BOEING 737 MAX

The failure of a safety culture

Sven E Hammarberg

Accident Investigator & Safety Culture Developer

1990-2010 Fighter Pilot

162. & 171. Fighter Squadron (Viggen, Gripen). SE Military Aviation Authority.

Accident & Incident Investigator

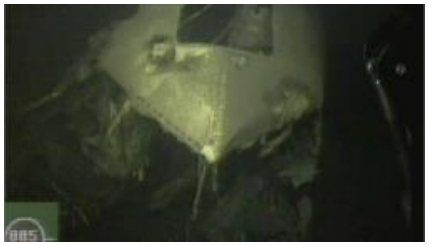
- Armed Forces, Accident Investigation Authority, United Nations
- Fighters, Transport a/c, Helicopter accidents; Gripen Fighters, Black Hawk, NH90...
- Tech Investigation Team Leader, Hercules Mt Kebnekaise 2012-2013
- UN Special Investigator, the Hammarskjöld accident (UN-SG, Ndola 1961)
- Dep IIC, DC-3 Investigation 2003-2007 (SIGINT a/c shot-down by USSR 1952)

Education & Training

- MBA (UK), MSc (KTH), Major (SwAF), Fighter Pilot's School (SwAF), Accident Investigator (US), Safety Management (US), Aircraft Fire Hazards (FRA), Quality Management, Jurisprudence (UU), Risk & Vulnerability Analysis (FOI), et c.

Assignments

- Investigations: Accidents & incidents; Fraud, "Grey Zones"…
- Safety Development & Training
- Safety analysis and certification (Saab Gripen E/F)
- Training courses (Safety management, investigation...)



BVR INVESTIGATIONS

Investigation & business research

- **Enhancing your decision basis**
  In-depth Research, Second Opinion.
- **Pre-Accident Investigation**
  Identify causes before the unwanted event.
- **Accident & Incident Investigation**
  Identify and eliminate the root cause.

BVR ACADEMY

Safety Culture & Safety Management

- **A Methodical Approach to Safety**
  Safety doesn't happen 'by accident'.
- **Crisis and Media Management**
  Leading through the crisis.
- **Investigation Training**
  Investigation skills for your organization.

Beyond Visual Range Academy & Investigations

Accident & Crime Investigators | Risk & Threat Analysts | Protection Experts

Extensive experience from the Swedish Armed Forces, Military Intelligence Services and the Swedish Security Service

Current assignments

- Saab Gripen E/F Certification (incl s/w)
- Investigator's Training @ SWE Airports
- Safety Analysis Mil C4I Systems
- Fraud Investigation
- …

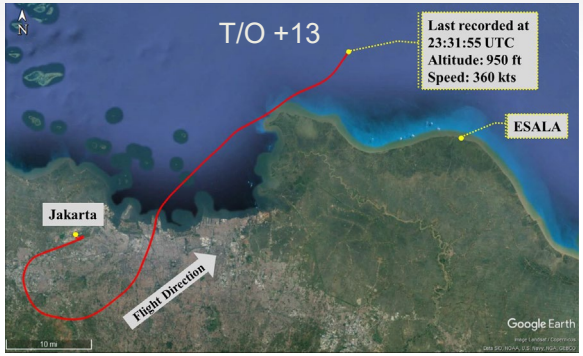
BVR

Boeing 737 MAX

Two high-profile accidents:

- **Lion Air JT610**
  Jakarta 2018-10-29
  189 victims (+1)

- **Ethiopian Airlines ET302**
  Addis Abeba 2019-03-10
  157 victims



Boeing 737 – History

- Twin-engine narrow-body a/c
- Short and medium haul flights
- Production started in 1967
- >10,000 produced a/c (March 2018)
  (More than any other commercial jet.)
- Biggest competitor: Airbus A320

Boeing 737-100 1968


CEO Thornton 737-400 "Classic" 1988

Boeing 737 MAX

4th generation B737

- New engines; some hull changes
- Developed to match the A320 NEO.
  - 12% lower fuel consumption than 737NG.
  - Lower consumption / pax than A320 NEO.
  - Longer range than the A320 NEO.
- First flight January 29, 2016
- First delivery 16 May 2017
- Boeing's fastest-selling model of all time (> 5,000 orders)

Background: B737 MAX vs A320 NEO

Spring 2011

- American Airlines ready to order hundreds of offered Airbus A320 NEO.
- Enormous prestige, billions of dollars and thousands of American jobs at stake.
- Boeing's promise to AA:
  A new 737 within six years.

737 MAX was born three months later.

Advantages of building on the 737:

- Avoid 10 years of development + certification
- Short pilot training; "No need for simulator training"
- "Well-known workhorse" + "New aircraft" .

Pilots trained for Boeing's 737 Max airplane with "an iPad lesson for an hour"

Background: B737 MAX vs A320 NEO

Pilots trained for Boeing's 737 Max airplane with "an iPad lesson for an hour"

"I want to stress the importance of holding firm that **there will not be any type of simulator training required** to transition from 737 NG to MAX. **Boeing will not allow that to happen.** We'll go **face to face** with any regulator who tries to make that a requirement."

