MAX CHAOS

> TWO 737-8 ACCIDENTS IN FIVE MONTHS RAISE FEARS

> REGULATORY COORDINATION VAPORIZES

> ACCIDENT SIMILARITIES GROW

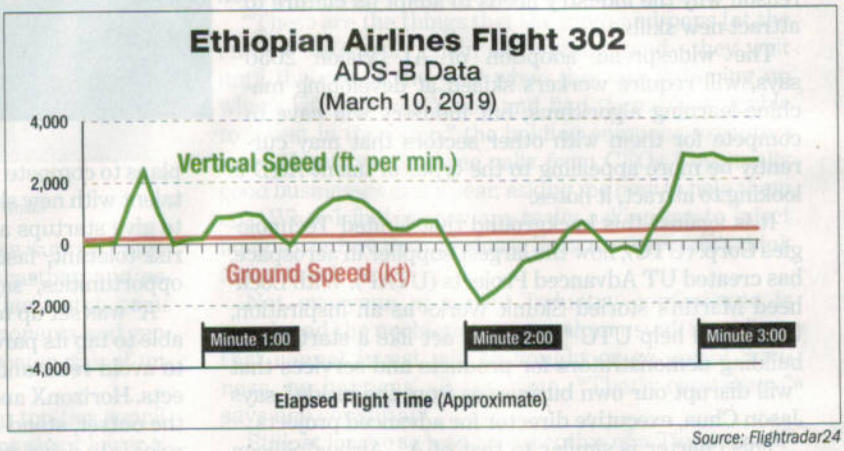
Sean Broderick Washington and **Thierry Dubois** Lyon

When Chinese regulators grounded the country's Boeing 737 MAX fleet less than 24 hr. after the type's second fatal accident in five months, many believed the move signaled an escalation in the simmering China-U.S. trade dispute. The move was indeed a signal, but not of heightened global trade tensions. Rather, it marked the likely pivot in aviation's fleet-grounding analysis process from a data-driven, problem-identification approach to one that prioritizes speed and caution over certainty.

The Chinese order came early March 11 Beijing time—about 19 hr. after Ethiopian Airlines Flight 302 (ET302) went down 6 min. after departing Addis Ababa's Bole International Airport, killing all 157 onboard.

Chinese officials did not know any more about what brought ET302 down than anyone else: The aircraft's crew reported flight-control problems and requested clearance to return to Addis Ababa, and the flight ended soon after.

Data from Lion Air Flight 610's (JT610) flight data recorder (see page 15) and ground-based ADS-B data that traces Ethiopian Airlines Flight 302's (ET302) path (right) have clear similarities, including vertical speed (depicted in green) and altitude variations. The JT610 probe is focusing on inaccurate angle-of-attack data that triggered nose-down inputs meant to keep the MAX from stalling but instead confused the pilots and caused the aircraft to dive. The flight profile comparison suggests ET302 may have faced the same issue.



Source: Flightradar24

The Civil Aviation Administration of China (CAAC) gave domestic operators 9 hr. to park their MAX aircraft, which, at nearly 100, is the largest concentration in any country. The CAAC cited "the management principle of zero tolerance for safety hazards and strict control of safety risks" in making the move, adding that both 737-8 accidents "have certain similarities"—a word choice that would prove prescient.

Weather did not seem to be an issue.

The few known facts aligned with those of October 2018's crash of Lion Air Flight 610 (JT610), another nearly new 737-8 that went down shortly after departure in clear weather after its pilots reported flight-control issues. Data from JT610's flight data recorder (FDR) confirmed what the pilots suspected: They were battling a flight-control problem. Faulty angle-of-attack (AOA) sensor data activated an automated feature meant to help the MAX handle like its 737NG predecessor during steep turns or at slow speeds in manual flight, by trimming the horizontal stabilizer nose-down. The feature, the Maneuvering Characteristics Augmentation System (MCAS) flight-control law, is both a certification requirement and the JT610 probe's focus.

A change to the MAX's flight-control computers and the MCAS' functionality was in the works well before the ET302 accident, and the Chinese knew this, as did everyone else. Chinese media reports say CAAC officials consulted with Boeing and the FAA just after ET302. Their conclusion? The MCAS' risks were not well-enough understood, by pilots or regulators, to allow the MAX to keep flying.

As the Chinese evaluated the situation, two operators, Ethiopian and Cayman Airways, made independent decisions to ground their MAXs. Neither was surprising: Ethiopian suffered the second accident, and Cayman had just introduced the type in November.

Soon, however, the worldwide momentum for grounding grew. Late on March 11, Indonesia's Directorate General of Civil Aviation said 737-8s operated by Lion Air and Garuda Indonesia would be grounded for inspection. South Africa's Comair and Morocco's Royal Air Maroc added their names to the growing list of those not waiting for more ET302 probe details.

That same day, the FAA spoke out

French accident investigation bureau the BEA extracted data from a damaged Ethiopian Airlines Flight 302 recorder at its Paris laboratory. It is now being analyzed by the Ethiopian authorities.

