

The ramifications of organizational transition in the digital era. A lesson from Boeing & the 737 MAX

SOFTWARE IS KILLING US

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Thesis

- Since World War II there has been a fundamental change in how our institutions are structured
 - With regard to corporate form, governance and responsibility
- That change can be summarized as organizational movement from bureaucratic to charismatic
 - Bureaucratic form can be viewed as intrinsically rational
 - Charismatic form is intrinsically ideological (though can be an ideology of one)
- This has changed how we think about and design solutions to our needs and problems
 - *Which tools we bring to bear*
 - *Role of Software is a focus of this presentation*
 - *How we "know" (epistemology)*
 - *Concept of Complexity is a focus of this presentation*
 - *What our constraints are*
 - *Concept of Efficiency (time and money) is a focus of this presentation*
 - *What our freedoms are*
 - *Concept of de-institutionalization and de-regulation is a focus of this presentation*
- We are increasingly becoming dysfunctional as a result
 - Prone to failures
 - Collapse of institutions (universities, regulatory (e.g. FAA), technical, social). Loss of the factories of civilization.

Plot

- Pre WW II:
 - Change in notion of what a corporation is – in particular corporate personhood
 - Santa Clara vs. Southern Pacific (1886)
 - Change in notion of what a corporation is responsible for – in particular shareholder return
 - Dodge v. Ford Motor Co (1919), Guth v. Loft (1939), Milton Friedman (1970 NYT)
- Post WW II:
 - Establishment of the United States as the institutional gold standard and model technocracy. Institutionalization.
 - World economic order: Bretton Woods, International Monetary Fund, World Bank, etc.
 - Technological dominance in aerospace, computers, automobiles, etc.
 - Legal and regulatory preeminence (court system, FAA, etc.)
 - Emergence of a Keynesian backlash. De-Institutionalization.
 - Germination of ideas about corporate governance & responsibility
 - Financial instruments
 - Complexity
 - Distaste for manufacturing
 - Preferences for “information economy.” Software
- Case Study: Boeing

Themes

- Information Destruction
 - Complexity
 - Role in concealing fraudulent activity
 - Role in normal failure
 - Estrangement
 - Outsourcing & Geographical separation of functions.
- Efficiency
 - Loss of flexibility (RONA, engineering solutions)
 - Constraints
- Authority and Organizational Structures
 - Weber's organizational forms of interest:
 - Bureaucratic (Rational/Legal/Meritocracy)
 - Charismatic
- The role of software in the above

The contagion of complexity

- "August 28, 1963

Last week CDC had a press conference during which they officially announced their 6600 system. I understand that in the laboratory developing this system there are only 34 people, "including the janitor." Of these, 14 are engineers and 4 are programmers, and only one has a Ph. D., a relatively junior programmer. To the outsider, the laboratory appeared to be cost conscious, hard working and highly motivated.

Contrasting this modest effort with our own vast development activities, I fail to understand why we have lost our industry leadership position by letting someone else offer the world's most powerful computer. At Jenny Lake, I think top priority should be given to a discussion as to what we are doing wrong and how we should go about changing it immediately."

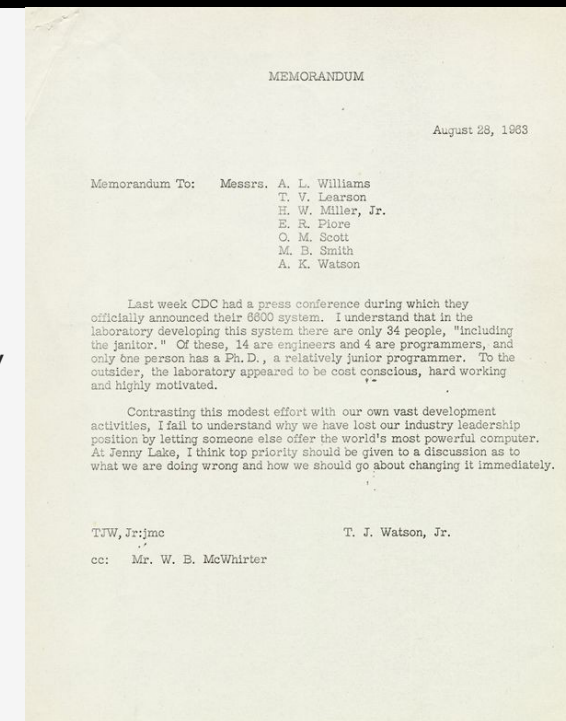
Thomas Watson, IBM CEO (1963)

- "I believe Mr. Watson has answered his own question."

Seymour Cray, Father of the 6600 (1963)

"[E]fficiency depends on the availability of information. " – Jean Pierre Landau

Complexity destroys information availability. It destroys value.



The forms of complexity

- “Complexity comes in two forms:

First, it appears in financial instruments themselves, as financial innovation has led, in recent years to a proliferation of so called structured – and, indeed, very complex – products.

Second, complexity shows up in the structure of the financial systems, which are based on interdependence between multiple actors and counterparties. Transmissions of shocks occur through networks whose structure and architecture is constantly transformed by financial innovation and **regulatory arbitrage. This potentially creates numerous feedback loops and amplification effects.** “

Jean-Pierre Landau “Complexity and the financial crisis”

- For our purposes, we will substitute “software” for “financial instruments themselves” and “Boeing” for “structure of the financial systems”

Our estrangement

"For most of us, computers are effectively magic. When they work, we don't know how. When they break, we don't know why. For all but the most rarefied experts, sitting at a keyboard is an act of trust."

***A human-to-machine relationship defined by estrangement** offers a unique sales opportunity: fomenting anxiety turns out to be an excellent way to draw in clients. "*

The New Yorker. "A Cybersecurity Firms Sharp and Stunning Collapse," Oct 2019

- That "estrangement" is the exact mechanism by which the architects of the 2008 financial collapse were able to perpetuate a dirt-simple Ponzi scheme, without arising suspicion.
- I would expand "for most of us" to include us software developers as well. We don't understand what we are making and, when it breaks, we don't know how to fix it
- This doesn't give much assurance that Boeing will be able to fix its own mistakes on the 737 MAX software

Engineering Aphorisms

- "Keep it simple, stupid" (KISS)
- "Simplify, then add lightness."

Weber's organizational forms

- Traditional (monarchy, church, feudal, etc.)
- Charismatic (cults)
- Bureaucratic (legal/rational/democratic)

Types of organizations

- Bureaucratic
 - Governed by well-promulgated rules
 - Suspicious of complication
 - Tolerates (and usually invites) well-reasoned dissent
 - Rational considerations (i.e. engineering) dominate over irrational considerations (i.e. financial)
 - Responds to market challenges strategically
 - Substance over form
 - This is the nature of Boeing from its inception until the McDonnell Douglas merger
- Charismatic
 - Governed by charismatic leadership characterized by corporate sloganeering
 - Utilizes complication as a tactical advantage. Faddish
 - Ideologically faithful
 - Irrational & emotional considerations (Keynes “Great Casino” and “Animal Spirits”) dominate over rational ones
 - Responds to market challenges tactically
 - Form over substance
 - This was the nature of McDonnell Douglas until its absorption/takeover into/of Boeing

The suzerainty of charisma

- In the 1960s, thinking about organizations began a change
 - Influence of the “Chicago School” and a new theory of corporate morality
- Ideological denigration of concepts of bureaucracy, oversight and the public interest
 - Favoring instead shareholder interests
- This thinking took root very early at the McDonnell Douglas corporation
 - And eventually destroyed McDonnell Douglas as a going concern
 - Market failure of the DC-10 & MD-11 was the result
- Boeing remained immune to it, however
 - Cemented Boeing’s absolute dominance in the commercial aircraft market 1955-2019
 - Ground-breaking developments such as the 707, 727, 737, 747 and 777 were the result

What is it about software?

- It is remarkably economical to “start over.”
 - In fact, this is ideologically enshrined in certain software aphorisms, notably “fail fast.”
- It is remarkably easy to import complexity
 - Frameworks, libraries, etc.
 - AI and Machine Learning
- Barriers to entry are extremely low
- There are few standards and what there is isn’t enforced
 - No equivalent of the Professional Engineer certification for Software

The elixir of “efficiency”

- Software holds out the promise of greater efficiency
 - For example, meeting specifications to the dot and not one iota more
 - Aircraft / Airframe design example
- Dark side of efficiency is that you lose fat. When you need to tighten your belt, you find you have already tightened as much as you can
 - You become constrained in your ability to deal with the unexpected

The empirical vs. the noumenal

"Software stands between man and machine" -- Ted Nelson

- We build machines we can see, touch, feel, hear and smell. They are real things that we build to do real things (heat water, cook food, drive, fly, etc.)
- We create software that we cannot see, touch, feel, hear or smell. It is a metaphysical thing.
- We place that software between ourselves and the machines we make.

