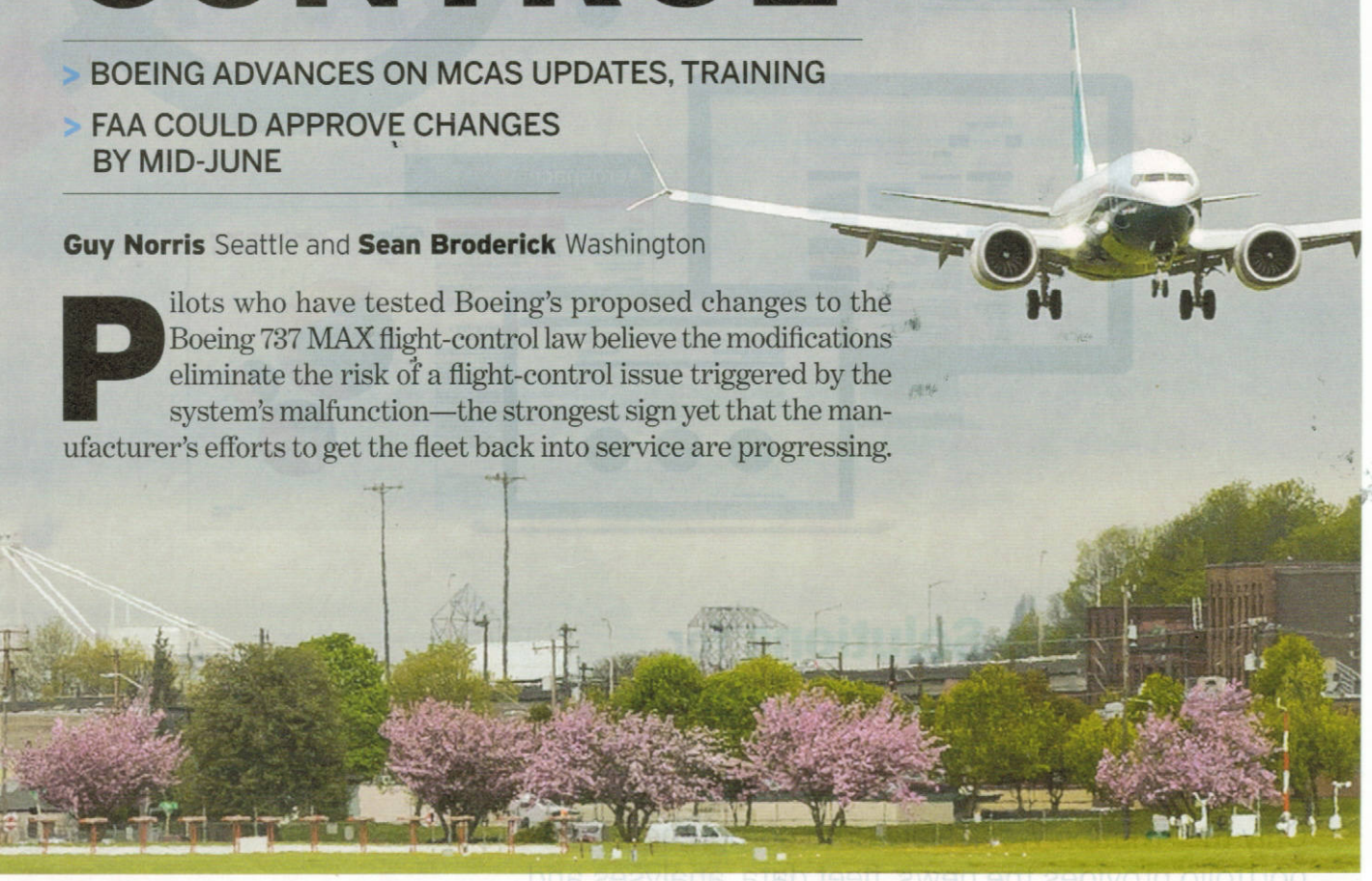
CRISIS CONTROL

> BOEING ADVANCES ON MCAS UPDATES, TRAINING

> FAA COULD APPROVE CHANGES BY MID-JUNE



Guy Norris Seattle and **Sean Broderick** Washington

Pilots who have tested Boeing's proposed changes to the Boeing 737 MAX flight-control law believe the modifications eliminate the risk of a flight-control issue triggered by the system's malfunction—the strongest sign yet that the manufacturer's efforts to get the fleet back into service are progressing.

