# Rational Accidents

## Reckoning with Catastrophic Technologies

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# 11 INCENTIVES IN ACTION: ON DEFICIENT 737s AND NEGLECTED SURVIVABILITY

> When it comes to profit over safety, profit usually wins.
> —James Frazee

## 11.1 BAD PRACTICES?

### A CONTROVERSIAL NOTION

Type "civil aviation news" into your preferred search engine and, on most days at least, the results will amply testify to the fact that the industry's safety practices are far from being above reproach. Not all reporting is well informed, of course, and not all reproach is fair, but US civil aviation has no shortage of credible critics. Ralph Nader, the crusading safety advocate and four-time presidential candidate, for example, has painted the industry as deficient in its commitment to safety (Nader and Smith 1994; Bruce and Draper 1970). So has Mary Schiavo, a former inspector general of the US Department of Transportation, who all but dedicated her retirement to excoriating the FAA for what she sees as dangerous negligence (Schiavo 1997). Such criticism poses a problem for the argument of chapter 10, in that it seems to contradict the claim that structural incentives lead airframers to prioritize long-term safety of their own accord. As with the claim about design stability, therefore, it is again worth pausing, briefly, to explore and substantiate this claim in more detail before moving forward with the wider argument.

To this end, this chapter will discuss two prominent test cases, both of which, in different ways, appear to challenge the argument that the industry is driven by economic incentives to pursue safety. Section 11.2 will look at the manifest failings around the Boeing 737-MAX; examining what the accidents suggest about the airframer's choices. The MAX's shortcomings clearly illustrate the powerlessness of regulators, I will argue, but they have more ambiguous implications for the industry's relationship to economic incentives. Section 11.3 will look at the industry's troubled relationship with crash-survivability measures, which are intended to make accidents less fatal. Interpreted properly, I will argue, the relationship offers much more straightforward and compelling evidence that economic incentives have shaped the industry's safety choices. As with the MAX, moreover, the story of crash survivability speaks to the difficulties that regulators face in policing jetliner designs, evidencing both the fact of those difficulties and their causes.

Much as the stories of Concorde and advanced composites in chapter 8 helped illustrate and substantiate the industry's commitment to keeping airframe designs stable, so the stories that follow shed light on its willingness (and the limits of that willingness) to prioritize long-term reliability over short-term profits.

Let us turn first, then, to the 737-MAX.

## 11.2 COMPROMISED BY DESIGN

### TWO DISASTERS

In October 2018, thirteen minutes after leaving Jakarta, LionAir Flight 610, a new variant of Boeing's venerable 737—the 737-MAX—began climbing and diving erratically until it eventually plummeted into the Java Sea, with the loss of all 189 passengers and crew. A preliminary report into the accident by Indonesian authorities pointed to mechanical issues with the airframe, but Boeing, which had introduced the MAX only the previous year, vigorously contested this finding. It offered a competing account that exculpated the airframe and focused instead on factors relating to maintenance and airline operations. Boeing's account assuaged the fears of global aviation authorities, which allowed the MAX to continue operating unhindered. At least, they did until almost five months later, in March 2019, when a second MAX—Ethiopian Airlines Flight 302—crashed under eerily similar circumstances. Soon after leaving Addis Ababa, the plane's altitude began fluctuating wildly until, six minutes after takeoff, it struck the ground at almost 700 miles per hour, again with the loss of all on board (Nicas and Creswell 2019; KNKT

2018). Global aviation authorities grounded the MAX after the second accident, and in the months that followed, there emerged a broad consensus that the airframe was at fault after all.

The primary cause of both accidents was determined to be the airplane's computerized flight controls. More specifically, the crashes were found to have been instigated by a system called the Maneuvering Characteristics Augmentation System—invariably referred to as "MCAS."

Boeing had developed MCAS specifically for the MAX in order to alter the airplane's flight behavior. As a variant of the 737, the company had designed the MAX to be a near-replica of the original, type-certified incarnation of that airframe: identical in every way except in the narrow areas where it was intended to differ. (The hardware running its flight software was decades old, for instance, and it even eschewed fly-by-wire to retain the original's hydraulic cables [Nicas and Creswell 2019; Ostrower 2011; Nicas et al. 2019]). But one way in which the MAX was intended to differ from preceding 737 variants was that it would employ larger, high-bypass engines. Earlier 737 variants had been too low to accommodate newer, more efficient, engines, so Boeing had made room for them on the MAX by slightly lengthening the front landing gear and, importantly, by moving the engines forward on the wing.

