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Improving Undergraduate Aerospace Engineer Professional Readiness through Boeing 737 MAX Crash Case Study

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This paper investigates using the Boeing 737 MAX crashes as a case study to improve undergraduate aerospace engineering students' comprehension of aircraft certification and the safety implications of engineering design. Two 737 MAX crashes happened within a period of six months and are linked to activation of the Maneuvering Characteristics Augmentation System (MCAS). As the investigations unfold, many important questions are being posed with respect to design decisions and operational assumptions. Current aerospace engineering students are exposed to media accounts and expert opinions via multiple sources as well as to classroom discussions on the topic. This paper investigates the effects of a systematic case study on student perceptions with respect to professional responsibilities and engineering design choice implications as linked to ABET student outcomes (2 and 4). Junior and senior aerospace engineering students' perceptions are assessed before and after participation in case study presentations.

I. Nomenclature

$737MAX$	=	Boeing 737 MAX 800 and 900 Models
AND	=	Aircraft Nose Down
ANU	=	Aircraft Nose Up
AOA	=	Angle of Attack
$BASOO$	=	Boeing Aviation Safety Oversight Office
CAA	=	Civil Aviation Authorities
$DFDR$	=	Digital Flight Data Recorder
$EASA$	=	European Aviation Safety Agency
$ECAA$	=	Ethiopian Civil Aviation Authority
$E-UM$	=	Engineering Unit Member
FAA	=	Federal Aviation Administration
$ICAO$	=	International Civil Aviation Organization
$JATR$	=	Joint Authorities Technical Review
$KNKT$	=	Komite Nasional Kelamatan Transportasi.
$LEAP$	=	Leading Edge Aviation Propulsion
$MCAS$	=	Maneuvering Characteristics Augmentation System
$NASA$	=	National Aeronautics and Space Administration
NCC	=	Non-Normal Checklists
$NTSB$	=	National Transportation Safety Board
$NTSC$	=	National Transportation Safety Committee (Indonesia)
ODA	=	Organization Designation Authorization
STC	=	Supplemental Type Certificate
$SWAPA$	=	Southwest Airlines Pilot Association
USA	=	United States of America

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II. Introduction

THE Bureau of Transportation Statistics state that transportation by airplane is the safest mode of transportation [1]. This reputation may be attributed to carefully detailed design, thorough certification processes, and a high quality training for pilots and maintenance personnel. However, the recent accidents involving Lion Air Flight 610 and Ethiopian Airlines Flight 302 have spiked conversations and questions as to whether the design and certification processes are as robust as thought. Lion Air Flight 610 and Ethiopian Airlines Flight 302 crashed within six months of one another, both involved the Boeing 737 MAX, and they appear to have very similar root causes. The crashes resulted in 347 deaths [2] and the resulting public, governmental and industry concerns and investigations have been in the media for many months. While the story is unfolding, the current cohort of aerospace engineering students is being exposed to information and opinions in the same way as the general public. However, unlike the general public, these students will soon enter a profession that is directly affected by these events and any changes in regulations that may result. These students are expected to understand and consider the implications of design decisions and to carry out their ethical and professional responsibilities appropriately. ABET engineering student outcomes identify the need to produce solutions "with consideration of public health, safety, and welfare" and for engineering students to "recognize ethical and professional responsibilities" [3]. While the full extent of root causes of the 737 MAX crashes are still being determined as of this writing, the situation offers a real-time opportunity to introduce students to the structure and basic processes in the aircraft certification industry. The goal of this work is to provide a framework for that introduction using a high profile and not yet concluded case, and to assess the changes in student's perceptions and abilities through the process. This study should also offer an opportunity to assess the differences in the effect of the case study on students at different points in their academic track (i.e., juniors versus seniors).

Section III summarizes the crash investigations and certification processes for the 737 MAX to establish a basis of knowledge for discussion, while also introducing the set of topics used the student case study. Section III is a reflection of the case study providing framework for discussion on the selection of material to present to the students. Section IV covers the methodology for pre- and post-assessment surveys and case study presentation. Results based off the survey results are discussed in Section V.

III. Crash Investigations

The Boeing 737 MAX is the most recent model of the Boeing 737, following the 737 NG (Next Generation). One of the major changes between the MAX and NG is the use of the LEAP-1B engine on the MAX. The LEAP 1B engine has a bigger diameter and therefore a larger nacelle. The larger engine and nacelle required the engines to be moved forward, to allow for a higher placement, giving the 737 MAX enough ground clearance for ground operations. This configuration resulted in an Aircraft Nose-Up (ANU) pitching moment when at high AOA and mid Mach number [4]. The Maneuvering Characteristics Augmentation System (MCAS) was implemented to address the unintended pitch up tendency of the aircraft by making inputs to the horizontal stabilizer.

