Brief by Gilles Primeau, M.Eng., Pilot (private)

To the Standing Committee on Transport, Infrastructure and Communities (TRAN)

Regarding the subject being studied of the Aircraft Certification Process

High-Level Summary

Author submits this brief as a private citizen, following his independent and voluntary study of practically two years regarding the crashes of 737 MAX flights JT610 & ET302. His efforts notably converged to him sending Boeing, via registered mail, on March 5th 2020, with US Federal Aviation Administration (FAA) Administrator and Canadian Transport Minister in copy, a highly-detailed 44-page document(1, Attachments 6&7) containing 24 main technical questions, and subsequently submitting, on September 21st 2020, to the FAA, highly detailed comments[1] expanding to 36 his list of questions, following notably a review of the ET302 Interim Report (1, Att.5) and FAA's published Notice of Proposed Rule Making (NPRM) documentation(1, Att. 3&4), as part of their process allowing independent expert and public inputs. Author was also invited to and testified twice to this Committee, on March 10th 2020[2] & November 24th 2020[3]. Author also collaborated with information media sporadically[4,5,6,7,8,9,10], although his main effort consisted in working to share his findings primarily with Transport Canada Commercial Aviation (TCCA), the FAA and Boeing. A detailed timeline of the author's effort, as well as an outline of his qualifications, are presented at the end of this brief.

Based on the results of this study (which included when deemed necessary verifications with other aerospace professionals for corroboration or to solidify confidence; some are in the public domain and are cited[11,12], but others of a private nature also occurred), and based on his interactions with TCCA certification authorities, his *key conclusions are*:

Design-related items:

1) **Only the strict minimum design changes were made to the 737 MAX design. As a result *the aircraft only meets minimum safety standards, thus not deserving the characterization claimed by some that "it is the safest airplane in the industry following the unprecedented scrutiny it has been subjected to"*, due to, but not limited to, the next items #2) to #6). *Allowing some 4000 aircraft to be introduced in the worldwide market with so many outdated (by a half century) technologies, while contemporary design solutions offer safer designs, borders irresponsibility*.**

2) *There remains a latent/dormant failure condition in the corrected MCAS logic* (in the new MVS segment), which if combined with a need for an abrupt collision avoidance maneuver, could prevent the MCAS from performing its intended function and therefore result in an aerodynamic stall of the aircraft (potentially catastrophic at low altitude).

3) *The Horizontal Stabilizer Trim System (HSTS) of all 737 variants*, which was commanded by MCAS, eventually causing an irrecoverable dive in both MAX variant accidents, *is obsolete and far from matching contemporary redundancy and safety monitoring design practices*. This limitation is exacerbated on the MAX variant by the requirement of a high integrity, safety-critical MCAS-HSTS integrated pitch trim control function. This is highly-detailed later.

4) Beyond the HSTS obsolescence from item #3) above, following a quick study of the recent SJ182 accident (Jan. 9th 2021, 737-500), *two other flight controls technology obsolescence situations* were identified, also applicable to all 737 variants and although unrelated to the two MAX accidents: (a) *operation in manual reversion in case of loss of hydraulics*, and (b) *likely absence of adequate equivalent of a rudder travel limiter (RTL) function*.

5) *The autothrottle (A/T) function on the 737 exhibited unexpected behavior on ET302*; it did not disengage(12), and combined with not only the MCAS nose down commands, but also the increased control columns pull back forces induced by the erroneous stall detection, *made extremely difficult for the crew to apply the well-known basic piloting*

technique of "pitching to speed, powering to altitude", i.e. crew could not raise pitch angle to trade thrust for altitude to clear obstacles. *Other A/T-related accidents have happened before and after the 737 MAX accidents*.

6) Recent review of a document from another aerospace professional who testified to the US Congress[(11)] highlighted *severe shortcomings on the MAX production line, affecting notably wiring/connections*, i.e. production sequence disruptions with non-executed or failed execution of functional test procedures, as well as a found *design weakness on the angle of attack (AOA) sensor*. Not only were both the JT610 and ET302 practically new aircraft each experiencing wiring or electrical problems prior to the accident, but in addition, *these could be an explanation to a hypothesis early in author's investigation, to explain the sudden divergence of the left AOA sensor on ET302*.

Certification-related items*:*

7) Author has made *two recommendations* regarding certification regulations: (a) *modify the Changed Product Rule (CPR) to severely restrict "grandfathering" privileges*, and (b) *impose, via a new paragraph in article 25.1309 or elsewhere, execution of testing of critical systems in an integrated fashion (in addition to the usual individual component or system tests)*. The former is shared as a common belief at TCCA, which declared in TRAN Committee hearings it is actually championing it on the international scale, and the Joint Authorities Technical Review (JATR) Final Report[13] actually made it its first main recommendation ("R1"). The latter still isn't embedded in law, although the JATR report essentially reached the same integrated testing recommendation through its R6, an indirectly R8.

8) *The scope of the 737 MAX* ***design changes*** *essentially has been determined solely between the FAA and Boeing.* ***TCCA effectively was unable to impose the same rigid standards they apply to Canadian aircraft designs' (re)certification***, as author can confirm to have been able to observe while working over many years with a Canadian airframer and some of their system suppliers, and could demonstrate it through several examples. Worthy of noting, the European Aviation Safety Agency (EASA) asked for the implementation of a 3rd AOA source (possibly synthetic) for the MCAS, *which would protect against the latent MVS-related failure condition outlined in preceding item #2)*, but has accepted to defer its implementation until the MAX 10 variant, thus meanwhile exposing the fleet to this identified/known hazard.

