B737 MAX: Lessons Learned from Tragedy

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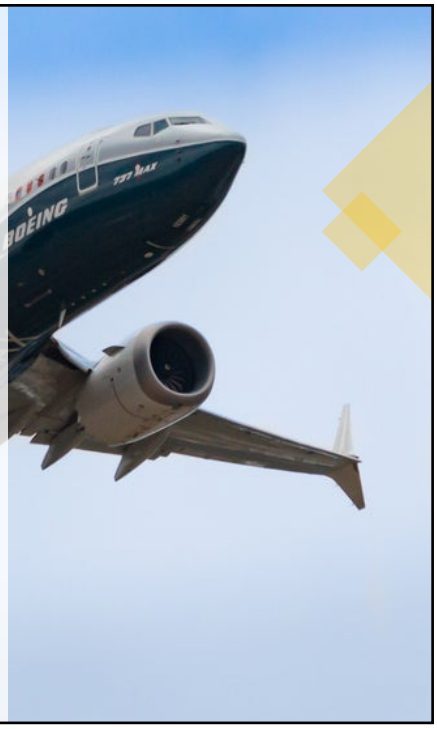
B737 MAX Overview

- 737 MAX is a derivative of the 737 Next Generation (NG) model; issued an “amended type certificate”
- Introduced to remain competitive with the Airbus A320 neo model
- 737 MAX incorporated larger, more fuel-efficient engines mounted higher and more forward on the wings



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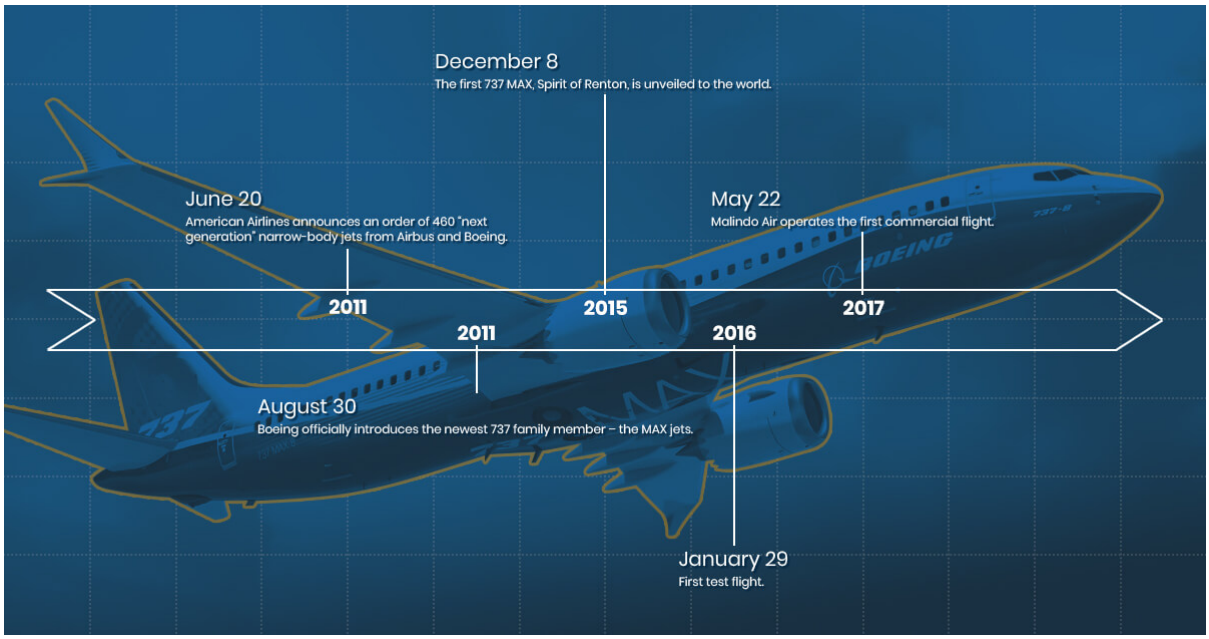

https://www.aerotime.aero/rytis.beresnevicius/23728-boeing-737-max-crisis

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Lion Air Flight 610

- 29 October 2018
- Scheduled passenger flight from Jakarta to Pangkal Pinang
- Crashed 12 minutes after departure at 0632 local time
- All 189 passengers and crew died

