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Cascading Effect of Boeing's 737 Max Technology Development

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***Abstract:** During March and April 2019, many countries had grounded Boeing's 737 Max 8 jets following two fatal crashes in a space of five months, between October 2018 and March 2019, killing 346 people. It was widely reported that the problem was with the software called Maneuvering Characteristics Augmentation System (MCAS). Aviation experts across the world accused Boeing of being lax in following safety protocols during 737 Max jet's development stage. It was reported that the company was in a hurry to face the fast growing competition from archival Airbus. Boeing faced a sever threat of losing its market share in the North American short haul market after the runaway success of Airbus A320. The A320 deployed several first of the kind technologies and grabbed significant market share in European and Asian short haul market. This article explores the strategies that Boeing followed while developing Boeing 737 jet technology over the years. Also the article focuses on the competitive strategy of Boeing in general while playing catch-up with its competitor Airbus. Secondary data was analysed to illustrate cascading effect on the technology development.*

***Keywords:** Boeing, Airbus, Global Aviation, MCAS, Technology Life Cycle, Crisis at Boeing, Competition in Global Aircraft Manufacturing*

I. INTRODUCTION

During March and April 2019, many countries had grounded Boeing's 737 Max 8 jets following two fatal crashes. In October 2018, a Lion Air, 737 Max 8, crashed into Java sea minutes after takeoff from Jakarta killing all 189 passengers on board.[1] In March 2019, an Ethiopian Airlines aircraft, also 737 Max 8, crashed shortly after taking-off from Addis Ababa, killing all 157 people on board.[2] Aviation experts across the world expressed concerns over safety of Boeing's 737 Max 8 and recommended grounded of 737 Max jets. On March 12, 2019, The European Union Aviation Safety Agency announced the suspension of all Boeing 737 Max 8 flights in Europe after China, Australia, the UK and several other nations announcing grounding of Boeing 737 Max 8 flights.

More than 300 Max jets were grounded by various operators across the world, "Of the top 10 countries by air passenger travel, all but the United States and Japan have halted flights of the 737 MAX. (Please refer to Annexure I (A and B) for list of countries and operators that grounded

737 Max jets).

The 737 had been the Boeing's largest selling aircraft model and accounted for almost one-third of operating profit. Between 1958 to March 2019, Boeing delivered 23,167 aircrafts of all its models, of which 10,533 units were from the 737 family. (Please refer to Annexure II for year wise delivery of Boeing's all models). By 2019, the company had an order for over 5,000 units of 737 worth around $600 billion[1] Grounding of 737 Max jets had a severe impact on company's financial position and reputation. Consequently, company's share that traded at $440.62 on March 1, 2019, dropped to $375.41 on March 12 and further to $362.17 on March 22, 2019, on the NYSE bourse [2] By March 12, 2019, the company's market capitalization was reduced by $40 billion [3] compared to March 1, 2019, of which over $26.6 billion was lost in two days, March 11 and 12, 2019.

In response to technologically advanced A320 airplanes which were quickly snatching away market share, Boeing had developed the Next Generation 737 (called 737NG) which included the 600, 700, 800 and 900 variants. (Please refer to Annexure IV for market share comparison of Boeing's 737 and Airbus A320 families). The 737NGs, were entirely new aircraft, sharing only the fuselage frame with previous B737s. The most significant engineering changes in Boeing 737 NGs were its new wings, new avionics and bigger engines. To accommodate the larger engine fan, Boeing lengthened the nose landing gear of the 737 Max, which necessitated the relocation of aircraft's electronics/equipment (E/E) bay. Boeing 737 chief programme engineer John Hamilton said,[4] heavy engine used in 737 Max was also placed forward compared to engine placement in 737, which altered designs involving aerodynamics, software, the design of the wings, strengthening of fuselage and many other components.

In order to lift the engine higher, nose wheel was increased by 8 inches. Therefore, engines had to mounted forward. This resulted in nose of the aircraft pitching in certain phases of flight upbringing. With the possibility of a stall [3] Boeing

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fixed a new system called MCAS on 737 Max, to prevent the possibility of aircraft entering a stalling in the flight phases. It was widely reported that the problem was with the software called MCAS which automatically intervened and controlled the plane when the plane flies at a very steep angle. Many pilots said they do not know that such software existed until after the Lion Air crash. Consequently, when the planes were flying at a steeper angle, both manual correction and auto correction acted simultaneously leading the plane on crashing. These changes were necessary to increase passenger capacity and range in order to compete with A320s. The 737-800 model was recognized as optimum 737 'NG' model sporting longer fuselage to increase seat capacity to 160. The 737-800 was commercially very successful, with more than 4,000 orders from almost 200 operators. After the two crashes, many pilots complained that Boeing kept them in dark about a new feature of 737 Max. Pilots opined that they did not receive any training on the new stall-prevention system.