Boeing on March 27 provided the first large-scale overview of Maneuvering Characteristics Augmentation System (MCAS) modifications to industry. The meeting was the de facto start of a global campaign by the embattled U.S. aerospace giant to convince regulators that the changes and related training are sufficient to clear the MAX for revenue flying.

The campaign encompasses a series of simulator demonstrations and briefings at multiple training sites throughout the U.S., Europe, Asia and Australia. More than 40 of the 50 MAX operators "have had the opportunity to see the update in action during simulator sessions," Boeing said April 17.

The outreach comes as Boeing attempts to manage an unprecedented situation. Because the MAX grounding started with a Chinese mandate and spread to other countries before the FAA followed suit, the company says it is imperative to build a caucus of international regulators willing to lift MAX operations bans that have been in place since mid-March.

Most affected airlines are preparing to be without the aircraft for a while. Many have removed MAXs from flight schedules into August at least.

The FAA, which usually sets the standards for U.S.-built aircraft, is also shifting gears. The agency has set up a Joint Authorities Technical Review (JATR) to review certification of the aircraft's automated flight-control system. Chaired by former NTSB Chairman Christopher Hart, the JATR team comprises FAA, NASA and international aviation authorities.

While the FAA seeks global consensus, the agency also is doing its own due diligence. On April 12 it hosted representatives from the three U.S. MAX operators—American Airlines, Southwest Airlines and United Airlines—as well as unions that represent the carriers' pilots. The 3-hr. meeting included reviews of the two fatal MAX 8 accidents—Lion Air Flight 610 on Oct. 29, 2018, and Ethiopian Airlines Flight 302 on March 10—that triggered the MCAS changes and fleet grounding. Boeing's progress on the upgrades and proposed training was also reviewed.

Boeing's 737-7E001 landed following an MCAS validation flight.

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While neither the final software nor the MCAS training curriculum have been presented to the FAA for certification, the agency has been working with Boeing for months. Confident of Boeing's progress, an FAA official told the April 12 gathering that late May or early June is a target date for approving Boeing's proposed changes, a source with knowledge of the proceedings tells Aviation Week. The FAA would then mandate the upgrades, clearing the way for U.S. MAX operations to resume—perhaps without consensus from other regulators. The return-to-service time line is not set in stone, the source adds.

Participants also discussed a recent FAA Flight Standardization Board (FSB) pilot-training and qualification review that determined MCAS training—like the rest of transition training from a 737 Next Generation (NG) to a MAX—can be accomplished without simulator time or an aircraft training device. FSB participants, including 737 pilots and FAA engineers, conducted trials on March 25 using 737-800 and MCAS version-12.1.1.-equipped 737-8 full-flight simulators. They also conducted "functional equivalence" and handing-qualities comparison flight tests per the FAA's FSB guidance.

The pilots detected no handling differences between the 737-800 and 737-8—mirroring conclusions reached by an FSB review conducted in August 2016 by pilots from American, Southwest and Delta Air Lines and representatives from Transport Canada and the European Aviation Safety Agency. The handling equivalency negated the need for simulator training, both boards determined.

The latest FSB review recommends adding the MCAS to a list of four "special emphasis areas" for 737NG pilots transitioning to the MAX. Already on the list: the MAX's Elevator Jam Landing Assist feature, landing attitude modifier, gear-handle operation and flight-crew alerting.

"MCAS ground training must address system description, functionality, associated failure conditions" and flight-deck alerts, the draft report adds. "These items must be included in initial, upgrade, transition, differences, and recurrent training."

The revised FSB review, which will be finalized following a public-comment period that runs until April 30, also adds the MCAS to a list of "master differences" between the MAX and NG. The current 737 FSB report, the document's 16th revision, does not reference MCAS.

Some regulators and operators are expected to push for mandatory simulator sessions that mimic MCAS failure modes. On April 16, Canada Transport Minister Marc Garneau confirmed his country will be among them. "It's not going to be a question of pulling out an iPad and spending an hour on it," he told Reuters.

The FAA could opt to require simulator sessions but will more likely follow the FSB's recommendation that calls for Level B, or computer-based, training to cover MCAS description and failure scenarios. This would set a minimum standard that regulators or operators could opt to exceed.