Moving the engines forward, however, had complex ramifications for the airplane and its economics. It altered the airplane's flight characteristics, giving it a tendency to pitch up more when climbing. This was not necessarily hazardous in itself, but it threatened Boeing's characterization of the MAX as a changed version of the already-certified 737, which created a problem. If the MAX flew differently from the rest of the 737 family, then there was a danger that regulators would subject it to significantly greater oversight requirements and demand that its pilots be extensively retrained, both of which would raise the MAX's costs and thereby lower its competitiveness. Hence MCAS: a suite of digital flight controls that were intended to make the MAX the same as the rest of the 737 family, but inadvertently created catastrophic differences.

The two MAX accidents were caused when faulty—and, notably, not redundant[1]—Angle of Attack (AOA) indicators communicated the wrong pitch information to MCAS. In both cases, this led the computer to keep pushing the airplane into a dive, repeatedly overriding its pilots, who struggled against their aircraft in confusion, and ultimately in vain (Nicas and Creswell 2019; KNKT 2018).

## EXEMPLARY FAILURES

In many ways, the MAX disasters illustrate the arguments and themes outlined in previous chapters. They exemplify the importance of redundancy, for example, and the complex interpretations involved in implementing it. (The decision not to make the AOA indicators redundant, for example, was justified on the judgment that the pilots could be considered an acceptable backup [Nicas et al. 2019; Nicas and Creswell 2019]). They also exemplify the difficulties that arise from the problem of relevance, as well as how those difficulties can contribute to accidents. (The flight simulators used for training MAX pilots failed to adequately reproduce MCAS behavior, for instance, and flight tests of the airframe were conducted within a normal operating envelope, which did not reproduce the AOA failure [Nicas et al. 2019].) More broadly, they exemplify the difficultly of judging the significance of design changes when making safety determinations, as well as the powerlessness—or perhaps unwillingness—of regulators to effectively police those determinations (Nicas et al. 2019; Tkacik 2019; Mihm 2019; Robison and Newkirk 2019). For whatever reason—be it captured regulators, the limitations of tests, or something else—a dangerous design flaw evaded the certification process.

Beyond this, the MAX disasters exemplify the dangers of innovation in civil aviation and the costs that can accrue to airframers that pursue it incautiously. For the first time in decades, two jetliners failed catastrophically because of a common design weakness that arguably might have been avoidable, or, at minimum, should have been correctable after the first failure. As such, Boeing committed the cardinal sin of civil aviation, and it is paying a steep price for its transgression.

It will probably be a long time before we can say with any authority how much the crisis will ultimately cost the company, but it is already an onerous price. Shortly after the second accident, the MAX was grounded by regulators across the world, instantly shuttering almost 400 recently delivered jetliners until they could be reengineered and recertified (which the FAA eventually approved in November 2020, and EASA approved in January 2021). This had far-reaching financial repercussions for Boeing (Kitroefff and Gelles 2019). In January 2020, the company reported that the crisis would cost it at least \$18.7 billion, a figure that included \$8.3 billion in compensation to airlines and \$6.3 billion in increased manufacturing costs (Isidore 2020b). This was a best-case scenario, however, and was premised on the airplane returning to operation in the middle of that year, which did not happen. That figure also excluded litigation costs, the scope of which became apparent in January 2021, when Boeing agreed to pay an additional $2.5 billion in penalties and damages after being charged with fraud for concealing information from safety regulators (DoJ 2021).