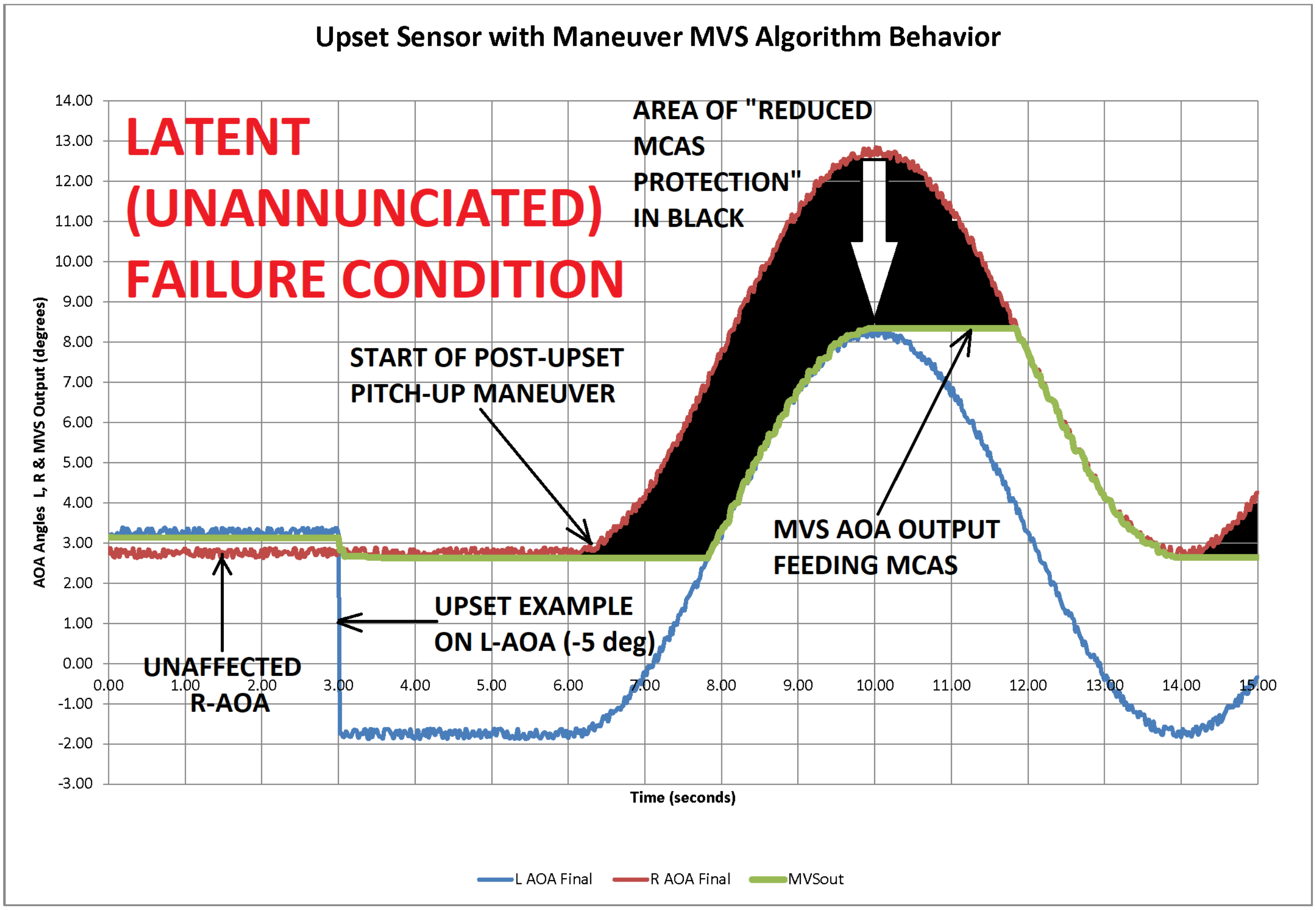
9) As a result of preceding item #8), *the only areas in which TCCA or other certification authorities were able to immediately affect change toward re-certification was regarding* ***procedures***, consisting for example in marking for ease of identification the stick shaker circuit breakers (CBs) and allow crew to disable them, or enhanced simulator crew training, and other operating procedure changes or additions.

10) As a result of preceding items #1) and #8), *ICAO rules which were crafted in the 1930s and still assign (re)certification authority only to the countries of design or manufacture, should be modernized*.

Detailed Justification of High-Level Summary Items (Same Numbering)

2) Remaining Latent/Dormant Failure Condition in Redesigned MCAS, in MVS Algorithm

FAA NPRM documentation[(1, Att.3)] described the *mid-value select* (MVS) algorithm which operates using 3 parameters: left AOA, right AOA, and MVS output, latter being the middle numerical value from those 3 choices, iteratively-computed. *Very importantly, the MVS algorithm does not trigger a fault if the difference between the L&R AOA signals is less than 5.5°*. The author developed a simulation of the MVS algorithm, with several adjustable parameters including independent random noise on each AOA source for representativeness. The scenario illustrated in the next figure highlights a potentially hazardous situation when a specific type of AOA upset is combined with a required crew maneuver:



Initially, both AOAs track each other normally and the MVS algorithm selects either the L or R AOA signal, both adequate. *Postulate firstly that suddenly, as happened on ET302, one AOA suffers an upset (L-AOA in blue), but toward LOWER values, and by less than the MVS algorithm's 5.5° differential fault threshold*. Due to the MVS algorithm logic, its output (green trace) will correctly switch to the unaffected other sensor (R-AOA in red). *Postulate also secondly that the crew later has to make a sudden high amplitude pitch up maneuver (typically for collision avoidance)*; the MVS output will remain constant despite both AOAs rising, until the affected L-AOA reaches the same MVS output value, at which point *the MVS output will switch to the signal from the* ***affected*** *L-AOA,* ***thus becoming biased down*** *by the magnitude of the L-AOA upset,* ***thereby feeding the MCAS with a lowered activation threshold***, delayed by a potentially critical amount of time to prevent an aerodynamic stall in this dynamic example. *It's extremely important to consider the latent (or dormant, i.e. unannunciated) nature of this failure condition, because the* ***crew would be misled into believing the MCAS would intervene to avoid a stall if their collision avoidance maneuver was too aggressive*** *(which tends to be the case for urgent maneuvers), since no MCAS fault would be posted to the crew to warn it to be careful*. *The upset could happen long before the flight, for instance due to the sensor being hit during ramp operations, and remain latent/dormant*. Even simulator training can be misleading, unless this specific type of dormant upset could be injected by the simulation instructor, *unnoticed by the crew*, followed by creating obstacle avoidance conditions. *This latent failure condition is real and undeniable. The dependable relief from it shouldin principle have to take into account statistical considerations of exposure time to the AOA sensor upset/failure probability,* ***combined*** *with the probability of the need for an aggressive collision avoidance maneuver*. TCCA told the author that the MVS was reviewed by TCCA Engineering and critical cases evaluated by TCCA Flight Test in Boeing's Engineering Simulator, that these reviews and evaluations included Loss of MCAS with consideration for the MSV contribution, which led to the conclusion that the design was deemed acceptable. This conclusion, in the author's opinion, implies that the engineering analysis/evaluation and simulator testing showed absolutely no adverse effect from the presence of the failure condition, and without quantified comparative results this is hard to accept; any quantified degradation in aircraft handling quality from a delayed MCAS intervention would have been expected to lead to consideration, in the author's experience, for a Certification Continued Maintenance Requirement (CCMR), intended to inspect and test the AOA sensors at a regular frequency pursuant to the failure condition probability analysis, to prevent any failure dormancy from exceeding the analysis' parameters.

In that regard also, the author reminds the fact there was a remotely similar Random Transport Aircraft Risk Analysis (R-TARA) made by the FAA between the JT610 & ET302 accidents (on December 3rd 2018), predicting 15 more accidents over approximately 30 years (thus an average of once every two years), such that an airworthiness directive (AD) was decided upon instead of grounding the fleet after the first crash, based on an implementation of the MCAS problem fix taking less than two years, and less than 400 airplanes then being in service out of a postulated well over 4000 to eventually be in service. We all know what happened next: Another 737 MAX crashed less than 5 months after the first crash. *This potentially unsafe latent failure condition was recorded as main question #35 in the author's study*[1, Att2&3].

3) The 737 HSTS Should be Modernized to Contemporary Standards, Especially for the MAX

NOTES: (1) Author suggested a possible means to allow the 737 MAX to fly without a modernized HSTS based on a temporary maximum operating velocity (Vmo) restriction to be quantified via test flight, to the point of either too high manual trim wheel forces, or horizontal stabilizer slippage, in relevant mistrimmed conditions. (2) Author's reflex to be highly cautious of HSTS matters rests on the deep, warranted scrutiny that certification authorities applied on these systems following the Alaska Airlines flight 261 accident (in 2000)[14], in which all occupants perished.

Here are the technical arguments supporting the author's position:

a) *The use of MCAS to protect against a stall, using the coarse ON-OFF movement at constant rate of the whole Horizontal Stabilizer (HS) through the HSTS, is less safe than contemporary fly-by-wire (FBW) flight controls* which gradually displace the elevators (and the HS slightly if required in extreme cases); *think of the* ***analogy of using a 5-pound sledgehammer as a precision alignment tool***, in which the MCAS is the sledgehammer equivalent, instead of a proper, more precise alignment tool which would be a FBW system.
b) *No independent experts have been shown conclusive quantified evidence of the justification for the need of the MCAS* to comply with applicable regulations. It is publicly-known this was initially at high airspeeds and most likely as a result of windup turn certification testing and associated stick force per g requirements (at the control column forces). It's also publicly-known the envelope of MCAS authority was later expanded to include lower airspeeds, presumably in regard to associated stall characteristics. The originating configuration changes which led to the MCAS included the position of the LEAP engines and their effect on longitudinal stability. *Independent experts are fully justified to be demanding access to actual associated data,* with and without MCAS intervention.
c) *The HSTS's horizontal stabilizer trim actuator (HSTA, which Boeing refers to as the "jackscrew") has insufficient redundancies, with only one actuation electric motor*. **ALL** similar systems the author has worked on have 2 actuation motors (some models even have 3). NOTE: There used to be two motors on the 737 HSTA, until their associated functions were merged to use a single one. At least one incident occurred requiring ATC prioritization and which led to a HSTA motor replacement (West Jet flight 1245 of Dec. 1st 2018). This failure is currently categorized as not requiring further study; such situations merit a reassessment. This can not only be a safety hazard in some circumstances, but it also reduces function availability to the detriment of operators. For details, refer to directly-related author's questions 8, 17, 28, 33 & 34, as well as indirectly-related questions 1, 13 & 20 (in main questions matrix Excel file[1, Att.2,4&6]).
d) *Boeing's answer to the single HSTA motor limitation is the muscles of the crew as the backup to it to actuate a manual trim wheel*, which requires 15 turns of the wheel to cause one degree of displacement of the HS (which has 17° of total travel; each MCAS command was causing a 2.5° displacement). *The biggest problem with this obsolete approach, is the extremely high manual trim wheel forces in some foreseeable mistrim conditions*; should the single HSTA motor fail (itself or its control), *think of the* ***analogy of an unreliable car assisted steering system("power steering") failing in a tight, high speed turn***. Manual trim wheel forces must have gotten progressively higher as larger 737 variants were introduced, hence reliance on human muscles can't be guaranteed any longer as a backup to the only HSTA