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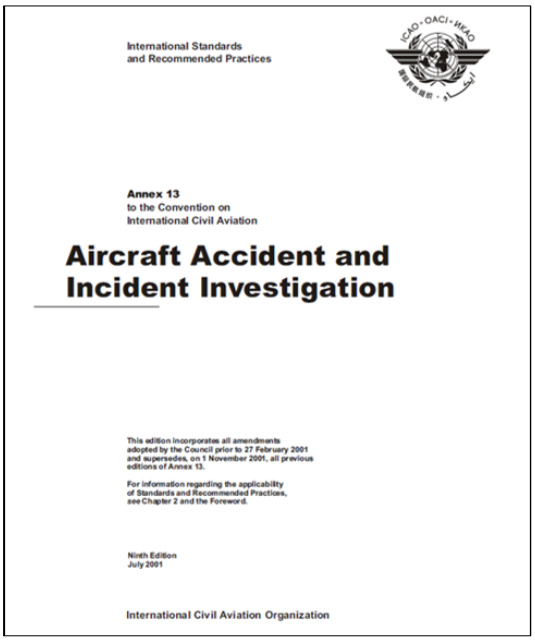
International Effort

- Led by National Transportation Safety Committee of Indonesia
- ICAO Annex 13
  - US Accredited Representative and Technical Advisors
    - NTSB, FAA, Boeing
- MOU with ATSB – data recorders


International Standards
and Recommended Practices

Annex 13
to the Convention on
International Civil Aviation

Aircraft Accident and Incident Investigation

This edition incorporates all amendments adopted by the Council prior to 27 February 2001 and supersedes, on 1 November 2001, all previous editions of Annex 13.

For information regarding the applicability of Standards and Recommended Practices, see Chapter 2 and the Foreword.

Ninth Edition
July 2001

International Civil Aviation Organization

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Details of Flight

- Captain was pilot flying, First Officer (FO) was pilot monitoring
- FDR data showed
  - 21° angle of attack (AOA) disagree on takeoff roll
  - Stick shaker activation when nose wheel off ground
  - Airspeed (IAS) and altitude (ALT) disagree messages
- Flight crew reported a “flight control problem” to ATC
- Flight crew did not declare an emergency or request a return to departure airport

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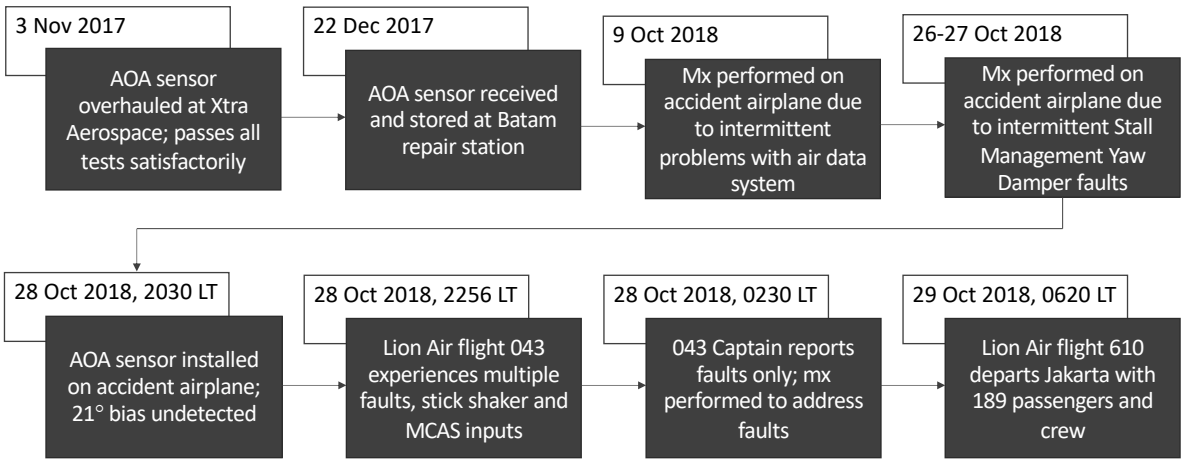
History of Maintenance on Aircraft