Mark Forkner, Chief Tech Pilot, Boeing

B737 MAX Development

”Frenetic tempo”

- Frequent deadlines and strict budgets
- Engineers pressured to produce drawings and constructions at doubled pace
- Competences absorbed from other departments

"Airbus mustn’t steal more of our market share"

- Boeing and senators push for FAA to a lower *Level Of Involvement* (LOI)
- The FAA agrees to this and accepts new ODA (Organization Designation Authorization) Procedures: increased self-control for Boeing
- The new LOI lower than within EASA

B737 MAX Development

”Frenetic tempo”

- Boeing engineers (AR) respond (= FAA Authorized Rep’s)
- FAA inspectors respond

  … but the pressure is too strong.
- Staff who report problems are reassigned / dismissed.
- The silence spreads and the safety culture is eroding.

> “There wasn’t a complete and proper review of the documents,” the former engineer added. “Review was rushed to reach certain certification dates.”

B737 MAX Development

Internal messages

"This airplane is **designed by clowns** who in turn are **supervised by monkeys."**

"I am hopeful we could **gang up on FAA** and **steer them** in the direction we want."

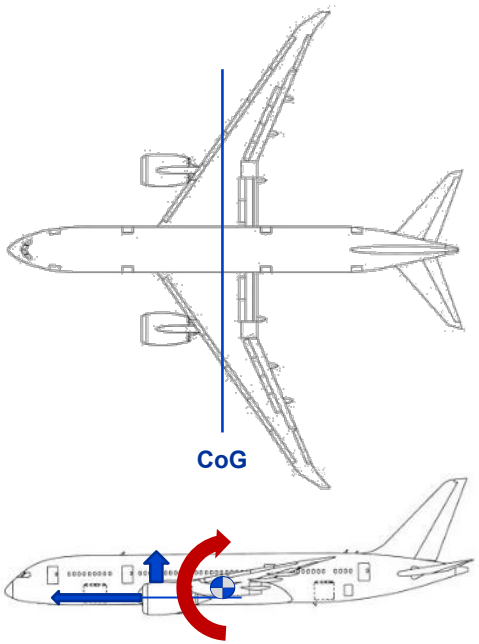
- **"Would you put your family on a MAX simulator-trained aircraft? I wouldn't."**
- **"No."**

"Our arrogance is our demise."

Boeing 737 MAX

Engines and aerodynamics

- Each "aerodynamic horizontal surface" in front of the center of gravity results in a nose-up pithing moment
- Increased torque increases the nose-up pitching moment (”canard effect” + thrust)



B737 MAX – Development

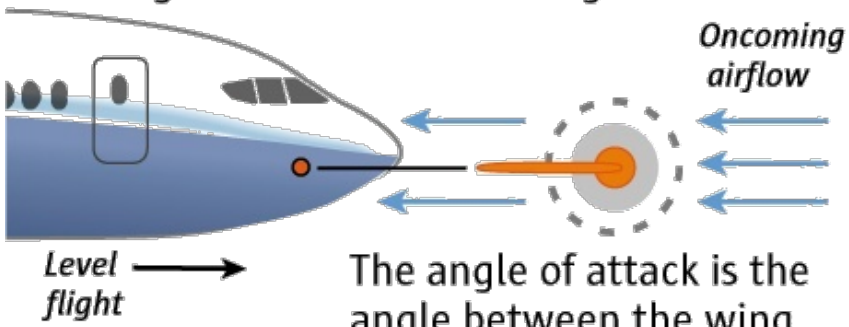
MCAS

- Great efforts are made to make the aircraft feel and behave like a regular 737 – despite higher weight, larger engines, etc.
- The nose-up pithing moment from the engines is considered a big problem.
- MCAS is implemented in order to prevent stall, according to FAA rules. (FAR §25.173)

  A flight control law, embedded into the Flight Control Computer software.

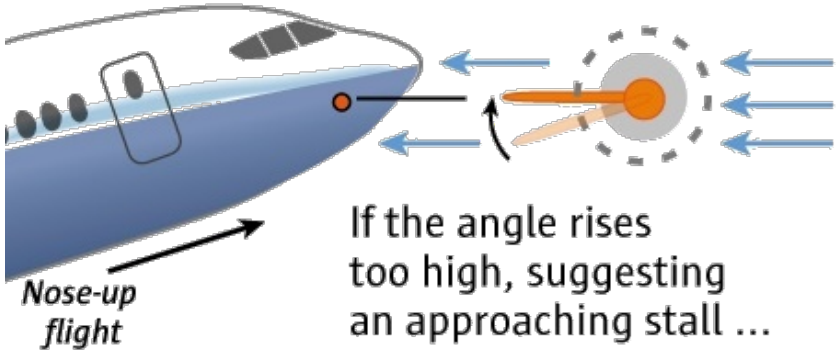
B737 MAX – MCAS

1. The angle-of-attack sensor aligns itself with oncoming airflow.



The angle of attack is the angle between the wing and the airflow.