actuation motor, in the high speed segment of the operating envelope and in all mistrim cases. ET302's Interim Report demonstrated this very well in sections 1.16.1 & 1.16.2[1, Att.5]. Note also that the former so-called "roller coaster maneuver" procedure was removed from documentation long before the introduction of the MAX variant, apparently without corresponding system design changes. For details, refer to directly-related author's questions 3, 5, 20 & 29, as well as indirectly-related questions 9, 10, 12 (with Fig. 3), 13, 16 & 17 (in main questions matrix Excel file[1, Att.2&6]).

e) *The manual trim wheel highly likely prevents distinguishing between genuine crew intent to trim manually, and an actual downstream HSTS component failure causing the actuator to be backdriven by aerodynamic loads. Therefore, the 737 HSTS is likely not equipped with adequate* ***uncommanded motion monitoring***. Author proposed a design solution consisting in sensing torque on the manual trim wheel to lift the ambiguity and allow proper *uncommanded motion* monitoring implementation. This is particularly relevant, based on a typical such monitor's capabilities from another aircraft model, which was compared against the ET302 HS uncommanded motion dynamics that occurred; this monitor would have detected the condition with **AMPLE** margin. On a typical HSTS, "tripping" the uncommanded motion monitor would lead to switching to a redundant channel, or function disabling with adequate crew annunciation (*which in the ET302 case would have prevented the last, 4th fatal MCAS command execution*). For details, refer to directly-related author's questions 3, 17 & 18 (in main questions matrix Excel file[1, Att.2&6]).

f) *The HSTA may be undersized in terms of capability to prevent slippage under high loads, and to actuate electrically against all foreseeable loads and mistrim cases in the operating envelope*. Notably, the last electric trim attempt by the ET302 crew, shortly before the 4th MCAS command, may not have provided the expected performance in terms of trim rate. For details, refer to directly-related author's questions 1, 18 & 19, as well as indirectly-related questions 8, 33 & 34 (in main questions matrix Excel file[1, Att.2,4&6]). *Author did not find Boeing's high-level responses on that matter, forwarded to him by TCCA, sufficiently satisfactory.*

g) *The HSTA appears to have slipped on both accident flights, sometimes below Vmo (and remarkably on ET302 whose HSTA had not suffered a abnormally-high duty cycle as on JT610)*. This is unexpected and raises the question regarding whether this actuator employs contemporary position holding means in the no-back section. *Has Boeing implemented on the 737 HSTA the intent of US Patent 6,109,415, granted to Boeing in 2000, which mandates use of skewed rollers ? Skewed rollers typically fail by jamming, thus causing a loss of function, which is considered less severe than slippage, which is the typical failure mode of carbon disks (now considered an obsolete technology), and causes a loss of integrity (actuator no longer reliable in preventing backdriving)*. For details, refer to directly-related author's question 2 as well as indirectly-related questions 18, 20 & 34 (in main questions matrix Excel file[1, Att.2,3,4&6]). *Author did not find Boeing's high-level responses on that matter, forwarded to him by TCCA, sufficiently satisfactory.*

h) *A very sudden, unexplained "jolt", in the order of 0.5°, of the JT610 HS surface position, near the end of the flight, was observed on higher resolution graphics of the FDR parameters* (a lower resolution version was used in the JT610 Preliminary and Final Report). The possibility that the HSTA's "no-back" function or some other braking feature failed or severely degraded on the JT610 HSTA following more than two dozen cycles of AND & ANU trimming, cannot be ruled out. *The other possible explanations could be (a) imprecision on the surface or actuator position sensing means, which would prevent detection of such movement as a signature of PLP failure followed by SLP engagement as mandated by TCCA in the author's experience, or (b) horizontal stabilizer surface backlash which could be a serious potential flutter problem.* For details, refer to directly-related author's question 13 (in main questions matrix Excel file[1, Att. 2&6]). [NOTE: Excel file defines the acronyms] *Author did not find Boeing's high-level responses on that matter, forwarded to him by TCCA, sufficiently satisfactory.*

i) *A new aircraft model ("clean sheet design") in the large transport aircraft category would have virtually NO CHANCE of certifying a HSTS design as on the current 737, primarily for the reasons outlined in the previous arguments. The FAA has mandated the design change for the HSTS wiring to comply with newer safety regulation regarding wiring separation; author* ***strongly*** *considers the rest of the HSTS should* ***also*** *get the benefits of contemporary means of HSTA failure detection and passivation*. Comparison with another critical system is useful here: Several years ago (pre-MAX) apparently the 737 wing high lift system (WHLS) was modernized; postulating that the modernized system has the (improved) capability of detecting (and react accordingly to) for example a slat panel skew caused by *a faulty system component which escaped quality control* (*such as what did occur recently with 737 slat tracks*[11]; one 737 aircraft could not complete its flight recently due to a flaps issue, but it is not known whether the case fits the example case description herein); *a modernized HSTS would be able to detect failures or degradations caused by a key faulty component; on another program the author worked on, a scenario of this type occurred, so the notion isn't speculative*. For details, refer to directly-related author's question 33[1, Att.2&4].