Comparisons

My 1990 Toyota Landcruiser

One recall in thirty years:

1990 TOYOTA LAND CRUISER




IMAGE NOT AVAILABLE

1

RECALLS

1

INVESTIGATIONS

5

COMPLAINTS

[See ratings details](#)

NO OVERALL SAFETY RATING

(source: NHTSA)

My 2018 Tesla Model 3

Fourteen software updates in eight months:

Your 14 Software Updates		
Average of 18 days between updates. It has been 13 days since your last update.		
Software Version	Date Installed	Days Since Previous Update
2019.32.12.2 58f3b76	10/16/2019 3:32 PM	12
2019.32.11.1 d39e85a	10/03/2019 9:49 PM	1
2019.32.11 bac8c51	10/02/2019 4:47 PM	42
2019.28.3.1 f9e95acd	08/21/2019 1:35 PM	23
2019.24.4 73fb1ab	07/29/2019 6:42 AM	30
2019.20.4.2 66625e9	06/28/2019 8:40 AM	7
2019.20.2.1 5659e07	06/20/2019 4:29 PM	27
2019.16.2 73d3f3c	05/24/2019 6:53 AM	20
2019.12.1.2 5c87371	05/03/2019 7:05 AM	2
2019.12.1.1 4b1dd29	05/01/2019 4:04 AM	26
2019.8.5 3aaa23d	04/04/2019 8:58 PM	2
2019.8.4 530d1d3	04/02/2019 6:53 AM	19
2019.5.15 f5def7e	03/13/2019 10:36 AM	28
2018.50.6 4ec03ed	02/12/2019 10:07 PM	

(source:
TeslaFI)

Software as the enabler

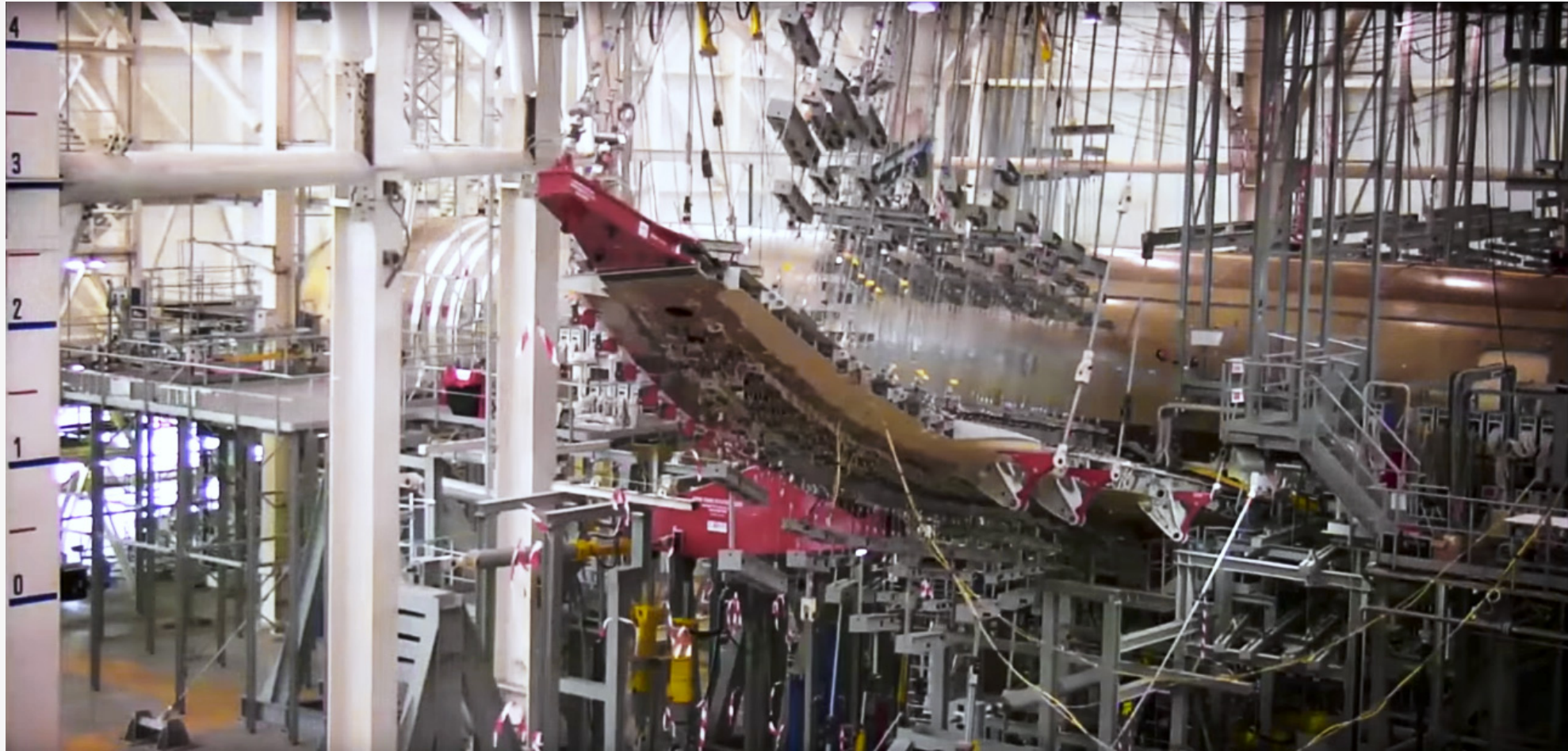
- Charismatic organizations favor “building” in software vs. hardware
 - Low capital investment
 - Low startup costs
 - Easy to complicate/obfuscate
 - Easy to hype
 - Wall Street appeal
 - (preference for non-capital intensive enterprises. Return On Net Assets (RONA))

Notable Software Failures

- Ariane 5
 - Overflow bug due to higher information rate from new engines
 - Lack of software heterogeneity (“multiple load paths”)
- Therac 25
 - Removal of hardware interlocks in favor of software protection (cost savings)
 - Poor quality software subject to race conditions
 - Attempts to “fix” problem with subsequent software updates. Didn’t work as software was still low-quality
- Hartford Stadium collapse
 - CAD software made incorrect assumption about bracing of structural elements
 - Overconfidence in “sophisticated software”
 - *“equate system complexity with system accuracy, despite the opaqueness it introduces.”*

Hardware testing

- Wing bending test



Hardware testing

- Fuselage Drop Test

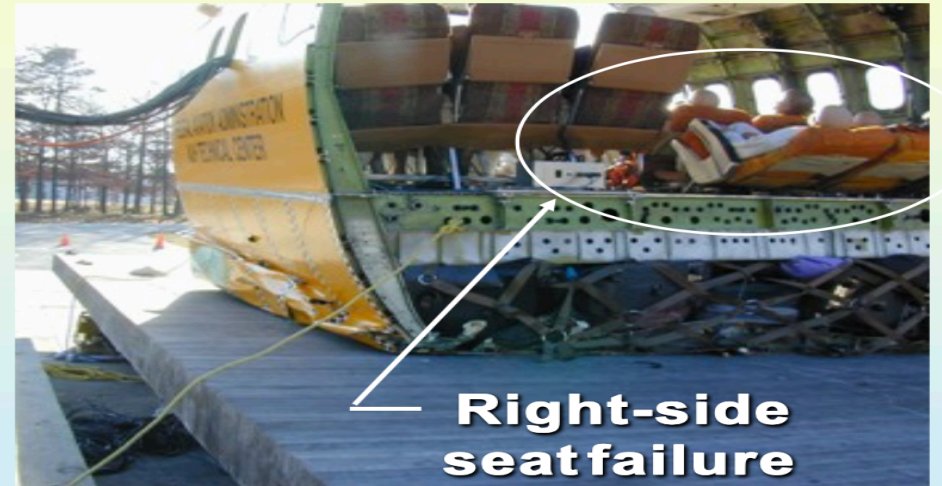


Vertical Drop Test of a B737 Fuselage Section



VEHICLE TECHNOLOGY DIRECTORATE

Post-test Photographs

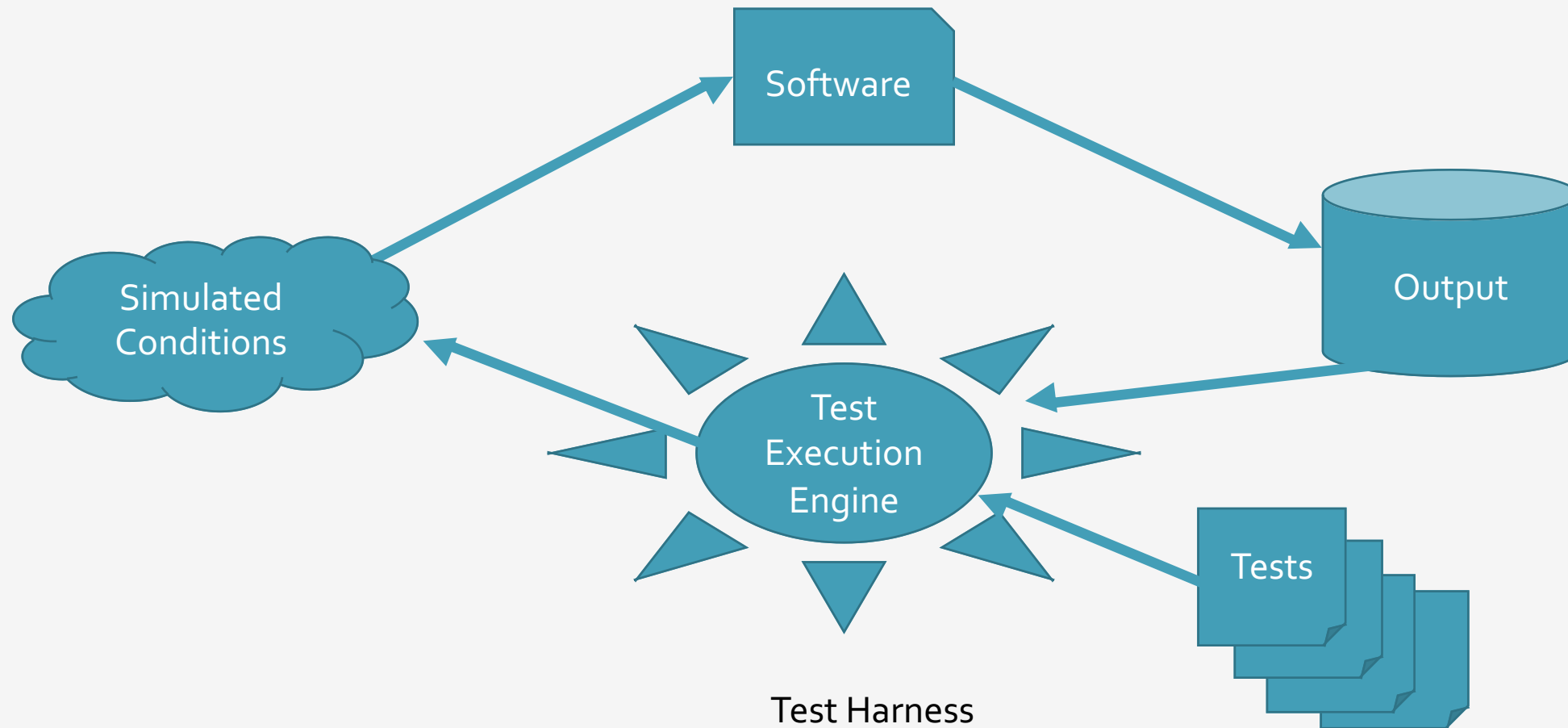


Asymmetric deformation of the lower fuselage

Nature of Hardware testing

- Time consuming
- Expensive

Software testing



Nature of software testing

- Generally much cheaper to test in software than hardware
- Ostensibly easier to achieve more “test coverage” with software testing than hardware
 - But in reality this is often not the case
 - “Safety driving” vs. simulation example for autonomous vehicles (i.e. Tesla) (Michael DeKort/Dectle)
 - Test scenarios limited by tester’s creativity and imagination (Stadium roof example)
 - Test scenarios limited by “not wanting to know” (737 MAX case)

What happened?