Meanwhile, Boeing is close to finalizing the MCAS upgrade. The updated software was put through its paces on a key engineering test flight on April 16. "That was the final test flight before the [FAA] certification flight," CEO Dennis Muilenberg says. "We're making steady progress toward certification." The software has been tested on 120 flights, many of them initial post-production, or B1, flights on MAXs built for customers.

While it works to finalize the new flight-control law logic, Boeing is confident that the global outreach program will lay the foundation for its proposed training package.

Mike Sinnett, Boeing Commercial Airplanes vice president of product development and future airplane development, says the briefings continue to emphasizes that the MCAS, which was added to the speed trim system (STS) to standardize handling qualities with those of the 737NG, is neither a stall protection or prevention function. "It is a handling-qualities function. There's a misconception it's something [other]," he says. Added to ensure a linear relationship between stick force per G, "speed trim is a function of airspeed, so if you're going fast it is a low angle-of-attack [AOA], and if you're going slow it is at higher AOA," Sinett says. "The thing you are trying to avoid is a situation where you are pulling back and all of a sudden it gets easier, and you wind up overshooting—making the nose higher than you want it to be."

Making the system work required changes from the 737NG STS. "Mechanically on the NG, there is a column cut-off switch that stops any automatic trim when the column is back to a certain spot," Sinnett says. "On the MAX, we still needed automatic trim when you got to that spot. MCAS differs from speed trim at elevated alpha because it bypasses that switch by design. To do so, it activates based on AOA rather than speed, which is what speed trim does. Speed trim is a function of airspeed, MCAS is a function of angle-of-attack and Mach number, but it only triggers off AOA."

The MCAS activation during the two MAX 8 accident sequences sparked Boeing's decision to reexamine how the system operates and modify its software. The work began shortly after the Lion Air accident. The March 27 gathering briefed key proposed MCAS changes to 200 pilots and regulators.

The first of three new main layers of

protection is provided by a cross-channel bus between the aircraft's two flight-control computers, which now allows data from the two AOA sensors, or alpha vanes, to be shared and compared. "In a situation where there is erroneous AOA information, it will not lead to activation of MCAS," says Sinnett, who underlines that the entire speed-trim system, including the MCAS, will be inhibited for the remainder of the flight if data from the two vanes varies by more than 5.5 deg. If an AOA disagree of more than 10 deg. occurs between the sensors for more than 10 sec., it will be flagged to the crew on the primary flight display.

The second layer of protection is a change to the logic in the MCAS algorithm that provides "a fundamental robust check to ensure that before it

Pilots Say MCAS Software Updates Prove Effective in Simulator Demo

- THE SYSTEM NOW COMPARES INPUTS OF BOTH ANGLE-OF-ATTACK SENSORS
- PILOTS ALWAYS RETAIN PITCH CONTROL AUTHORITY OVER THE MCAS INPUT TO THE STABILIZER

Fred George

Boeing has demonstrated the old and new versions of the MAX's Maneuvering Characteristics Augmentation System (MCAS) to pilots and regulators in its 737 MAX engineering cab simulator in Seattle. The MCAS is a new flight-control-computer (FCC) function added to the MAX to enable it to meet longitudinal stability requirements for certification.