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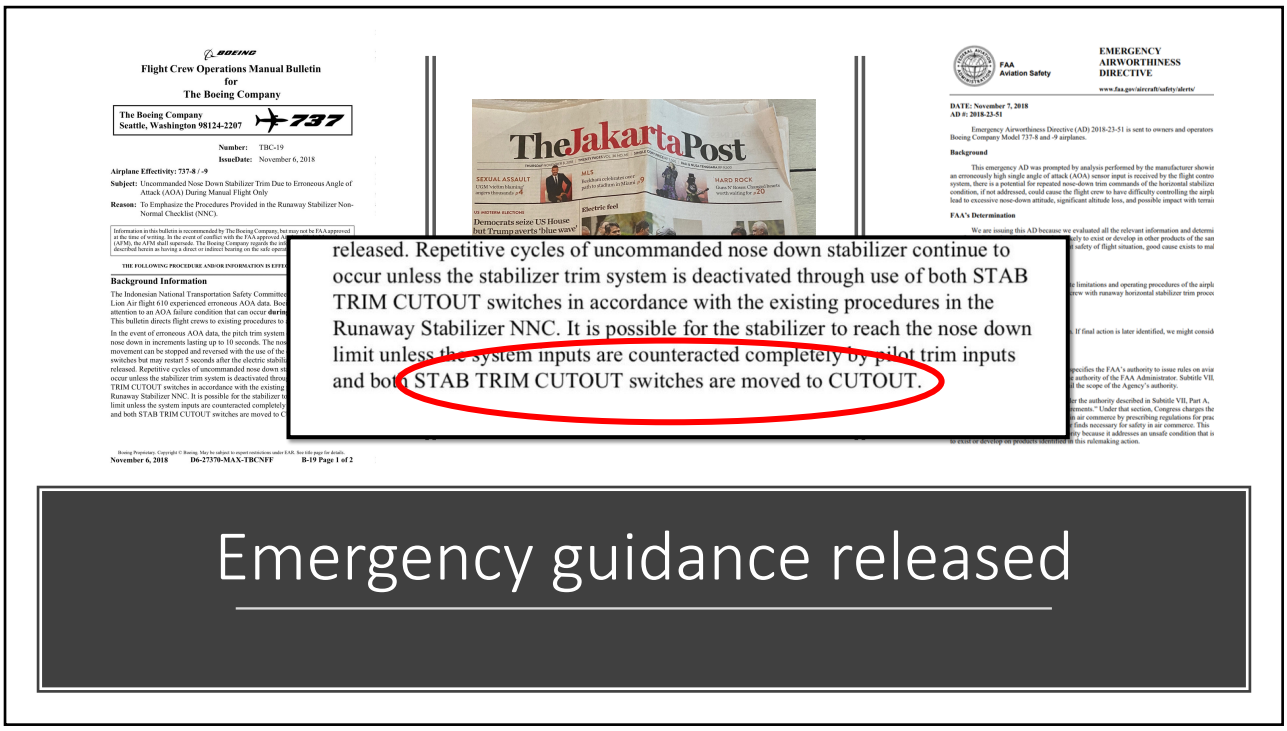

Emergency guidance released

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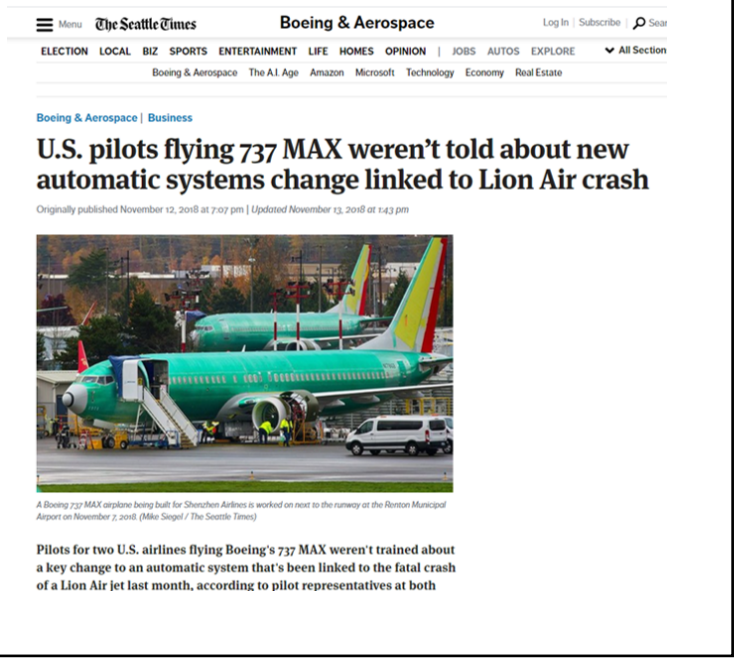
No mention of new "automatic system" in pilot or aircraft manuals