2. Data from the **sensor** is sent to the flight computer.



If the angle rises too high, suggesting an approaching stall …

… the **MCAS** activates.

3. MCAS automatically swivels the **horizontal tail** to lift the plane's tail while moving the nose down.

In the Lion Air crash, the angle-of-attack sensor fed false information to the flight computer.

Sources: Boeing, FAA, Indonesia National Transportation Safety Committee, Leeham.net, and The Air Current

Reporting by **DOMINIC GATES**,
Graphic by **MARK NOWLIN / THE SEATTLE TIMES**

B737 MAX – Development

MCAS

- Great efforts are made to make the aircraft feel and behave like a regular 737 – despite higher weight, larger engines, etc.
- The nose-up pithing moment from the engines is considered a big problem.
- MCAS is implemented in order to prevent stall, according to FAA rules. (FAR §25.173)
- MCAS controls the rudder directly, not via trim or lever forces.
- The established SSA*, submitted to the FAA, allows an extension of the rudder to 0.6^{o} 'nose down' (physical limit 4.2^{o}).

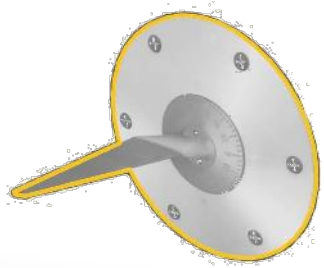
**) System Safety Assessment*

B737 MAX – Development

MCAS

- However, 0.6^{o} proves to be insufficient; the movement is **increased to 2.5^{o}**
  - More than half the maximum movement
  - Without change of the SSA
  - Without FAA knowledge
- Since no change to SSA, the risk analysis remains:

  MCAS Failure = ”Major” ~~Hazardous~~ | ~~Catastrophic~~
  - *“Failure is significant, but … leads to passenger discomfort rather than injuries”*
  - <u>One</u> sensor is considered sufficient as input.
- No flight tests of incorrect AOA input to MCAS.
- No flight tests of AOA sensor failure.



Boeing knew in 2013 that introducing the Maneuvering Characteristics Augmentation System (MCAS) to the 737 MAX might trigger additional training requirements, so it made a decision: referring to MCAS internally was fine. But externally, particularly when talking with regulators, the MCAS would not be named, but rather described as an extension of an existing 737 system.

Aviation Week January 2021

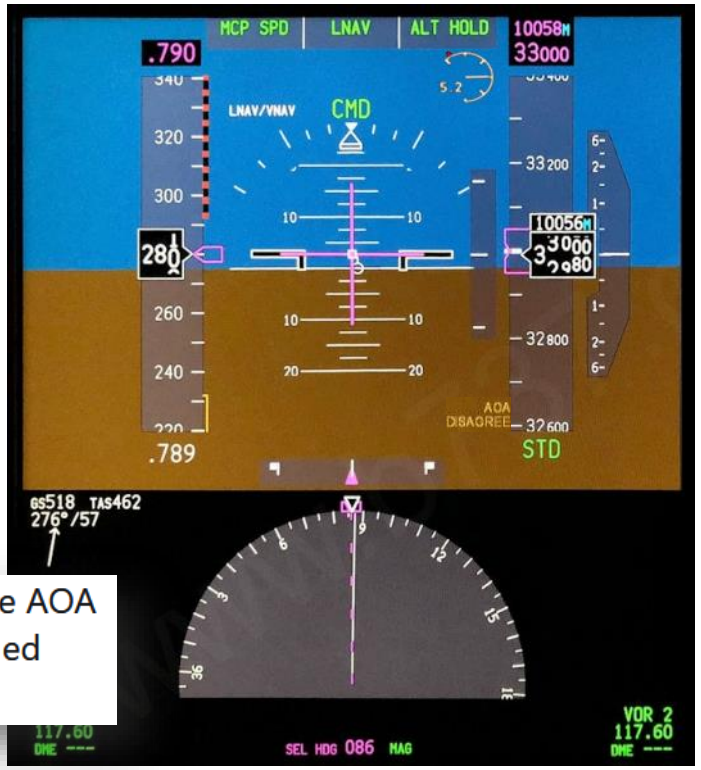
B737 MAX – Development

AOA-sensors

B737 equipped with two AOA sensors.

- AOA Indicator ”optional”.
- AOA Disagree Alert ”not necessary”.
- Information and manuals from Boeing: *“**Disagree warning is standard** across the Max fleet”…*

The function *“was not operable on all airplanes because the feature was not activated as intended”.*



"Boeing and the U.S. Federal Aviation Administration (FAA) made the AOA alert an optional feature for the 737 MAX, meaning it was not deemed critical for safe operation."

B737 MAX – MCAS

- The accident in Oct 2018 was largely blamed on the pilots.
- However, neither companies nor pilots were informed about MCAS.