THE BOEING 737 MAX SAGA

The Boeing 737

- Developed in 1960s
 - Take advantage of existing 707/727 tooling
 - *Started* life as a derivative design
 - Market was envisioned as one of unimproved airfields / developing countries
 - This drove single greatest architectural constraint: 737 sits very low to the ground to make loading passengers and luggage easy
- Expansion of model variations has been primarily constrained by distance to the ground
 - Size of engines
 - Length of fuselage
- Primary engineering focus since first market has been
 - Increase passenger capacity w/out raising airplane
 - Increase fuel efficiency (larger engines) w/out raising airplane
- Does not attract “best and brightest” engineers w/in Boeing. Legacy & “not sexy.”
- Largest contributor to Boeing’s profits, by far

What we know about airplanes

- Over their economic lifespan, all successful commercial airliners do two things:
 - They grow in size. New models that carry more passengers
 - They adopt new technologies where the technologies lower seat/mile (fuel) costs
 - This is particularly true with engines and flight controls
- Because of decisions made early in the 737's life, accomplishing the above has been difficult compared to other airplanes
 - Sits too low to the ground to easily adopt to larger and larger engines
 - Sits too low to the ground to easily provide adequate takeoff and landing clearance when lengthened
 - Hampered by early autopilot architecture which is inherently balkanized and non-redundant
- None of these constraints plague the Airbus A320 series (mid-1980s)

The Boeing 737

737-100 (Original)



(Image credit: Peter Scharkowski)

737 MAX 8



(Image credit: Franz Josef Strauss)

What we know about the MAX's competitor

- Airbus A320 series is a direct competitor to the 737 MAX
 - Nearly identical passenger capacity & seat-mile economics
 - *Started* life with the CFM56 engine and much higher ground clearance
 - *Started* life with an extremely sophisticated “fly by wire” automation architecture that is far more capable, far more redundant and far more reliable than the system(s) in the 737
- Boeing was able to hold off A320 competition throughout the 1990s and 2000s
- With the emergence of the CFM LEAP engine, the 737 faced an existential crisis vs. the A320

The Airbus A320

A320-100 (Original)



(Image credit: Wikipedia)

A320neo



(Image credit: Airbus)

The A320 vs. the 737



(Image credits:
Wikipedia &
Felix L @
aviation.stackexchange.com)

Notes on the images

- Both the A320neo and the 737 MAX 8 use the CFM LEAP engine
 - However the LEAP engine on the MAX is a smaller version of the one used on the A320 Neo
 - Nonetheless, the nacelle still has to be “flattened” on the 737 MAX 8 to provide adequate ground clearance
- The engine thrust exit (exhaust) on the 737-100 is behind the wing. The thrust exit on the 737 MAX is in front of the leading edge
 - Pitch change difference w/power over development of 737
- Thrust exit of the A320-100 and A320 Neo are nearly identical
 - No pitch change difference w/power over the development life of the A320 vs. 737
- Distance from bottom of wing (where engine is) to ground:
 - 737 MAX: Approx 8 feet
 - A320Neo: 12.4 feet

Emergence of the digital autopilot

- In early 2000s, Boeing became frustrated with the cost of constantly updating the SP-300 autopilot whenever new models of 737 were developed
 - Involved lengthy and expensive hardware changes
- At that time the digital autopilot was coming into existence in the industry as a commodity
 - (Actual emergence of digital controls traced back to Airbus and A320 development in 1980s. Boeing was heavily critical of that, then)
- Boeing floated proposals for replacing the SP-300 with a new digital autopilot
- Rockwell Collins won the proposal. Sperry/Honeywell was out
 - Rockwell's autopilot called the EDFCS-730
- Primary directive from Boeing: EDFCS-730 must be functionally and aesthetically identical to SP-300
 - Previous functions that had been implemented in hardware ("Speed Trim") now implemented entirely in software
- Secondary directive: EDFCS-730 architecture should be identical to existing autopilot architecture
 - I.e. notion of two separate and non-interconnected flight control computers (FCC)
 - This is why the original MCAS implementation used only a single AOA vane

Comparisons

SP-77 autopilot
1967-1980

Electromechanical

No significant changes/
fifty-two years

Nature of change:
entirely hardware

SP-177 autopilot
(1980-1988)

Minor digitization
(integration with FMC)

Twelve changes/
forty years
(average change
every 3.3 years)

Nature of change:
predominantly hardware

SP-300 autopilot
(1984-2003)

First "software defined" autopilot
Gained field-update capability
in 1997

Fourteen software updates/
thirty-five years
(average change
every 2.5 years)

Nature of change:
hardware / software

EDFCS-730 autopilot
(2004-present)

Full digital autopilot

Fifteen software updates/
fifteen years
(average change
one/year)

Nature of change:
entirely software

(source:
Boeing 737
Technical
Manual)