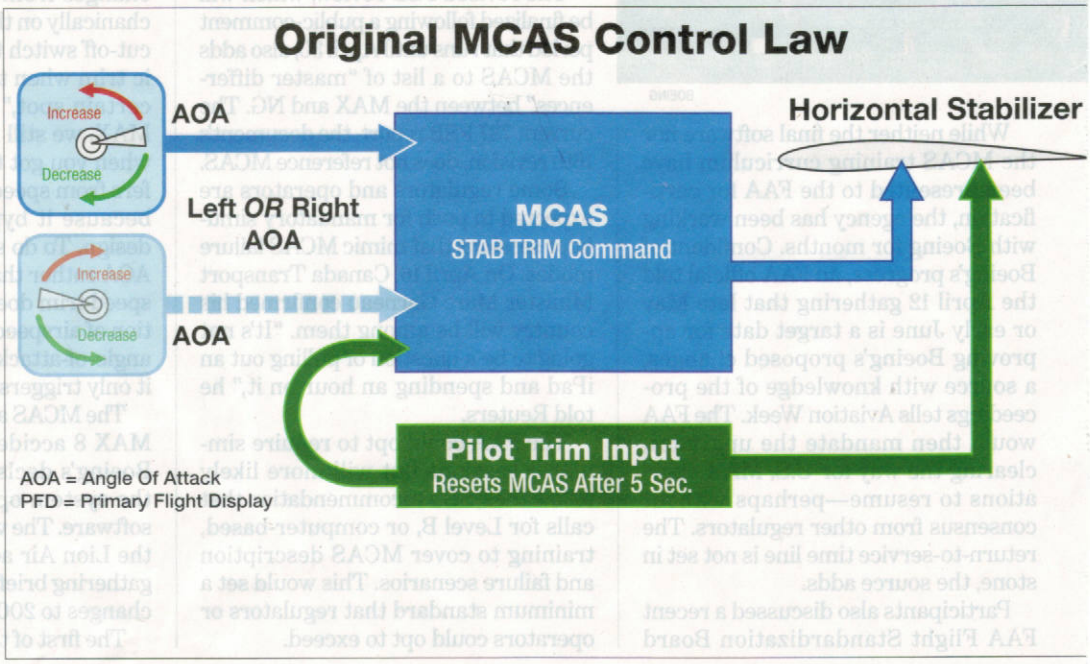
However, the system is only needed to enhance stability with slats and flaps retracted at very light weights and full aft center of gravity (cg). The aircraft exhibits sufficient natural longitudinal stability in all other parts of the flight envelope without the MCAS to meet the rules. Boeing emphasizes that the MCAS is not an anti-stall or stall-prevention system, as it often has been portrayed in news reports.

The new software load (P12.1) has triple-redundant filters that prevent one or both angle-of-attack (AOA) systems from sending erroneous data to the FCCs that could falsely trigger the MCAS. It also has design protections that prevent runaway horizontal stabilizer trim from ever overpowering the elevators. Boeing showed that the pilots can always retain positive pitch control with the elevators, even if they don't use the left and right manual trim wheels on the sides of the center console to trim out control pressures after turning off the trim cut-out switches.

Most important, the MCAS now uses both left and right AOA sensors for redundancy, instead of relying on just one. The FCC P12.1's triple AOA validity checks include an average value reasonability filter, a catastrophic failure low-to-high transition filter and a left versus right AOA deviation filter. If any of these abnormal conditions are detected, the MCAS is inhibited.

Three secondary protections are built into the new software load. First, the MCAS cannot trim the stabilizer so that it overpowers elevator pitch control authority. The MCAS nose-down stab trim is limited so that the elevator always can provide at least 1.2g of nose-up pitch authority to enable the flight crew to recover from a nose-low attitude. Second, if the pilots make electric pitch trim inputs to counter the MCAS, it will not reset after 5 sec. and repeat subsequent nose-down stab trim commands. And third, if the MCAS nose-down stab trim input exceeds limits programmed into the new FCC software, it triggers a maintenance message in the onboard diagnostics system.

According to a pilot who was shown the changes in a simulator session, the demonstration begins with the original MCAS software load. During a normal takeoff, at rotation, the left AOA indication moves to its maximum reading—as seen from the flight data recorder in the Ethiopian Airlines accident. Pilots currently do not expe-



ever activates a second time, pilots really want it to activate," says Sinnett.

The third layer of defense ensures pilots always retain some control-column authority to counteract MCAS nose-down stabilizer commands. "The column itself will always provide at least 1.2g of maneuvering capability," he says. "So you don't just have the ability to hold the nose level, you can still pitch up and climb."

Sinnett says pilots seem satisfied that the three main layers of protection now added to the MCAS will prevent any potential repeat of the circumstances detected in the tragic Lion Air and Ethiopian accidents. "The most compelling thing is that the AOA failure case turns into a run-of-the-mill AOA failure case [one] might have on any other airplane."

Normal PFD Image at Takeoff

The red-and-white stall-warning tape on the airspeed indicator is well below the aircraft's indicated airspeed.