NNC Bulletin November 2018:

BOEING

Flight Crew Operations Manual Bulletin
for
The Boeing Company

The Boeing Company
Seattle, Washington 98124-2207

737

Number: TBC-19
IssueDate: November 6, 2018

Airplane Effectivity: 737-8 / -9

Subject: Uncommanded Nose Down Stabilizer Trim Due to Erroneous Angle of Attack (AOA) During Manual Flight Only

Reason: To Emphasize the Procedures Provided in the Runaway Stabilizer Non-Normal Checklist (NNC).

"Runaway Stabilizer Checklist"

Additionally, pilots are reminded that an erroneous AOA can cause some or all of the following indications and effects:

- Continuous or intermittent stick shaker on the affected side only.
- Minimum speed bar (red and black) on the affected side only.
- Increasing nose down control forces.
- Inability to engage autopilot.
- Automatic disengagement of autopilot.
- IAS DISAGREE alert.
- ALT DISAGREE alert.
- AOA DISAGREE alert (if the AOA indicator option is installed)
- FEEL DIFF PRESS light.

Operating Instructions

In the event an uncommanded nose down stabilizer trim is experienced on the 737-8 /-9, in conjunction with one or more of the above indications or effects, do the Runaway Stabilizer NNC ensuring that the STAB TRIM CUTOUT switches are set to CUTOUT and stay in the CUTOUT position for the remainder of the flight.

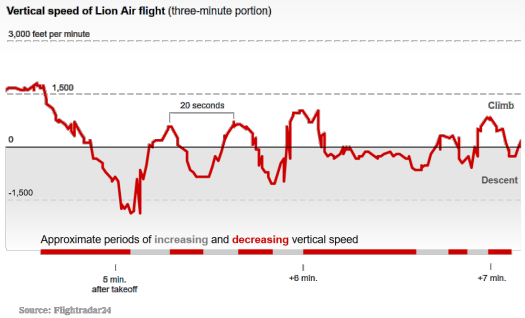
Note: Initially, higher control forces may be needed to overcome any stabilizer nose down trim already applied. Electric stabilizer trim can be used to neutralize control column pitch forces before moving the STAB TRIM CUTOUT switches to CUTOUT. Manual stabilizer trim can be used after the STAB TRIM CUTOUT switches are moved to CUTOUT.

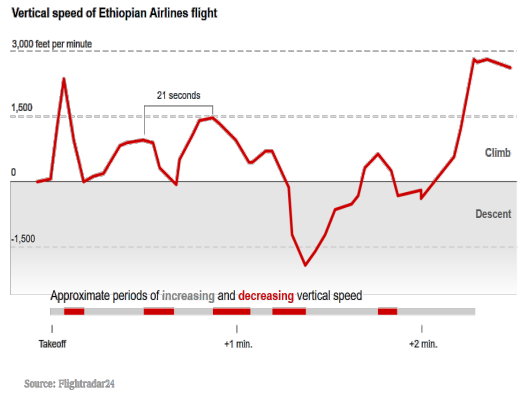
Accident course

- Soon after T/O: Unexpected and complex situation.
  - Powerful nose down movement; IAS DISAGREE, ALT DISAGREE, FEEL DIFF PRESS, Stick Shaker, “GPWS DON’T SINK”, “PULL UP”…
- Crew occupied with Emergency checklists but lacking possibility to identify the root cause.
- The rudder is activated automatically by MCAS, repeated nose down commands.
- Electric trim activated, followed by new automatic nose down commands.
- Very high Control Column forces. **Recovering impossible.**

➢ **Crash.**

- **Initial root cause: Malfunctioning AoA sensor.**
- **Cause of accident: The MCAS software design.**





April 2019 – January 2021

Boeing conducts 500 test flights of troubled 737 Max jets in bid to restore trust following crashes

Company test pilots have conducted more than 700 flights

Pilot procedure confusion adds new complication to Boeing 737 Max return

Exclusive: Boeing kept FAA in the dark on key 737 MAX design changes - U.S. IG report

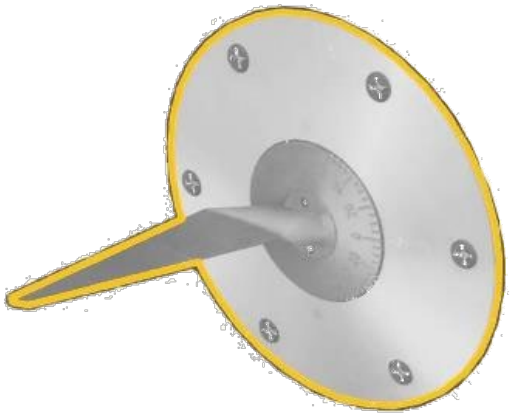
Actions taken

Boeing's actions:

- Basic system changes for s/w
  - Both FCCs are used in parallel; 2-channel
- Both alpha sensors provide input to MCAS
- MCAS activated only once
- The "column force" can always be overridden by a pilot
- It's always possible to disconnect MCAS
- Flight Manual updates
- Pilot training including simulator

Boeing 737 MAX

A large number of reports produced.