The National Transportation Safety Board (NTSB) investigated the cause of the crashes and made recommendations to the Federal Aviation Administration (FAA). According to the NTSB report, the Lion Air flight 610 flight crew communicated with air traffic control about the issues with the flight controls and altitude before the aircraft disappeared from the radar [4]. The Digital Flight Data Recorder (DFDR) indicated that the left and right Angle of Attack (AOA) sensors were reading different angles. Likewise, the left and right attitude sensors disagreed the throughout the flight [4]. The pilots tried inputting commands and noted that they could not retain complete control of the aircraft for more than five seconds, due to the unintended control by MCAS. The DFDR showed a 10 second automatic input of Aircraft Nose Down (AND) before the pilots used the elevator to apply an Aircraft Nose-Up (ANU). Five seconds later MCAS implemented another automatic input of AND. The pattern of MCAS control and pilot correction recurred for over six minutes before the crash [4]. A similar sensor malfunction was observed in the Ethiopian Airlines Flight 302 crash by NTSB [4].

The final report on the Lion air crash by Komite Nasional Kelamatan Transportasi (KNKT), Indonesia's National Transportation Safety Committee, broke the crash causes down into nine different factors, listed below to illustrate the complexity of the crashes. [5]

1) "During the design and certification of the Boeing 737-8 (MAX), assumptions were made about flight crew response to malfunctions which, even though consistent with current industry guidelines, turned out to be incorrect.
2) Based on the incorrect assumptions about flight crew response and an incomplete review of associated multiple flight deck effects, MCAS's reliance on a single sensor was deemed appropriate and met all certification requirements.
3) MCAS was designed to rely on a single AOA sensor, making it vulnerable to erroneous input from that sensor.
4) The absence of guidance on MCAS or more detailed use of trim in the flight manuals and in flight crew training, made it

more difficult for flight crews to properly respond to uncommanded MCAS.

5) The AOA DISAGREE alert was not correctly enabled during Boeing 737-8 (MAX) development. As a result, it did not appear during flight with the mis-calibrated AOA sensor, could not be documented by the flight crew and was therefore not available to help maintenance identify the mis-calibrated AOA sensor.
6) The replacement AOA sensor that was installed on the accident aircraft had been mis-calibrated during an earlier repair. This mis-calibration was not detected during the repair.
7) The investigation could not determine that the installation test of the AOA sensor was performed properly. The mis-calibration was not detected.
8) Lack of documentation in the aircraft flight and maintenance log about the continuous stick shaker and use of the Runaway Stabilizer Non-Normal Checklists (NNC) meant that information was not available to the maintenance crew in Jakarta nor was it available to the accident crew, making it more difficult for each to take the appropriate actions.
9) The multiple alerts, repetitive MCAS activations, and distractions related to numerous ATC communications were not able to be effectively managed, this was caused by the difficulty of the situation and performance in manual handling, NNC execution, and flight crew communication, leading to ineffective CRM application and workload management. These behaviors had previously been identified during training and reappeared during the accident flight [5]."

A. 737 MAX Certification Process

Boeing undertook the 737 MAX project instead of pursuing the planned next project of designing a new aircraft. Boeing's decision was a rapid response to the Airbus A320 NEO, one of Boeing's main commercial aircraft competitors [6]. In 2011, Boeing was under threat of American Airlines making the company's largest order ever for the Airbus A320 NEO. The threat of loosing Americans' orders created a high-pressure environment on the company personnel [6]. The Joint Authorities Technical Review (JATR), an international team comprised of FAA, National Aeronautics and Space Administration (NASA) and nine other Civil Aviation Authorities (CAAs) of different countries [7]. The JATR was commissioned to investigate the crashes with specific focus on the certification process. The findings and observations of the JATR report formed much of the framework for the case study. The JATR report noted "Some of the Boeing engineers the JATR team spoke with described the Boeing process in a manner that reflected an emphasis on meeting individual certification requirements, without necessarily having an appreciation for the overall safety-based reasons for those requirements" [7]. To help understand the environment under which the 737 MAX was certified, this section describes the relevant FAA Organization Designation Authorization processes and the realities of government and industry responsibilities.