BEA

Check 6 *Aviation Week editors discuss the latest from the two MAX accident investigations and look back at the compromises that led to the controversial MCAS system:* **AviationWeek.com/podcast**

for the first time, issuing a Continued Airworthiness Notification to the International Community, reiterating that Boeing's MCAS fix, based on lessons learned from the JT610 investigation, is in progress, and that the agency is on site assisting in the ET302 probe. "All data will be closely examined during this investigation, and the FAA will take appropriate action if the data indicates the need to do so," the agency said.

More groundings followed March 12, with the Civil Aviation Authority of Singapore and Australia's Civil Aviation Safety Authority banning operations. Australia acted "in the best interests of safety . . . in light of the two recent fatal accidents," says CASA CEO Shane Carmody. "This is a temporary suspension while we wait for more information to review the safety risks of continued operations of the Boeing 737 MAX."

Later in the day, Europe broke ranks—both with the U.S. and its European Aviation Safety Agency (EASA) regulator. The UK, France, Germany, and Ireland announced MAX operational bans. EASA soon followed.

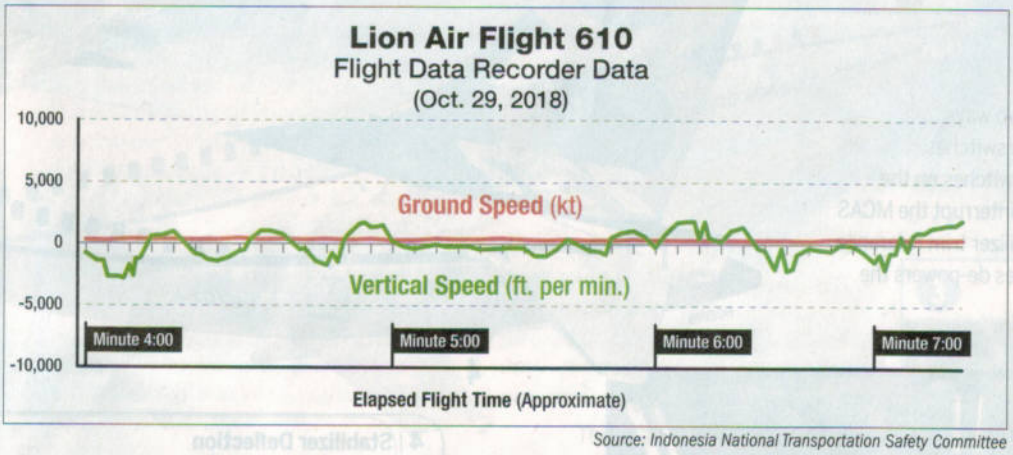
The European regulator was arguably as close to the evolving situation around MCAS as any non-U.S. entity. The bilateral aviation safety agreement between the U.S. and European Union has forged strong ties between the FAA and EASA. The Europeans were presented with Boeing's proposed MCAS changes on Feb. 7, including an automatic AOA-disagree alert and software modifications to reduce the amount of nose-down input it can give. On March 7, just three days before ET302 crashed, Boeing applied for approval of proposed new training requirements tied to the changes.

But with pressure mounting as state regulators and some operators grounded the MAX, EASA late on March 12 issued its own edict. Executive Director Patrick Ky cited the ADS-B automatic dependent surveillance-broadcast (ADS-B) data and reports of flight-control problems as key factors. EASA saw "a number of differences" between the two accident flight profiles, Ky says, "but also a large amount of similarities."

Meanwhile, the FAA, which had remained largely silent since the Ethiopian accident, finally spoke up. Encouraged by news that ET302's flight data recorder and cockpit voice recorders were recovered on March 11, the agency was holding out for more concrete data linking the two 737-8 accidents. "Thus far, our review shows no systemic performance issues and provides no basis to order grounding the aircraft," FAA Acting Administrator Dan Elwell said late on March 12. Then, in what could be seen as a swipe at regulators grounding the new Boeing cash cow: "Nor have other civil aviation authorities provided data to us that would warrant action."

The FAA's stance stunned almost everyone outside of aviation and many within the industry, but it should not have. The agency's approach to system-safety analysis, while often criticized as too deliberate, produces results. Challenged by a White House-led commission in 1997 to cut the commercial fatal accident rate by 80% in a decade, the FAA—through its Commercial Aviation Safety Team—met the deadline, and beat the target. In 1994, following the crash of an ATR 42 near Chicago, the agency ran 300 wind-tunnel tests on a one-fifth-scale ATR 42's wing, and high-speed ground tests with an actual aircraft within a month, before banning the type from operating in icing conditions.

Within hours of Elwell's March 12 statement, however, everything would change. Data captured by Aireon's space-based ADS-B system and refined by the company helped to establish ET302's flight profile. The data, provided to the FAA, Transport Canada and investigators, showed a series of altitude changes that suggest ET302 was struggling as JT610 had.



Source: Indonesia National Transportation Safety Committee

Continued on p. 18

FAA Reviews Enhanced MAX Flight-Test Data

> UPDATED MCAS SOFTWARE TESTED ON 737-7

> SYSTEM EVALUATED UNDER MULTIPLE HIGH ANGLE-OF-ATTACK SCENARIOS

Guy Norris Los Angeles

Boeing has completed a key certification flight test of enhanced 737 MAX flight-control computer software, marking a major step toward returning the grounded fleet to service.