Abnormal PFD Image at Takeoff Due to Erroneous AOA

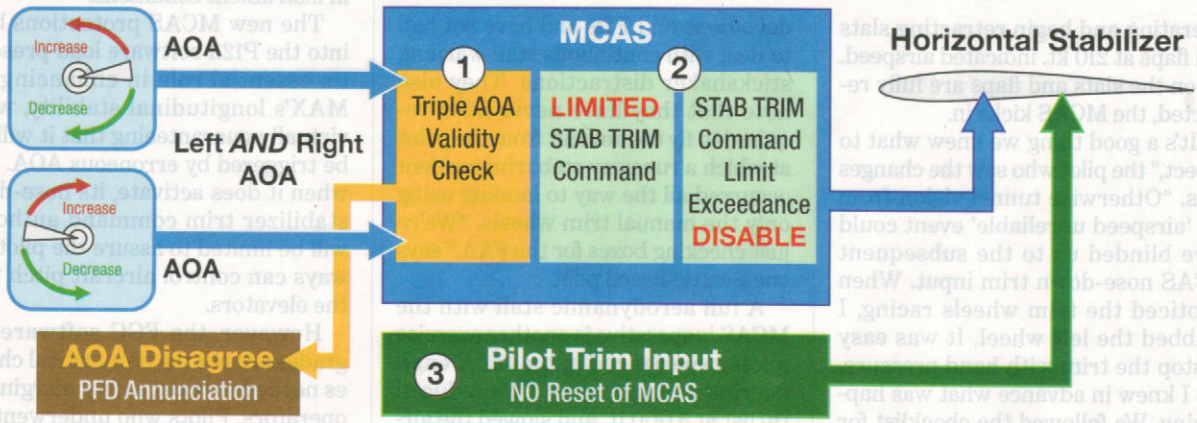
The updated PFD display indicates angle-of-attack sensing errors as illustrated by the "AOA disagree" icon at lower right along with the red-and-white stall-warning tape extended well above indicated airspeed.

FRED GEORGE/AW&ST

rience this during initial or recurrent simulator training. The stickshaker fires continuously, using a loud sound and control-wheel vibration to focus the pilot's attention on the critically high AOA indication. The erroneous AOA reading also creates large-scale indicated airspeed (IAS) and altitude errors on the primary flight display (PFD) that can be both distracting and disorienting.

AOA is used by the aircraft's air data computers to correct pitot and static pressure variations induced by changes in nose attitude in relation to the relative wind. Large errors in AOA can cause 20-40-kt. errors in IAS and 200-400-ft. errors in indicated al-

New MCAS Control Law



MCAS Changes

1. Both AOA Sensors Compared: the MCAS is inhibited if sensors vary by ≥5.5 deg., there is a sudden spike-up in AOA or if the AOA change rate is unreasonable.
2. Elevator pitch authority exceeds MCAS stab pitch authority; the MCAS is disabled if the command limit is reached.
3. The MCAS will activate only once for each elevated AOA input. There is no 5-sec. reset after pilot trim inputs.

GUY NORRIS/AW&ST

titude. This is accompanied by the illumination of annunciators on both PFDs that warn of disparities in the IAS and altitude between the left and right displays. As part of the MCAS redesign, Boeing also is upgrading the MAX with AOA-disagree-warning annunciators on the PFD as standard; AOA dial indicator displays are an option.

After the high-AOA indication, pilots then follow the checklist for "airspeed unreliable," which assures that auto-pilot, auto-throttles and flight directors are turned off. They then pull back power to 80% fan speed, set 10-deg. nose-up pitch attitude and climb to 1,000 ft. above ground level. At that point, they lower the nose, start accelerating and begin retracting slats and flaps at 210 kt. indicated airspeed. When the slats and flaps are fully retracted, the MCAS kicks in.

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The only change pilots will notice with the upgraded MCAS will be angle-of-attack-disagree symbology availability on the primary flight displays.

"It's a good thing we knew what to expect," the pilot who saw the changes says. "Otherwise tunnel vision from the 'airspeed unreliable' event could have blinded us to the subsequent MCAS nose-down trim input. When I noticed the trim wheels racing, I grabbed the left wheel. It was easy to stop the trim with hand pressure, but I knew in advance what was happening. We followed the checklist for runaway stabilizer, checking again for auto-pilot off and auto-throttle off. We turned off both trim cut-out switches and cranked the 'frisbees' [manual trim wheels on both sides of the center console] to relieve control pressures. We used manual trim for the remainder of the flight to landing touchdown and rollout. That was quite an eye-opener, as I had never been exposed to that during sim training," he notes.

It is critical to follow the checklist memory items: Pull back thrust to 75% after retracting slats and flaps and set attitude at 4 deg., nose up. If speed builds up beyond 220-250 kt., controllability becomes increasingly difficult, he adds.