Delegating some of the certification process of the parts is a common practice between the FAA and larger aerospace companies such as Boeing, Gulfstream, and Textron. Delegation of certification is used throughout the aerospace industry. The certification process includes companies establishing certification organizations that are vetted and monitored by the FAA under the Organization Designation Authorization (ODA) process. There are different types of ODAs: Type Certification ODA (TC ODA), Supplemental Type of Certification (STC ODA), and Production Certification ODA (PC ODA). TC ODA holders help make finding of compliance on design aspects of aircraft. The findings of compliance state that a design or performance aspect of an aircraft is in compliance with federal regulations. However, the TC ODA cannot offer an original type certificate [8]. Boeing's ODA is overseen by the FAA's Boeing Aviation Safety Oversight Office (BASOO). BASOO performs certification and reviews the compliance requirements. The FAA is responsible for staffing and providing for the necessary resources to enable BASOO to perform its duties [7].

The JATR review into the working relationship between BASOO, ODAs, and E-UMs (Engineering Unit Members) found potential issues. Engineering Unit Members help contribute and verify the basis of information that informs a finding of compliance. The BASOO had an imbalance in staffing, with 45 BASOO members tasked with oversight of 1500 E-UM personnel. The JATR was also concerned about a possible lack of experience in BASOO with a many of the limited numbers being younger engineers—the FAA delegates around 40 %of the certification plans to the Boeing ODA. The JATR observed that this level of delegation did not seem like a widespread practice. The JATR identified hindrance of communication between Boeing's ODA E-UMs and FAA engineers as anoter protential problem. Boeing's policy was to first try to solve issues within the ODA instead of involving BASOO experts [7]. This contributed to BASOO and Boeing not being on the same page for some design choices.

IV. Methodology

To determine the effects of a case study on students at different points in their academic track, we conducted a survey with aerospace engineering students in their junior and senior years at Oklahoma State University (OSU). Our experiment consisted of a pre-survey, followed by the presentation of a case study, and a post-survey. Both sets of students were in the second semester of their respective years. The aerospace engineering curriculum at OSU is fixed such that all students of a given year move through the core courses together. Significant differences between the student sets are the extent of their aerospace engineering domain knowledge, design project practice opportunities, and nearness to graduation. The juniors completed all required engineering science and math courses, and the Fundamental of Aerodynamics course. At the time of our experiment, the juniors were enrolled in the Applied Aerodynamics and Performance course (MAE 3423). MAE 3423 offers a preliminary view of aircraft design. Seniors have completed all core courses except for their Senior Capstone Design and Aerospace Engineering Laboratory (MAE 4223). Aerospace Engineering Laboratory gives the students exposure to experimental design and flight testing. All seniors completed at least two major design projects and several smaller design projects.One of the major design projects is a multi-class aircraft design during the Fall semester of their senior year. This project spans three classes, Structures, Propulsion and Power, and Stability and Control. The project included the development of a Federal Aviation Regulations (FAR) certification compliance matrix. The creation of this matrix required the students to step through their aircraft design and prove it was in compliance with all of the FARs. Through this exercise seniors gained exposure to some of the certification documentation, such as the FARs [9]. At the time of the survey and case study seniors were three weeks away from graduating.

The survey aimed to assess the degree to which students understand and can apply engineering design skills with consideration to public safety (ABET SO 2) and can recognize their professional and ethical responsibilities (ABET SO 4) in a complex aerospace industry environment. Questions in the pre-case study surveys address the students'

1) Extent of awareness of the 737 MAX situation and investigation results,
2) Ability to identify key questions and assumptions for risk assessment and design safety,
3) Awareness of the implications of certification requirements on aerospace design activities, and
4) Awareness of implications for their professional conduct.

A. Case Study and Survey Presentation Method

The case study was conducted in three steps: presentation of information, guided student group discussion and debriefing of group conclusions. Due to the restrictions put in place due to the COVID-19 virus, the original plan was not possible. The case study was shifted to an online format. The case study and surveys were posted on Canvas, the learning management system (LMS) at Oklahoma State University. Canvas has a built in survey platform that was used to post the surveys. Presentation of the case study was done in video format instead of the planned in class presentation. The surveys and case study were posted over a week. The discussion was done with a posted discussion section to the class website. The video shown to the students is posted to YouTube for reference [10]. The information in the video was structured in a similar format as the planned presentation. However, the discussion pages saw very little traffic.

B. Survey Design

The format of the surveys did not have to change due to the virus since the plan was always to administer via an online format. Participation in the pre-survey required each student to consent question as per Institutional Review Board (IRB) requirements. Professors of both classes offered extra-credit for taking the surveys and watching the video. The consent question was added so students could receive the extra credit without having to participate in data collection. The first eight questions in the pre-survey, shown in Table 3 in the Appendix, addressed demographic information. The pre-survey included one yes/no question relating to their exposure to the FARs, five Likert scale questions, and one question asking if the students expected to have a job relating to the certification industry (Table 4). Table 5 lists the post survey questions. The question numbering in the Appendix will remain consistent in our discussion sections.