The test flight, conducted using the first 737-7 variant of the MAX, validated a set of updates to the Maneuvering Characteristics Augmentation System (MCAS) flight-control law as well as improved pilot displays. Although the changes are part of a set of upgrades developed in the aftermath of the Lion Air Flight 610 accident in 2018, they are also expected to address a similar set of control problems implicated in the crash of Ethiopian Airlines Flight 302 earlier this month.

Boeing says it has been "working closely with the FAA on development, planning and certification of the software enhancement, and it will be deployed across the 737 MAX fleet in the coming weeks." It adds, "The update also incorporates feedback received from our customers." The FAA is expected to mandate the enhancement with an airworthiness directive at the end of March.

Although the company will not comment on the current status of flight tests, or say whether they have concluded, Boeing Chairman and CEO Dennis Muilenburg says: "[While investigators continue to work to establish definitive conclusions, Boeing is finalizing its development of a previously announced software update and pilot-training revision that will address the MCAS flight-control law's behavior in response to erroneous sensor inputs."

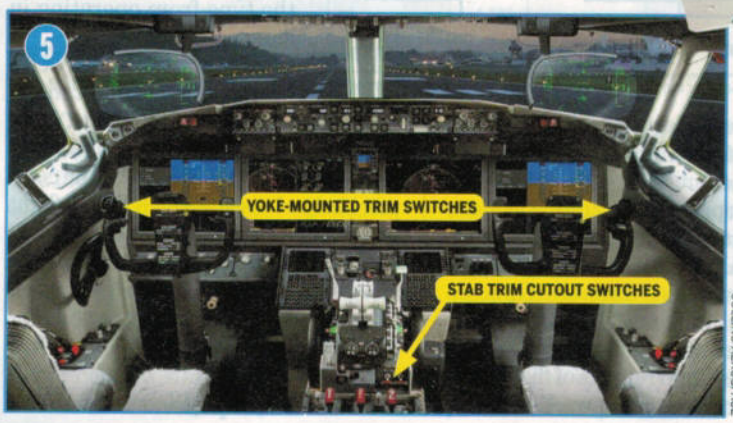
The software upgrade package, known as the EDFCS (enhanced digital flight-control system), significantly modifies the MCAS that was introduced on the MAX to match

THE 737 MAX MCAS EXPLAINED

The Maneuvering Characteristics Augmentation System (MCAS) is a flight-control law managed by the flight-control computer (FCC) and introduced on the 737 MAX to help it handle like a 737 Next Generation (NG), particularly at slow speeds and high angles of attack (AOA).

5 | Disabling the System

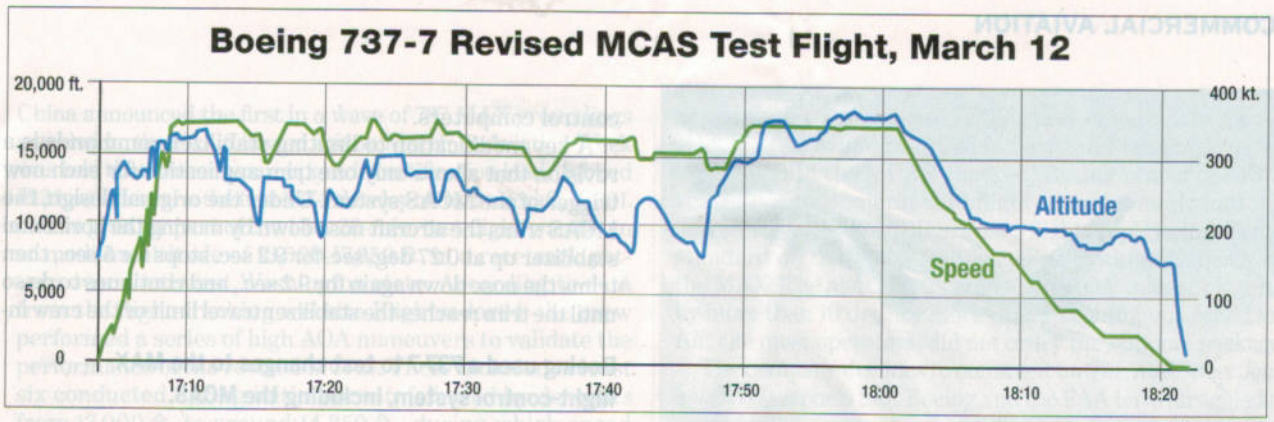
Pilots can interrupt the MCAS in two ways: via the yoke-mounted electric trim switches, or using the STAB TRIM CUTOUT switches on the center console. The trim switches interrupt the MCAS for 5 sec. and establish a new stabilizer trim reference point. Toggling both cutout switches de-powers the MCAS and the speed-trim system.



COLLINS AEROSPACE

4 | Stabilizer Deflection

When threshold AOA is reached, the MCAS commands 0.27 deg. of aircraft nose-down stabilizer deflection per second for 9.3 sec.—a total of 2.5 units of trim. When the FCC reads the AOA as back to below threshold, the MCAS is reset, and the aircraft's trim returns to the pre-MCAS configuration. Inaccurate AOA data will trigger the MCAS every 5 sec. until the data is corrected or the system is disabled.