This paper attempts analyze the cascading effect of Boeing's technology development in the process of striving to compete with Airbus A320 through secondary data. Through the secondary data analysis for the failure of Boeing Max8 showed that probably the organization had rushed the development and missed on the training and communication part of the technology implementation, in the process of achieving technological excellence. Second section of this paper presents the competitive scenario between Airbus and Boeing. Third section presents the Boeing's lag in technological development compared with Airbus, while section four presents Boeing's 737 Max8 development and section five presents crashing design and development time and finally paper concludes with the cascading effect of Boeing Max8 development.

II RESEARCH METHODOLOGY

To conduct our study, we have used exploratory research methodology. Exploratory research is usually carried out when the problem is at a preliminary stage to have a better understanding of the existing problem, but may not provide conclusive results. Particularly, when a problem could not be clearly defined as in the case of Boeing Max8 planes crashing. Therefore, we conducted our study starting with general idea used collecting secondary data to identify the issues from various perspectives with key word search method using the keywords such as, Boeing max8, Boring innovation, Boeing technology, Boing innovation etc. Secondary data was collected from the authentic sources such as well-known Newspapers and magazines with long standing such as, New York times, Washington Post Wall street journals, Times, Forbes Business Week etc. this has prevented non-descript sources information. We have considered only Newspapers and magazines originating out of US for two reasons.

1. The US media will have in detailed coverage of the company as well as the issue over a long period of time
2. The information published in US media would be more authentic as the reporters will have direct access to the company.

Trade related journals and magazines along with reports from consulting houses were further explored. Data was analyzed in a Chronological order. While exploring the causes for the Boeing Max8 crash, we noticed an emerging cascading effect of technology development and the cause was its direct competition with Airbus, pressure for innovation, and economies of business. Further the cascading effect of technology development was studied and presented in this paper.

III. BOEING 737 FAMILY AND ITS COMPETITION WITH AIRBUS 320

The competition between two aircraft manufacturers, Airbus from EU and Boeing from the USA, had rendered aircraft manufacturing a duopoly. In the fierce competition, the two companies were left with no choice but to react to each other's strategical and tactical moves.

A significant proportion of the civil aviation industry market was comprised of the short haul flights capable of ferrying 150-200 passengers across 3,000 to 4,000 nautical miles. Boeing was early to recognize this and marketed the 737 series aircrafts to that segment during late 1960s, subsequently becoming the bestselling commercial aircraft of all time. Airbus entered short haul segment during 1980s competing with second generation Boeing 737s, with A320 series. While Boeing's 737 clocked 10,533 units of delivers till March 2019, the closest competitor was Airbus 320 series at 5,923 units. (Please refer to Annexure III for delivery of all models from Airbus). A combined delivery numbers of A320 and A321 series, at 7,157 units, also fell short of Boeing's 737 deliveries.

Boeing launched 737 model around 1964 whereas Airbus A320 was launched in 1984, but since then A320 outsold the 737 by 438 planes by September, 2018 [4] Many industry observers ascribed the success of A380 to its technological advancements such as fly-by-wire technology[5], side-stick controls, and cockpit commonality [6] in commercial airliners. Adaptation of Airbus reduced costs significantly to airlines, national airline of Belgium, Shabena reported $2.2 million annual savings in pilots training cost and Austrian airlines saved $6.5 million operational costs in five years[7] Further, the 180-seater A320 offered better fuel economy than a 148-seater B737-400, as the A320 carried 32 more passengers with almost same fuel consumption. Apart from cockpit standardization and fuel savings, Airbus also offered longer range and more capacity.