The five Likert-scale questions listed in Table 4 in the appendix were designed to measure perception and understanding of the certification and design process. The scale consisted of five discrete responses ranging from Strongly Agree to Strongly Disagree (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree).

1) Proper and thorough risk assessment is an important part pf certification and safety.
2) Certification occurs at all points of the design process.
3) I am familiar with the types of certifications (Type Certificate (TC), Supplemental TC, Amended TC).
4) The certification process is a guide to help promote safety throughout the design process.
5) I have an understanding of the causes and implications of the Boeing 737 MAX crashes.

The first question was designed to measure the students' understanding of the importance of proper risk assessment to the safety and certification of the aircraft. Risk assessment is discussed throughout the engineering curriculum. However, there is an increased exposure during the design projects between the class level of the juniors and seniors. We expected the seniors to rank risk assessment as being more important. The purpose of the second question was to determine the student perception on the breadth of the certification process. The seniors are expected to have more experience on how certification fits into design. The third question's aim was to gauge the students' technical understanding of certification, which is expected to be low for both classes. The fourth question aimed to measure the students' perception of the link between certification and safety. The exposure to the FARs should give the seniors a better understanding of this link. The purpose of the fifth question was to assess the students confidence of there understanding of the crashes. Ideally the case study will increase the students' understanding and this question will reflect that increase between the pre- and post-survey.

The post-survey followed a similar format as the pre-survey, with the demographic questions removed, and a technical Likert-scale question and a short free response question added. The extra Likert-scale question stated "I am confident in my ability to properly identify the risks of aircraft systems like MCAS." We expected a difference in the responses to this statement between classes. Having spent more time on risk analysis the seniors were expected to feel more confident. The free response question stated "Based off the video discussion, in 1-2 sentences briefly discuss one aspect of the certification process that could have been changed to improved the certification of the 737 MAX." This question was designed to serve multiple purposes. Alongside the technical question, the free response question should provide information on how many students carefully watched the video before attempting the post-survey. Both questions should be easy to answer after viewing the video. The free-response question also provides an opportunity to see how capable the student is at comprehension and critical discussion of certification topics.

V. Results

This section summarizes the demographics of this experiment's sample, compares the results among pre- and post-survey groups, and junior and senior students, and discusses the effect of the case study based on post-survey results. The raw data of the pre-survey results are included in Table 1 in the Appendix. Table 2 in the Appendix contains the post-survey results.

A. Demographics

The junior class had 86 students—out of the 78 students who consented and participated in this study, 6 are female (8%) and 71 male (91%). One respondent selected "other." Participant age varied from 19 to 32 years old. Four of the students are getting a bachelor's degree in aerospace engineering only and 75 students are studying both aerospace and mechanical engineering. No students are pursuing a mechanical engineering degree only. For the senior class, 68 out of the 75 students participated in the pre-survey. The demographics of the senior group were similar to the junior class with 71 male (91%) and 6 female (8%), with ages between 20 and 32 years old. Due to the fact that the Aerospace Laboratory class is a class specifically for Aerospace Engineering degree-seekers, there were no Mechanical Engineering students, unlike the junior class. Most of the senior students (93%) were pursuing the double major, with 7% pursuing a pure aerospace degree.

In the junior class, 32 students (41%) have had an internship experience in an engineering field. The senior class had slightly higher internship numbers (56%), as expected, since seniors have had more time to seek those experiences.

B. Comparison Questions

As shown in Figure 1, the students perceived risk assessment as important even before the survey, indicating that the undergraduate curriculum is adequately teaching the relationship between risk assessment and certification and safety. There was a slight increase between the juniors and seniors, most likely due to the seniors' increased experience with risk assessment for their designs. There is a slight increase between pre- and post-survey agreement for both classes, indicating the survey may have had a positive effect.

Fig. 1 Comparison of Results for Question 1

For both classes, there was an increase in the belief that certification occurs throughout the design process between pre- and post-survey as shown in Figure 2. The juniors only had a small increase in their agreement. The seniors had an increase of 13 % in agreement after the case study. Both classes had a low disagreement, which was expected, especially for seniors, who have been exposed more to the FARs and certification in general.