Pilots for three U.S. air carriers tell Aviation Week that during their sim training they had never been exposed to extreme and continuous AOA indication errors, they have not experienced AOA-induced airspeed and altitude deviations on PFDs and have not had to deal with continuous stall-warning stickshaker distractions. They also note that they have never been required to fly the aircraft from the point at which a runaway stab trim incident occurred all the way to landing using only the manual trim wheels. "We're just checking boxes for the FAA," says one Seattle-based pilot.

A full aerodynamic stall with the MCAS inoperative is another exercise pilots experienced in the MAX engineering cab simulator. "We reduced thrust at 5,000 ft. and slowed the aircraft at about 1 kt. per sec. We were at a midrange cg with gear, slats and flats up. We trimmed until we reached 30% above stall speed and then just continued to ease back on the control wheel," one of the pilots says.

"Pitch feel was natural, progressively increasing as airspeed decayed. Somewhere between the audible low airspeed warning and stickshaker, I felt the slightest lightening on control pressure in my fingertips," he continues. "Quite candidly, if I had not been watching for it, I don't think I would have noticed any difference between the MAX and the Next Gen [NG] models. I kept pulling back through stickshaker, then buffet, then elevator feel shift [a function that doubles the artificial control feel forces near stall] and finally until the yoke was buried in my lap. The nose just flopped down gently at the stall and I initiated recovery as I would in most other airplanes I've flown."

During design of the MAX, Boeing added two more leading-edge vortilons [generating vortices over the top of the wing at high AOA] in 2018, for a total of six per side, and also lengthened and raised the inboard leading-edge stall strips to assure stall behavior would be as docile as that of the NG.

Repeating many of the same maneuvers in the engineering cab simulator with the new software load would have been academic at best, as the triple-redundant AOA validity checks all but assure that the MCAS will not be triggered by erroneous AOA inputs in the future. But FCC P12.1 changes do not protect against erroneous AOA causing stickshaker or large-scale distortions in indicated airspeed and altitude values. Those malfunctions still can cause distraction and disorientation, especially when flying at night and/or in instrument conditions.

The new MCAS protections built into the P12.1 software load preserve its essential role in enhancing the MAX's longitudinal stability, while virtually guaranteeing that it will not be triggered by erroneous AOA. And when it does activate, its nose-down stabilizer trim command authority will be limited to assure the pilots always can control aircraft pitch with the elevators.

However, the FCC software upgrades are not the only critical changes needed to boost safety margins for operators. Pilots who underwent the demonstration also say the sessions underscored the need for additional simulator training for dealing with compound emergencies involving AOA and runaway trim failures.

737 MAX Crisis Raises Questions About NMA Timing and Definition

> GROUNDING AFTERMATH DELAYS BOEING NMA CUSTOMER TALKS

> MAX REPLACEMENT WILL BE NEEDED SOONER, ANALYSTS SAY

Jens Flottau Frankfurt

The MAX crisis is affecting Boeing in myriad ways. Most important, 346 lives were lost in the two recent 737-8 accidents. As a consequence, the company's approach to aircraft development and safety is being publicly scrutinized, leading it to establish an internal review board concerning its processes.

Boeing's public image is tarnished beyond anything seen in recent memory. Because of the global grounding, it cannot deliver its highest-volume product. The financial and industrial impact will be painful now that it has cut its production rate. But the crisis is also reviving a debate about the proposed new midmarket airplane (NMA).

Before the March 10 crash of Ethiopian Airlines Flight 302, Boeing was widely expected to seek authority to offer the NMA to airlines soon and to use the Paris Air Show in June to present more details of its latest project, planned to be positioned between the traditional narrowbody and widebody segments.

However, some industry observers believe a change in course is now imperative. "The cold commercial reality is that an already pressing need to replace MAX soon has now become all but unavoidable," writes Nick Cunningham, managing partner and analyst at London-based A&D research company Agency Partners. He believes the NMA as currently planned would be the wrong aircraft for the job.

Vertical Research Partners analyst Rob Stallard is raising questions as well. "A number of investors are starting to consider longer-term, strategic issues," he says. "For example, does this push back Boeing's plans for another 737 rate increase and the launch of the NMA? And does this in turn bring forward a next-gen Boeing narrowbody?"

Cunningham maintains that, unrelated to the accidents, the MAX loss of market share against the Airbus A320neo has worsened recently "and is now unrecoverable." Boeing lost most of that share at the top end of the narrowbody segment. "[That is] driven by the technical inadequacies of the 737 MAX—it is low to the ground, so it has a smaller fan, thus less power and worse fuel economy than the Neo," he says.

