verify the above.

4.7.12. Part 23, SFAR No. 23, § 20. Performance information**:** "*The Airplane Flight Manual must contain the performance information determined in accordance with the provisions of the performance requirements of this regulation. The information must include the following: (e) An explanation of significant or unusual flight or ground handling characteristics of the airplane*". This explanation is also required in FAR 23.1585(a)(1) Operating procedures.
Part of the "*explanation of significant or unusual flight handling characteristics*" would be the requirement to maintain straight flight after one engine failed and maximum asymmetrical thrust is set. When turns must be made, the airspeed needs to be increased by 20 − 30 kt or more, depending on the type of airplane, or the asymmetrical thrust needs to be decreased a little, both of which handling characteristics are significant and unusual. As shown in Figure 5 above, and discussed in papers[11, 12] is the significant and unusual requirement for the pilot to decrease the rudder and reverse the deflection when banking more than 5° into the good engine (at maximum asymmetrical thrust), for maintaining the equilibrium of forces and moments acting on the airplane, i.e. to prevent the loss of control.
Following an engine failure, the flight is no longer coordinated, rudder and aileron deflections are required to maintain straight flight. The flight handling while an engine is inoperative is significantly different and unusual, which requires thorough explanation to avoid the loss of control. No such guidance is presented in the Specification No. 1, because the writers and reviewers were obviously not aware of the lateral/directional equilibrium of forces and moments required to maintain control of an engine-out airplane, as is described in the paper referred to in footnote 12 on the previous page. Pilots tell each other that turning into the good engine(s) is preferable, because the control margin is larger. This is a fable, and only the case when the bank angle is between 3° and 6° (Figure 5), i.e. when the actual V_{MC} is a bit lower than the AFM published V_{MC}.

4.7.13. The significance of V_{MC} (FAR 23.1583(a)(1) and (2)), and the significant effects of bank angle and thrust level on V_{MC} and on control and on scheduled performance when an engine is inoperative are often not adequately explained and presented in an AFM/POH, as required by FAR 23.1585(a)(1). Addressing this in Specification No. 1 and in AFM/POH developed using it will save lives.

4.7.14. GAMA Specification No. 1 should recommend to include with V_{MC} and OEI performance data in the AFM/POH the small 5° bank angle into the good engine for the AFM-published V_{MC} to be valid, and for the smallest possible sideslip angle, hence for minimum drag and maximum Rate of Climb. Dr. Jan Roskam of Kansas University wrote in Airplane Design Part VII, page 286, of his college series of books for airplane design engineers, who already use V_{MC} for sizing the vertical tail: "*the V_{MC} value ultimately used ties takeoff performance to engine-out controllability*".

4.7.15. Pilots receive their multi-engine rating in Part 23 airplanes, and take this experience with them during their whole career in Part 25 airplanes. Wrong learned is wrong applied. Even Boeings 747 crashed after engine(s) separation because the pilots were not made aware of the increase of the actual V_{MC} during turns or with the increase of the asymmetrical thrust. ICAO would call this Systemic Errors. GAMA Specification No. 1 is relevant to preventing Systemic Errors as well.

[14] AvioConsult, *Background information for the definition, theory, flight test and use of V_{MC}*, https://www.avioconsult.com/downloads/Background VMC(A) Regulations and Flight Test.pdf

4.8. **V_R** is required (FAR § 23.51(a), but is not included. V_R is the rotation speed, the speed at which the pilot makes a control input, with the intention of lifting the airplane out of contact with the runway or water surface. V_R for multi-engine airplanes must not be less than the greater of 1.05 V_{MC} or 1.10 V_{S1}. For single-engine landplanes, V_R must not be less than V_{S1}.

4.9. **V_{YSE} and V_{XSE}** are not included either, while these are used in § 3.3 (b) Airspeeds for Emergency Operations.

4.9.1. The description of both can be the same as for V_X and V_Y respectively, with the addition in both: 'when one engine is inoperative', and 'while maintaining a small bank angle into the good engine'. The manufacturer determines the magnitude of the bank angle at this higher than V_{MC} speed, which usually is 3° (for minimum sideslip and hence, maximum Rate of Climb). The bank angle should also be included in the legend of the OEI performance data charts.

4.10. **Pressure Altitude**. *"Altitude measured from standard sea level pressure (29.92 in. hg.) by a pressure or barometric altimeter. It is the indicated pressure altitude corrected for position and instrument error. In this Handbook, altimeter instrument errors are assumed to be zero"*.