January 2021 and the aftermath

FAA Rele
Proposed
Tr
The FAA approved the Boeing 737 Max to fly again after extensive investigations.
EASA
Boeing 737 MAX is safe to fly

Boeing Charged with 737 Max
Fraud Conspiracy
to
Boeing Reports
A former Boeing test pilot
has b
conne
oss

Boeing's MCAS on the 737 Max may not have been needed at all
www.theaircurrent.com

Safety and Costs

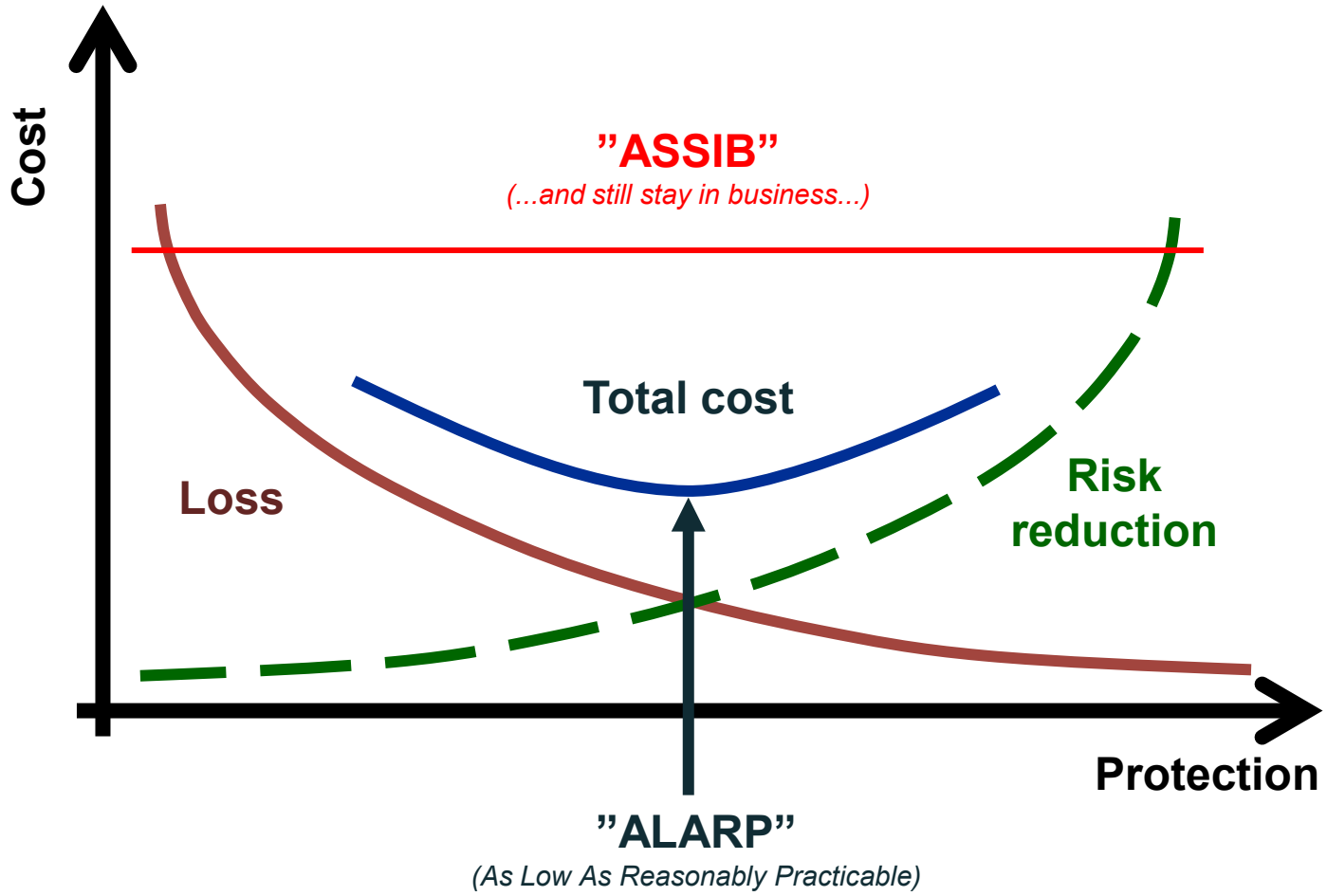
B737 MAX: From 8 600 flights/week to 0.
At most 840 a/c grounded for 21 months.