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What was this new “system”?

- Changes produced an ANU (aircraft nose up) pitching moment when the airplane was operating at high AOA and mid Mach numbers
- Maneuvering Characteristics Augmentation System (MCAS) was introduced as a modification to existing speed trim system.
- Conditions to activate:
  - Manual flight (autopilot not engaged)
  - Flaps fully retracted
  - Airplane’s AOA value exceeded a threshold based on Mach number

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MCAS Characteristics

- Automatic nose down trim commands (up to 2.5 degrees) until AOA falls below threshold
- MCAS inputs can be stopped or reversed by pilot use of trim switches

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MCAS Assumptions

- Uncommanded system inputs are readily recognizable and can be counteracted by … the flight crew and do not require specific procedures.
- Action to counter the failure shall not require exceptional piloting skill or strength.
- The pilot will take immediate action to reduce or eliminate increased control forces by re-trimming or changing configuration or flight conditions.
- Trained flight crew memory procedures shall be followed to address and eliminate or mitigate the failure.

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Additional Details of Flight

- Crew raised flaps to “clean up” airplane after takeoff
- Activation of unintended/automatic nose down trim inputs
  - Nose down trim inputs activated a total of 24 times
  - Crew countered nose down trim with nose up trim
- Captain transferred control to FO about 54 seconds before crash
  - Shorter/less nose up trim inputs after transfer of control
  - Control column force increased up to 103 lbs. (46 kg)

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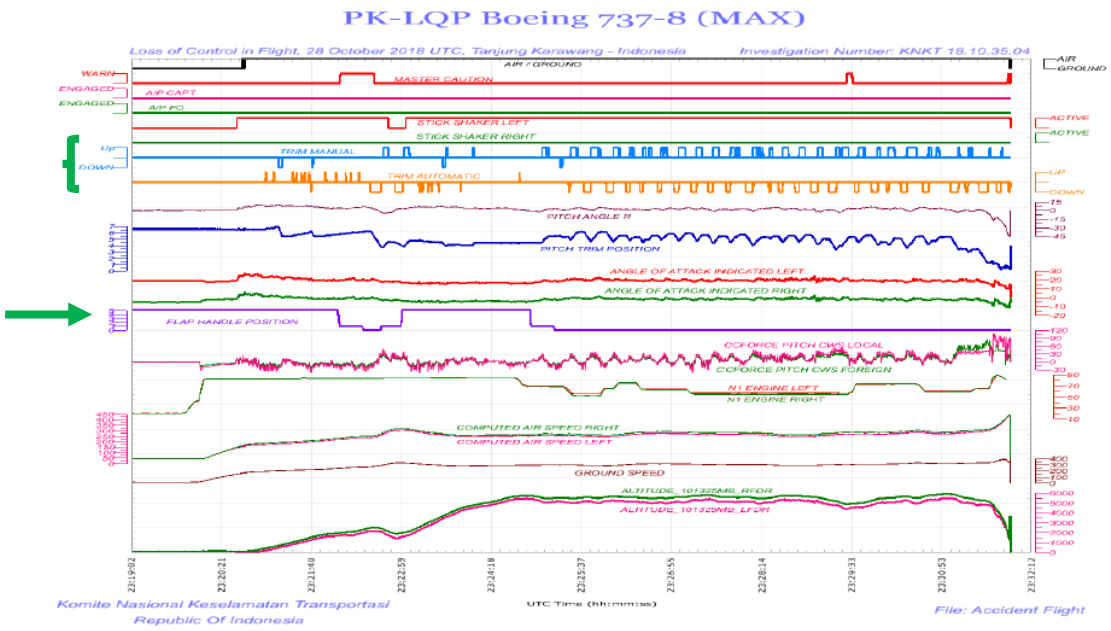

