Information pilots need to fulfill their duty under FAR 91.3 & FAR 91.7

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There is great uncertainty regarding the nature of the MCAS system

- Is it for handling or is it a certification requirement?
 - If for certification, does a disabled MCAS system pose a safety of flight risk and require flight termination per FAR 91.7(b)?
 - If for certification, do inoperative MCAS components such as the AOA sensor heaters, render the aircraft un-airworthy per FAR 91.7(a)?
- The FAA has not been responsive to requests for the information that would allow an independent determination of those questions
- Without access to that information, pilots cannot be expected to be able to meet their legal obligations under FAR 91.3 and FAR 91.7

This exposes pilots to unacceptable legal liability

Issues to explore

The Pilot in Command (PIC) is the "captain" of the aircraft. They may not be at the aircraft's controls, but they are legally responsible for all aspects of the flight

- This awesome responsibility is recognized by the power of the PIC to do anything they need to do – deviate from any rule
- In order to accept this responsibility, the PIC must be confident that they have comprehensive knowledge of all aspects of the flight, including how all of the aircraft systems behave when operating normally <u>and when inoperative</u>

§ 91.3 Responsibility and authority of the pilot in command.

(a) The pilot in command of an <u>aircraft</u> is directly responsible for, and is the final authority as to, the operation of that <u>aircraft</u>.

(b) In an in-flight emergency requiring immediate action, the <u>pilot in command</u> may deviate from any rule of this part to the extent required to meet that emergency.

(c) Each <u>pilot in command</u> who deviates from a rule under <u>paragraph (b)</u> of this section shall, upon the request of the <u>Administrator</u>, send a written report of that deviation to the <u>Administrator</u>.

The Concept of Pilot-in-Command

- Boeing says MCAS exists to "enhance the pitch stability" of a 737 MAX
 - This is an independent clause (stands on its own)
- So that it feels like other 737s
 - This is a dependent clause (relies on "enhance the pitch stability")

"Enhance" implies "make better"

That the pitch stability of other 737s is superior to the pitch stability of the 737 MAX

Overview

The Maneuvering Characteristics Augmentation System (MCAS) flight control law was designed and certified for the 737 MAX to enhance the pitch stability of the airplane – so that it feels and flies like other 737s.

MCAS is designed to activate in manual flight, with the airplane's flaps up, at an elevated Angle of Attack (AOA).

Boeing has developed an MCAS software update to provide additional layers of protection if the AOA sensors provide erroneous data. The software has been put through hundreds of hours of analysis, laboratory testing, verification in a simulator and numerous test flights. Before it is finalized, the software will be validated during in-flight certification tests with Federal Aviation Administration (FAA) representatives.

The additional layers of protection that are being proposed include:

- Flight control system will now compare inputs from both AOA sensors. If the sensors disagree by 5.5 degrees or more with the flaps retracted, MCAS will not activate. An indicator on the flight deck display will alert the pilots.

Why Does MCAS exist?

"Pitch Stability" is a problem Different airplanes have different pitch stability characteristics

Just as some cars have differing cornering characteristics

It is perfectly acceptable to have one airplane have poorer pitch stability than another (this is often desirable in fact) There are limits to how much you can relax pitch stability

However there are *limits* to this. In order to meet certification requirements all commercial aircraft must meet *minimum* pitch stability requirements

 If they do not, they are not considered "airworthy" and the design is an inherently (because it does not meet the certification criteria) unsafe

- One fundamental question that is unanswered is whether MCAS is present only to match the handling qualities of the 737 MAX to the rest of the 737 series
 - Or if it is there to meet fundamental certification requirements regarding pitch stability
 - Boeing is vague

The FAA is not responsive to this question and has refused to provide the information and data necessary for its determination

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MCAS: For handling or For certification? MCAS For handling or for certification We don't know if MCAS is there just for handling or for certification because the FAA will not respond with the information necessary to answer that question

• This deprives pilots of the ability to fulfill their responsibilities under FAR 91.3 and FAR 91.7

Let's explore the former (it's there for handling), first

MCAS is simply to improve the handling

If MCAS is only to provide better handling and not required for certification then:

- Why was its existence kept secret from pilots and the airlines until after the first Lion Air crash?
- Why did they not implement the handling in the Elevator Feel Computer (EFC), a component that exists expressly to provide pitch handling forces to the pilots? Why design an entirely new system to duplicate the function of an existing system?