Airbus offered clutter free cabin as one pilot commented, "While the 737 has switches everywhere to control generators, air conditioning, hydraulics, et cetera, the Airbus does most of the work by itself in normal operation."[8] Because of its fuel and operational efficiencies, the A320's next generation A320neo and A321neo with added long-haul capabilities became favorites for airlines operating trans-Atlantic flights

Table -1 Comparison of B737 and A320

Boeing

	Variant	Passengers	Range(nm)
First Generation	737-100	118	1,540
	737-200	130	2,600
Second Generation	737-300	140	2,255
	737-400	168	2,060
	737-500	132	2,375
Third Generation (NG)	737-600	130	3,235
	737-700	140	3,010
	737-800	175	2,935
	737-900	215	2,950
Fourth Generation (NG)	737 MAX 7	153	3,850
	737 MAX 8	178	3,550
	737 MAX 9	193	3,550
	737 MAX 10	204	3,300

Airbus

Variant	Passengers	Range(nm)
A318	117	3,100
A319	160	3,750
A320	190	3,300
A321*	230	3,200
A319 neo	160	3,750
A320 neo	195	3,500
A321 neo	240	4,000

Source: Nicholas, "The Boeing 737 vs Airbus A320 – What Plane Is Best?," www.simpleflying.com/boeing-737-vs-airbus-a320/ March 24, 2019

*

"The A321 was designed to compete with the B757 and not 737, but as it is built on the same frame and is the same 'type' aircraft, it was included it for reference.

- The A320 was designed to compete with the 2nd Generation 737
- Third generation 737 to compete with the A320
- A320neo to compete with the third generation 737
- The fourth generation 737 to compete with the A320neo"

The 737-300, was the first aircraft in the second generation. The successor of 737-300, the 737-400, which took its first flight in 1988, was Boeing's attempt to counter Airbus' claim on the 150-seat segment.

In 1999, Boeing launched the 737-500 replacing similar sized 737-200. The 500 was the smallest aircraft in 737 series, but had longest range. The 737-500 had comparatively high seat-mile costs. The 300s, 400s and 500s were called the 'Classics', while the successors were named 'Next Generation' or NG aircrafts. The 737-600, introduced during 1998 was the first Next generation 737 aircraft. The 100-seat 737-600 was the same in cabin dimensions as the 737-500.

Unlike 737-600, the 140 seater 737-700 (introduced in 1997), which shared the fuselage of the 737-300, was commercial success. Its main competitor, the Airbus A319, was equally successful and the two models shared 130-160seat market for years. However, with the operators veering towards bigger aircrafts in subsequent years and increasing competition from significantly more efficient aircrafts such as CS300 from Bombardier and A319neo from Airbus, Boeing launched the 737 MAX 7 in 2011.

In the interim period 737-700 remained competitive with technological upgrades related to performance and interiors. The CFM56-7BE 'Evolution' engines along with aerodynamic refinements were used to improve the performance, while adherence to the new Sky Interior improved the cabin appearance and utility. It was reported that aggressive pricing was also critical factor in keeping the 737-700 competitive. Blended Winglets that promised 3-5% fuel efficiency improvement and that could be retrofitted also played an important role in continuation of the model.

From 2006 Boeing was planning to the replace the 737 with a new design ground-up. In March 2006, the company announced a team under Mike Cave (the then vice president for aircraft programmes at Boeing Commercial Airplanes (BCA)), to develop a replacement of Boeing 737 with a target date between 2012 and 2015. The 737 Replacement Study (called 737RS) was taken up as part of Yellowstone Project.[9] The 737 RS was expected to develop the design template of 737's replacement by 2009, which would provide 20-25% savings in operational costs to operators. However, the 737 RS was put on hold in 2008 as intended efficiency was not met and the savings amounted to just over 10%.

IV. BOEING LAG BEHIND AIRBUS TECHNOLOGICAL DEVELOPMENT

Introduction of A320neo with more efficient specifications, in 2010, Boeing got into pressure. With the pressure to retaliate quickly Boeing introduced the 737 Max Family in 2011, which was publicized as more modern and more efficient compared to 737NG Family. According to industry observers the introduction was premature with a single objective of countering A320neo's success and that 737 Max Family was an up gradation of 737 NG Family rather a new model. In November 2014, it was reported that Boeing intended to replace the 737 by 2030 with a new airplane, with a composite airframe, code-named Boeing Y1.

New CFM International LEAP-1B engine was most important feature of the 737 Max which claimed 12-14% fuel efficiency over the CFM56-7B engine used on the 737NG. For improved fuel efficiency, new engine's fan diameter was increased by 7.6 inches (19.3cm, new fan diameter reached 69.4 inches (176 cm)), which required better ground clearance. Boeing had to increase the nose gear height by 8 inches, to maintain a ground clearance of 16.9 inches. This increased height necessitated redesigning of forward electronics equipment bay that enclosed nose gear. Aerodynamic modifications were carried out on the fuselage with a new tail cone to improve fuel efficiency. To improve the fuel efficiency, a new winglet was also designed.

Design of 737 Max was frozen during 2013 and first flight was successful in January 2016. The first commercial flight of the 737 Max Family was that of a 737 Max 8 from Kuala Lumpur to Singapore by Malindo Air10 during May, 2017.