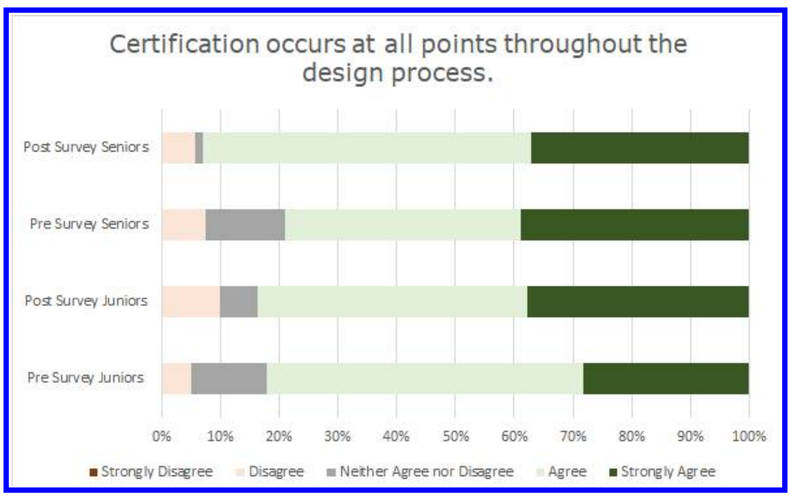

Fig. 2 Comparison of Results for Question 2

The certification familiarity question saw the most dramatic change in results from pre- to post-survey. There was a 40% increase in the agreement for the juniors and a 30% increase for the seniors. These results show a strong indication that the case study was successful in the goal to increase the students understanding of certification basics. This understanding is important for the students to be able understand the environment that many of them will work in. Type Certification is often the goal of aerospace projects. An understanding of Type Certification basic will help the students understand the importance of their work on a larger scale.

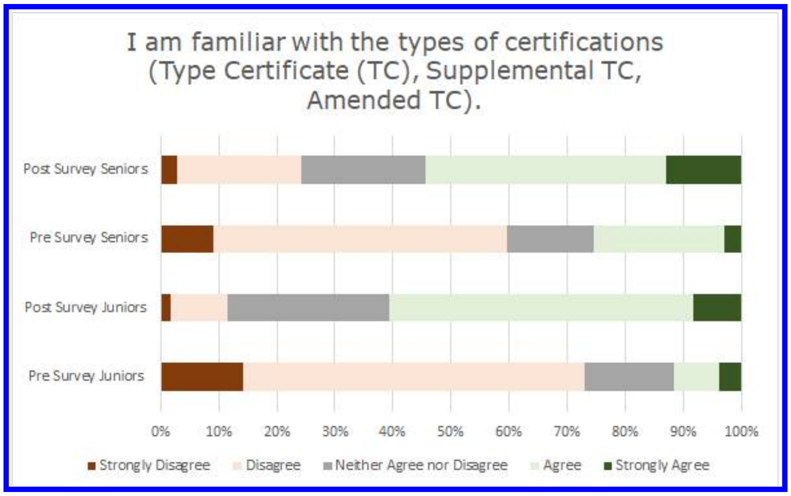

Fig. 3 Comparison of Results for Question 3

There was an increase in agreement and strength of agreement in both groups with respect to certification impact throughout the design process. The junior class showed the larger increase in strong agreement (20%). These results indicate that the case study was successful in increasing the students' understanding of the link between certification and safety.

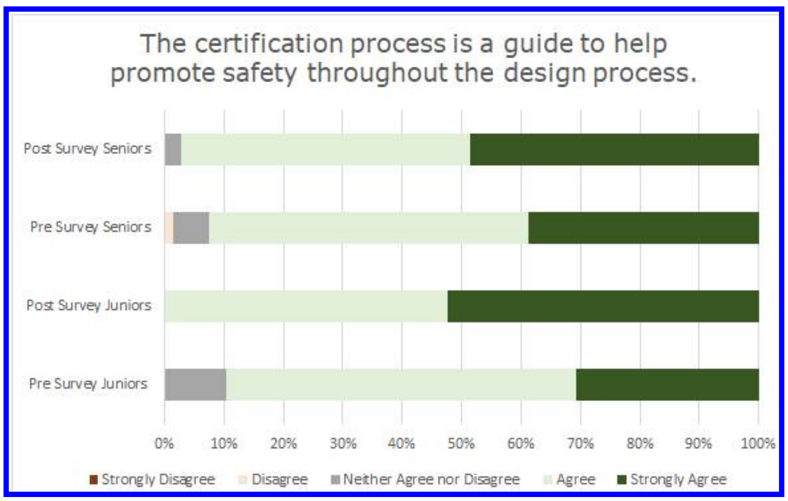

Fig. 4 Comparison of Results for Question 4

Figure 5 shows increases in the students' perceived knowledge of the Boeing 737 MAX crashes. The juniors had around a 15% increase in agreement and a 34% increase in strong agreement. The seniors had a 30% increase in agreement and a 15% increase in strong agreement. The case study appears to have increased the students' understanding of the Boeing 737 MAX crashes in general. This increase in understanding is important because if the students are able to understand the causes and implications of accidents they may be able to learn from them and make more informed decisions in their career.