Source: Flightradar24

aircraft-handling characteristics with those of the 737 Next Generation and decrease pitch-up tendency at elevated angles of attack (see graphic). The MCAS changes are focused on three areas: improving activation logic, enhancing angle-of-attack (AOA) inputs and limiting stabilizer-command authority.

Boeing says the changes are designed to increase overall system redundancy, limit stabilizer trim commands in response to an erroneous AOA reading, and retain elevator authority by limiting the degree of stabilizer command. The company is not yet detailing how these are being implemented. For example, Boeing has not clarified whether the AOA changes include adding more sensors or, as is considered more likely, revising the MCAS architecture to enable data from both the AOA vanes in the current configuration to be fed into both flight

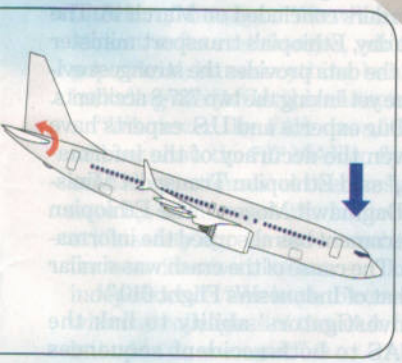
The test flight simulated stalls and other maneuvers meant to test the revised automatic stabilizer-trim input system.

1 | Leap Engines and Pitch-up Moment

The MAX's larger CFM Leap 1 engines create more lift at high AOA and give the aircraft a greater pitch-up moment than the CFM56-7-equipped NG. The MCAS was added as a certification requirement to minimize the handling difference between the MAX and the NG.

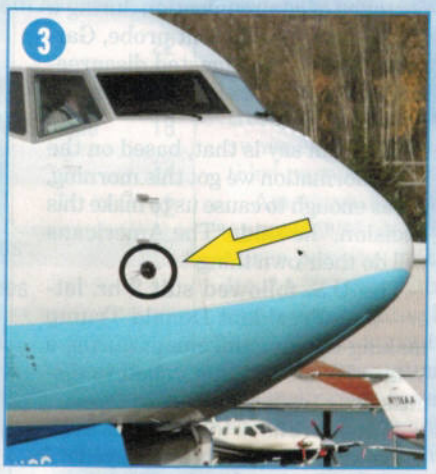
2 | MCAS Activation

The system activates when the aircraft approaches threshold AOA, or stickshaker activation, for the aircraft's configuration and flight profile. The MAX flight-control law changes from speed trim to the MCAS because the MCAS reacts more quickly to AOA changes.



3 | Angle of Attack Vanes

The MCAS' primary data sources are the MAX's two AOA sensing vanes, one on either side of the nose. Boeing designed the MCAS to receive input from only one of the sensors during each flight. The left and right sensors alternate between flights, feeding AOA data to the FCC and the MCAS.



BOEING

control computers.

A key modification to limiting stabilizer commands is a revision that allows only one trim application for each new trigger of the MCAS system. Under the original design, the MCAS trims the aircraft nose down by moving the horizontal stabilizer up at 0.27 deg./sec. for 9.2 sec. stops for 5 sec., then trims the nose down again for 9.2 sec., and continues to do so until the trim reaches the stabilizer travel limit or the crew intervenes. Boeing says that, as before, the crew will retain the capability to override the flight-control law either by electric or manual trim, or by following the existing runaway stabilizer procedure and using the cutout switches as reinforced in the Operations Manual Bulletin issued on Nov. 6, 2018.

Boeing used a 737-7 to test changes to the MAX flight-control system, including the MCAS.

The enhanced software was demonstrated for the FAA on March 12, the day after the Civil Aviation Administration of

Continued from p. 15

The Canadians were convinced. They told their U.S. counterparts they would ground the MAX, and at 11 a.m. Canada EDT March 13, Transport Minister Marc Garneau told the world.

"We know what happened with the Lion Air flight," Garneau said. "We wanted to see if the Ethiopian flight resembled it." While the links between the two accidents "are not conclusive, there are similarities that exceed a certain threshold in our minds."

He said that while the U.S. and Canada were in regular communication over the MAX issue, he did not know if the U.S. had the Aireon data, and could not say if Canada's move would alter the U.S.' thinking. Considering how close the countries and their regulators are, and the importance of communication during a major aviation accident probe, Garneau's answers suggested disagreement between the FAA and Transport Canada.

"All I can say is that, based on the new information we got this morning, it was enough to cause us to make this decision," he said. "The Americans will do their own thing."

The U.S. followed suit 3 hr. later—with President Donald Trump making the announcement during a White House briefing called to discuss drug trafficking.

"We didn't have to make this decision today. We could have delayed it," Trump said. "We maybe didn't have to make it at all. But I felt it was important both psychologically and in a lot of other ways."

The chain of events made clear that the FAA wanted to wait for even more definitive data, but the White House had seen enough. The move put all 371 MAXs worldwide on the ground.

The FAA followed with a statement and emergency order that provided context. "[The] investigation of the ET302 crash developed new information from the wreckage concerning the aircraft's configuration just after takeoff that, taken together with newly refined data from satellite-based tracking of the aircraft's flightpath, indicates some similarities between the [ET302 and JT610] accidents that warrant further investigation of the possibility of a shared cause for the two incidents that needs to be better understood and addressed," the FAA said in its emergency order.