At the behest of large customers, the 737 Max7 was redesigned adding 1.93 meters to fuselage for aircraft to carry two more rows of seats. Besides this, the 737-7 also had higher-gauge aluminum wing allowing more fuel and consequently additional range. These additions further reconfigured landing gear.

The 737-800 was recognized as optimum 737 'NG' model sporting longer fuselage to increase seat capacity to 160. The 737-800 was commercially very successful, with more than 4,000 orders from almost 200 operators[11] Industry observers considered the 737-800 to be an equal match to its chief rival the A320-200 and thus Boeing operated without conceding much ground to Airbus. Airbus launched the A320neo was 10-15% more efficient than 737-800. To counter the threat, Boeing launched the B737 Max 8 to offer same benefits as that of the A320neo.

The 737-900 extended by 7-feet 8-inch over the 737-800 to add 14 more passengers, but Boeing failed to leverage the additional capacity as an additional emergency exit was not incorporated. This limited the seating capacity of 737-900 to 189 same as that of the 737-800. On top of that, it also lacked the range of its main competitor.

Consequently, the model could not attract market attention from its competitor the A321-200, albeit it matched some of the A321-200 key capabilities. It was reported that the delay in commercialization coupled with limitations of the model specifically in hot/high take-off conditions severely hurt the order-book of the Boeing. While the Airbus A321neo received 1,200 orders, the 737-900ER had just 222 orders[12]

It was clear that Boeing was simply responding to the Airbus, instead of setting the plot. In the process of responding, according to analysts, the company was apparently trying hard to save short term interests and lost sights on long term strategy. Every model that the company launched in the 150-200 seat segment was in response to an initiative from Airbus. Albeit being harbinger of the segment during 1960s, it relinquished initiative to its competitor during 1980s and was since playing catch-up. The most significant initiative from Boeing was its project Yellowstone, announced in 2003, however, that was more out of desperation than best laid plan. "It was 2003 and Boeing Co. – the company that defined modern air travel – had just lost its title as the world's largest plane manufacturer to European Rival Airbus. Its CEO had resigned in a defense-contract scandal. And its stock had plunged to the lowest price in a decade. Two years after the 9/11 terrorist attacks, financially troubled airlines were reluctant to buy new planes. Boeing needed something revolutionary to win back customers. Salvation had a code name: Yellowstone."[13]

1960s witnessed Boeing defining air travel between short distances with 737s and in the following decade Boeing redefined long haul journeys with its 747 jumbo jet. As name suggests, the huge plane with higher capacity and longer range made global air travel affordable. For the rest of the century, Boeing was the global leader in aviation industry with its hold on short and long haul segments.

During the last quarter of 20th century and the beginning of the 21st century, technological advancements from Boeing were incremental. Developments in the aviation industry did not help as consolidation left commercial jet manufacturing a duopoly between Boeing and Airbus[14] While Boeing formed in 1916, the Airbus consortium formed in 1970. The late entry of Airbus made Boeing executives complacent and they had not considered Airbus a serious competitor.

Airbus since inception was at the forefront of technological advancements and was ahead of Boeing. The Airbus product line started with the A300 world's first twin-aisle and twin-engine aircraft which was commercially introduced in 1974. A shorter variant of the A300, the A310 was commercially launched 1983. Both the planes were successful and Airbus, buoyed with that success, commercially launched the A320 in 1988 which was a phenomenal commercial success. Riding on the success of A320, Airbus delivered 305 jets in 2003 against Boeing's 281 to become the world's biggest plane manufacturer.

V. BOEING 737 MAX8 DEVELOPMENT

After the crash of Lion Air flight in October 2018 and Ethiopian Airlines flight in March 2019, investigations on how Boeing developed 7373 Max were intensified against claims from some quarters that the Boeing 737 Max was rushed through and that corners were cut in the standard certification process. For instance, *New York Times* opined, in March 2019, that Boeing created the 737 Max to compete with Airbus A320neo plane and that the engineers were asked to complete designs at twice the normal pace. (Refer to Annexure V on comparison of 737 Max with A320 neo)

It was in 2005 that Boeing initiated a project (under Yellowstone) to build an efficient aircraft by updating the design of Boeing 737 Next Generation family. The project's objective was reducing fuel consumption by 20-25%, but the results were around 10% savings. Boeing learned that achieving higher savings required complete reengineering the design right from the material used in body building and that new technologies had to be developed. Subsequently, in 2008, the project was shelved.