Paths of every Max 8 flight in a week

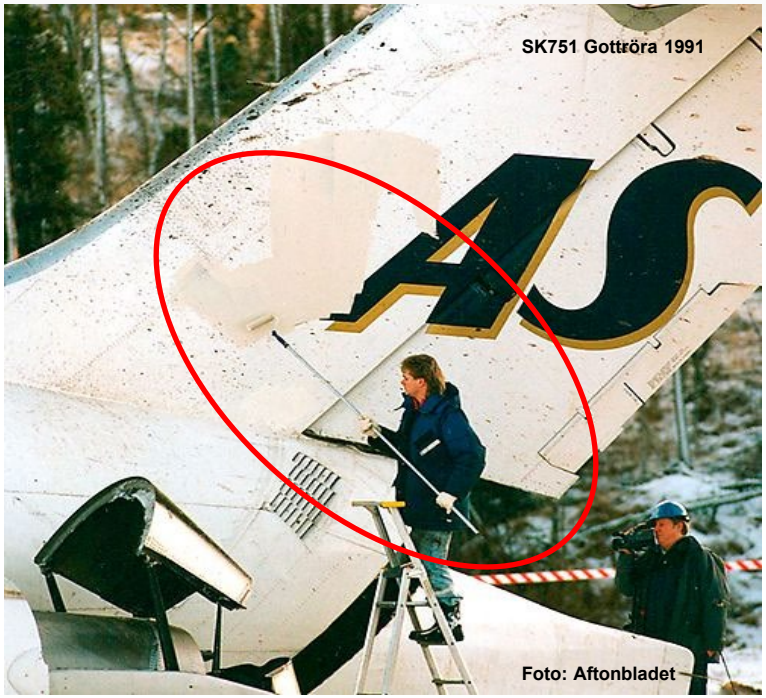
Boeing Dedicates $50 Million of Pledged $100 Million to Near-term Relief for Families of the Victims of the Lion Air Flight 610 and Ethiopian Airlines Flight 302 Accidents

Loss 2019: ***>$18 Bn*** *(first loss in > 20 years)*
Compensation to Air Carriers: Secret amounts, estimated >$11 Bn
Compensation to relatives, pilot organizations, insurance policies, production stop, …

Safety and Costs



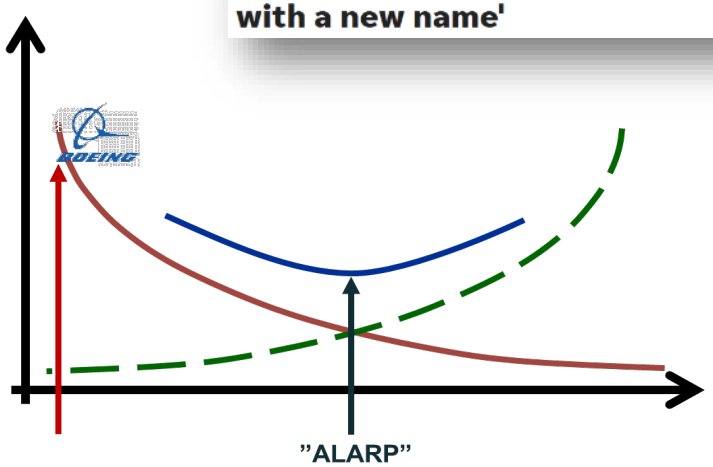
Safety and Costs

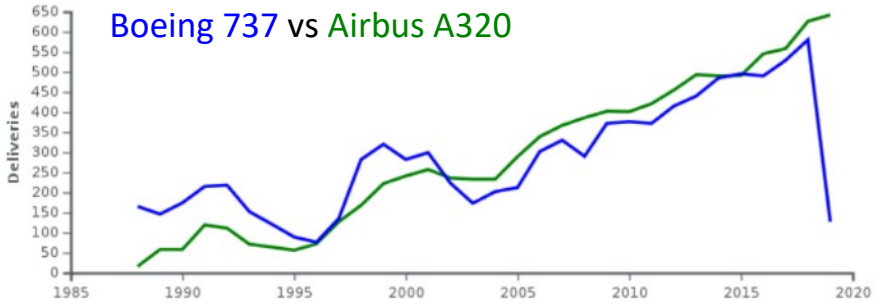


"We've asked Boeing to get rid of that word MAX. I think that the word MAX should go down in the history books as a bad name for an aircraft."

Steven Udvar-Hazy, founder Air Lease (400 a/c)

Donald Trump to Boeing: Fix the 737 Max and 'REBRAND the plane with a new name'