"Suffice it to say, the evidence found on the ground made it more likely that the flightpath was closer to Lion Air," Elwell says, referring to what would be confirmed as a stabilizer jackscrew trimmed nose-down.

The wreckage, and Aireon's refined satellite data, helped U.S. and Canadian aviation safety experts present a clearer picture of ET302's 6-min. flightpath.

"The way the [initial] data was presented, it was not showing credible movement of an aircraft," Elwell says.

While neither U.S. nor Canadian officials would detail their findings, both said the resulting track, including ET302's altitude variations, lined up closely with the JT610's known track. This suggests ET302 was struggling to maintain altitude, and then dove rapidly to Earth. "We are a fact-driven, data-based organization. We make actions based on data, findings and risk assessment," Elwell says. "That data coalesced, and we made the call."

He says the FAA's reliance on the satellite data was in part due to uncertainty over delays in processing ET302's FDR data. "We had been hopeful all along that with black boxes discovered soon, that we could get them on the table and start pulling data," Elwell says. "That process was lengthened more than I had hoped."

The FAA's order does not spell out the steps for getting the MAXs back in service. The agency confirmed that validation and installation of the flight-control system update being developed by Boeing in response to the JT610 findings will be part of the package. "We have not tied the [grounding] order specifically to the software patch," Elwell says.

Preliminary analysis of data from ET302's flight data and cockpit voice recorders concluded on March 16. The next day, Ethiopia's transport minister said the data provides the strongest evidence yet linking the two 737-8 accidents.

"Our experts and U.S. experts have proven the accuracy of the information," said Ethiopian Transport Minister Dagmawit Moges. "The Ethiopian government has absorbed the information. The cause of the crash was similar to that of Indonesia's Flight 610."

Investigators' ability to link the MCAS to both accident sequences

China announced the first in a wave of 737 MAX groundings worldwide; the FAA followed suit on March 13. Aviation Week was told that the software upgrade certification load, dubbed P12.1, was flown on the first 737-7 developmental aircraft, 1E001.

The greater part of the 1-hr. 20-min. test flight was flown at medium altitude of 13,500-17,350 ft. in a racetrack pattern over southwest Washington state. According to data from the flight-tracking website Flightradar24, the crew performed a series of high AOA maneuvers to validate the performance of the revised MCAS. These included at least six conducted during initial ascent, followed by descents from 17,000 ft. to around 14,250 ft., during which speed dropped from more than 330 kt. to less than 180 kt.

The aircraft was then flown to 17,350 ft. and 265 kt. before pitching steeply nose down and recovering at around 15,900 ft. and 295 kt. The maneuver was repeated at a slower speed, before a further test point was conducted during which the 737 descended steeply from about 15,550 ft. to 13,500 while speed increased from 180 kt. to almost 270. Two further steep descents and recoveries were then performed before the aircraft leveled off and returned to Seattle for landing.

Along with the MCAS changes, Boeing is also updating training requirements and flight-crew manuals and will add an AOA DISAGREE primary flight-display alert that is standard on the 737NG but is now an optional package on the MAX. The alert is triggered when AOA values "disagree by more than 10 deg. for more than 10 continuous sec." Lion Air, like most operators, did not order the optional package.

The company declines to comment on *The Wall Street Journal (WSJ)* reports that Boeing and the FAA have struggled to agree on the extent of some of these changes, particularly to the revised training procedure. Alterations are planned for the Airplane Flight Manual and Flight Crew Operations Manual, as well as new notes for the speed trim fail checklist in the Quick Reference Handbook. Other changes are being made to the Airplane Maintenance and Interactive Fault Isolation manuals.

Boeing has also outlined updated training documents to advise pilots of the changes but, according to the *WSJ*, the FAA has pushed for more extensive training.

would further implicate the controversial system, which most pilots did not know existed prior to the JT610 accident and subsequent probe. But it also may expedite lifting the global MAX operations bans.

Boeing has been working on the flight-control modifications for months. If regulators determine the fixes and related training go far enough to reduce the MCAS' risk and improve pilots' understanding, the ban could be lifted without waiting for further progress in the ET302 probe.

Early indications are that, like the groundings, clearing the MAXs to resume operations will not be a unified effort.

Transport Canada and EASA each plan to scrutinize Boeing's upgrades instead of accepting the FAA's evaluation. EASA's Ky says the agency wants to check each failure mode in detail before clearing the modified aircraft. "What we intend to do is to go in depth into the design, looking at the software and its interaction with the physical systems in the cockpit and the human-machine interface," he says. "We will not only look at software changes, which are superficial, but everything behind it, including the [MCAS] architecture."

"Whatever the FAA does," EASA will not allow the 737 MAX to fly again until all questions have been answered, says Ky, adding that the bilateral aviation safety agreement meant to foster coordination also leaves room for independence. "We hope to coordinate with our colleagues at the FAA, but we intend to do our work."