If MCAS is simply to improve the handling

- Why were/are pilots not required to be trained in how the 737 MAX handles when MCAS is inoperative?
 - They need this information in order to accept the responsibility placed on them by FAR 91.3
- Were 737 pilots surveyed and asked if they would rather retain MCAS or remove it and simply receive training in how the 737 MAX handled differently than the 737s they had been flying?
 - Pilots have a fundamental right as a condition of accepting the responsibility of pilot in command to have a voice about the conditions and context of that responsibility

MCAS is simply to improve the handling? When MCAS' issues became known, why did Boeing not choose to delete it altogether from the 737 MAX and move forward to train pilots in the different flight characteristics of the 737 MAX vs. older 737s? Boeing calls MCAS a "Flight Control Law"

- Flight control laws refer to the level of *protection* being afforded by automatic systems
- Inherent in the concept of a flight control law is the concept of degradation of protection through failure and a *loss of protection*
- Systems that exist merely to provide improvements to handling are not flight control laws. Flight control laws are fundamentally about safety, not handling

The Maneuvering Characteristics Augmentation System (MCAS) flight control law was designed and certified for the 737 MAX to enhance the pitch

stability of the airplane - so that it feels and flies like other 737s.

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That's hard to believe it's there for handling Boeing has tenaciously retained MCAS far and away beyond any utility it could provide if it was there just for handling

The billions Boeing spent to re-design MCAS and the years that the 737 MAX was grounded are not comprehensible for a system that exists only to improve handling. Especially since there is already a system designed to do just that (EFC)

Boeing refers to MCAS as a "Flight Control Law." Flight control laws are not about handling. They are about envelope protection and safety. Pilot In Command Why does the FAA not require pilots to be trained in how to fly the 737 MAX with MCAS inoperative?

The pilot in command cannot fulfill their legal responsibility without understanding the nature of the failed system & its impact on aircraft control and maneuverability MCAS is there to meet minimum pitch stability requirement s for certification If any system that was required for certification fails then the aircraft becomes un-airworthy

This is does not imply that the aircraft is unsafe, however

- Navigation lights are a required item for certification
 - The failure of a navigation light renders the aircraft un-airworthy but not unsafe
- Propulsion (engines) are a required item for certification
 - The failure of an engine renders the aircraft both un-airworthy and unsafe

Before every flight the pilot in command is legally responsible to determine that the aircraft is airworthy

- The engines AND the navigation lights must all work or the airplane may not be flown
- There is something called the "[Master] Minimum Equipment List" that helps pilots of complex airplanes make this determination (more on that later)

During a flight the pilot in command is legally responsible to terminate the flight whenever the airplane becomes unsafe

I.e. an engine (but not a navigation light) fails

§ 91.7 Civil aircraft airworthiness.

(a) No person may operate a civil aircraft unless it is in an airworthy condition.

(b) The pilot in command of a civil aircraft is responsible for determining whether that aircraft is in condition for safe flight. The pilot in command shall discontinue the flight when unairworthy mechanical, electrical, or structural conditions occur.

Pilot In Command Pilot In Command Why does the FAA not require pilots to be trained in how to fly the 737 MAX with MCAS inoperative?

The pilot in command cannot fulfill their legal responsibility without understanding the nature of the failed system & its impact on aircraft control and maneuverability MCAS has new failure modes

- Boeing changed the MCAS system to now use both of the 737s angle of attack sensors instead of just one
- Now if the sensors disagree by 5.5 degrees or more, MCAS will shut itself off
- MCAS failures (shut downs) will become extremely common
 - AOA sensor disagreements are common due to component failure
 - Both the Lion Air and the Ethiopian crashes had sensor disagreement as one component of the crash

Is a 737 with disabled MCAS merely unairworthy or is it unsafe?