4.10.1. The symbol for pressure is in. Hg (Inches Hydrargyrum – or Mercury) or hPa (hecto Pascal).
Pt.23, SFAR No. 23 requires in § 14: *"The altimeter system calibration must be determined and shown in the Airplane Flight Manual. FAR § 23.1325 (e) also requires calibration. FAR § 23.1587(a)(11) requires to furnish the altimeter system calibration in the AFM"*.
Assuming altimeter instrument errors to be zero is not in compliance with FAR 23.

5. Section 2. Limitations

5.1. **§ 2.3 Airspeed Limitations**. *"Provide airspeed limitations and the operational significance of such limitations. The name, symbol, value in knots, CAS, and IAS (assuming zero instrument error), and the significance of each airspeed, shall also be provided. Where the airspeed values may be applicable to more than one configuration, the more conservative IAS value shall be used. (See Figure 2-1)"*.

5.1.1. This requirement complies with FAR 23, except for *"IAS (assuming zero instrument error"*. So, GAMA recommends the airplane manufacturers to provide the pitot-static position errors, but not the airspeed indicator instrument error, which can be as large as the position error. The writer of this phrase obviously has objection against the use of the instrument correction, and hence tells pilots, via the recommended contents of the AFM/POH, to ignore the error, despite the requirement in FAR 23 to furnish the error (§ 4.3.2 above). When the instrument error is assumed zero, the pilot cannot explain the differences in airspeeds indicated on the two or three different airspeed indicators in the cockpit either. In a type generic AFM/POH, the IAS cannot be provided because the instrument errors are not known to the AFM-writer, but must be furnished to the pilot in a different way.

5.1.2. Both the instrument and the position errors are required for the pilot to determine the Indicated Airspeed to maintain a desired AFM-published limiting, procedural, or performance Calibrated Airspeeds.

5.2. **Figure 2-1. Airspeed Limitations, general.** This Figure (Table) has four columns, Speed, CAS, IAS, and Remarks. The fact that an IAS column is included indicates that the writer expects that the manufacturer supplies IAS data, besides CAS data. As explained in § 3.4.1 above, this is impossible. The writer may also expect the airplane manufacturer or the pilot to fill in the IAS, but the manual is usually for a series of airplanes, not for only one tail number which has an ASI of which the instrument error might be known. Often there are more ASIs in one cockpit; then the question is for which ASI is the IAS column in Figure 2-1? And when an ASI is maintenance replaced, is the airplane then grounded until the AFM/POH is amended? Limiting airspeeds are usually in the AFM/POH part that requires approval of the FAA or equivalent organization, which takes time during which the airplane cannot be operated. To prevent this from happening, FAR 23 requires the ASI to be calibrated separately from the pitot-static system, of which the writer obviously was not aware.

5.3. **V_{MCA}.** The remark in Figure 2-1 is: "*This is the minimum flight speed at which the airplane is directionally and laterally controllable, determined in accordance with the Federal Aviation Regulations*".

5.3.1. This remark is neither in accordance with the Federal Aviation Regulations (FAR 23.149), nor with the design methods used by the airplane manufacturers, and nor with the FAA Flight Test Techniques either. The AFM-published V_{MC} is the Calibrated Airspeed at which it is possible to recover from a sudden engine failure, and thereafter maintain straight flight and, at the option of the manufacturer, with an up to 5° of bank into the good engine. Being controllable is quite different from the capability to maintain straight as required in FAR 23.149. Pilots often turn immediately after engine failure, or do not prevent a turn, and lose control. Turning at V_{MC} with maximum asymmetrical takeoff thrust is not required in FAR 23.149; airplanes do not have to be designed to do this. When the bank angle is smaller or larger than the favorable 5° into the good engine, the actual V_{MC} increases, and if the airspeed is as low as the published V_{MC}, then control will be lost (Figure 5 above). Many airplanes crashed due to the loss of control during turns while one or two engines were inoperative or separated from the wings, even several Boeings 747. Hence, the airplane is not controllable, the pilot cannot move around at airspeed V_{MC}, because the control surfaces are only sized to maintain steady straight flight. Pilots must be thoroughly made aware of this limitation (§ 4.7.12 above).

5.3.2. The interpretation of V_{MC} in Table 2-1 is very wrong; and has caused, and will again cause fatal accidents if not improved.

5.4. **Figure 2-2. Airspeed Indicator Markings**. This Figure also has, besides a Markings column, an *"IAS Value or Range"* column, and a column headed *"Significance"*. The *"IAS Value or Range"* column in Specification No. 1 is empty; the writer may expect here as well that the manufacturer completes this column with IAS data, which he cannot; he can only provide CAS data. Refer to § 5.2 above.