4) Other 737 Flight Controls Obsolescences

a) Manual reversion operation and inoperative rudder in case of total loss of hydraulics: This typically occurs following dual engine failure; the rudder becomes inoperative and the elevators and ailerons are operated in manual reversion, which can require up to 200 lbs force application on the control columns for instance and is very difficult; contemporary designs now rely on safer use of a ram air turbine (RAT) to maintain minimum hydraulic supply. *See also flights Air Transat 236 (in 2001)[15] & US Air 1594 (in 2009)[16] for additional justification; in both of those serious incidents, propulsion was lost, and had the crew been only able to rely of manual reversion, the likelihood of their becoming a catastrophe with several fatalities would have been much increased*.

b) *Likely absence of rudder travel limiter (RTL) function or adequate equivalent*; contemporary designs now rely on safer use of a RTL to prevent excessive rudder surface displacement at high speed, which can make extremely difficult continued safe flight and landing and even cause structural damage/failure. *See also flights United Airlines 585 (in 1991)[17] & US Air 427 (in 1994)[18] for additional justification; in both accidents, all occupants perished*; it's unclear which design changes resulted from those accidents, however the use of higher integrity contemporary RTL functionality would be expected to reduce the likelihood of such accidents.

5) 737 Autothrottle (A/T) Problems

ALL variants of the 737 may still be suffering from problems induced by the A/T function. Beyond its unexpected behavior on ET302 that was described in the accident's Interim Report[1, Att.5] and recently publicly-corroborated by a FAA safety engineer[12]. The Preliminary Report recently published on the January 9th 2021 accident of 737-500 flight SJ182[19], in which all occupants perished, also clearly outlines the contribution of the A/T. *Furthermore, Turkish Airline flight 1951 (in 2009, a 737-800) also involved the A/T function; in this accident, 9 occupants perished*, and an independent expert's extensive study and report outlined several shortcomings seemingly not given due diligence and subsequent action[20].

6) 737 Production Line Issues (Wiring Notably) and Possible AOA Sensor Design Weakness

Less than a day after the publication of the ET302 Preliminary Report, the author noticed the sudden divergence of the L-AOA signal, from approximately 15° that both AOA sensors were then reading, to approximately 75°. Immediately, the author identified that this was a close equivalent to the L-AOA's signal being subjected to a 90° value reduction, followed by a sign inversion; (15 – 90) x (-1) = 75.

AOA vanes use, for sensing/measuring rotation, resolvers or rotary voltage differential transformers (RVDTs), which are essentially electrical transformers in which the (usually fixed) primary windings are excited with a set sinusoidal frequency & amplitude, and the (usually movable) secondary windings' induced voltages are measured and compared to the primaries' signals to determine the amount of rotation. There will also typically be two secondary windings to help resolving ambiguity on the direction of movements, mounted in electrical quadrature, i.e. with a 90° effective electrical phase difference.

There are two main possibilities that ***might*** explain a hypothetical 90° shift and sign inversion of an output signal: a "jump" to a wrong segment of decoding algorithm (or, instead of through software, which may be implemented in part by electronic circuitry), or a malfunction affecting the wiring of one or more of the windings. *Or, this jump from 15° to 75° could simply have been an impressive coincidence; this is what was concluded shortly thereafter before concentrating on flight controls aspects, author's main expertise domain*. But the finding of the failing epoxy adhesive in the AOA sensor that had been removed and replaced on the aircraft just before the JT610 accident, and which was tested and also found to have an intermittent signal on one of its coils below 60°C (probe heat dependent), as found in the JT610 Final Report and re-emphasized by an independent researcher who also testified to the US Congress[11], reminded the author of a similar situation he had worked on in another program, in which another type of adhesive would yield and cause breakage of resolver windings on HSTA motors; *the design was fixed on that other program to prevent reoccurrences, and there is no indication that the same was done for the 737 AOA sensor.*

This is an element that allows questioning the hypothesis made by some of a bird strike on the ET302 flight to explain its left AOA sensor signal divergence; author peripherally referred to Ethiopian Airlines maintenance actions in the ET302 Interim Report (p. 22 2nd paragraph from bottom & pp. 27-28), under main question #26, as well as in main question #27 regarding functioning/logic of the probe heater[1, Att. 2&5].

NOTE: It must also be remembered that the L-AOA signal divergence not only triggered repeated MCAS activation, but also in parallel caused a erroneous stall detection which activated the stick shaker and massively increased the control columns pull back forces (while in parallel increasing airspeed also increased the manual trim wheel forces).