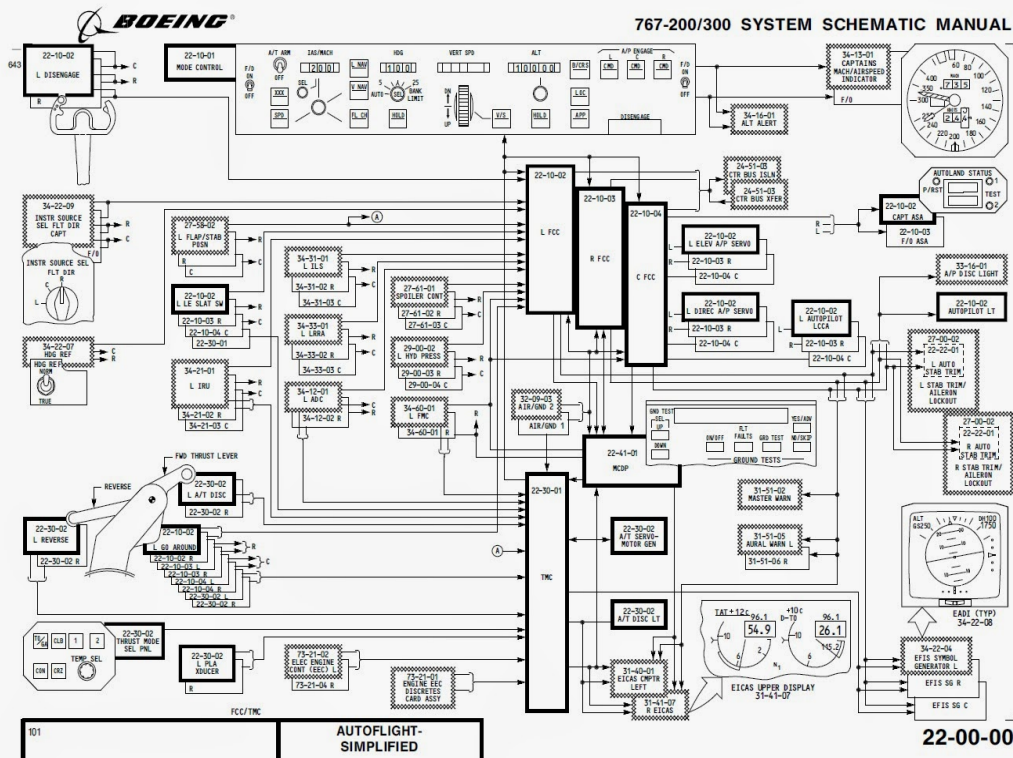
Hardware

Predominant nature of the autopilot system

Software

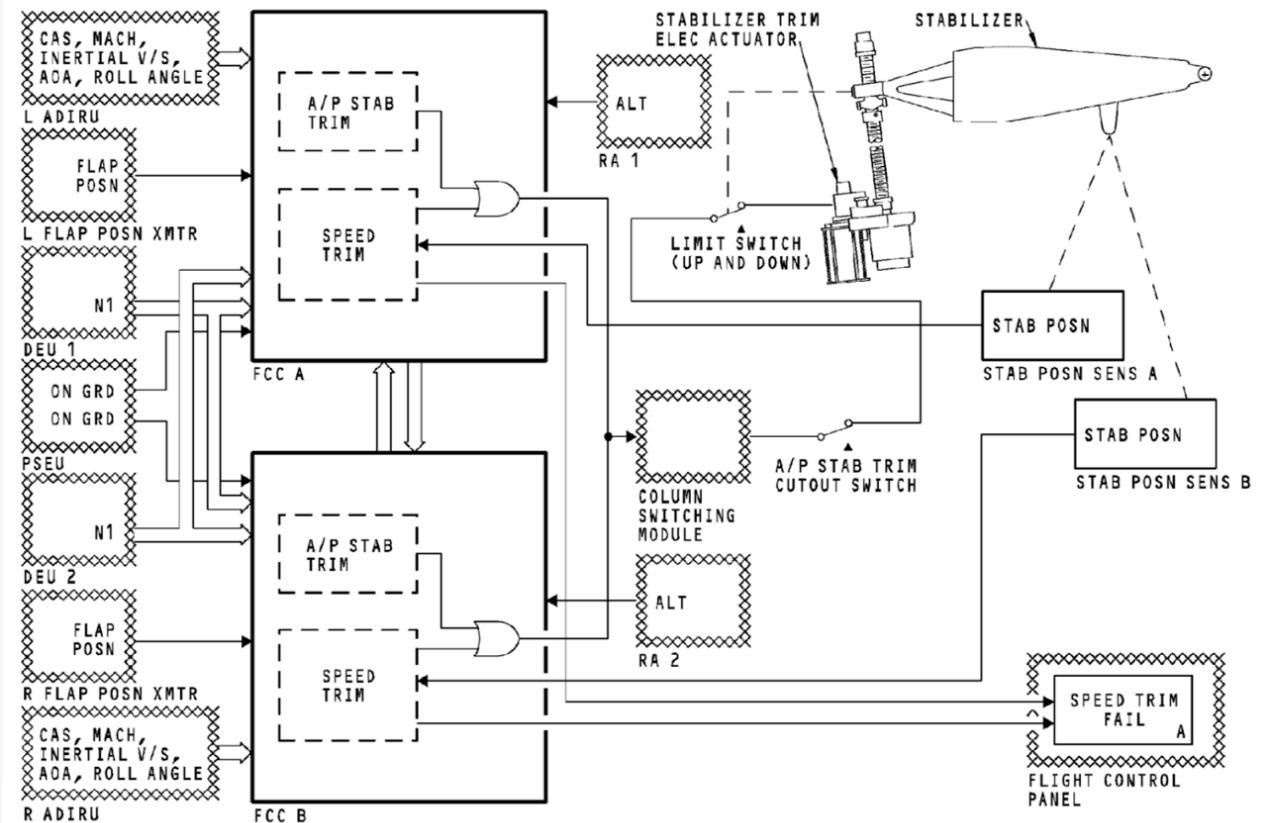
767 vs. 737 flight control architecture

767



(Boeing)

737



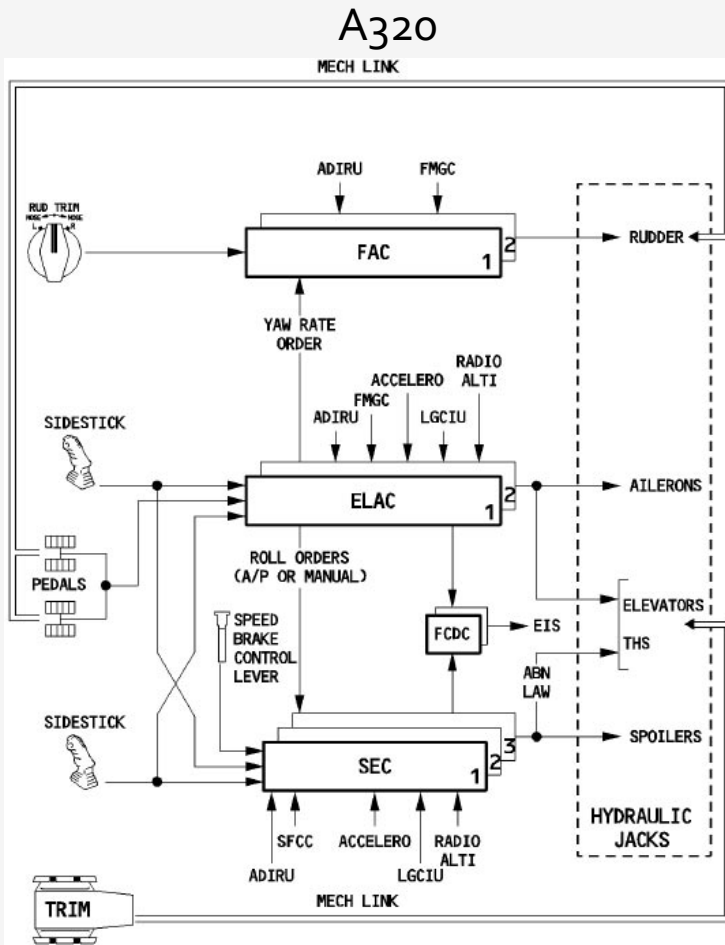
Notes on the architecture differences

- “Flight control” in 767 is done via:
 - Flight Control Computers (FCC) (3)
- Flight control is integrated with autopilot function
- All FCCs are active on each flight
- All external sensors (AOA, pitot, etc.) (ADIRU data) available to all FCCs
 - Easy to detect discrepancies
- Flight control in 737 MAX is done via:
 - Flight control computers (FCC) (2)
- Flight control computers are not actually flight control computers. They are digital autopilot computers “hacked” to provide flight control functions such as speed trim and MCAS
- Only one FCC is “in charge” on a given flight. Other FCC exists only as a “hot standby” and each FCC can only see “its” sensors (two ADIRUS (“L” and “R”) are connected to only “their” FCC).
 - Difficult to detect discrepancies
 - THIS IS WHY ORIGINAL MCAS IMPLEMENTATION ONLY USED ONE OF THE TWO AOA SENSORS ON 737
- There is a communication channel between the two FCCs
 - Boeing is NOW apparently going to use that channel to send AOA information from the “inactive” FCC to the active one
- No software heterogeneity

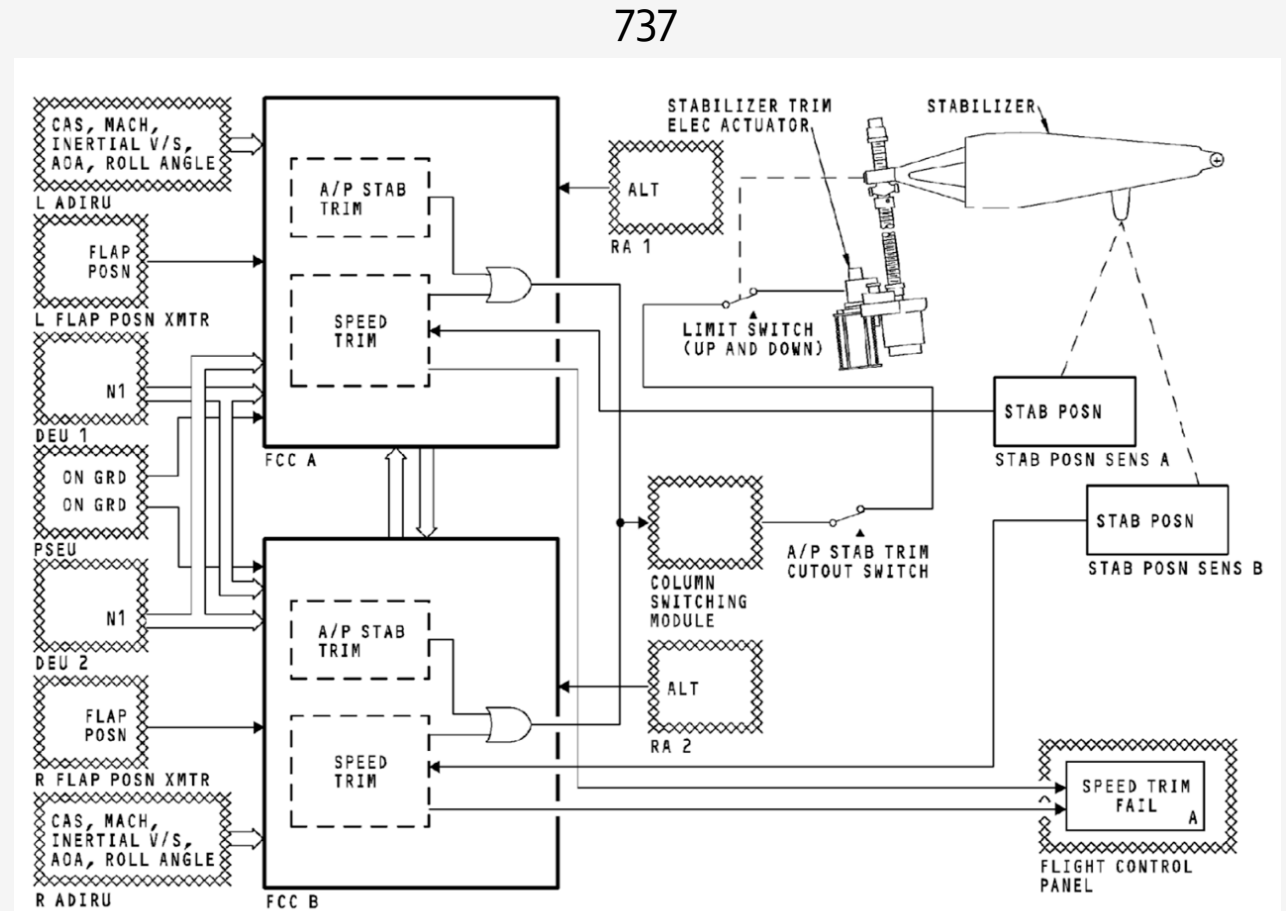
MCAS in the KC-46 (767) vs. 737

- Totally different systems
 - Similar only in their acronym
 - Boeing intentionally put out that 737 MCAS was derived from 767 MCAS so that regulators would believe 737 MCAS not “new” and unproven.
 - Again, their similarity begins and ends with the acronym
 - KC-46 MCAS designed to deal with changes in aircraft center of gravity as fuel is offloaded (KC-46 is a tanker)
 - 737 MCAS designed as an anti-stall system dealing with high angles of attack
 - KC-46 MCAS not hampered by primitive flight control architecture of 737
 - In particular, easy to integrate all ADIRU (including AOA) information in 767. Hence use of all 767 AOA in 767 MCAS
 - Very difficult to do that in 737 architecture (hence initial use of only one AOA in 737 MCAS)