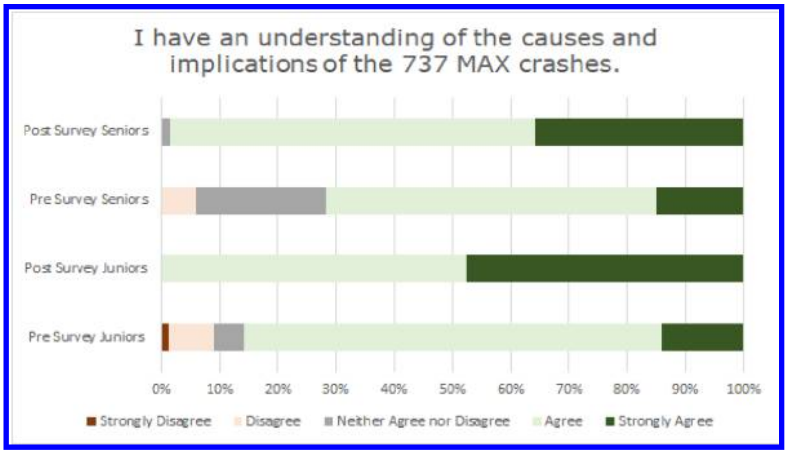

Fig. 5 Comparison of Results for Question 5

The last question for comparison purposes was "Post-graduation, do you expect to have a job that will involve the aircraft certification process?" The answers stayed constant pre- and post-survey. For the post-survey, 82% of the junior students and 57% of the senior students answered yes. The discrepancy between the juniors and seniors is most likely due to the fact that many of the seniors already knew their post-graduation plans. Many of these students will pursue a graduate education or have jobs outside of the aerospace industry, as reflected in these results. A high percentage of the students we surveyed expect to encounter certification as they work in the industry. Learning while at school the certification and the different roles involved could be beneficial to the students careers by giving them increased perspective on their work.

C. Post-survey

A total of 62 junior students took the post survey, which was administered after the case study was presented. The senior class had 71 students take the survey. When asked under which kind of Type Certificate the Boeing 737 MAX was certified, the majority of students in both classes (92%) answered correctly (amended type certificate). This question, partnered with the free responses, which are discussed later, give confidence that the majority of the students watched and comprehended the video.

When asked if they have practiced verification and validation of assumptions in their undergraduate studies, 85% of the juniors agreed while 15% disagreed. Only one senior disagreed—99% agreed. The high agreement ratio indicates that the undergraduate curriculum is effective at teaching students how to validate their designs.

Lastly, when asked if they are confident in their ability to properly identify the risk of aircraft systems like MCAS, 18% of junior students strongly agreed, 50% agreed, 19% neither agreed nor disagreed, and one student strongly disagreed. The seniors had nearly identical results.

The students were asked to briefly identify one aspect of the certification process that could have been changed to improve the certification of the 737 MAX. Overall the students gave thorough and well-thought-out answers. The students addressed the information given in the case study well and often added information on the crashes that were not discussed in the case study. Many of the respondents discussed some of the certification aspects well. For example, a junior student responded *"Better communication between the FAA's BASOO and Boeing's ODA certification staff would have improved the overall process as it appears that lack of effective communication led to both groups overlooking the MCAS system during development. Furthermore, more specific/stringent requirements for the improvements to the 737 design by Boeing should have been included in the Amended Type Certificate as a lack of requirements regarding the internal aircraft systems changes also contributed to the MCAS system being overlooked."* Communication was one of the most mentioned aspects among respondents, with testing and evaluation also being a focus area throughout. Overall, the responses supported that the students came away with a better understanding of the certification process.