7) Other Observations Relative to Certifications Authorities Beyond Summary Items #7)8)9)

a) Retroactive application of the 2 recommended regulatory changes (see High Level Summary item #7) would force HSTS modernization. Said differently, had those regulations existed before the 737 MAX certification, chances are excellent that those two accidents would have been prevented not only by an improved HSTS, but also by discovering and fixing the MCAS original design flaws. The cost and time required would have been negligible compared to the enormous cost those tragedies have brought about. Boeing had the time, and certainly access to the financing, to implement a proper HSTS modernization, in the current pandemic environment of reduced air travel. Doing so would certainly have shown willingness to go beyond the strict minimum, acting honorably to regain the confidence of the public and of the certification authorities. For details, refer to the first four pages of the main 44-page document sent by the author to Boeing, particularly items 1a) and 1b) on page 1[1, Att. 6&7].

b) *The author believes the civil aviation industry requires a long-needed shift away from focusing on blaming the crews for accidents, to forcing the airframers to clean up their designs*. This predates the MAX crashes by decades, actually. It was reasonable to hope the MAX tragedies would initiate this shift, but this is not at all what took place.

c) *Two critical pieces of information were not included in EAD 2018-23-51 issued 11/07/2018: (1) hat a 5-second delay (after last HS movement) would reset the MCAS, and (2) that MCAS would not be armed when the flaps are at a non-zero position. Either of these two elements, had the ET302 crew been aware, could have prevented the 2nd crash (ET302).* Regarding the 1st element (5-second MCAS reset delay), crew would have understood the importance of putting back the STAB TRIM CUTOUT pedestal switches to the CUTOUT position after attempting electric trim near the end of the flight, and this would have prevented the last, fatal 4th MCAS command from being executed. Regarding the 2nd element (non-zero flaps positions), crew could have deployed them to the 1st detent (smallest selectable deployment), thus disabling the MCAS, and this remained feasible for a while until airspeed exceeded maximum velocity flaps extended (Vfe) for the 1st detent. For details, refer to directly-related author's main question 30[1, Att 2, 4&6].

d) *Other observations relative to potential interpretations of the same EAD: (1) It contains some text open to interpretation which may have compelled the ET302 crew to maintain some level of aft control column forces instead of fully trimming the HS back to maintaining a climbing attitude, before setting the pedestal STAB TRIM switches to the CUTOUT position*. ET302 crew may have thought, based on NG logic per which moving column in a direction opposite to HS trim movement interrupts trim action, that doing so could have prevented re-activation of MCAS; (2) The ET302 crew may have adopted a strategy trying to engage the A/P, based on EAD 2018-23-51 because it stated that an attribute of a repetition of the JT610 problems might prevent A/P engagement. Crew did succeed to engage the A/P on ET302 on the 3rd attempt and it remained engaged 33 seconds, so this could have contributed to confusion of the crew regarding whether they were experiencing the same problem as on JT610. For details, refer to directly-related author's questions 11 & 14, respectively[1, Att. 2,3&6].

e) *Additional argument in favor of having grounded the 737 MAX fleet after the 1st accident (JT610)*: In addition to the late finding of the R-TARA argument at the end of the detailed MVS algorithm matter, this topic was developed as a corollary/comment to author's main question 7[1, Att.2,3&6]. There is at least one precedent of this happening. It occurred in 2011, on a certified/operational Falcon 7X from Dassault Aviation. There was an incident that could have resulted in the catastrophic loss of an airplane and its crew; there was a pitch trim runaway, nose up, that only the skills of the copilot, a former air force fighter pilot, were able to contain, through essentially a 90° bank which transformed a pitch up situation into a high-g turn[21]. Control was recovered after approximately 30-seconds, *when motor thermal protection triggered* (full current to the motor kept being fed despite the actuator being hardover in full ANU position), *i.e. not through typically-implemented monitors that could have reacted much* faster. The motor thermal protection disengaged the faulty channel and switched control to another, unaffected channel (driving another redundant motor, which the 737 doesn't have…). After this event, the airframer went to the authorities to request that the fleet be grounded worldwide.

8) Author's Intent to Follow-Up with ICAO

The author intends to follow-up his study with efforts intended to reconsider the current certification authority framework. Since this framework was devised in the late 1930s, all major airframers now market their designs internationally. Structural elements, and aircraft systems, now largely consist in an international pool of suppliers. TCCA enjoys a very good reputation but was unable to impose design changes beyond those agreed between the FAA and Boeing, while EASA had to settle for a deferred implementation to what would seems as an adequate fix to the MVS algorithm risk. Instead of relying on limited resources from a given national certification authority, the opportunity exists to put resources in common on an international basis. The professionalism of international experts far outweighs ill-conceived intellectual property arguments, which should regardless yield to overriding safety considerations.