Airlines Struggle To Minimize Impact of Boeing 737 MAX Grounding

> CARRIERS SEARCH FOR SPARE AIRCRAFT, REPLACEMENT CAPACITY

> NORTH AMERICA AND CHINA MOST AFFECTED

Jens Flottau Frankfurt, **Sean Broderick** Washington and **Helen Massy-Beresford** Paris

With the Boeing 737 MAX grounded worldwide, airlines are grappling with the fallout as they near the busy summer timetable. The airframer may face massive compensation claims and some, although limited, cancellations of existing orders.

More than 370 MAX aircraft were in operation when the grounding took effect in the days after the March 10 crash of Ethiopian Airlines Flight 302. With around 100 deliveries to several different airlines, China's air transport industry is the most affected. Significant MAX fleets are also in service in North America, at Air Canada, WestJet, United Airlines and Southwest Airlines. Europe also has some large operators, most prominently Norwegian Air Shuttle, which has been the most vocal about compensation claims.

Top 10 737 MAX Operators	
Southwest Airlines	32
China Southern Airlines	24
Air Canada	22
American Airlines	22
Norwegian Air Shuttle	18
SpiceJet	12
WestJet	12
United Airlines	12
Hainan Airlines	11
FlyDubai	11

Source: Boeing

Airlines are trying to reallocate capacity, but dealing with the MAX crisis still means thousands of canceled flights. Wet-lease capacity is hard to secure in some parts of the world, particularly in Europe, where carriers have taken extra caution to ensure they are better prepared for air traffic control disruption in the summer by leasing third-party capacity.

American Airlines operated 85 departures per day with its 24 737-8s. "Our operations center is working to reroute aircraft throughout the system to cover as much of our schedule as we can," the carrier says. "Cancellations will vary, as our team has rerouted aircraft throughout our network."

Southwest Airlines is backfilling around 200 daily departures that its 34 MAXs—North America's largest MAX fleet—flew prior to the grounding. The airline, which is adding MAXs for growth and to replace older 737-700s, has been canceling about 150 flights per day and shuffling the remainder of its 750-aircraft fleet to operate the rest. It is modifying its schedule daily and attempting to give customers at least five days' notice when flights are canceled.

United Airlines operated about 40 daily departures with its 12 737-9s. "Through a combination of spare aircraft and rebooking customers, we do not anticipate a significant operational impact," the carrier says.

Alaska Airlines has 32 MAXs on order but has not taken delivery of any. Air Canada has pulled the MAX from its schedule until "at least" July 1 and reshuffled its schedule and aircraft assignments to accommodate the capacity reductions. Its 24 MAX 8s accounted for about 75 of the airline's 1,600 daily departures.

The MAX grounding has forced Air Canada to make significant schedule changes. Among them: suspending flights between London Heathrow Airport and both Halifax, Nova Scotia, and St. John's, Newfoundland. It also retimed its Toronto-London route to the evening and cut frequencies in a number of markets. In some cases, it is upgauging to maintain capacity. Toronto-Vancouver daily frequencies saw three MAX flights cut and one 777-300ER added, for a new total of up to 10 daily departures. The airline listed 25 routes affected by the MAX grounding. The crisis also led Air Canada to suspend financial guidance for 2019 until it has more information.

WestJet, which grounded its 13 MAXs within an hour of Canada's March 13 operations restriction, also suspended financial guidance. But the carrier has needed fewer changes to cover for its out-of-service fleet. It is benefiting from recent entry into service of two 320-seat Boeing 787-9s, which are being used on the airline's Calgary, Alberta-Toronto route until their international entry into service in late April. This has given WestJet some extra capacity. It also moved a 767 to the Calgary-Hawaii market that was being flown with a MAX and canceled certain flights. Its MAX operation supported about 35 daily departures.

Sunwing Airlines, which voluntarily grounded its four 737-8s on March 12 because regulators in several of its destinations had banned operations, reworked its schedule to accommodate the move.

An upgrade to the MAX Maneuvering Characteristics Augmentation System (MCAS) flight-control law is expected to be ready in the coming weeks (see page 16). But Canadian carriers will not be cleared to fly until the country's regulator, Transport Canada, validates the changes, Transport Minister Marc Garneau said March 18. This mirrors the European Aviation Safety Agency's planned approach. Both Canada and the European Union have bilateral aviation safety agreements with the U.S., and normally work done by one regulator is accepted by the other. Deeper scrutiny over how the FAA handled the MAX's certification—and the aircraft's MCAS flight-control law specifically—is leading to more independence among regulators.

With their MAXs grounded since March 12, European carriers are scrambling to find replacements to shore up their schedules. Flag carrier LOT Polish Airlines, which has five 737-8s and seven on order, has called on Slovakia-based aircraft, crew, maintenance, insurance (ACMI) specialist Go2Sky, which is providing three of its Boeing 737-800 fleet on a wet-lease basis to ease any LOT schedule disruptions. Go2Sky's aircraft have an all-economy, 189-seat capacity; the Slovak airline is also providing six crews.

"The MAX ban in Europe has triggered a serious lack of capacity in an ever-growing market, with demands on available aircraft increasing every year," Go2Sky CEO Daniel Ferjancek said.