VI. Conclusion

The 737 MAX circumstances provide an opportunity to improve the aerospace engineering practice. The tragic accidents of Lion Air and Ethiopian Airlines can serve as motivation for engineering students to better understand and carry out their responsibilities in the hopes of preventing such losses in the future. We hope that the lessons that the aerospace industry draws from this case will be shared with the next generation effectively, so that new engineers can apply them better. One of the motivators for this case study was that the 737 MAX could provide a unique look at the certification process. The case study's evaluation criterion was its effectiveness at improving students' understanding of and ability to apply engineering design skills with consideration to public safety (ABET SO 2) and recognition of their professional and ethical responsibilities (ABET SO 4) in a complex aerospace industry environment. The case study has been effective in these two areas. From the survey, Some of the major conclusions are:

- The case study exposure increased student familiarity with certification types. After the case study, 40% more of the juniors and 30% more of the seniors stated they were familiar with certification.
- The students perceived knowledge of the Boeing crashes increased (15% increase in agreement among juniors, 30% increase in agreement among seniors).
- The students had an increased understanding in the link between certification and safety (juniors had a 20% increase in strong agreement, the senior already had a high agreement)

Going into the case study many of the students did not have a good understanding of the certification environment. This result was expected, since certification discussion in the classroom at the undergraduate level is typically kept to the FARs. An understanding of the larger certification and aircraft design picture could be an improvement to the aerospace engineering curriculum, since it would improve the students' abilities to meet ABET SO 4 by giving them a better understanding of the complex aerospace environment that their professional and ethical responsibilities fall into. A basic understanding of the certification process also improves the students' ability to meet ABET SO 2. Certification regulations are an application of engineering design skills in consideration to public safety. Many students may find themselves a part of this process. Graduating college with an understanding of how the process is designed to function will empower engineers to recognize when the certification process is not functioning correctly, which could help create a more accountable system with better engineered and certified aircraft.

Appendix

Table 1 Pre-Survey Results

Applied Aerodynamics Pre-survey results summary				Aerospace Laboratory pre-survey results			
	Question	**Percentage**	**NO of Students**		**Question**	**Percentage**	**NO of Students**
2	Female	8%	6	**2**	Female	7%	5
	Male	91%	71		Male	91%	61
	Other	1%	1		Other	1%	1
4	Aerospace	4%	3	**4**	Aerospace	7%	5
	Mechanical	0%	0		Mechanical	0%	0
	Both	96%	75		Both	93%	62
5	MAE 4223	0%	0	**5**	MAE 4223	100%	67
	MAE3253	99%	77		MAE3253	0%	0
	No answer	1%	1		No answer	0%	0
6	Yes	41%	32	**6**	Yes	57%	38
	No	59%	46		No	43%	29
8	Yes	32%	25	**8**	Yes	37%	25
	No	68%	53		No	63%	42
10	Yes	56%	44	**10**	Yes	96%	64
	No	44%	34		No	4%	3
11	Strongly Agree	77%	60	**11**	Strongly Agree	87%	58
	Agree	23%	18		Agree	13%	9
	Neither Agree nor Disagree	0%	0		Neither Agree nor Disagree	0%	0
	Disagree	0%	0		Disagree	0%	0
	Strongly Disagree	0%	0		Strongly Disagree	0%	0
12	Strongly Agree	28%	22	**12**	Strongly Agree	39%	26
	Agree	54%	42		Agree	40%	27
	Neither Agree nor Disagree	13%	10		Neither Agree nor Disagree	13%	9
	Disagree	5%	4		Disagree	7%	5
	Strongly Disagree	0%	0		Strongly Disagree	0%	0
13	Strongly Agree	4%	3	**13**	Strongly Agree	3%	2
	Agree	8%	6		Agree	22%	15
	Neither Agree nor Disagree	15%	12		Neither Agree nor Disagree	15%	10
	Disagree	59%	46		Disagree	51%	34
	Strongly Disagree	14%	11		Strongly Disagree	9%	6
14	Strongly Agree	31%	24	**14**	Strongly Agree	39%	26
	Agree	59%	46		Agree	54%	36
	Neither Agree nor Disagree	10%	8		Neither Agree nor Disagree	6%	4
	Disagree	0%	0		Disagree	1%	1
	Strongly Disagree	0%	0		Strongly Disagree	0%	0
15	Strongly Agree	14%	11	**15**	Strongly Agree	15%	10
	Agree	72%	56		Agree	57%	38
	Neither Agree nor Disagree	5%	4		Neither Agree nor Disagree	22%	15
	Disagree	8%	6		Disagree	6%	4
	Strongly Disagree	1%	1		Strongly Disagree	0%	0
16	Yes	85%	66	**16**	Yes	57%	38
	No	15%	12		No	42%	28