5.5. Each airspeed indicator is calibrated, after which the instrument error is known. It could be given thought to place the markings at the instrument corrected airspeeds Vic (§ 3.2.10 above), or even at a point including the position error, if the ASI part number is for a generic type and series of airplane. Then the pilot can see in a blink of the eye whether the airspeed pointer is above or below the CAS limits, which the writer of Specification No. 1 obviously likes.

5.6. **Figure 2-2. Red Line**. The significance of the Red Line is "*Airspeed Control Speed (Multi-Engine Only)*"

5.6.1. This must be 'Minimum Control Speed (Multi-Engine Only)'.

6. Section 3. Emergency Procedures

6.1. **§ 3.1 (a) General**. *"Airspeeds used in the Emergency Procedures shall be specified in terms of Indicated Airspeed, assuming zero instrument error. in order to make the information as directly usable as possible."*

6.1.1. It would be preferrable to have safety critical airspeeds in Emergency Procedures directly readable from the ASI, but this is regrettably impossible, as explained in § 3.2 above. This line calls for neglecting both the position error and the instrument error, which is not in compliance with FAR 23. The sum of both errors, being the difference between CAS and IAS, is allowed to be up to (5 + 2 =) 7 knots. Hence, the Indicated airspeed is, in a worst case, allowed to be up to 7 kt higher or lower than the Calibrated Airspeed that is presented in emergency procedures in the AFM/POH. As explained above, a type generic AFM/POH can only present such data in CAS. The pilot must know about this, has the right to know for the sake of his own safety and of his passengers. Airspeeds can never be directly useable because of the unavoidable manufacturing errors in air data systems, see also § 5.1 above. The writer of this line is obviously and regrettably not familiar with air data systems and with FAR 23.

6.1.2. V_{MCA} is the minimum airspeed to be observed in anticipation of, and following an engine failure. When the pilot maintains V_{MCA} as displayed on the ASI and the errors, assumed to be zero, but happen to be maximal, the Calibrated Airspeed of the airplane might be lower than V_{MCA} (in CAS). When indeed an engine fails during takeoff, control will be lost at once.

6.1.3. This paragraph is a call for catastrophic accidents.

6.2. **§ 3.3 (b) Airspeeds for Emergency Operations**. *"In addition, for multi-engine airplanes, include the one engine inoperative best rate of climb speed (V_{YSE}), the one engine inoperative best angle of climb speed (V_{XSE}), and the air minimum control speed (V_{MCA}) with the critical engine inoperative. For these speeds, provide the significant conditions under which they may be obtained (aircraft weight, atmospheric conditions, etc.)"*.

6.2.1. V_{YSE} and V_{XSE} were not defined in § 1.31 (a). Here the critical engine is mentioned, but knowing which of the engines is the critical engine is only of relevance to the test pilot who determines V_{MCA} (§ 4.7.3); the AFM-published V_{MCA} is the V_{MCA} when the critical engine is inoperative, is the highest V_{MCA} after failure of either engine, the worst-case. When the other engine fails, actual V_{MCA} is a few knots lower, which is safer. For (airline) pilots, it should not make any difference which engine fails. The published V_{MCA} applies in anticipation of, and following the failure of either engine. The engine emergency procedures are the same after failure of either engine. So, don't mention *"critical engine"* in a procedure for pilots.

6.2.2. The significant conditions under which the mentioned speeds are obtained include not only aircraft weight and atmospheric conditions, but also the bank angle and the thrust level of the remaining engine. In fact, the magnitude of control deflections should also be mentioned, because when the rudder is not maximum deflected, as was used to determine V_{MCA}, the airspeed needs to be higher for the rudder to generate an adequate aerodynamic side force to counteract the engine yawing moment. Every pilot remembers the lift equation:
Lift = $C_{L\alpha}$ ½ρV^2 S. The aerodynamic forces generated by not only the wings, but also by the fin with rudder are proportional to the shape of the airfoil ($C_{L\alpha}$), in this case fin with rudder, and to the square of the airspeed (V^2), see also § 3.4.4 above.