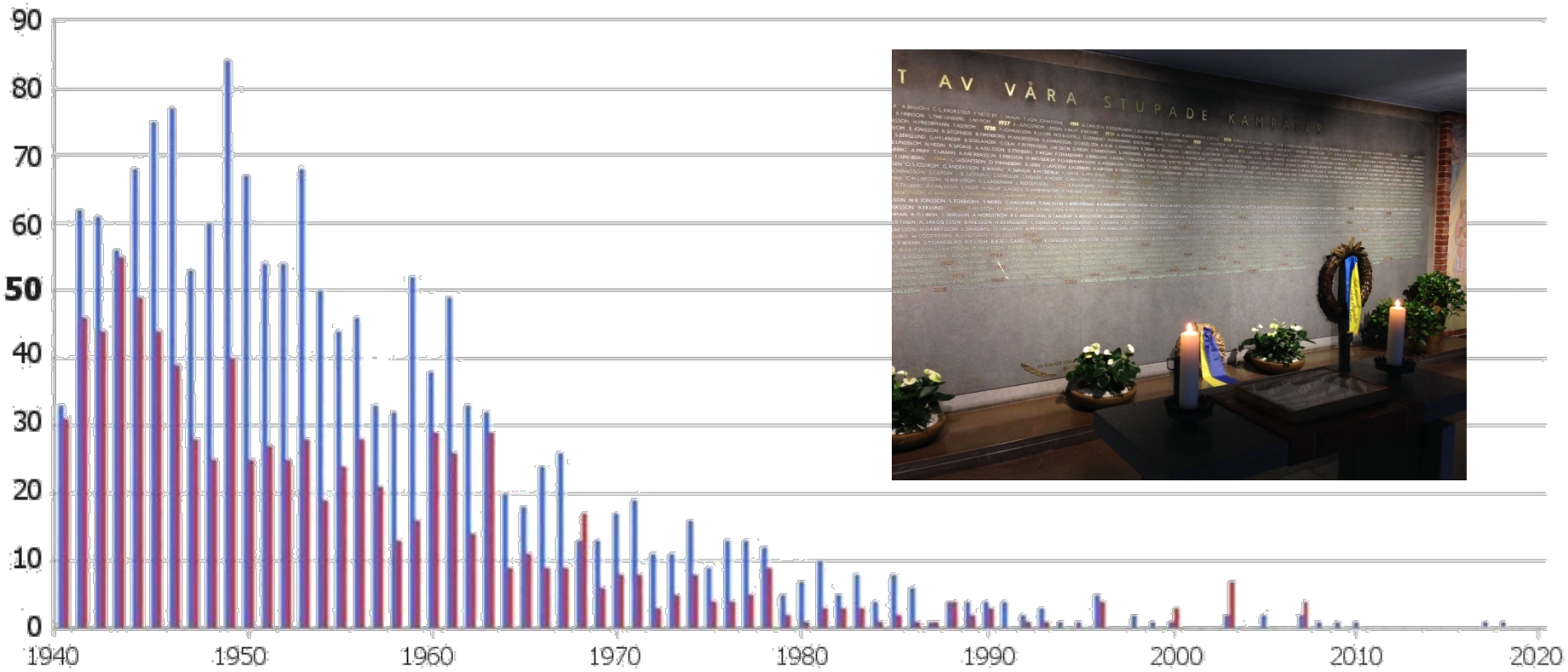




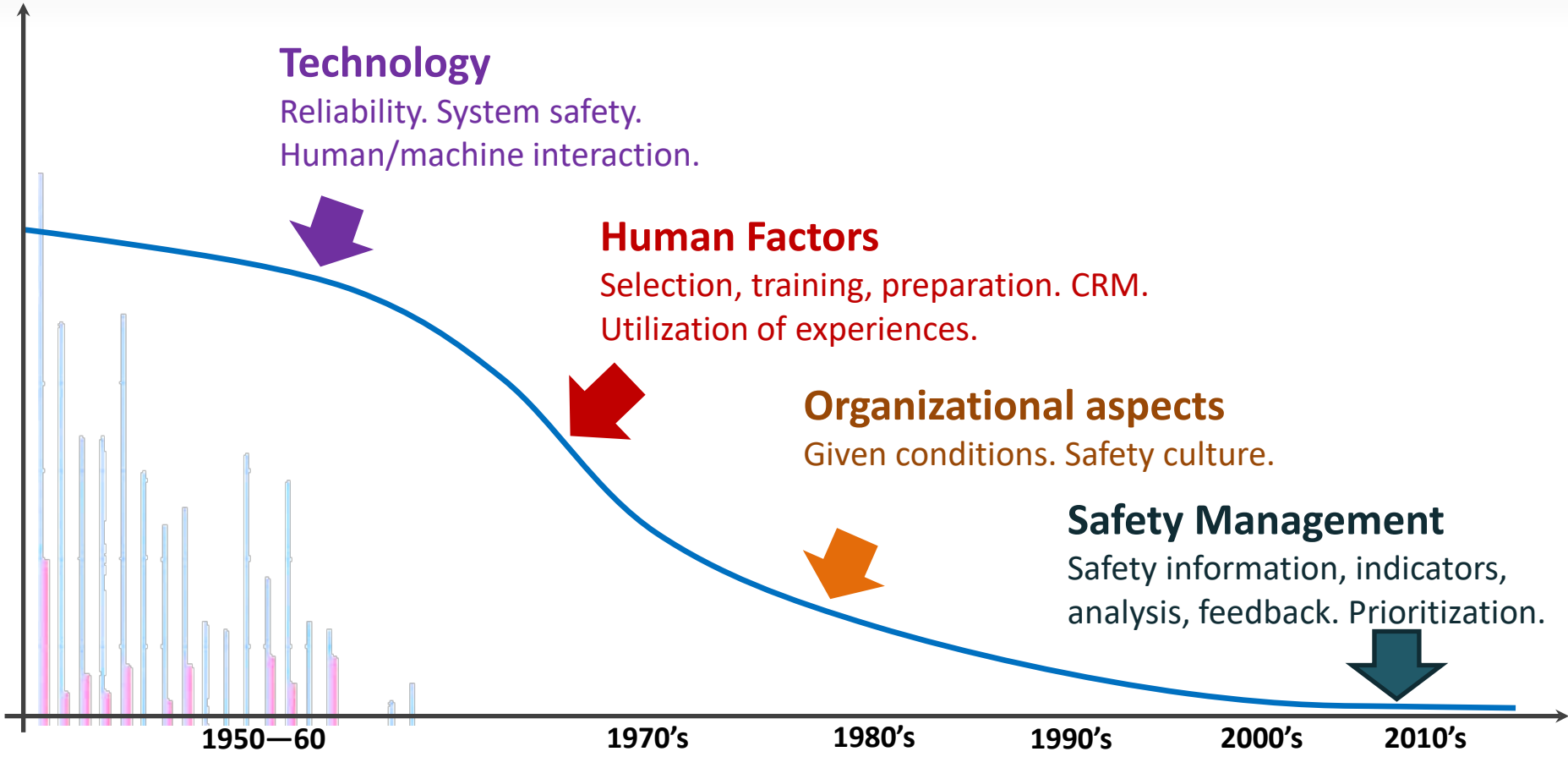
"If you think that safety is expensive, try an accident (or two)."