A320 vs. 737 flight control architecture



(Image credits:
Airbus &
Boeing)



Notes on the architecture differences

- Flight control in A320 is done via:
 - Flight Augmentation Computers (FAC) (2)
 - Elevator/Aileron computers (ELAC) (2)
 - Spoiler/Elevator computers (SEC) (3)
- Flight control is not integrated with autopilot function
- FACs provide yaw damper function and autopilot rudder control
 - Pilot rudder control is manual (hydraulic)
- ELACs are double redundant. SECs are triple redundant
- SECs can provide elevator/stabilizer control if both ELACs fail
- Both ELACs and SECs can provide roll control
- Software in SECs not written by same entity that wrote software in ELACs (software heterogeneity)
- All external sensors (AOA, pitot, etc.) (ADIRU data) available to all ELACs and all SECs
 - Easy to detect discrepancies
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Notable difference #1 between A320 / 737

“Mechanical control of the trimmable horizontal stabilizer is available from the pitch wheel at any time, ***if the green or yellow hydraulic system is functioning***”

Mechanical control from the pitch trim wheel ***has priority over electrical control*** “
(source: AIRBUS TRAINING, FLIGHT CREW OPERATING MANUAL)

What does this mean?

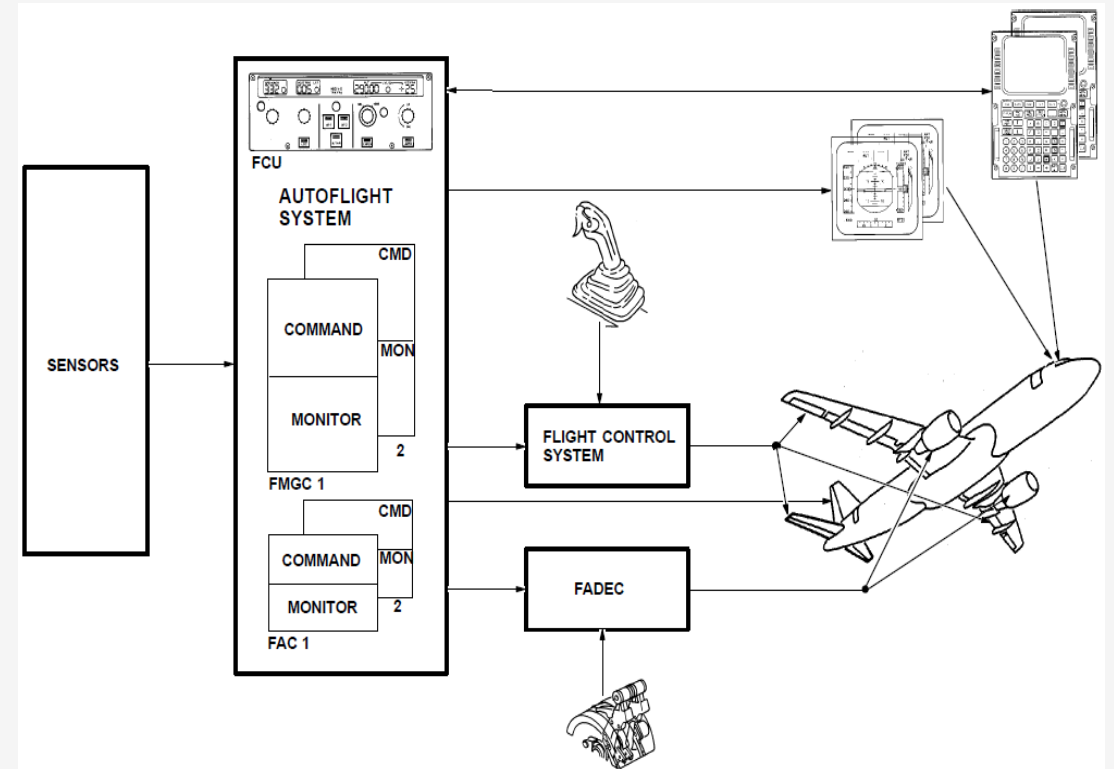
It means two things:

- 1) Even manual control of the stabilizer on the A320 is power-assisted (hydraulic). Would not have had the same issues as the Ethiopian 737 flight (aerodynamic forces made manual trimming impossible)
- 2) Touching the trim wheel on the A320 STOPS any automatic trim function (contrary to MCAS function)

THIS IS THE DIFFERENCE BETWEEN STEERING AND POWER STEERING IN A CAR. With regard to manual trim, the A320 has power steering. The 737 does not.

Notable difference #2 between A320 / 737

- In 737 “flight control” functions (such as MCAS) are incorporated in the autopilot computer
- In A320 “flight control” functions are completely separate from the autopilot
 - Autopilot has its own computers, called “Flight Management Guidance Computers” (FMGC)
- CRITICAL DIFFERENCE: A320 autopilot is subject to exact same “flight control” protections as the pilots are
 - The A320 autopilot NEVER drives the pitch or roll control surfaces directly. It can only drive them through the flight control system



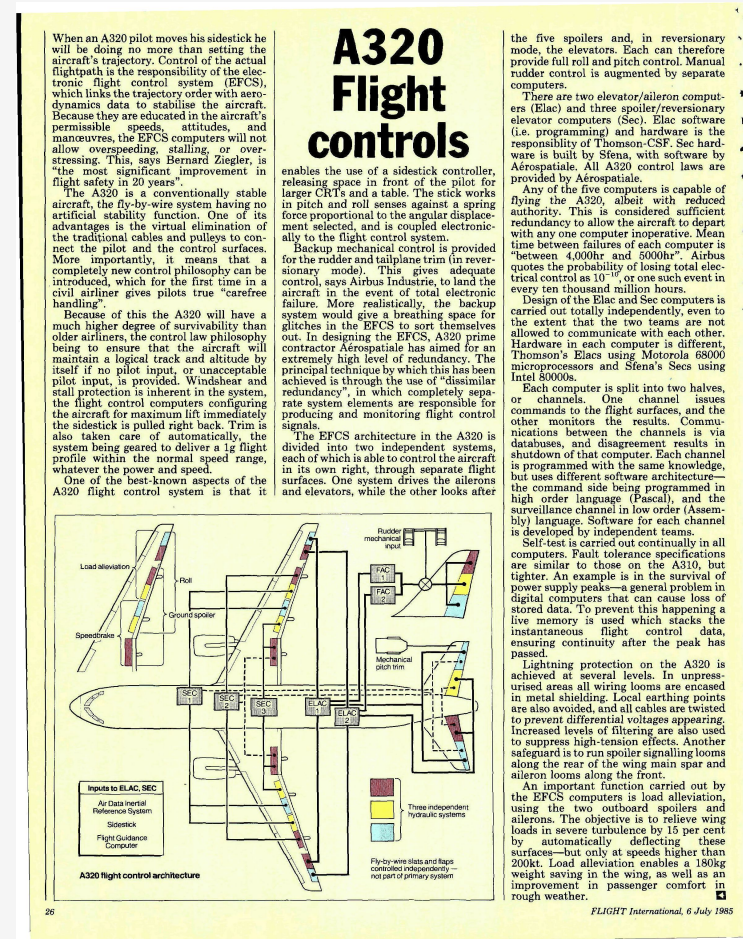
(Image credit: Airbus)

Notable difference #3 between A320 / 737

- Even though it is *heavily* automated, the A320 does not use or need software to compensate for aerodynamic issues caused by its engines.
- The 737 MAX, with a less redundant, less reliable, less robust and unproven automation system, does.