6.2.3. It is good to include these speeds in the engine emergency procedures, but these speeds must be accompanied by *"the significant conditions under which they may be obtained"*, and hence, for which they are valid, which do not only include *"aircraft weight and atmospheric conditions"*.
This objective in fact requires the manufacturer to also provide the bank angles for which V_{YSE}, V_{XSE} and V_{MCA} are valid and, in addition, to mention that these airspeeds are valid only during *"straight flight"*, while the asymmetrical thrust is maximum, which is regrettably never done because AFM/POH writers don't know, and reviewers don't notice, while FAR 23.149 requires to determine V_{MC} for maintaining *"straight flight"* after the initial motions due to a sudden failure (§ 4.7.2). Also, a Caution should be included in Engine Emergency Procedures reminding pilots never to turn at airspeeds as low as or near V_{MCA}, but to increase airspeed first, to prevent the loss of control (§ 4.7.12 above). The manufacturer should advice.
The writer of the Specification regrettably did not mention the asymmetrical thrust level, the control deflections, and the bank angle as associated significant conditions either, because he obviously didn't have the required aeronautical engineering knowledge, and was never made aware. Safety Critical Procedure Development requires high level multi-disciplinary knowledge (refer to the paper in footnote 8).

7. Section 3A. Abnormal Procedures

7.1. § 3A.1 (a) General. *"Airspeeds used in this Section shall be specified in Indicated Airspeed, assuming zero instrument error, in order to make the information as directly usable as possible"*.

7.1.1. This is almost the same objective as is quoted in § 6.1 above. Refer to the remarks from § 6.1.1 above.

8. Section 4. Normal Procedures

8.1. **§ 4.1 (a General)**. *"Airspeeds used in this Section shall be specified in Indicated Airspeed, assuming zero instrument error, in order to make the information as directly usable as possible".*

8.1.1. Refer to § 6.1.1 above as well for remarks.

8.2. **§ 4.17 Procedures for Practice Demonstration of V_{MCA}**

8.2.1. During reducing the airspeed to demo V_{MCA}, several false ϕ = 0 points can be observed, when the ball is not centered; pilots need to be made aware. Demo V_{MCA} during straight flight with bank angle zero, and with bank 5° into the good engine, and note the difference. Demonstration of V_{MCA} is not without risks; spin, spiral, and V_{MCA} recovery should be reviewed, and the demo conducted at a safe altitude (≥ 5000 ft AGL). Also refer to the paper in footnote 11.

8.2.2. Avio*Consult* has available a syllabus for *V_{MCA} Training and Demonstration In-Flight*, which includes the description of the preparation, of preflight review requirements, and of the safe conduct of the demo in-flight or in a simulator.

9. Section 5. Performance

9.1. **§ 5.15 Associated Conditions**. *"Each item of Airplane Performance shall include a statement of significant conditions associated with the data".* The last sentence is: *"All calibration data should cover the appropriate speed operating range. (Figure 5-2 and 5-3)".*

9.1.1. A minimum list of eight significant associated conditions is provided, but the most important ones are not, which are bank angle and speed, that should be added on top of the list. Refer to § 4.7 above.

9.1.2. The last sentence raises a question. Does *"all calibration data"* cover the pitot-static system error only, or also the instrument error, which elsewhere in the Specification is to be assumed zero?

9.2. **§ 5.41 Minimum Performance Presentations for ME Airplanes**.
(b) Airspeed Calibration. *"Data shall be presented as Calibrated Airspeed (CAS) versus Indicated Airspeed (IAS) assuming zero instrument error."*

9.2.1. What in fact is written here is that the difference between CAS and IAS is only the position error of the pitot-static system. The instrument error, which is allowed to be ± 2 kt, is neglected. Refer to § 3.3 above; it is not authorized by FAR 23 to use Indicated Airspeed and assume zero instrument error.

9.2.2. These remarks also apply to Specification § 5.37 for single engine airplanes.

9.3. **§ 5.41 (d) Stall speeds.** *"Data shall be presented as indicated and calibrated airspeed versus flap configurations (any flap position for which performance has been quoted), angle of bank and weight with throttles closed"*.

9.3.1. Like the other speeds, stall speeds in an AFM/POH are also determined in CAS. That is how the test pilots report V_S following flight-testing. CAS minus position error and lag error is Vic, the instrument corrected airspeed. This is the indicated airspeed minus the instrument error. V_S cannot be presented as indicated airspeed (because the applicable instrument error is not known).

9.4. **§ 5.41 (h) Rate of Climb**.
"*3. Rate-of-Climb-one engine inoperative with flaps set to the enroute position and landing gear retracted*".

9.4.1. When one of the engines failed or is inoperative, and the wings are kept level, the airplane settles in an equilibrium of forces and moments with an unavoidable sideslip. This causes drag and reduces the climb performance. The sideslip can be reduced with attaining and maintaining a small bank angle of approximately 3° into the good engine (§ 4.7.4 above). Hence, it is important for the pilot to know whether the AFM-presented Rate of Climb data are valid with or without the small bank angle. This should be included in the legend of the data tables or charts.