Norwegian Air Shuttle will seek compensation from Boeing over the grounding, according to the low-cost airline's CEO, Bjorn Kjos. In a video posted on Twitter, he said only a small part of its operation is affected—about 1% of seat capacity. But he added: "It is quite obvious that we will not take the cost related to the new aircraft that we have to park temporarily. We will send this bill to those who produce this aircraft. . . . What happens next is in the hands of European aviation authorities, but we hope and expect that our MAXs will be airborne soon."

JOEPRIESAVIATION.NET

Norwegian says it will file claims for compensation from Boeing for the MAX grounding.

Norwegian said it would temporarily deploy a Boeing 787-9 on U.S. flights from Dublin as part of efforts to minimize disruption by reallocating other aircraft, rebooking passengers and combining flights.

Meanwhile, Air Italy, which has three 737-8s grounded, is partially offsetting the loss with the lease "at very short notice" of an Airbus A319 through Bulgaria Air. Just two weeks ago Air Italy announced the commencement of a codeshare with the Bulgarian airline.

Not only are airlines with in-service MAX fleets affected, but operators that were expecting their first MAX deliv-

eries imminently must now change their plans. Among them is Ryanair, whose order for 135 MAX 200s makes it one of the largest future operators of the type. It has a fleet of over 460 aircraft; the order will enable it to grow that to 585 by 2024.

The first MAX is due for delivery in April 2019. "There is no risk for Ryanair's summer program," Chief Legal and Regulatory Officer Juliusz Komorek says. "Our fleet of 450 planes includes a lot of emergency planes, which are located strategically."

Ryanair CEO Michael O'Leary said on March 11, before the widespread groundings, that the carrier had no immediate plans to change its delivery schedule of one aircraft in April, two in May, two in June and 50 more before summer 2020.

TUIfly, a German leisure airline, was due to take its first two 737-8s in March and a total of six by year-end. Scheduled MAX flights were due to start on April 14 from the airline's Hannover base.

In Indonesia, flag-carrier Garuda Indonesia and Lion Air say they are reconsidering their MAX orders. Garuda President Director I Gusti Ngurah Askhara Danadiputra says the airline "lost confidence in the model following two crashes" and is in talks with Boeing for the potential cancellation of the remaining 49 737-8s on order. Garuda's first and only 737-8 has been grounded since March 11, under orders by the Indonesian transport ministry. Garuda was to take delivery of the remaining 49 aircraft through 2030, part of a 50-aircraft deal signed in 2014.

Lion Air also considered canceling its order of over 180 aircraft, replacing them with more Airbus A320neos. It already has 113 A320neos and 65 A321neos on firm order. The airline is still studying the legal options and says it has suspended the delivery of four 737 MAXs due for this year. Lion Air had made similar threats in December 2018, following the crash of its MAX operating as Flight 610 and disagreements between Boeing and the airline over responsibility for the incident.

The group has both the 737-8 and -9 in service, also flown under the Malindo Air and Thai Lion Air subsidiaries in Malaysia and Indonesia, respectively.

—With Chuanren Chen in Singapore and Alan Dron in London

Boeing Continues MAX Production at Unchanged Pace

> BOEING CAN FLY FINISHED AIRCRAFT FROM RENTON TO STORAGE

> PRODUCTION TEST FLIGHTS EXEMPT FROM GROUNDING

Guy Norris Los Angeles and **Michael Bruno** Washington

Amid mounting concerns that the grounding of Boeing's 737 MAX family may well extend beyond April, the company is evaluating a range of contingency plans to ferry completed aircraft to storage sites while deliveries to operators remain at a standstill.

Although MAX-series aircraft are currently prohibited from being flown by U.S. operators and in U.S. territory, special flight permits for the purposes of ferrying to storage and production flight testing are allowed under terms of the FAA emergency order grounding the 737-8/9. Boeing is therefore continuing to build 737s as before, and as of March 18 at least eight MAX aircraft had made predelivery test flights.

Five of these were "B1" first flights from Boeing's 737 production facility in Renton, Washington, to the nearby predelivery and flight-test site at Boeing Field, while others were additional production test or functional check flights to and from Boeing Field.

The OEM is not commenting directly on which storage sites it is considering. "We have paused delivery of 737 MAX airplanes due to the temporary grounding," it says. "We continue to build at rate 52/month, while assessing how the situation, including potential capacity constraints, will impact our production system." The company is believed to be evaluating facilities closer at hand such as Moses Lake, Washington, as well as locations in other Western states.

The company knows from its experience in 2018 how fast the already congested Renton facility fills up when disruption occurs. However, unlike the problems last year, which were caused by delays primarily in shipments of CFM Leap 1B engines, the silver-lining for Boeing is that this time it will at least be able to ferry aircraft away from the site.

As of mid-March, Boeing had an estimated 42 completed 737-8/9s on the ramp area and production flight line at Renton, in addition to five 737 Next Generation (737NG) aircraft. As many as 29 MAXs are now also thought to be on the flight line at Boeing Field, too, plus approximately 10 737NGs. Some of the latter include military C-40 and P-8 derivatives.

Five other MAX aircraft are also believed to be in paint facilities in Spokane, Washington; Portland, Oregon; and Victorville, California, while two MAXs are reportedly in storage at Boeing's Everett site.