In 2010 December, Airbus launched the A320 NEO (New Engine Option), which was touted to be 15% more efficient than A320 and way ahead of Boeing's 737. It was an instant success with its savings despite increased range and in no time it became the fastest selling aircraft [15] In August 2011, the Boeing board approved the 737 Max project to develop Boeing Max 7, Max 8, 9 and Boeing 737 Max10.

It was reported by *New York Times* that during 2011, following the success of Airbus A320neo, American Airlines[16] considered Airbus over Boeing to place its largest order ever. "Boeing was at risk of losing an exclusive 10-year relationship with American Airlines to Airbus."[17] Boeing sensed the need to react swiftly to retain its business with American Airlines and subsequently launched the Max program in 2011.

To this end Boeing asked its engineers to quicken the designing and technical drawings process and finish the process in half the standard time. To ensure that the Max project was on schedule, employees from other departments were deputed, when any member left the Max team. Some observers labeled the response from Boeing to develop Max aircraft on the existing 737 design as "hasty."

Boeing designed 737s in the 1950s with a lower ground clearance, at 83 inches (211 cm), to shorten turnaround times, which become popular with operators. As irony would have it,

the same creative ground clearance design of 737 proved to be a major hurdle while designing the re-engine 737 Max. The Max was being designed to carry a bigger and more fuel efficient CFM Leap-1B engine. To adapt to lower ground clearance, Boeing opted to customize the 737 Max engine fan. The company had to choose between a 66-inch (168 cm) engine fan size or a 68-inch (173 cm) engine fan. Engine fan drove the propulsive efficiency and bypass ratio, which together would influence specific fuel consumption (SFC). It was noted that every inch increase in the fan size in general resulted in a 0.5% reduction in fuel burn. Also, a bigger engine led to more drag and more weight, which negatively impacted SFC.

Boeing decided that the 68-inch engine fan size optimized SFC, weight and drag of the engine as against 78-inch engine fan of A320 neo. To accommodate the larger engine fan, Boeing lengthen the nose landing gear of the 737 Max, which necessitated the relocation of aircraft's electronics/equipment (E/E) bay. Heavy engine used in 737 Max was also placed forward compared to engine placement in 737, which altered design changes involving aerodynamics, software, the design of the wings, strengthening of fuselage and many other components.

To mount a heavy engine on 737 Max, Boeing fitted a pylon to push engine forward from the wing to enable higher ground clearance. Also, the engines were lifted higher by increasing wheel strut by 8 inches. This redesign of engine placement altered aircraft dynamics while in flight. In certain flight phases, it was found that the nose of the aircraft might pitch possibly creating a stall[18] To alert the pilots over possible stall, Boeing fixed a Maneuvering Characteristics Argumentation System (MCAS) on 737 Max. The MCAS was designed to prevent the aircraft from entering a stall. The MCAS used the horizontal stabilizer trim to push the nose of the aircraft down whenever it sensed a high angle of attack that may lead to stall. (Refer to Annexure VI for diagrammatic representation of stall)

VI. CRASHING DESIGN AND DEVELOPMENT TIME

While these design changes were made, Boeing made little or no changes to the cockpit enabling easier migration of pilots to 737 Max, reducing expenditure to operators. Some analysts observed that Boeing had to redesign its 737 model to be swifter and smoother in less time. So, Boeing pursued a path that reduced regulatory scrutiny. Boeing also had to ensure that its big customers do not require a long time to train pilots to fly the new models, thus the new models need to be close to the outgoing models[19]

Rick Ludtke, a former Boeing engineer who worked on 737 Max cockpit features (but not on MCAS) expressed that "throughout the development Boeing was concern on minimizing design changes to negate extra pilot training there by reducing time and training costs for airlines to introduce the Max into service". It became extremely difficult for engineers to identify changes which would not necessitate additional training for pilots. Mr. Ludtke alleged that "midlevel managers conveying subordinates that Boeing committed to pay $1 million per plane to Southwest Airlines, largest customer of Boeing, if new design required pilots to spend additional simulator time". (Please refer to annexure VII for biggest customers of Boeing) "We had never, ever seen commitments like that before," Mr. Ludtke observed[20] Southwest Airlines reported that "it developed 737 Max training based on information from Boeing and thus was a recipient of, not a driver of, the training mandates".