Figure 29: The significant parameters from the accident flight

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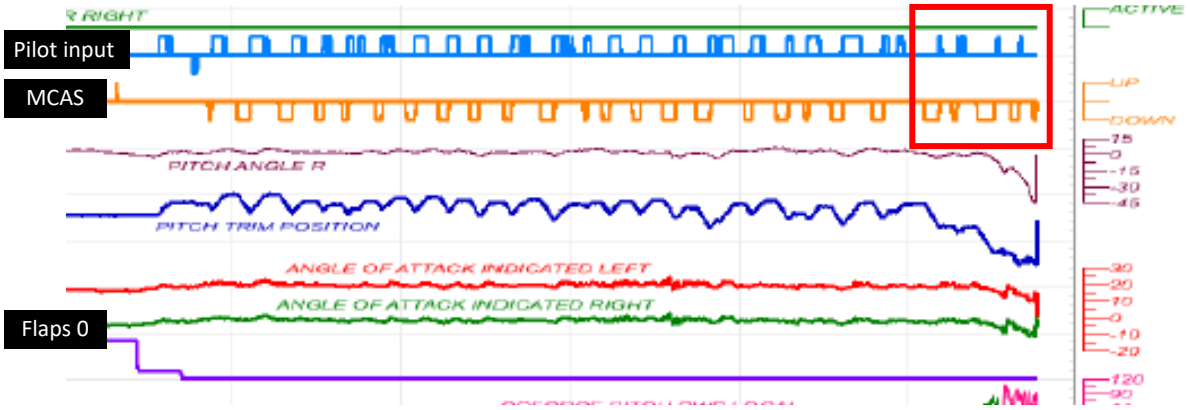
MCAS Activation



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Human Factors Issues: Crew

Significant crew workload

- Erroneous stick shaker activation
- Multiple indications and alerts
- Radar vectors to avoid traffic 6 times

Limited/lack of situation awareness

- Previous problems on aircraft
- Reason for repetitive, automated nose down inputs

Poor crew resource management

- Lack of shared mental model
- No clear allocation of crew duties
- Inadequate communication

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Human Factors Issues: System

- A single failure (a high bias AOA) triggered several aircraft level effects including stick shaker, erroneous airspeed and altitude displays and MCAS after the flaps were retracted.
- If a pilot counters MCAS inputs and an elevated AOA condition persists, MCAS would command another nose down input (up to 2.5°) after 5 seconds.
- If a pilot does not fully trim out the forces of MCAS, level flight cannot be maintained.

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B737 MAX Concerns Continue

- 10 March 2019 – Ethiopian Airlines flight 302 crashed near Addis Ababa killing all 157 onboard
- B737 MAX has been grounded since 13 March 2019

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Conclusions/Findings

- A 21° bias was introduced during the AOA sensor overhaul that went undetected during testing triggering multiple aircraft level effects, including MCAS initiation.
- No information was provided about MCAS in the flight crew manuals or training.
- During the design and certification of the Boeing 737-8 (MAX), assumptions made about pilot response to malfunctions were incorrect.
- Flight crew did not respond to MCAS activation as expected.
- The multiple alerts, repetitive MCAS activations, and distractions related to numerous ATC communications increased flight crew's workload and was not able to be effectively managed.

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Lessons Learned

Consider the effect of all possible flight deck alerts and indications on pilot recognition and response.

Design enhancements, procedures, and/or training requirements should be used to minimize the potential for and safety impact of pilot actions that are inconsistent with manufacturer assumptions.

Robust tools and methods are critical for validating new and existing assumptions of pilot recognition and response to safety significant failure conditions as part of the design certification process.

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Lessons Learned

Design standards must be developed for aircraft system diagnostic tools that improve the prioritization and clarity of failure indications (direct and indirect) presented to pilots.

Implement system diagnostic tools on aircraft to improve the timeliness and effectiveness of pilots' response when multiple flight deck alerts and indications are present.

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Questions?

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