The production line, which is due to increase to a rate of 57 per month later this year, is meanwhile filled with up to 23 MAX and nine 737-800/900s in various stages of assembly.

Airlines With 20 Largest Outstanding MAX Orders (March 2019)

	Number of Aircraft
Southwest Airlines	262
Lion Air (Indonesia)	258
Unknown	258
FlyDubai	237
VietJet Air	200
United Airlines	171
SpiceJet	153
GOL Transportes Aeroes	140
RyanAir	135
Jet Airways	128
Norwegian Air Shuttle	92
American Airlines	76
Copa Airlines	65
China Southern Airlines	64
Turkish Airlines	63
Xiamen Airlines	59
AeroMexico	55
Garuda Indonesian Airways	49
China Eastern Airlines	44
Hainan Airlines	43

Source: Aviation Week Network Fleet Discovery

The full extent of the grounding and the added time required to complete the FAA-led certification of the flight control computer software and training system upgrades remain unknown. However, analysts at Credit Suisse believe that any major financial impact on the company will be recouped later in the year, as long as production continues in the interim. "While Boeing builds but does not deliver aircraft, we further assume it will continue to collect predelivery payments," it says.

The report adds that Boeing "normally collects around 42% of the cash price in advance. A 2% deposit is taken with the order, and then 40% is collected in roughly equal quarterly installments during a 6-8 quarter period leading to delivery, with the final 58% due upon delivery." Based on adjustments, "this leaves Boeing to temporarily fund the difference of around $14 million per aircraft," it adds. "At 52 units per month, the resulting drag on cash flow is then around $607 million per month."

Projecting up to a six-month delivery hiatus, Credit Suisse estimates this would cost an estimated $3.7 billion in cash flow, much of which could be recaptured later.

Vertical Research Partners, meanwhile, raised the question of growing inventory based on up to 40 shipments per month being postponed. "At around $50 million/copy that's an extra $1.8 billion/month of inventory—and some of that would be seen (in this scenario) in the first quarter 2019 cash flow, before flowing out in subsequent quarters. For calendar 2019, it's quite possible that all the delayed MAX shipments could be out of the door by year-end," its analysts write.

Several financial analysts say they expect the MAX groundings to last 2-3 months, but that assumes an FAA-approved software fix will be the crux of the answer and that authorities worldwide will allow the MAX to return to the skies.

Increasingly, some observers think if the groundings and delivery suspension persist through the July Paris Air Show, Boeing might take a hit to projected financial results for 2019, depending on whether it can recover in the second half of the year. There also could be knock-on effects such as a delayed rate ramp-up to 57 737s a month, or further hesitation about the planned authority to offer the new midmarket airplane (NMA)—both previously envisaged by the air show—as well as for any potential major acquisitions.

Still, analysts say that for long-term investors in Boeing, the MAX groundings and delivery halt—as well as other issues, including hiccups in Washington with the U.S. Air Force KC-46A or NASA Space Launch System—do not portend a stock falloff. While Boeing's stock price has declined more than 11% since just before the Ethiopian Airlines crash, it appears to have found a floor for now. Of course, that could change if more bad news emerges.

Boeing is continuing MAX production at unchanged volumes for now, despite the in-service fleet grounding. Fifty-two aircraft per month are built at its Renton, Washington, facility.

STEPHEN BRASHEAR/GETTY IMAGES

"We are now in a much longer sort of wait-and-see period, where headline risk is a little bit higher," says Melius Research analyst Carter Copeland.

"All of us collectively know very little at this point, and conjecture is naturally filling the information vacuum," admit analysts at Vertical Research Partners. "With the FAA's approval process for the MAX now being called into question, we would accept that a two-month grounding for the aircraft could turn out to be an optimistic assessment," they say.

Nevertheless, few think the supply chain should be worried yet. Boeing was expected to keep production humming because it would ultimately be more disruptive and expensive to stop, analysts say.

Indeed, despite ongoing, unrelated supply issues that started in late 2017, Boeing has maintained 737 production, parking unfinished airframes on Seattle-area tarmacs. It also kept KC-46A production going despite holdups there in recent years.

In the end, Boeing weathered the production issues financially without much trace of an issue, posting record 2018 revenue of $101.1 billion and expectations of $109.5-111.5 billion this year. Analysts say the Chicago company has the wherewithal to endure more negative headlines.

"The company has ample liquidity to deal with any impact, with $8.5 billion of cash and short-term investments and $5.1 billion of revolving credit facilities . . . as of Dec. 31, 2018," S&P Global Ratings says.

The 737, and the MAX specifically, are critically important to Boeing and its supply chain. Canaccord Genuity estimates that the 737 accounts for around 25% of Boeing's total 2019 free cash flow—the money pot that fuels shareholder returns. Some suppliers with significant exposure include Spirit AeroSystems, where about half its future annual sales are tied to the narrowbody, as well as Triumph Group and Ducommun, each at 15-20% of estimated 2020 sales.

Spirit CEO Tom Gentile promises to keep his workers updated. "We are proud to be a partner on the 737 MAX program and stand prepared to offer Boeing whatever support they need as they work to understand the cause of the accidents," he says. "We will continue producing to the current schedule until Boeing advises differently."