Table 2 Post-Survey Results

Applied Aerodynamics Post-survey results summary				Aerospace Lab Post-survey results summary			
	Question	**Percentage**	**NO of Students**		**Question**	**Percentage**	**NO of Students**
1	STC	3%	2	**1**	STC	4%	3
	TC	3%	2		TC	4%	3
	ATC	93%	57		ATC	91%	64
2	Agree	87%	53	**2**	Agree	99%	69
	Disagree	13%	8		Disagree	1%	1
3-1	Strongly Agree	84%	51	**3-1**	Strongly Agree	93%	65
	Agree	16%	10		Agree	7%	5
	Neither Agree nor Disagree	0%	0		Neither Agree nor Disagree	0%	0
	Disagree	0%	0		Disagree	0%	0
	Strongly Disagree	0%	0		Strongly Disagree	0%	0
3-2	Strongly Agree	38%	23	**3-2**	Strongly Agree	37%	26
	Agree	46%	28		Agree	56%	39
	Neither Agree nor Disagree	7%	4		Neither Agree nor Disagree	1%	1
	Disagree	10%	6		Disagree	6%	4
	Strongly Disagree	0%	0		Strongly Disagree	0%	0
3-3	Strongly Agree	8%	5	**3-3**	Strongly Agree	13%	9
	Agree	52%	32		Agree	41%	29
	Neither Agree nor Disagree	28%	17		Neither Agree nor Disagree	21%	15
	Disagree	10%	6		Disagree	21%	15
	Strongly Disagree	2%	1		Strongly Disagree	3%	2
3-4	Strongly Agree	52%	32	**3-4**	Strongly Agree	49%	34
	Agree	48%	29		Agree	49%	34
	Neither Agree nor Disagree	0%	0		Neither Agree nor Disagree	3%	2
	Disagree	0%	0		Disagree	0%	0
	Strongly Disagree	0%	0		Strongly Disagree	0%	0
3-5	Strongly Agree	48%	29	**3-5**	Strongly Agree	36%	25
	Agree	52%	32		Agree	63%	44
	Neither Agree nor Disagree	0%	0		Neither Agree nor Disagree	1%	1
	Disagree	0%	0		Disagree	0%	0
	Strongly Disagree	0%	0		Strongly Disagree	0%	0
3-6	Strongly Agree	18%	11	**3-6**	Strongly Agree	19%	13
	Agree	51%	31		Agree	54%	38
	Neither Agree nor Disagree	20%	12		Neither Agree nor Disagree	17%	12
	Disagree	10%	6		Disagree	9%	6
	Strongly Disagree	2%	1		Strongly Disagree	1%	1
4	FRQ	FRQ	FRQ	**4**	FRQ	FRQ	FRQ
5	Yes	84%	51	**5**	Yes	57%	40
	No	16%	10		No	43%	30

Table 3 Demographic Questions

Demographic questions		
NO	Question	Response
1	What is your gender	Male
		Female
		Others
3	What is your major	Aerospace Engineering
		Mechanical Eningeering
		Aerospace and Mechanical Engineering
		Others
4	Which of the following classes are you currently taking?	MAE 4223 Aerospace Laboratory
		MAE 3253 Applied Aerodynamics and Performance
5	Do you have internship experience?	Yes
		No
6	If your answer to the previous question about internship experience was yes. If you willing please specify where your internship experience was	Free Response
7	Do you have other engineering or aerospace related work experience outside of an internship or class?	Yes
		No
8	If your answer to the previous question about other engineering related work was yes. If you willing please specify where your work experience was	Free Response
9	Have you ever consulted the Federal Aviation Regulations (FARs) for a class or class project	Yes
		No
10	Post-graduation,do you expect to have a job that will involve the aircraft certification process?	Yes
		No
11	I have practiced verification and validation of assumptions in my undergraduate student	Agree
		Disagree

Table 4 Likert-Scale Questions about Certification

Certification Process knowledge						
NO	Question	Response				
1	Proper and through risk assessment is an important part of certification and safety	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
2	Certification occurs at all points throughout the design process	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
3	I am familiar with the type of certification (Type Certificate (TC), Supplemental TC, Amended TC	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
4	The certification process is a guide to help promote safety throughout the design process	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
5	I have an understanding of the causes and implications of the Boeing 737 MAX crashes	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
6	I am confident in my ability to properly identify the risk of aircraft systems like MCAS	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree

Table 5 Questions to check if Students watched the video

Check if Students Watched the video		
NO.	Question	Response
1	As discussed in the case study, what kind of Tpe Certificate was Boeing 737 MAX certified under?	Supplemental Type Certificate
		Type Certifcate
		Amended Type Certificate
2	Based off the video discussion, in 1-2 sentences briefly discuss one aspect of the certification process that could have been changed to improve the certification of the 737 MAX	Free Response

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