Main Milestones of Author's Study of the 737 MAX Crashes

1. 03/11/2019 Effort initiated, i.e. day after 2nd crash (ET302); initial approach to ICAO could not lead to author's direct offered involvement, but this initial effort led to establishing contact with Ethiopian Embassy in Ottawa, which was subsequently kept informed of author's major developments (unilaterally, with no expectation of feedback from Ethiopian authorities).
2. 04/01/2019 First public disclosure of author's concerns, at his initiative, on SRC TV 22h *Téléjournal* [4]; focus on HSTA motor was result of many cuts for montage, leaving out other hypothesis of no-back subcomponent degradation which later became more likely; decision to work with certification authorities rather than media taken at that point.
3. 04/23/2019 Letter sent to Transport Minister Marc Garneau, requesting meeting to communicate him author's concerns at that point; occurred on 05/03/2019 after which Minister Garneau asked author to present his findings to his TCCA experts team, which happened on 06/18/2019 (2h presentation).
4. 11/10/2019 Second public disclosure of author's evolving analysis, at SRC *Découverte*[5] TV program's request, in collaboration with flight controls engineering expert Sylvain Alarie.
5. 03/05/2020 Transmission to Boeing, CC to FAA & TCCA, of an extensive study summary document (44 pages containing 24 main questions); proof of reception obtained on 03/10/2020[1, Att. 6&7].
6. 03/10/2020 1st, invited testimony to TRAN Committee of Canadian Parliament[2].
7. 09/21/2020 Filing of Comment serial # 172 under FAA NPRM commenting process, providing 7 attachments and expanding the questions list (from above item #5) from 24 to 36, including important question 35 on latent failure condition in new MVS algorithm of MCAS[1 & Att. 1,2,3,4,5,6&7].
8. 11/18/2020 FAA lifts 737 MAX ban; on same day, by coincidence, author's 1st contact with a family member of one of the crash victims, and soon learning of upcoming TRAN Committee hearing; after informing Committee of having new information since author's 1st testimony, author invited to testify again[3].
9. 11/24/2020 2nd testimony to TRAN Canadian Parliament Committee, in which notably statement is made of intent NOT to board a 737 MAX as a passenger; technical rationale provided for decision[3].
10. 11/26/2020 Additional TRAN Committee hearing, Mr Turnbull of TCCA answers questions referring to author's involvement and prior comments, he confirms author's credentials but incorrectly states author was communicated by TCCA answers to his questions to Boeing[1, Att.6] which they had pressed on Boeing on my behalf; he states author was misinformed and did not have access to all data. Decision made to prepare response to TCCA, and simulate MCAS MVS algorithm to verify latent failure hypothesis.
11. 11/30/2020 MVS simulation completed, discovery of unsafe issue (latent/dormant failure condition) on 12/01/2020, and communication of it to TCCA on 12/03/2020 along with response to 11/26/2020 statement.
12. 12/03/2020 Globe & Mail print edition publishes article it had requested from Ralph Nader, who cites one of two quotations he had requested from author for said article; Mr. Nader is uncle of 1st crash victim family member contact established on 11/18/2020 (from above timeline item #8).
13. 12/16/2020 Cordial verbal exchange with Mr. Turnbull of TCCA, with his parallel written communication to author of high level summary of 8 Boeing answers to some of author's questions, in which a surprising obvious error is spotted in response to author's main question #13 regarding sudden 0.5° HS displacement on accident flight JT610 (not communicated back to TCCA yet).

14. 12/17/2020 Transmission to EASA of comments (reception acknowledged) to their FAA NPRM equivalent (EASA_PAD_20-184), stating publicly in detailed and backed by a simulation for the 1st time the concern about the MVS algorithm latent failure condition. On same date, TCCA validated 737 MAX design changes, and CBC aired piece on The National newscast in which a segment of an interview retakes MVS concern(9).
15. 01/08/2021 Written communication to TCCA pointing out ascertained error in Boeing response to author's question #13 about 0.5° JT610 HS jolt (from above item #13). TCCA responds to it in 4 segments on 01/22/2021, first acknowledging author had correctly pointed out erroneous response, explaining it was their misidentification of an element of their 4-segment response.
16. 01/09/2021 Flight SJ182, 737-500, crashes. After brief study of fragmentary publicly-available ADS-B data (from FlightRadar24), likely stall detected, which prompts author to make other verifications, uncovering two more serious 737 flight controls obsolescence segment, i.e. manual reversion flight in case of loss of hydraulics, and likely absence of proper RTL (rudder travel limiter) function (see main item #4).
17. 02/07/2021 Detailed rebuttal and response written/sent to TCCA regarding not only their 01/22/2021 response to author's original question #13 on JT610 0.5° jolt (from above item #15), but also detailed analysis of the other 7 Boeing responses (from above item #13), as well as identification of two 737 flight controls obsolescences from quick SJ182 study (16 pages document transmitted and not yet requesting a response).
18. 02/09/2021 SJ182 Preliminary Report released(19). Immediately reviewed and contents thereof shared with TCCA; apparent autothrottle (A/T) malfunction and possible inadequate crew response leading to stall (very short report without FDR data); however note made of prior crash with fatalities caused by A/T in 2009 (Turkish Airlines flight 1951, 737-800(20)).
19. 02/16/2021 Last TRAN Committee hearing, attended as observer; question asked to Mr. Turnbull regarding Challenger 300 manual reversion which is known by author to have been reluctantly approved by TCCA (same but worse situation on 737 due to larger aircraft size); no significant answer.
20. 02/22/2021 Mr. Ed Pierson's 01/20/2021 16-page document reviewed, and described electrical wiring production line problems and failing AOA sensor adhesive as well as intermittent coil signal dependent of temperature, causes enough concern to reconsider initial hypothesis to explain sudden ET302 LH AOA sudden 15° to 75° shift; Zoom meeting on 03/06/2021 firmed up corroboration on this document's main item #6).
21. 03/07/2021 Article in Seattle Times referring to A/T issue on ET302 and citing FAA Safety Engineer Joe Jacobsen, firmed up corroboration on matter described in item #5).