We don't know because the FAA has not responded with the information necessary to make that determination

This deprives pilots of the ability to fulfill their responsibilities under FAR 91.3 and FAR 91.7

737 Annunciators

- The 737 like all aircraft has annunciators that indicate the status of various systems
- On the 737 the annunciators are colored:
 - RED: A critical condition requiring immediate action. Intrinsically unsafe. Example: Engine fire
 - YELLOW: Cautionary, requires timely corrective action. Example: Flaps misconfigured
 - BLUE: Advisory. Valve positions, etc. Example: fuel tank selection
 - GREEN: Satisfactory/on (Example: landing lights on)





What is the nature of an MCAS failure annunciation ? Boeing has added an annunciator to indicate when the two angle of attack sensors disagree by more than 5.5 degrees

- By assumption, if that annunciator is "lit" MCAS is disabled
- What color is that annunciator?
 - We do not know because the FAA has not responded to this request for information
- If it is red, the pilot would need to terminate the flight at the earliest opportunity
 - The aircraft is intrinsically *unsafe*
- If it is yellow, the aircraft could become unsafe (i.e. if more than one system failure were to occur)
- If it is blue then this indicates that MCAS is indeed a handling augmentation and not a safety of flight item

If MCAS is a certification requirement but not a safety of flight issue

- Does the AOA disagree indicator function on the ground?
 - We do not know because the FAA has not provided the information necessary
- If it does not function on the ground, how can pilots determine that the 737 MAX is airworthy prior to operating the aircraft per FAR 91.7?
- If the AOA sensor heaters are inoperative, does that render the 737 MAX unairworthy?
 - If not, why not?

The Boeing 737 MAX may be flown with *all* AOA sensor heaters inop Revision 2 of the 737 MAX Master Minimum Equipment List (MMEL), dated 04/10/2020 allows the Boeing 737 MAX to take off, with passengers, with *both* of the angle of attack sensor heaters (necessary to assure the sensors do not freeze in position) INOPERATIVE

U.S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION				MASTER MINIMUM EQUIPMENT LIST		
REVISION NO. 1				PAGE NO. 30-4		
DATE: 01/17/2018						
AIRCRAFT: B-737-8/-9			Т	TABLE KEY1. REPAIR CATEGORY2. NO. INSTALLED3. NO. REQUIRED FOR DISPATCH4. REMARKS OR EXCEPTIONS		
30. Ice and Rain Protection				\cap		
Sequence No.	Item	1	2	3	4	Change Bar
31-03	Angle of Attack Sensor Heaters	C	2	0	Except for ER operations beyond 120 minutes, may be inoperative provided airplane is not operated in known or forecast icing conditions.	

The Airbus A320 may not be flown if it does not have at least two operating heaters The Airbus A320, which has three angle of attack sensors and three heaters may not be flown unless at least two are operable

U.S. DEPARTMENT OF TRANSPORTATION MASTER MINIMUM EQUIPMENT LIST FEDERAL AVIATION ADMINISTRATION **REVISION NO. 28** PAGE NO. 30-7 DATE: 11/22/2019 TABLE KEY 1. REPAIR CATEGORY AIRCRAFT: 2. NO. INSTALLED Airbus A320 NO. REQUIRED FOR DISPATCH REMARKS OR EXCEPTIONS 30. Ice and Rain Protection Change Bar Sequence No. Item 1 2 31-04 С 2 (M)(O) F/O's heater may be Angle of Attack Probe з Heaters inoperative provided ADR, heaters, and failure warnings associated with CAPT and STBY probes (pitot, static, AOA, TAT) are verified to operate normally once each flight day. С з 2 (M)(O) STBY heater may be inoperative provided ADR, heaters, and failure warnings associated with CAPT and F/O probes (pitot, static, AOA, TAT) are verified to operate normally once each flight day. С 3 2 (M)(O) Except for ER operations beyond 120 minutes, CAPT's heater may be inoperative provided: a) ADR, heaters, and failure warnings associated with F/O and STBY probes (pitot, static, AOA, TAT) are verified to operate normally once each flight day, and b) Airplane is not operated in visible moisture or in known or forecast icing conditions.