§ 5.41 (h). *"4. Rate-of-Climb-Balked Landing. The climb speeds appropriate to each configuration shall be scheduled in IAS. (Figure 5-13 or 5-14)"*

9.4.2. Once again, the climb speeds cannot be provided accurately in IAS, for reasons described above. All performance data should and can be provided in CAS only, in a type-generic AFM/POH.

9.5. **Figure 5-1**. **Introduction to tabulated performance.** In this Figure, IAS is presented in tabulated takeoff performance data.

9.5.1. Performance data in IAS are not accurate; CAS should be used as mentioned many times before. The airspeeds for lift-off and 50 ft height above the takeoff surface are presented in IAS. Lift-off speed is normally not used; rotation speed V_R is (FAR 23.51(a)).

9.6. **Figure 5.2. Airspeed Calibration Error – Normal System**. *"Note: Indicated Airspeed Assumes Zero Instrument Error"*.

9.6.1. Although titled Airspeed Calibration − Normal System, the chart does not present airspeed calibration, but Instrument Corrected speed (Vic) versus Calibrated Airspeed, i.e. only the position error. The note in the heading tells the pilot that the indicated airspeed assumes zero instrument error, hence, the instrument error is not included, but on the horizontal axis, the label is IAS Indicated Airspeed – knots which the pilot reads from the ASI, while the label should be IAS – Instrument Corrected speed (Vic, § 3.3.3). The pilot must add the (±) instrument error before entering the chart (Figure 1). When the instrument error is indeed zero, then Vic is equal to IAS, but most ASIs have an instrument error up to ± 4 kt (§ 3.2.8 above), while the position error as shown is − 3 to − 4 kt. In the legend of this chart should be included to add the instrument error to the IAS (the sum is Vic) before entering the chart to read CAS for use in performance data and for limiting speeds. The instrument error should not and may not be neglected (by FAR 23).
An example. If the V_{MCA} of the airplane is 84 KCAS, as measured during flight-testing, the instrument corrected IAS is 80 kt (Figure 5-2). When the instrument error is zero, the V_{MCA} shows as 80 KIAS on the airspeed indicator. However, if the instrument error was +2 kt, then the V_{MCA} of the airplane is 82 KIAS on the airspeed indicator. If the pilot maintains the redlined V_{MCA} of 80 KIAS and an engine fails, the airspeed is 2 kt below the actual V_{MCA}, and control will be lost, while the pilot believes to be safe. If the airspeed was decreasing, the instrument error due to lagging might be 3 kt. If the wings are kept level, the actual V_{MCA} increases too, for a DHC-6-100 with 6 kt[13]. And during other bank angles actual V_{MCA} increases even more (Figure 5 above). Airspeed theory is a bit more complicated than GAMA makes us believe it is.

9.6.2. Is *"assumed zero"* just meant for the Specification No. 1, because no airplane type/ ASI Serial Number is used? Or do manufacturers consider it an advice to assume the airspeed indicator instrument error to always be zero? Recommending to assume an error to be zero is misleading, and will have caused fatal accidents. This is not in compliance with Airworthiness Regulation FAR 23 either. The airplane may not be considered airworthy if not both the position and the instrument errors are available to the pilot and are being used. Refer to § 3.4.4 above for the large effect on airplane control of a small airspeed error.

9.7. **Figure 5.3**. **Airspeed Calibration Error – Normal System**.

9.7.1. The same remarks apply as for the previous Figure 5-2.

9.8. **Figure 5-4**. **Altimeter Correction − Normal System**". *Note: Indicated Airspeed and Indicated Altitude Assume Zero Instrument Error*".

9.8.1. The graph on the left side is the position error for flaps up, the graph on the right side the position error for flaps down. The errors depend not only on airspeed, but also on altitude, as shown. The airspeed on the horizontal axis for both graphs is shown to be IAS, but should be the instrument corrected IAS (Vic). Adding the instrument error to the IAS reading is required to obtain Vic.

9.8.2. As concluded above for Airspeed Calibration, these altimeter correction graphs are misleading because IAS is used, rather than instrument corrected IAS (Vic).

9.9. **Figure 5-5**. **Altimeter Correction Table**.

9.9.1. Same comments as above for Figure 5-3.

9.10. **Figure 5-6 and 5-7. Stall speeds, Power Idle**.