The way the engines have been installed on the MAX wings—forward and more upward—led Boeing to develop the now infamous Maneuvering Characteristics Augmentation System (MCAS), with the aim of bringing MAX flying characteristics more in line with the 737 Next Generation. Untimely MCAS activation played an important role in both the Ethiopian and the Oct. 29, 2018, Lion Air accidents.

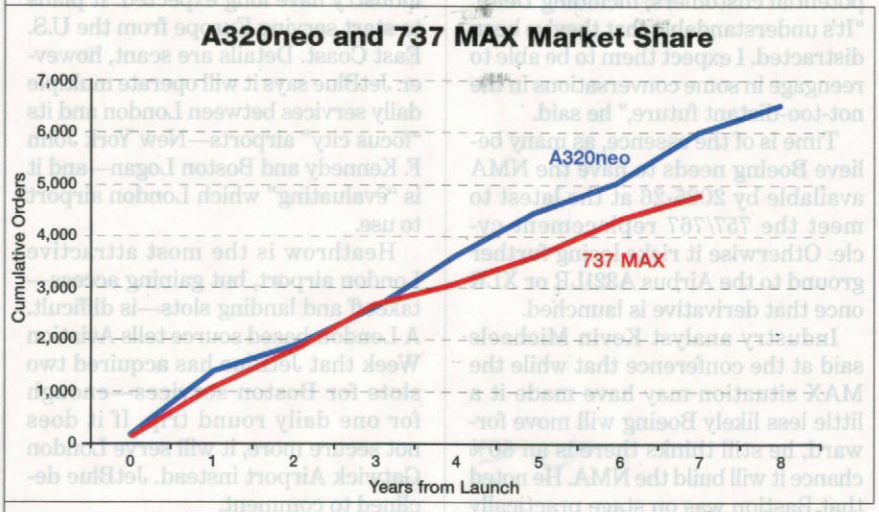
In the short term, the loss of market share that has been visible for some time will likely worsen, given Boeing's decision to cut rates to 42 aircraft a month, from 52. Rates were about to go up to 57 aircraft per month later this year, so by then the gap will be 15 aircraft per month if planned production is not reinstated quickly. Given that high costs are incurred in short-notice rate cuts and recovery is difficult, Cunningham considers Boeing's decision very surprising.

That is unless "Boeing is expecting to deliver fewer MAX aircraft, not temporarily, but permanently," he says. There could be two main reasons for that. First, bringing MAX deliveries back could take longer than originally expected because of lengthy software upgrades, and an exhaustive global certification process in which regional and national airworthiness authorities do not automatically follow the FAA. Second, airlines could be indicating to Boeing that they want fewer of the aircraft.

So far there is little public evidence to support the latter point. Only Garuda Indonesia, Lion Air and possibly Ethiopian have expressed a wish to cancel existing orders. That does not necessarily mean that other carriers will not follow suit.

Here is where NMA definition is key. "We have long suspected that NMA may really be a cover for a much wider program to replace MAX, starting at the top end," Cunningham writes. "It would have been necessary to hide the program because making it public would immediately damage MAX sales. That is now much less of a consideration and was already headed that way, given that long backlogs were already impacting orders." He says worries that orders might be lost to a new aircraft are irrelevant, in the sense that if Boeing delays a MAX replacement orders will be lost anyway.

A 2018 joint Aviation Week-Bank of America Merrill Lynch survey showed that a large number of airlines want an aircraft that looks like a 737 replacement, not the larger, more capable NMA concept Boeing has pursued so far. They did like the idea of a small widebody, though, which is seen



Source: Agency Partners

as efficient for quick turnarounds in hub-feeding roles.

But others are not so convinced the concept is about to change. And there are still NMA fans, particularly among carriers such as Delta Air Lines that have to replace many 757s and 767s in the coming years. Delta CEO Ed Bastian said at Aviation Week's MRO Americas conference in early April that an appropriately designed product remains high on Delta's wish list. "We are very interested in the NMA and have talked to Boeing at some length," he said. "We've given Boeing our expectations. You can rest assured we are spending time in Seattle talking about that."

However, Boeing's focus on the MAX crisis has diverted attention from the NMA, Bastian confirmed, leading to a slowdown in dialog with potential customers, including Delta. "It's understandable that they've been distracted. I expect them to be able to reengage in some conversations in the not-too-distant future," he said.