The A320 alternate law If the A320 has an angle of attack sensor disagreement it goes into what is called "alternate law"

• Amber annunciators on the pilot's displays indicate that the aircraft has gone into alternate law

In alternate law

- All protections except for load factor maneuvering are lost
- The aircraft can be stalled
- Pilots are trained extensively on how the aircraft handles when it is in alternate law
- Alternate law activation may constitute an emergency

Boeing explicitly refers to MCAS as being a "flight control law"

- This identical to Airbus' identification of different flight laws
 - For Airbus the laws are: Normal->Alternate->Abnormal Alternate and Direct. Each progression represents some level of failure and some degradation of protections.
- On the 737 MAX "MCAS Law" equates to Airbus' "Normal" law

The MCAS flight control law

- MCAS disabled equates to Airbus' Alternate law
 - Airbus enters alternate law whenever the AOA sensors are disabled

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Boeing does not consider the angle of attack sensors critical to safe flight

- Airbus does
- This leads us to believe that Boeing does not consider the MCAS system to be critical to safe flight

Boeing's position on angle of attack sensors

- Pilots cannot determine for themselves whether this is true because the FAA has not been responsive to information requests on these issues
 - The lack of response makes it impossible for pilots to fulfill their responsibilities under FAR 91.3 and FAR 91.7

737 MAX Flight Deck Displays

All primary flight information required to safely and efficiently operate the 737 MAX is included on the baseline primary flight display. This is true of all our commercial products. Boeing doesn't put a price on required safety features. Crew procedures and training for safe and efficient operation of the airplane are focused around airplane roll and pitch attitude, altitude, heading and vertical speed, all of which are integrated on the primary flight display. All 737 MAX airplanes display this data in a way that is consistent with pilot training and the fundamental instrument scan pattern that pilots are trained to use.

The AOA (angle of attack) indicator provides supplementary information to the flight crew. The AOA disagree alert provides additional context for understanding the possible cause of air speed and altitude differences between the pilot's and first officer's displays. Information for these features is provided by the AOA sensors.

There are no pilot actions or procedures during flight which require knowledge of angle of attack.

Simulation

If simulators are used to train pilots on 737 MAX handling characteristics it is essential that the simulators faithfully reproduce the exact handling of the actual aircraft

Particularly in the situation where MCAS is disabled

Without independent verification that the simulators fully and faithfully reproduce all aspects of 737 MAX handling, pilots cannot fulfil their legal obligations under FAR 91.3 and FAR 91.7 with only simulator training "New" MCAS will fail often Because of the provision for MCAS to shut itself off if there is a disagreement between the two AOA sensor readings, MCAS failures (shutdown) will be common

- AOA sensor failures are common due to component failure, freezing, physical damage, etc.
- Pilots will need explicit training on 737 MAX handling characteristics with an inoperative MCAS system in order to fulfill their legal obligations under FAR 91.3 and FAR 91.7

Boeing vaguely asserts that MCAS exists only to augment handling

- Yet did not utilize the existing Elevator Feel Computer
- Boeing has spent billions of dollars and lost billions in revenue in a desperate effort to retain MCAS at all costs
- MCAS will disable itself if the two angle of attack sensors disagree by 5.5 degrees or more
- An indicator has been added that indicates if the AOA sensors disagree
- The 737 MAX can be dispatched with all AOA sensor heaters failed
- MCAS can be expected to shut down routinely due to AOA sensor disagreement
- Boeing calls MCAS a "Flight Control Law."

What we know

What we don't know The information necessary to understand what we know given the manifold contradictions

 Specifically the information necessary to understand how the 737 MAX behaves with an inoperative MCAS system

 Without that information, it is impossible for pilots to fulfill their legal obligations under FAR 91.3 and FAR 91.7 There is great uncertainty regarding the nature of the MCAS system

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Conclusion