9.10.1. In this graph, the IAS and CAS are represented by a solid resp. dashed line that decreases with decreasing weight, as the stall speed normally does. The airspeed difference between the IAS and CAS lines is not specified as being the position error. The instrument error is not mentioned to be assumed zero, as in the legend of other graphs. The position error is usually presented in a separate graph, because it is airspeed dependent. In the Specification, the position error is presented in Figure 5-2, but the numbers are very different from the numbers in Figure 5-6. So, what do the graphs in Figure 5-6 show? Pilots have the right to be able to find correct data.

9.10.2. The remarks on Figure 5-7 are as before on tabulated CAS and IAS data. These data cannot be correct for any installed ASI.

9.11. **Figure 5-13**. **Rate of Climb − One Engine Inoperative.**

9.11.1. The associated condition that a small, usually 3° of bank angle is required to achieve maximum Rate of Climb is not included in the legend of this Figure. The small bank angle reduces the sideslip, and hence the drag, increasing the climb rate (Refer to Figure 5). Here again, climb speed is presented in IAS, while the origin of the data is in CAS, as provided by the flight-test department of the manufacturer. IAS in one airplane is not IAS in another airplane of the same type.

9.11.2. The same remarks apply to the legends in Figures 5-14 to 5-20.

9.12. **Figure 5-30. Identification of Graphs or Tables Multi-Engine Airplanes**.

9.12.1. It must be possible for a manufacturer to calculate and present a graph with the effect of bank angle on V_{MCA}, like Figure 5 above. This will remind pilots of the requirement to increase the airspeed when turns must be made while One Engine is Inoperative. The paper referenced in footnote 12 on page 17**Fout! Bladwijzer niet gedefinieerd.** also presents the method to calculate a graph with V_{MCA} versus weight and bank angle when stability derivatives of the required configuration are available.

10. Conclusions of the Review of GAMA Specification No. 1

10.1. GAMA Specification No. 1 was, according to its Preface (§ 2.1.1 above), "*developed by representatives of member companies of the General Aviation Manufacturers Association (GAMA) for use in preparing Pilot's Operating Handbooks that:*

a. Are of maximum usefulness as an operating reference book for pilots;

b. Meet government regulatory requirements where applicable; and

c. Meet industry standards for scope of material, arrangement, nomenclature, and definitions".

10.2. Given the remarks in this limited review, the representatives of member companies of the GAMA who prepared Specification No. 1 were regrettably not competent at a high level of knowledge of pitot-static systems, of the function and role of airspeeds used in airplanes, and of flying qualities of multi-engine airplanes when one of the engines fails or is inoperative.
A Pilot Operating Handbook prepared using this Specification is not of maximum usefulness on these subjects as a reference book for pilots, does not meet safety-critical regulatory requirements of FAR 23, does not meet airplane design methods as taught at aeronautical universities, and does not meet experimental flight test techniques as prescribed by the FAA in Advisory Circular 23-8C as taught at test pilot schools and as used by their graduates in the industry either. Pilot's Operating Handbooks that are prepared using the guidance in Specification No. 1 do not meet the intent of requirements in FAR 23, which is to provide the pilot with all the information needed to operate his aircraft in a safe manner. In terms of the Cooper-Harper scale that test pilot schools teach to be used for rating handling qualities, the guidance in Specification No. 1 has major deficiencies; its improvement is mandatory.

10.3. The members of GAMA, who used Specification No. 1 to prepare the AFM/POH of their airplanes, were put on the wrong foot by a deficient Specification which obviously remained undisclosed and/or uncorrected, neither by their own engineers and test pilots during the past 50 (!) years, nor by inspectors of the FAA and equivalent authorities, nor by accident investigators of NTSB and equivalent organizations worldwide. It is incomprehensible that obviously nobody in the 50 years that the GAMA Specification No. 1 exists reviewed it with proper knowledge and recommended improvements. This proves that there is much incompetence out there; aviation is drifting into failure. People lose their lives because of improper procedures and lack of knowledge. The deficient guidance in the GAMA Specification No. 1 on the use of calibrated and indicated airspeeds and of engine failure related definitions, procedures, and safety speeds must have contributed to many if not all 520 fatal accidents and 4,150 casualties after engine failure during the past 25 years (§ 1.1). A few specific conclusions follow.