Time is of the essence, as many believe Boeing needs to have the NMA available by 2025-26 at the latest to meet the 757/767 replacement cycle. Otherwise it risks losing further ground to the Airbus A321LR or XLR once that derivative is launched.

Industry analyst Kevin Michaels said at the conference that while the MAX situation may have made it a little less likely Boeing will move forward, he still thinks there is an 80% chance it will build the NMA. He noted that Bastion was on stage practically begging for a new aircraft.

Canaccord Genuity analyst Ken Herbert said at MRO Americas that "it is difficult to determine what impact this will have on the NMA, or even the [KC-46A tanker]." Ongoing issues with the U.S. Air Force's acceptance of the tanker have been overshadowed by the MAX grounding. "But to us it sounds like the NMA decisions are slipping to the right," he says, adding: "I would not be surprised to see eventual changes at [Boeing Commercial Aircraft] management once the MAX is successfully returned to service, but this will likely come much later." A change in management now would only create more uncertainty around future product strategy.

—With Michael Bruno, Sean Broderick and Joe Anselmo in Atlanta

JetBlue's London Plans Advance Its Mint Strategy

> JETBLUE PLANS TO SERVE LONDON IN 2021

> FLIGHTS WILL BE WITH AIRBUS A321LRs

Sean Broderick Washington

JetBlue Airways' plans to enter the highly competitive transatlantic market in 2021 represent a new chapter for the 19-year-old airline, but it is not a completely unfamiliar one. Judging by the success of its U.S. transcontinental market-focused Mint offering, betting against the carrier's success would be unwise.

The New York-based airline on April 10 confirmed what many in the industry have long expected: It plans to start serving Europe from the U.S. East Coast. Details are scant, however. JetBlue says it will operate multiple daily services between London and its "focus city" airports—New York John F. Kennedy and Boston Logan—and it is "evaluating" which London airport to use.

Heathrow is the most attractive London airport, but gaining access—takeoff and landing slots—is difficult. A London-based source tells Aviation Week that JetBlue has acquired two slots for Boston services—enough for one daily round trip. If it does not secure more, it will serve London Gatwick Airport instead. JetBlue declined to comment.

The routes will be flown by Airbus A321LRs, which the airline will acquire by converting 13 of its 85 outstanding A321neo orders. The A321LRs, which will become an ETOPS subfleet, will be configured with a revamped version of its highly successful Mint two-class product, which JetBlue created for high-demand transcontinental routes and has expanded to other markets. The carrier's 35 Mint-configured A321s have 159 seats, including 16 lie-flat premium seats. The A321LRs will have more than 16 premium seats, JetBlue says.

With JetBlue's London launch still two years off, accurately gauging the market it will face is challenging. A Bernstein Research analysis notes that the largest threat may be to low-cost, long-haul operator Norwegian, which is shifting from a rapid-growth strategy—it launched 35 new routes in 2018, many connecting the Europe and the U.S.—to one focused on making money. The change has led to cost cutting, including scrapping some U.S.-Europe routes.

While changes are inevitable, it is a safe bet that JetBlue's primary London competition will be the joint venture linking British Airways, American Airlines, Finnair and Iberia, and a similar cooperation between Air France-KLM, Virgin Atlantic and Delta Air Lines. The two groups control 70% of transatlantic seats between Europe and North America, Bernstein calculates, and 75% of business-class seats. Looking at routes between London and the two U.S. cities JetBlue is targeting, the concentrations are even higher: 80% for transatlantic seats and 88% for business class.

Looking at the big picture, JetBlue's capacity additions, assuming twice-daily frequencies in each market, will be minimal. Bernstein's analysis shows the carrier will boost daily seats less than 3% and will add about 2% to business-class inventory. Filling them with U.S. passengers figures to be less challenging than selling to European customers. JetBlue's brand is strong in the U.S., and the joint ventures have the advantage of tailoring their marketing to the brand that makes the most sense geographically while offering each partnership's entire package.

"In the joint ventures, each airline markets the entirety of the joint venture in its home markets," Bernstein says. "While JetBlue will have a sales presence and established corporate contracts in the U.S., building those in Europe . . . will be tough."

Delta and Virgin Atlantic, already well-established between London Heathrow and both New York Kennedy and Boston Logan, intend to make it even tougher. The partners announced plans to add flights from both U.S. airports and London Gatwick, which Delta has not served in nearly a decade. The flights will start in 2020.