After the two crashes, many pilots complained that Boeing kept them in dark about a new feature of 737 Max. Pilots opined that "they received no training on a new stall-prevention system and had a little mention of it in manuals". Added to that, warnings to alarm the pilots over failure of certain systems malfunctioned would go invisible in the cockpit. They were not even trained on simulators that could sensitize to the kinds of problems believed to be behind twin crashes. Safety experts and former Boeing employees accused "Boeing of hastening to market the plane, by excessively trusting its design and engineering, particularly the MCAS which was supposed to make the plane safer".

Some suspected that Boeing was aware of the problems that 737 Max models could face in midair. Dan Carey, president of American Airlines' pilot union, recalled that on November 27, 2018, Mike Sinnett, vice president of engineering and the chief project engineer for the 787 program, saying that American Airlines' pilots will not encounter the kind of problems that crashed the Lion Air flight because American Airlines opted for an additional cockpit warning light that was not present in Lion Air[21]

Boeing defending its position stated that the Federal Aviation Administration (FAA) checked final design of the system during certification of the aircraft and that FAA concluded that Boeing met all regulatory requirements. However, one senior Boeing official said the company did not disclose all details about the system as it felt such details would overwhelm an average pilot with technical data than the pilot needed or could comprehend.

Some reports suggested that Boeing offered the plane to American Airlines even before its board of directors approved the design and that the board formally signed on designs of Max a month later. Bryan Lesko, a pilot with United Airlines who wrote on 737 Max for an in house magazine, before it entered service, reportedly approached Boeing on numerous occasions seeking if there were any major new systems, but never got information.

The Max entered service before the first flight simulators were even ready and the ones that were introduced had no ability to simulate the malfunction the Lion Air crew faced. In the Lion Air crash, MCAS repeatedly pushed the plane's nose down due to specious information it received from stall-sensors. Pilot though tried hard lost control causing the plane crash into Java Sea. Experienced pilots and aviation safety experts informed *The Wall Street Journal* that it is next to impossible for pilots to identify why the plane went into steep dive and respond accurately in the fractional time window that they got.

VII. CONCLUSION

Following the two crashes, Boeing was facing the biggest crisis in memory. The 737 jet had been its flagship for decades and the mantle was supposed to be carried forward by 737 Max. However, by the end of April 2019, the entire 737 MAX fleet was grounded. Shares tanked and the company is staring at a bleak future.

Company was facing investigation from multiple agencies on a wide array of issues. It could take years, if not decades, for Boeing to cultivate trust among all stakeholders. For the company to regain its glory, suggested analysts, it must focus on its innovation culture, as Richard Aboulafia, an aviation analyst at Teal Group, put, "One lesson is that Boeing has to refocus on engineering excellence and be less dominated by marketing and sales. That might make it more stringent about technologies with unpredictable outcomes."[22]

For a company that had been at the forefront of developing jets for civil aviation and had helped reducing both time as well as cost of global transportation for decades, the current situation was some sort of an existential crisis. And, what was more intriguing was that the origination of the situation. Boeing was at the helm of aviation engineering for a long time and had accumulated a treasure of experience in meeting the demands of the industry, even before the demand had risen. For a company of that stature, making such fundamental errors in the process of developing an aircraft to effectively meet competition was rather puzzling.

The general belief among industry experts was that the company will emerge out of the crisis, but it will be a long time before it came back to normalcy. It was opined that the process of returning to normalcy might leave a deep scar in the history of Boeing.

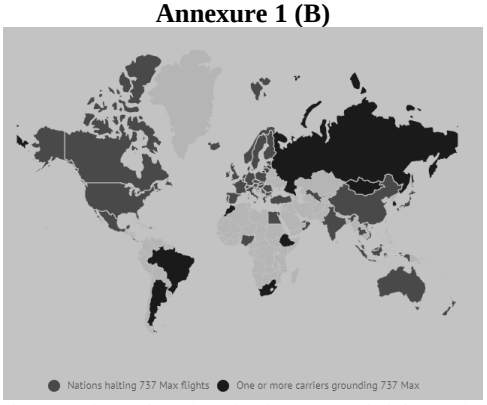
This paper attempted to analyze the cascading effect of Boeing's technology development in the process of striving to compete with Airbus A320 through secondary data. Through the secondary data analysis for the failure of Boeing Max8 can be attributed to the rushing of the organization for the development, missing on the training and communication part of the technology implementation, in the process of achieving the technological excellence.