10.4. GAMA Specification No. 1 instructs the members to use Calibrated Airspeed only as necessary to comply with certification requirements, *"as the pilot works exclusively with Indicated Airspeed"*. It indeed seems easier for a pilot to work with IAS, but this is not the intention of, and is not approved by FAR 23, because IAS includes errors that a pilot needs to compensate for by adding two corrections, the position error and the instrument error. These errors cannot be avoided (in mechanical instruments). GAMA recommends to assume the instrument error to be zero, and therefore does not comply with FAR 23 which requires this error to be determined and furnished to pilots. Considering the instrument error to be zero has great effect on maintaining the level of safety that airspeed limitations, furnished in the POH/ AFM, are supposed to provide. A two-knot instrument error might not seem large, but such a small error on an airspeed of 80 knots has a very large effect on the control power generated by the aerodynamic control surfaces, which is proportional to V^2 ($80^2 – (80 − 2)^2$ = 316 units of force), and hence, on the equilibrium of forces and moments for maintaining control of the airplane (§ 3.4.4).
As the use of zero-instrument errors is not in compliance with airworthiness regulation the airplane cannot be considered airworthy. Takeoff could be conducted at too low an airspeed, the stall speed might be higher than indicated, control could be lost when an engine fails or is inoperative, or a tail scrape could occur during touchdown. Both the position and the instrument errors are required to be furnished too, and used by the pilots.

10.5. GAMA recommends to use Indicated Airspeeds in tables and charts in an AFM/POH, but the instrument error cannot be included in the AFM/POH of a series of a type of airplane, because the errors of all individual Airspeed Indicators in the whole fleet, for which the AFM/POH applies, are and cannot be not known. Working with IAS in an AFM/POH would require a specific AFM for every tail number, i.e. for every individual Airspeed Indicator, because of the instrument errors that are different for each Airspeed Indicator. Each of these many manuals would require approval by the responsible authorities. Replacing a defective Airspeed Indicator would require an AFM/POH amendment over many pages, and approval by the authorities, which cannot be achieved, can it?
Therefore, as also required in FAR 23, all the performance data, the airspeed limitations, and the operational speeds in the AFM/POH should be furnished in CAS, because CAS is measured by a calibrated system, applies to a whole fleet of the same airplane type, and is independent of position and instrument errors. Temperature and altitude do not affect CAS; CAS has the same significance on any day, CAS today, even if hot or high, is CAS during a standard day. CAS is therefore the most important airspeed for pilots.
GAMA Specification No. 1 does not comply with FAR 23 and FAA Flight Test Guides on these subjects, and should not have been approved by the authorities (§ 3.4.4).

10.6. The definition and use of the minimum control speed V_{MC} or V_{MCA} is neither in compliance with its definition in FAR 23.149, nor with the way V_{MC} is determined during flight-testing in accordance with FAA Flight Test Guide AC 23-8C, nor with the airplane design techniques. When one of the engines is inoperative, the airplane is not designed to be controllable during turns at V_{MC}, but is designed to maintain straight flight only, when the thrust is maximum (FAR 23.149), and while maintaining a small bank angle away from the failed engine. A much higher airspeed than V_{MC} is required for keeping the wings level during straight flight and during turns when an engine is inoperative. A pilot controls V_{MC} with bank angle and asymmetrical thrust level (§ 4.7.10). Pilots are not made aware of these associated conditions. GAMA Specification No. 1 does not recommend to include these in the V_{MC} definition and in engine emergency procedures as a reminder (FAR 23.1581(a)(2)), § 4.7.12 above); the writers of Specification No. 1 were obviously not aware either. Physics is everywhere, though.

10.7. Pilots receive their multi-engine training in Part 23 airplanes, and take this experience with them during their whole career in Part 23 or 25 airplanes. Wrong learned is wrong applied. Flawed foundational knowledge inevitably leads to incorrect implementation in the future, as proven by accidents after engine failure with large airplanes. ICAO would call the misuse of V_{MC} Systemic Errors. Hence, GAMA Specification No. 1 is relevant to preventing Systemic Errors as well (§ 4.7.15). AFMs of Part 25 airplanes should be reviewed on the same subjects.

10.8. **The FAA** has reviewed the Specification (as stated on page v). This review by Avio*Consult* proves that a POH that meets the Specification does not meet the intent of all of requirements in FAR 23 and does not use the guidance for and experience of flight-testing airplanes in FAA Advisory Circular 23-8C (§ 2.3.1), and the limitations caused by sizing the aerodynamic control surfaces by the manufacturer. The review by the FAA was not adequate, and could not prevent the many accidents after engine failure during the period that Specification No. 1 was available and used to prepare AFMs and/or POHs. The FAA approved inappropriate definitions of the minimum control speed, and the use of zero instrument errors of airspeed Indicators, while FAR 23 requires these to be calibrated and the errors to be furnished to the pilots. Airspeed errors up to 5 kt are obviously acceptable, but can easily lead to the loss of control at low flying speeds after engine failure (§ 3.4.4 and § 6.2.2). The FAA inspectors of Specification No. 1 were obviously not (made) aware.