Swedish Air Force Accidents

Accidents and victims 1940-2020



Aviation Safety Development



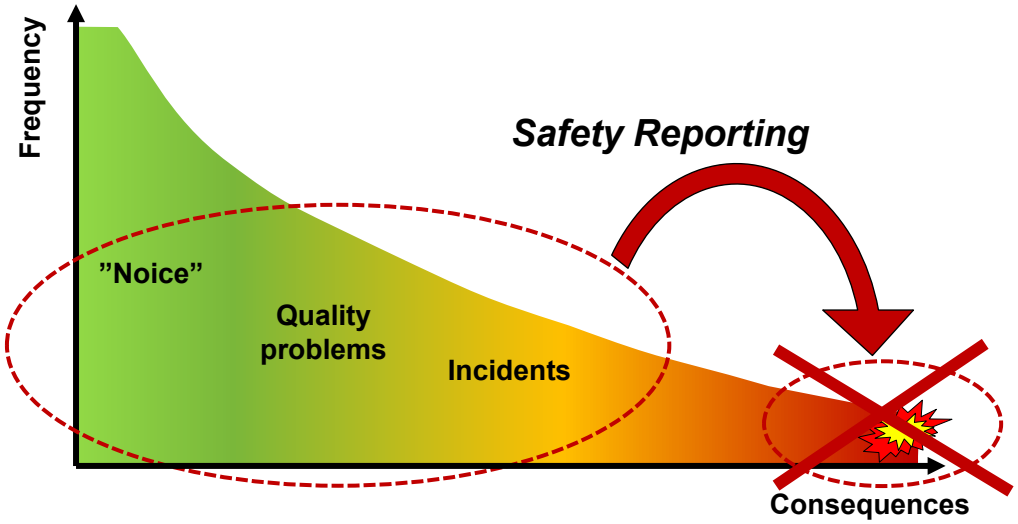
H – T – O + I = SAFETY MANAGEMENT

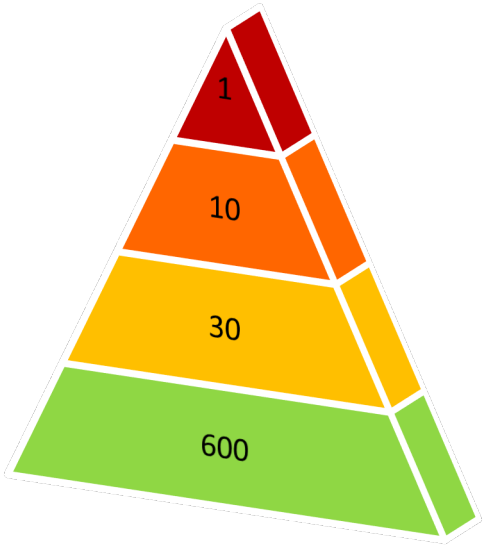
Safety Reporting

The circulatory system in every safety culture!

”If we become aware of incidents, we can avoid accidents.”

- A culture to be nurtured by top management level.
- A responsibility of all people involved.





The failure of a safety culture

- Boeing manufactures a new aircraft by **maximizing the design** from an old one.
- Hardware related problems are **solved with software**.
- **Date of delivery** is the sole target; not safe design.
- The organization is **streamlined** for fast delivery.
- Other business projects are **drained** of skills and resources.
- **Whistleblowers are forced out**, internal auditors silenced.
- Development, flight tests and certification **stressed out**.
- **System safety, analysis and customer info suffer.**
- Certifying authority is **unable to resist**.

Result: 346 fatalities and extremely high costs.