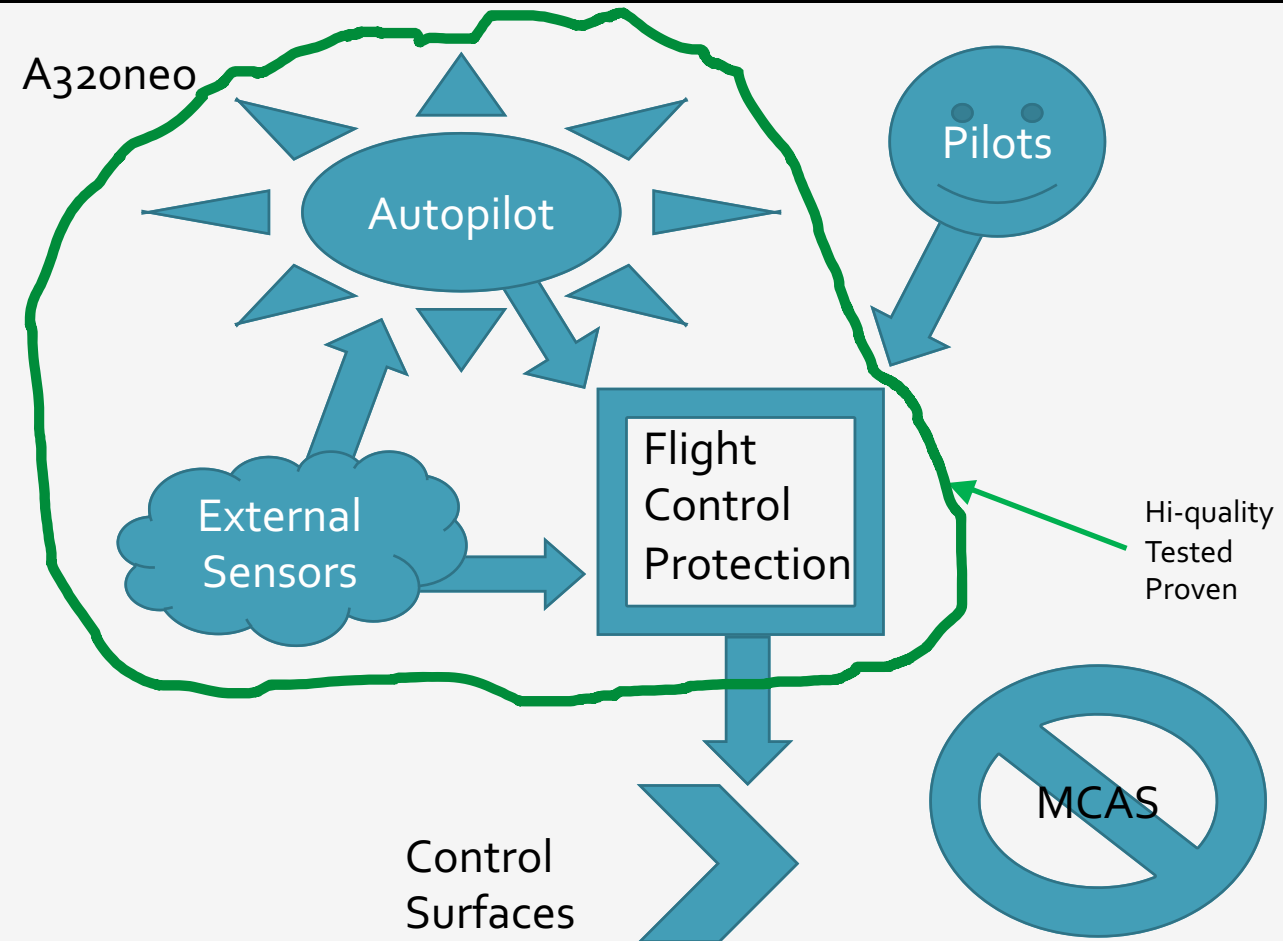
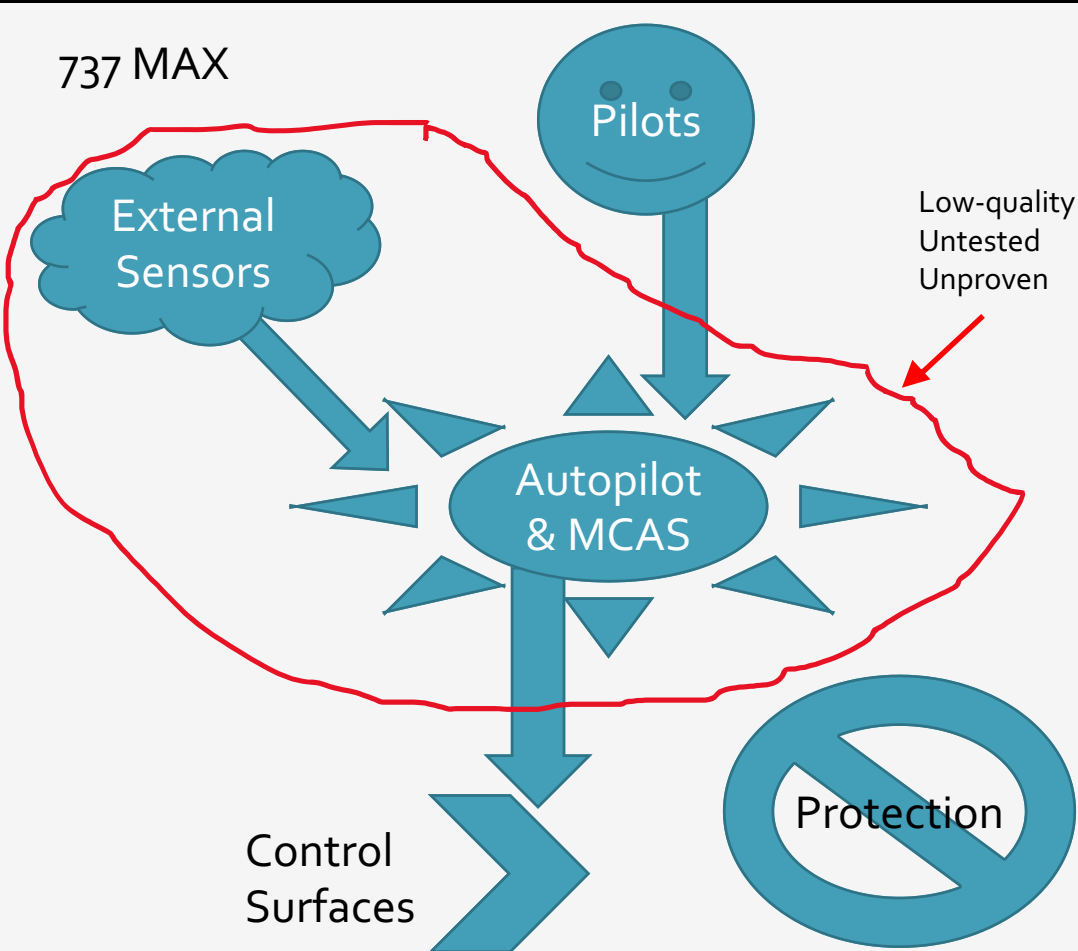
“The A320 is a conventionally stable aircraft, the fly-by-wire system having no artificial stability function”

Flight International, “A320 Flight Controls” (1985)



(Image credit:
Flight International)

Visualization of the differences



What we know about the MAX's origin story

- 2010: Airbus announced A320neo ("New Engine Option") to use the CFM LEAP engine
 - At least 15% more fuel efficient than the previous A320 generation with CFM56 engine
 - Program cost ~\$1.3 billion estimated in 2010
 - First flight 2014
- Boeing initially shrugged it off saying "They're going to have trouble with that" (paraphrase)
- Several airlines began sending messages to Boeing that they were considering ordering new A320neos, instead of 737 NG ("Next Generation"). American in particular
 - How credible a threat this was is not clear
- Boeing looked at its options:
 - Develop a new airframe at expected cost of ~\$12 billion
 - Modify 737 NG airframe to accommodate CFM LEAP engine at expected cost of ~\$3 billion
- We know which option they chose

Then they ran into a great big hassle

- Because of the radical change in engine mounting (Boeing already had experience with the changes in aircraft handling that come with a larger engine (CFM56))
- With the CFM56, they modified the airframe itself with various aerodynamic hardware (vortex generators, larger surfaces, etc.) to mitigate the changes.
 - Those modifications are expensive in both time and money
- They anticipated similar issues with the CFM LEAP (their computer models indicated such)
- Apparently when they got to actual flight testing, they found the changes in aircraft handling to be far greater than they anticipated.
- From the outside, it appears they began to panic

Cultural Transformation @ Boeing

- Prior to 1997 McDonnell Douglas merger, Boeing had a bureaucratic/rational/engineering culture
 - Sequential development of “bet the company” airplanes
 - Very painful in short term
 - Very successful in long term (strategic)
- Prior to merger, McDonnell Douglas had a charismatic/irrational/financial culture
 - Focused relentlessly on milking existing airframes, not creating new ones (tactical)
 - Lost its dominance and never recovered
- Pentagon essentially forced Boeing to acquire McDonnell Douglas so that it would not go out of business
- Terms of the merger heavily favored takeover of Boeing by McDonnell Douglas leadership
 - In particular, John McDonnell and Harry Stonecipher
- Transformation of Boeing began almost immediately

Mission confusion @ FAA

- FAA is saddled with a “dual mandate”
 - Regulate the aviation industry
 - Promote the aviation industry
- Congress tried to remove this dual mandate through legislation in 1996
 - However culture trumps strategy. Culturally the dual mandate has never disappeared
- Promotion of the industry gradually eroded the mandate to regulate the industry
 - FAA became very cozy with the manufacturers, often referring to them as “customers.”
 - FAA very receptive to lobbying by the manufacturers
- Largest result of this was the development of the DER (Designated Engineering Representative) program and then the Organizational Delegating Authority (ODA) program in early 2000s
 - ODA effectively surrendered then entire certification and regulation function for large aircraft manufacturers to the manufacturers themselves

Technological Transformation

- Airbus pioneered all digital flight controls in commercial aircraft in the 1980s, with the A320
- For a long time Boeing resisted this technology, denigrating it as taking control away from the pilots
 - This is the “Langewiesche argument” -- that technology emasculates pilots and makes them not “special.”
 - Relies on concept of pilot that is not real, inherently racist and inherently sexist.
 - Boeing revisited this argument when trying to deflect blame for 737 MAX design to pilots of crashed airplanes
- Problem was: The airlines (Boeing’s customers) want control taken away from the pilots
 - Increases safety
 - Decreases cost
- Boeing succumbed to customer pressure fully with the 787 Dreamliner
- Inflection point: The arrival of the commodity digital autopilot in early 2000s

Legacy constraints

- Everything about the 737 eventually leads back to:
 - How low it sits to the ground
 - Flight control architecture
- Both of which were determined fifty years ago
- And set in stone by the requirement to add each successive 737 to the original type certificate
- Any pilot with a single 737 rating can fly ANY 737, from the first 737-100 of 1967 to the latest 737 MAX (737-8 on type certificate data sheet)

Certificate: AIRLINE TRANSPORT PILOT [Print](#)

Ratings:

AIRLINE TRANSPORT PILOT

AIRPLANE MULTIENGINE LAND

COMMERCIAL PRIVILEGES

AIRPLANE SINGLE ENGINE LAND

AIRPLANE SINGLE ENGINE SEA

Type Ratings:

A/B-737 A/BE-300 A/BE-1900 A/DHC-6

DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION

TYPE CERTIFICATE DATA SHEET A16WE

This data sheet, which is part of Type Certificate No. A16WE, prescribes conditions and limitations under which the product for which the type certificate was issued meets the airworthiness requirements of the Federal Aviation Regulations.