Annexure 1 (A)

Major Airlines That Grounded 737 Max Fleet By March, 2019

Country	Airline	Grounded 737 Max Fleet
USA	Southwest Airlines	34
USA	American Airlines	24
Canada	Air Canada	24
China	China Southern Airlines	22
Norway	Norwegian Air	18
UK	TUI Fly	15
China	Air China	15
India	SpiceJet	13
Canada	WestJet	13
Turkey	Turkish Airlines	11
Dubai	FlyDubai	11
China	Shanghai Airlines	11
China	Hainan Airlines	11
China	Xiamen Airlines	10
Indonesia	Lion Air	10
Czech Republic	Smartwings	7
Brazil	GOL Airlines	7
China	Shandong Airlines	7
Singapore	SilkAir	6
Mexico	Aeromexico	6
China	Shenzhen Airlines	6
India	Jet Airways*	5
Poland	LOT	5
Oman	Oman Air	5
Argentina	Aerolineas Argentinas	5
Canada	Sunwing Airlines	4
China	China Eastern Airlines	4
Ethiopia	Ethiopian Airlines	4
Iceland	Icelandair	3
Italy	Air Italy	3
China	Lucky Air	3
Poland	Enter Air	2
Fiji	Fiji Airways	2
Russia	S7 Airlines	2
Cayman Islands	Cayman Airways	2
China	Fuzhou Airlines	2
China	Kunming Airlines	2
China	Okay Airways	2
South Korea	Eastar Jet	2
Mauritania**	Mauritania Airlines	1
Turkey	Corendon Airlines	1
Kazakhstan	SCAT Airlines	1
China	9 Air	1
Morocco	Royal Air Maroc	1
South Africa	Comair	1
Mongolia	MIAT Mongolian Airlines	1
Indonesia	Garuda Indonesia	1
Thailand	Thai Lion Air	1

Annexure 1 (B)



Source: "The countries and carriers that have grounded the Boeing 737 Max", March 15, 2019, https://www.smh.com.au/business/companies/the-countries-and-carriers-th

at-have-grounded-the-boeing-737-max-20190313-p5140l.html

Annexure 2
Historical Deliveries of Boeing Model and Year Wise

Model	707	717	727	737	747	757	767	777	787	DC-8	DC-9	DC-10	MD-11	MD-80	MD-90	Total
Year	1010	155	1831	10533	1550	1049	1145	1592	817	556	976	446	200	1191	116	23167
1958	8															8
1959	77									21						98
1960	91									91						182
1961	80									42						122
1962	68									22						90
1963	34		6							19						59
1964	38		95							20						153
1965	61		111							31	5					208
1966	83		135							32	69					319
1967	118		155	4						41	153					471
1968	111		160	105						102	202					680
1969	59		114	114	4					85	122					498
1970	19		55	37	92					33	51					287
1971	10		33	29	69					13	46	13				213
1972	4		41	22	30					4	32	52				185
1973	11		92	23	30						29	57				242
1974	21		91	55	22						48	47				284
1975	7		91	51	21						42	43				255
1976	9		61	41	27						50	19				207
1977	8		67	25	20						22	14				156
1978	13		118	40	32						22	18				243
1979	6		136	77	67						39	35				360
1980	3		131	92	73						18	41		5		363
1981	2		94	108	53						16	25		61		359
1982	8		26	95	26	2	20				10	11		34		232
1983	8		11	82	22	25	55					12		51		266
1984	8		8	67	16	18	29					10		44		200
1985	3			115	24	36	25					11		71		285
1986	4			141	35	35	27					17		85		344
1987	9			161	23	40	37					10		94		374
1988				165	24	48	53					10		120		420
1989	5			146	45	51	37					1		117		402
1990	4			174	70	77	60						3	139		527
1991	14			215	64	80	62						31	140		606
1992	5			218	61	99	63						42	84		572
1993				152	56	71	51						36	43		409
1994	1			121	40	69	41						17	23		312
1995				89	25	43	37	13					18	18	13	256
1996				76	26	42	43	32					15	12	25	271
1997				135	39	46	42	59					12	16	26	375
1998				282	53	54	47	74					12	8	34	564
1999		12		320	47	67	44	83					8	26	13	620
2000		32		282	25	45	44	55					4		5	492
2001		49		299	31	45	40	61					2			527
2002		20		223	27	29	35	47								381
2003		12		173	19	14	24	39								281
2004		12		202	15	11	9	36								285
2005		13		212	13	2	10	40								290
2006		5		302	14		12	65								398
2007				330	16		12	83								441
2008				290	14		10	61								375
2009				372	8		13	88								481
2010				376			12	74								462
2011				372	9		20	73	3							477
2012				415	31		26	83	46							601
2013				440	24		21	98	65							648
2014				485	19		6	99	114							723
2015				495	18		16	98	135							762
2016				490	9		13	99	137							748
2017				529	14		10	74	136							763
2018				580	6		27	48	145							806
2019(March)				89	2		12	10	36							149
Total	1010	155	1831	10533	1550	1049	1145	1592	817	556	976	446	200	1191	116	
Model	707	717	727	737	747	757	767	777	787	DC-8	DC-9	DC-10	MD-11	MD-80	MD-90	