Professional & Personal Qualifications of 737 MAX Crashes Study Author

1. Degrees: B.Eng., Electrical Engineering (1988); Space Studies Certificate (ISU, 1994, with Honors); M.Eng., Nuclear/Energy Engineering (2005) – Lifelong aerospace enthusiast with recognized skills.
2. Over 30 years of experience & expertise in aerospace engineering, with specialization in flight controls systems, initiated by their modelization (for the 737-300 notably) for full flight crew training simulators, and followed by actual hands-on in their design, certification & sustaining, at several airframers. Also, strong technical knowledge of all other aircraft systems, structural elements and specialized disciplines, gathered notably as the person in charge of technical risk oversight for a recent & major new aircraft development, which had author interact regularly with approximately 300 engineers and upper management up to the Chief Engineer.
3. Example of achievement in this study: Under main question #23(1, Att.2, 6 p.36 Fig.16), author using early career 737-300 simulation knowledge predicted in Oct. 2019 a *120 lbs* column force during ET302 2nd MCAS command; in March 2020 ET302 Interim report(1, Att. 2&5 p.96 Fig68) estimated columns force at *119.4 lbs* at same moment.
4. Private pilot, trained in a controlled airspace environment at a US international airport where Air Force One and several heavy military aircraft were also conducting training. Notably, during pilot training, encountered highly formative situations of unexpected technical malfunctions (including one on first solo flight) and an unexpected weather situation; those situations enabled author to understand the instant decision obligations of aircrews and the value of their underlying training.

[1] https://www.regulations.gov/comment/FAA-2020-0686-0172. Link contains top-level comment as well as links to 7 attachments respectively-named "FAA-2020-0686-0172_attachment_n" where "n" is attachment number. All attachments except #2 (which is a Microsoft Excel .xlsx file) are PDF files. The attachments correspond exactly to the following author's files: Ref 01_GP comments to 737 MAX NPRM_Master Document.pdf; Ref 02_GP comments to 737 MAX NPRM_Main Questions Matrix.xlsx; Ref 03_200803_FAA_737-MAX-RTS-Preliminary-Summary-v-1_with GP comments.pdf; Ref 04_200803_FAA_737 MAX NPRM_19_035n-R3-8-3-20_with GP comments; Ref 05_Interim-Report-B737-800MAX-ET-AVJ_official_200309_with GP comments_SHRUNK for size.pdf; Ref 06_Communication to Boeing_GP_200305_Rev A.pdf; Ref 07_Transmission letter to David Calhoun Boeing CEO_GP_200305_Rev A.pdf

[2] https://parlvu.parl.gc.ca/Harmony/en/PowerBrowser/PowerBrowserV2/20200310/-1/32853. Author's opening statement starts at time mark 15:45:37. Viewer through web page controls can access floor (untranslated), English or French audio, and closed captions

[3] https://parlvu.parl.gc.ca/Harmony/en/PowerBrowser/PowerBrowserV2/20201124/-1/34342. Author's opening statement starts at time mark 16:54:57. Viewer through web page controls can access floor (untranslated), English or French audio, and closed captions

[4] Link to April 1st 2019 newscast report in French and related web article at SRC: https://ici.radio-canada.ca/nouvelle/1161828/boeing-737-max-ecrasement-lion-air-ethiopian-airlines-gilles-primeau. Alternate link to TV broadcast: https://www.youtube.com/watch?v=BbY5P-ylYS4

[5] Link to November 10th 2019 specialized scientific program report in French on SRC *Découverte* program web site (scroll down for English-subtitled version): https://ici.radio-canada.ca/tele/decouverte/site/segments/reportage/141372/boeing-max-ecrasement. Also, link to related web article at SRC: https://ici.radio-canada.ca/nouvelle/1382157/boeing-737-max-experts-questions-enquete-verin-systeme-anomalie-aeronautique

[6] https://www.theglobeandmail.com/politics/article-fatal-flaw-in-boeing-737-max-could-have-been-easily-detected/. Published March 10th 2020

[7] https://www.theglobeandmail.com/opinion/article-canada-must-keep-the-737-max-grounded-until-it-is-truly-safe/, see quote from Gilles Primeau cited by article author Ralph Nader. Published December 2nd 2020, and December 3rd 2020 in print edition

[8] https://www.cp24.com/news/crash-victims-families-told-approval-of-737-max-by-transport-canada-looks-imminent-1.5216024. Published December 3rd 2020

[9] Link to December 17th 2020 newscast report in English and related web article at CBC: https://www.cbc.ca/news/politics/canada-boeing-737-max-1.5845096, Alternate link to report TV broadcast: https://www.youtube.com/watch?v=Fi46wpwBKbE

[10] Link to February 3rd 2021 newscast report in French, retaking elements of bilingual interview conducted for previous reference (December 17th 2020 newscast report): https://ici.radio-canada.ca/tele/le-telejournal-avec-celine-galipeau/site/segments/reportage/342018/boeing-aeronautique. Alternate link to TV broadcast: https://www.youtube.com/watch?v=paypDbenJmQ

[11] https://edpierson.com/, see link on page to PDF document entitled "737 MAX – STILL NOT FIXED", published January 20th 2021

[12] https://www.seattletimes.com/business/boeing-aerospace/faa-safety-engineer-goes-public-to-slam-the-agencys-oversight-of-boeings-737-max/, article authored by journalist Dominic Gates, published March 7th 2021

[13] https://www.faa.gov/news/media/attachments/Final_JATR_Submittal_to_FAA_Oct_2019.pdf

[14] https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR0201.pdf

[15] https://en.wikipedia.org/wiki/Air_Transat_Flight_236

[16] https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1003.pdf

[17] https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR0101.pdf

[18] https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR9901.pdf

[19] http://knkt.dephub.go.id/knkt/ntsc_aviation/baru/pre/2021/PK-CLC%20Preliminary%20Report.pdf

[20] https://www.nytimes.com/2020/01/20/business/boeing-737-accidents.html

[21] https://www.bea.aero/uploads/tx_elydbrapports/hb-n110525.en_01.pdf