10.9. The requirement for presenting all AFM operational airspeeds as indicated airspeeds (FAR 23.1581(d) is contrary to the requirement to calibrate and furnish both the position and instrument errors separately (FAR 23.1323(b)). FAR 23.1323(a) requires calibration to indicate true airspeed at sea level with standard atmosphere, which is equal to CAS. It is impossible to present accurate indicated airspeeds in an AFM/POH that applies to a series of a type of airplane (§ 4.5). FAR 23 is not consistent in the use of airspeeds (§ 3.3).

10.10. This review proves that it indeed takes well educated engineers and pilots to write faultless manuals and verify the content; it is worth the cost and effort, because it will prevent accidents and save lives, of both pilots and their passengers. Flight Manuals of many more, if not all multi-engine airplanes require review and improvement. During the research for the written papers and this review, it was regrettably noticed that also very many inappropriate papers and videos on engine-out flight are published on the Internet, and on YouTube.
Poverty of knowledge leads to disinclination and incompetence, causing aviation to drift into failure, which is a process that is ongoing at an increasing pace. *Philosopher* Arthur Schopenhauer wrote *"Every man takes the limits of his own field of vision for the limits of the world"*.
For the sake of aviation safety, the self-assumed high levels of training, competence, and experience, i.e. the own field of vision, of many people in aviation, is not sufficiently wide to prevent fatalities. Universities and Test Pilot Schools widen the field of vision of aviators which results in deep understanding; opinions of the incompetent don't and require unlearning.
Douglas Adams once said: *"Human beings, who are almost unique in having ability to learn from the experience of others, are also remarkable for their apparent disinclination to do so".*
NTSB Board member Dr. Earl F. Weener used this expression in an NTSB Most Wanted List presentation *"Loss of Control During Takeoff and Landing"* (April 13, 2013)[15]. Dr. Weener regrettably did not respond to a letter from Avio*Consult*, nor did the FAA, ATSB, and many more organizations and manufacturers who were informed. Douglas Adams obviously hit the right note. *"The Truth Is Not Always Welcome"* as Schopenhauer also wrote.

11. Recommendations

11.1. Withdraw Specification No. 1 immediately, and Inform member manufacturers of the deficiencies in Specification No. 1 as presented in this review. The Specification must be revised by people who indeed have the proper high level aeronautical expertise, who studied pitot-static systems and airplane control at MSc or test pilot school level, using this review. Airline pilots are educated and trained to operate airplanes and must participate, but are not qualified to describe and explain pitot-static systems and flying qualities of airplanes, including engine-inoperative flight. Safety Critical Procedure Development requires high level multi-disciplinary knowledge (§ 6.2.3).

11.2. To prevent any more unnecessary catastrophic accidents, GAMA should recommend member manufacturers to inform all operators of their multi-engine airplanes about unsafe definitions and associated conditions in the AFM/POH of multi-engine airplanes that were prepared using the guidance of Specification No. 1, emphasizing that airspeed and altitude instrument errors must be used rather than zero instrument errors, and that V_{MC} and other single engine speeds are valid only during straight flight, and increase considerable during turns.
Pilots have the right to know and understand how to prevent a dead engine from turning into a killing engine. They have the right to read reliable airspeeds on the indicators in the cockpit. They have the right to be provided with excellent AFMs, POHs and training manuals. It is the duty and responsibility of the members of GAMA to provide these (FAR 23.1585(a)(1) – § 4.7.12 above).

11.3. Include in Section 10, Safety and Operational Tips, in GAMA Specification No. 1 a summary of airspeed measurement, calibration, and display. Also explain flight with an inoperative engine of multi-engine airplanes, including the effects of bank angle, weight, and thrust level on the minimum control speed. There is some important unlearning to do.

11.4. Recommend manufacturers of computerized air data systems to enable entering both the calibrated position error of the pitot static system and the errors of the air pressure converting

[15] NTSB Most Wanted List, Presentation by Board Member Dr. Earl F. Weener https://www.youtube.com/watch?v=f78kS4Xzbis

system (instrument) errors into the computer system following proper calibration, and display only airspeeds as CAS to pilots (§ 3.2.11).
In addition, present cues on the attitude display, such as advisory bank angle eyebrows, which are continuously calculated using the lateral-directional stability derivatives of the airplane for the current configuration and (asymmetrical) thrust setting, to indicate to the pilot the bank angle limits of the current airspeed and thrust setting for maintaining control of the airplane (refer to the report in footnote 11, § 7.5.6).

11.5. Recommend the FAA to review FAR 23 and equivalent for consistent use of airspeeds (§ 3.3).