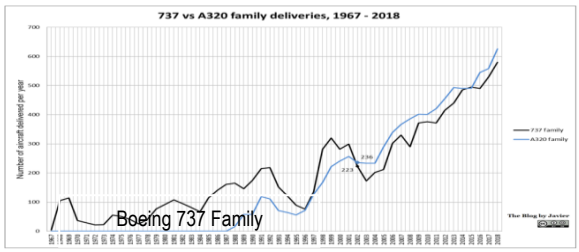
http://active.boeing.com/commercial/orders/displaystandardreport.cfm?&optReportType=HistAnnDel

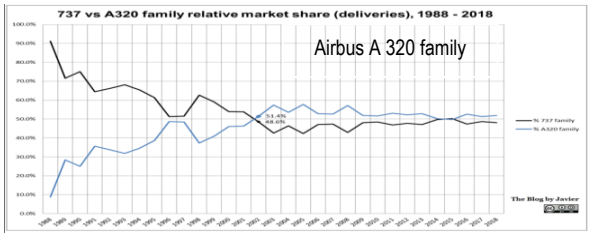
Annexure III
Airbus Orders and Deliveries

Breakdown by aircraft	Orders	Deliveries
A220-100	85	17
A220-300	451	48
A318	80	80
A319ceo	1486	1476
A319neo	35	
A320ceo	4770	4716
A320neo	4159	577
A321ceo	1799	1728
A321neo	2310	154
A300	561	561
A310	255	255
A330-200	665	634
A330-200F	42	38
A330-300	789	766
A330-800	8	
A330-900	230	6
A340-200/300	246	246
A340-500/600	131	131
A350-900	710	240
A350-1000	180	17
A380	290	235
TOTAL	19282	11925

Source: https://www.airbus.com/aircraft/market/orders-deliveries.html, Accessed in March 2019Annexure IV

Market Share Comparison of Boeing's 737 and Airbus A320 families



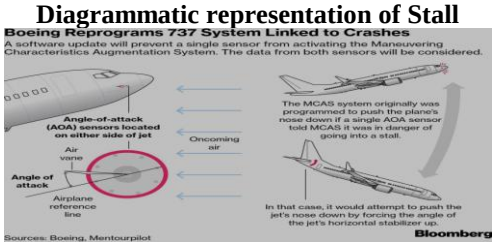


Source: https://theblogbyjavier.com/2019/01/24/boeing-737-vs-airbus-a320-family-deliveries-1967-2018/

Annexure V
Comparison of 737 Max with A320 neo

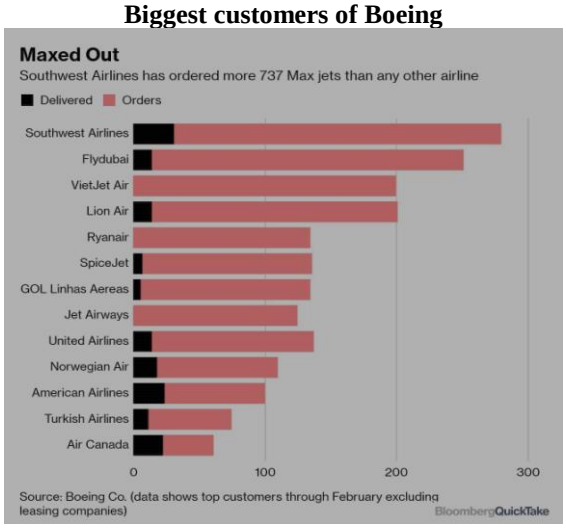
Karolina Prokopovič, "Airbus A320 Neo vs Boeing 737 MAX," https://aviationvoice.com/airbus-a320-neo-vs-boeing-737-max-2-2016021 21522/, 2016-02-12

Annexure VI
Diagrammatic representation of Stall



Source: Kyunghee Park, "Boeing's Grounded 737 Max: The Story So Far," https://www.washingtonpost.com/business/boeings-grounded-737-max-the-story-so-far/2019/04/07/7b0306a0-59aa-11e9-98d4-844088d135f2_story.html?noredirect=on&utm_term=.b82a019a58a3, April 8, 2019

Annexure VII
Biggest customers of Boeing



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