Type Certificate Holder:

The Boeing Company
1901 Oakesdale Ave SW
Renton, WA 98057-2623

I - Model 737-100 (Approved December 15, 1967) Transport Aircraft

Engines:

2 Pratt and Whitney Turbofan Engines JT8D-7, JT8D-7A, JT8D-7B, JT8D-9, JT8D-9A, and JT8D-15; refer to the FAA Approved Airplane Flight Manual for aircraft engine and engine intermix eligibility. (Engine Type Certificate No. E2EA)

A16WE
Revision 61
BOEING
737-100 Series
737-200 Series
737-300 Series
737-400 Series
737-500 Series
737-700 Series
737-800 Series
737-600 Series
737-700C Series
737-900 Series
737-900ER Series
737-8
737-9
Date February 15, 2018

Four seeds of demise...

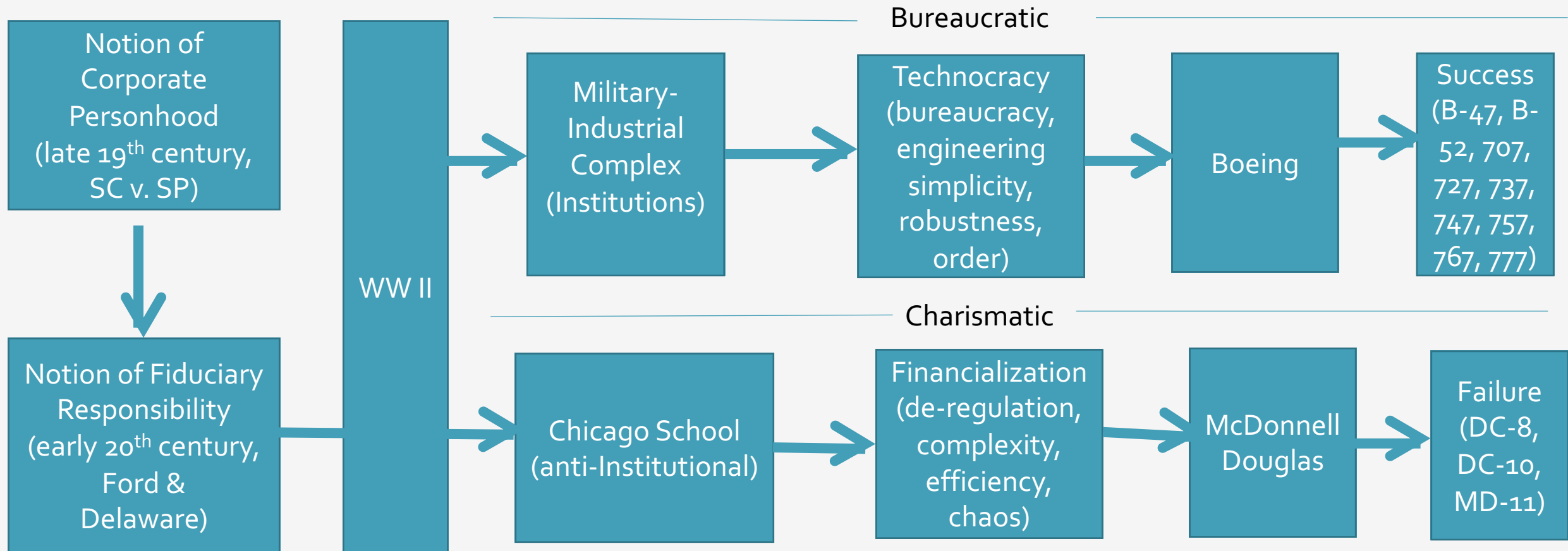
- In the early 2000s, Boeing had decided to replace the hybrid electromechanical/digital autopilot on the 737NG with a new “digital” autopilot (EDFCS-730)
 - A digital autopilot is one whose functionality is almost entirely defined by computer software, not hardware
 - This would produce great efficiencies and cost reductions going forward...
 - Due to its age, however, the 737 was not an appropriate platform for a digital flight control system
 - **Cultural transformation @ Boeing allowed this engineering reality to be dismissed**
- The ODA process allowed Boeing to hide the engineering defects from the FAA
 - **Mission confusion @ FAA allowed Boeing to “self-certify” its own defective designs with no oversight**
- The Rockwell Collins EDFMS-730, while never intended to perform a function like MCAS, became an extremely attractive platform for MCAS
 - **Technological transformation introduced this option**
- Need to grandfather onto existing type certificate
 - **This locks in the legacy architectural constraints**

Four seeds combined to produce a TINA mindset: There Is No Alternative
Another word for that is *tragedy*.

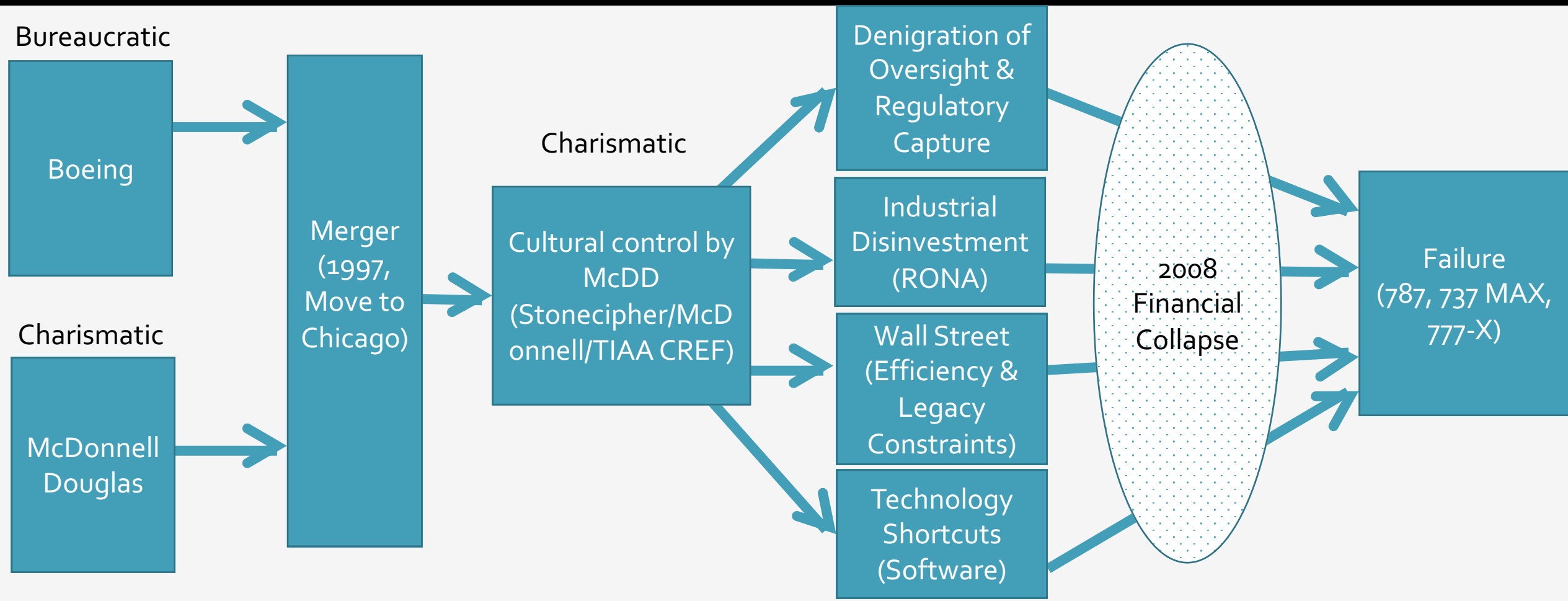
... killed 346 people and destroyed the company

- Boeing's implementation of MCAS was fatally flawed:
 - Used untested, unverified and hastily-produced software of extremely low quality **due to cultural change at Boeing**
 - Hid the details of the software and the whole MCAS system from not only the FAA but also its customers and its own test pilots **enabled by mission confusion at FAA (regulatory capture)**
 - Architectural nightmare **enabled by emergence of digital autopilot retrofit to legacy airframe/architecture**
 - Relied on data from a single sensor (AOA)
 - Did not check the data for sanity
 - “Lives” where it should not live (autopilot computers, not flight control computers (despite Boeing's misleading nomenclature))
 - Used sensor data to drive the most powerful control surface on the airplane at high speed
 - Through repeated actuations could drive that control surface to its stops.
 - Quickly rendered the aircraft uncontrollable by any pilot of any skill level

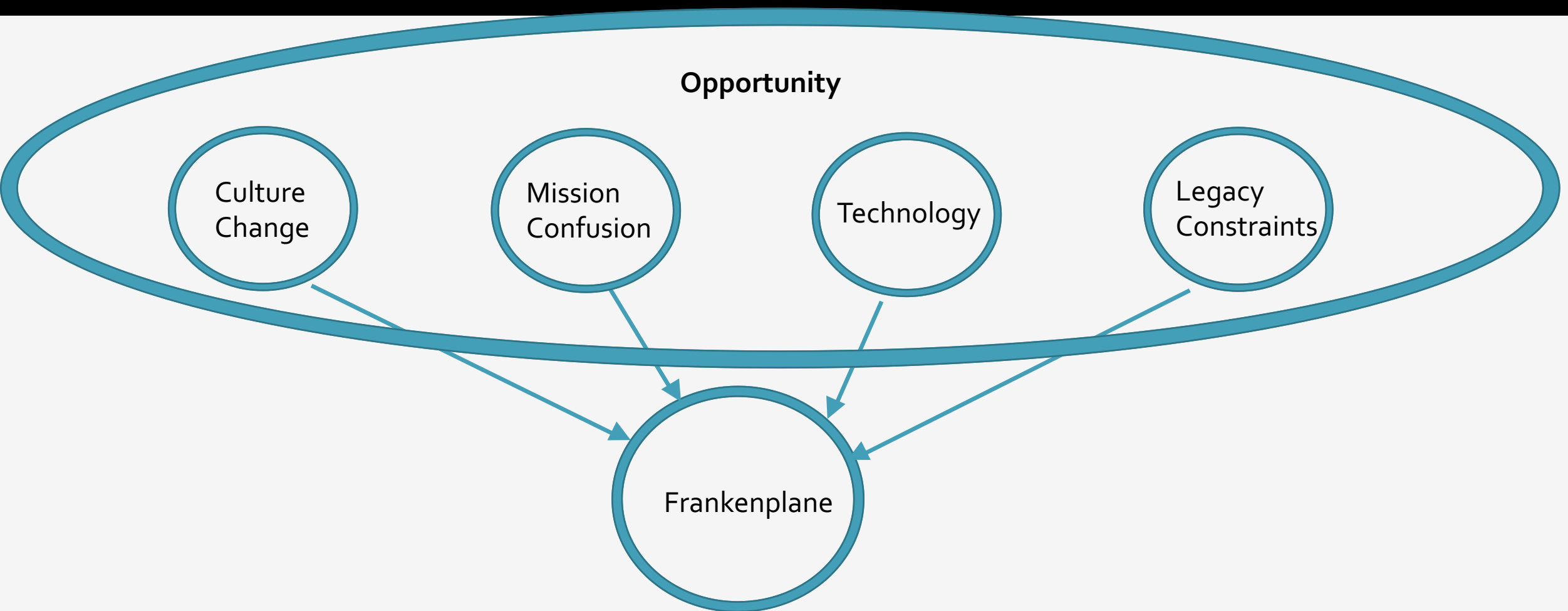
Pre-Merger: Seeds



Post-Merger: How it fell apart



The tragedy of Frankenplane



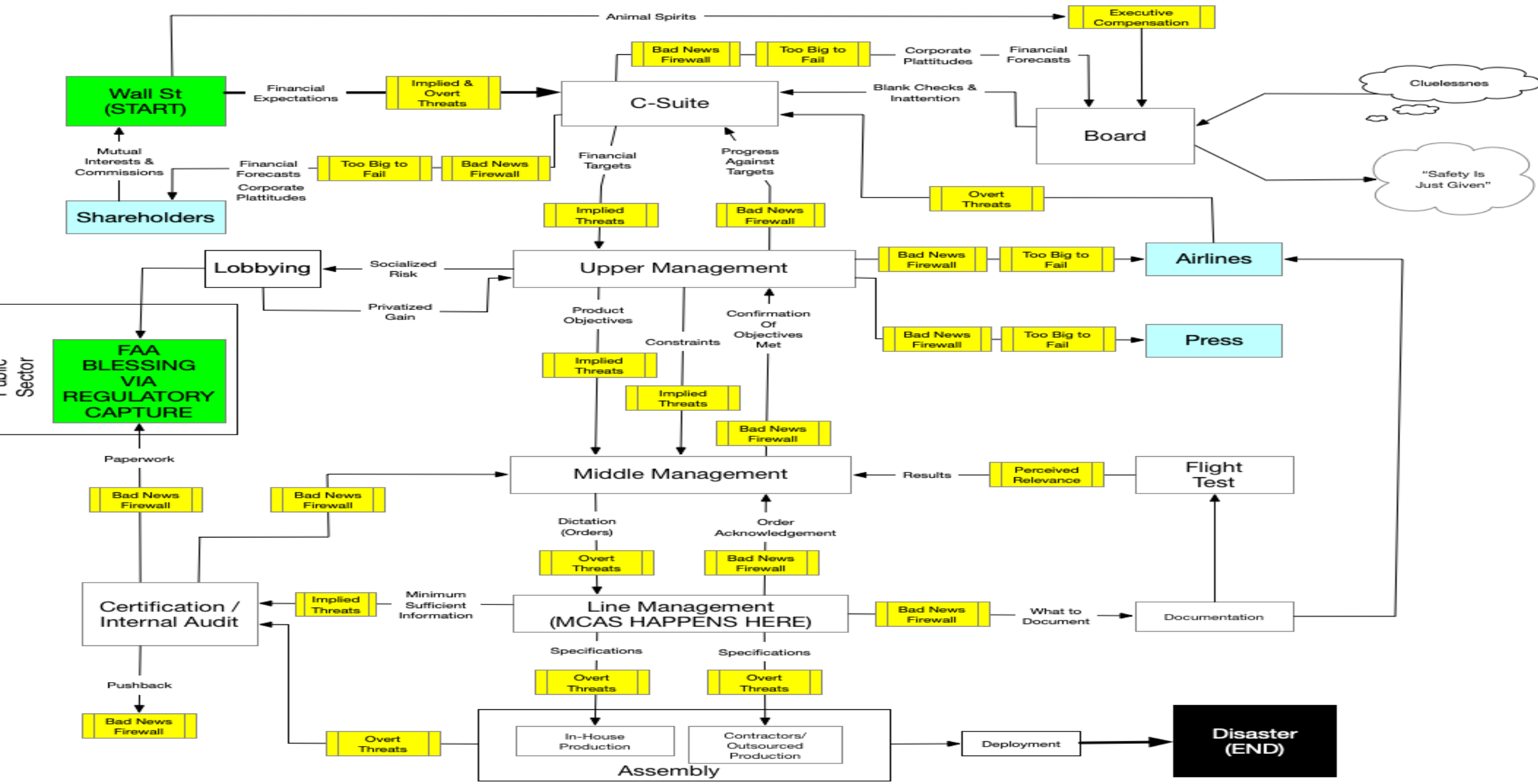
The tragedy of Frankenplane

- Competing against Airbus, Boeing again found it necessary to fit larger engines (CFM LEAP) to the 737
- They ran into the same aerodynamic issues they had run into when fitting the CFM56
- It looked like they would have to extend 737 MAX development and significantly increase cost to mitigate the problem “traditionally” (i.e. in hardware)
- They realized they had an option: The EDFCS-730 could be programmed to mask the aerodynamic issues and make them “go away”
- Cultural transformation at Boeing allowed this as an option
- Developed in a panic / chaotically
- Limits of communication between teams
- Increased complexity
- Result: FRANKENPLANE & failure modes not understood by anyone

Why Boeing should never build another commercial airliner

- Risk of certainty
 - “What Boeing is doing is a ‘deep dive’ into the software and addressing other areas where there is insufficient redundancy.”
 - Boeing CEO Dennis Muilenburg, during congressional testimony when asked why MCAS changes were taking so long
 - This is terrifying given:
 - The unsuitability of software solutions for defects in the 737 due to legacy constraints and architecture
 - The incompetence displayed in the original MCAS implementation
- Tactical limitations of shareholder return maximization
 - Constraints of efficiency (i.e. MCAS as only solution to airframe issues)
 - Inability to commit to long-term investment (i.e. new airplane)
 - Inability to tolerate meritocratic reward

WELCOME TO THE MACHINE



For further reading/listening

- “How the Boeing 737 MAX looks to a software developer” (Gregory Travis)
 - <https://spectrum.ieee.org/aerospace/aviation/how-the-boeing-737-max-disaster-looks-to-a-software-developer>
- “Why Boeing should never build another airplane” (Gregory Travis & Marshall Auerback)
 - <https://www.alternet.org/2019/05/anatomy-of-a-disaster-why-boeing-should-never-make-another-airplane/>
- “How self regulation fails, the Boeing case” (Gregory Travis)
 - <https://medium.com/@gregoryreedtravis/how-self-regulation-fails-the-boeing-case-5e29c1e4bbc>
- “Why an MCAS failure does not present as ‘runaway trim’” (Gregory Travis)
 - <https://medium.com/@gregoryreedtravis/why-an-mcas-failure-does-not-present-as-runaway-trim-144e902385a7>
- Berkeley presentation: (Gregory Travis)
 - https://drive.google.com/file/d/1DltuoBgJlvqkgJtl_dKRjU_fCrWKgThu/view?usp=sharing
- Software won’t fix Boeing’s faulty airframe (George Leopold)
 - https://www.eetimes.com/document.asp?doc_id=1334482#
 - https://www.eetimes.com/document.asp?doc_id=1334532. (Interview with Greg Travis)
- Eastern Airlines Radio Show (interview with Greg Travis)
 - <https://www.blogtalkradio.com/capteddie/2019/04/15/episode-409--eal-radio-show>
- Boeing officials discuss future of 737 MAX (interview with Greg Travis)
 - <https://www.aljazeera.com/news/2019/05/boeing-officials-discuss-future-737-max-190523150945094.html>
- Boeing crashes highlight worsening reliability crisis (George Leopold)
 - https://www.eetimes.com/document.asp?doc_id=1335110
- The case against Boeing (Alex MacGillis)
 - <https://www.newyorker.com/magazine/2019/11/18/the-case-against-boeing>
- Crash Course: How Boeing’s Managerial Revolution Created the 737 MAX Disaster (Maureen Tkacik)
 - <https://newrepublic.com/article/154944/boeing-737-max-investigation-indonesia-lion-air-ethiopian-airlines-managerial-revolution>
- The limits of William Langewiesche’s “airmanship.” (Elan Head)
 - <https://medium.com/@elanhead/the-limits-of-william-langewiesches-airmanship-52546f20ec9a>