As with the Comet and DC-10, moreover, the most serious financial repercussions arising from the MAX are likely to come long after the accidents, in the form of reputational damage and lost sales. Early into the crisis Boeing launched a major publicity offensive to offset such damage, but its reputation and that of the airframe both clearly suffered, with many analysts reporting declining customer confidence. In February 2020, for instance, Boeing's internal research was indicating that 40 percent of travelers would be unwilling to fly on the MAX when it reentered service (Gelles 2019). "Our passengers are nervous," one anonymous airline executive told a journalist, adding that "the expectation is that we will not resume flying the MAX until the industry is satisfied with the fix. But that's going to take time, and that will be damaging for us in the long run as a Boeing 737 MAX customer trying to operate as a competitive airline" (Macheras 2019). Airlines could not ignore such concerns, and by 2020 the 737 program, which once accounted for about 40 percent of the company's earnings, was in serious peril (Topham 2020; Gelles 2019; Isidore 2020b, 2019; Macheras 2019; Mihm 2019; Robison and Newkirk 2019; Nicas and Creswell 2019). There is also good evidence that the crisis significantly affected orders for the next jetliner that Boeing planned to build: the airplane's naming and introduction being delayed while Airbus's rival for the same market segment—the A321-neo XLR—enjoyed strong sales (Isidore 2020b).

Boeing is better positioned to weather this storm today than it would have been a few decades ago, for reasons I will explore, but the accidents will undoubtedly cost the company and its shareholders dearly. In this, therefore, the MAX crisis reaffirms the previous chapter's argument that it is never economically rational for airframers to risk accidents caused by design weaknesses. In supporting that argument, however, the crisis also appears to undermine the subsequent argument: that economic rationality incentivizes airframers to prioritize reliability of their own accord. It is to this tension that we now turn.

## IRRATIONAL BEHAVIORS

It is difficult to deny that the MAX disasters are rooted in real failings and compromises by Boeing. Not all accidents are avoidable, as we have seen, and postaccident reportage reflexively paints routine technical practices as wrongdoing. But even so, the accidents do strongly suggest meaningful organizational shortcomings. Boeing's decision not to link the MCAS system to redundant AOA indicators seems to violate core principles of jetliner architecture, for example, and its disavowal of the first accident does not evince a strong commitment to recursive practice. The impression of organizational failings is bolstered further by a slew of other significant safety issues with the MAX that have come to light since 2019, ranging from foreign object debris in fuel tanks (Isidore 2020a) to previously unreported concerns about insufficient wiring separation (Duffy 2020; Tkacik 2019). There is also good evidence, from internal communications and other sources, that most of these issues were viewed as compromises by many of Boeing's engineers at the time, and that they reflected explicit managerial decisions to prioritize profit over reliability (Tkacik 2019; Nicas et al. 2019; Topham 2020; Useem 2019). (The decision to forgo redundant AOA indicators, for example, was reportedly driven by concerns about triggering costly regulatory scrutiny. By the account of one Boeing engineer, the problem lay with the extra management systems that redundant indicators would have required to manage disagreements, which would have required regulatory attention [Tkacik 2019]).

So what should we make of the claim that airframers are driven by economic incentives to prioritize long-term reliability over short-term profits?

In making sense of Boeing's lapses with the MAX, it is important to understand that, even if it is economically rational for airframers to subordinate short-term profits to long-term reliability, it is not necessarily the case that airframers always and infallibly act rationally. Organizations might not be straightforwardly prone to the kinds of cognitive biases that interest behavioral economists (see Harrington and Downer 2019), but they are not immune to irrationality. All are complex, heterogeneous, and imperfect entities, which, as sociologists have long understood, are eminently capable of acting against their own best interests and incentives (e.g., Cohen et al. 1972). Airframers are no exception in this regard, as the story of McDonnell Douglas testifies. Organizational cultures must constantly be reaffirmed and reinvented as their personnel change, and scholars routinely find that even the most valued safety practices tend to "drift" or "migrate" over time unless they are carefully guarded (e.g., Snook 2000; Rasmussen 1997). Economic incentives have driven the reliability of modern jetliners as much by culling errant airframers that failed to prioritize it as they have by keeping such airframers in line (and that the former mechanism played an important role in the latter).

Insofar as the MAX's flaws reflect design compromises made for near-term economic gain, therefore, then it is very possible that Boeing—so successful for so long—simply lost sight of its incentives. In fact, many long-time observers of the aerospace industry maintain that this is exactly what happened. Tkacik (2019) and Useem (2019), for example, both recount a major culture shift within Boeing in the years preceding the accidents, wherein a proud tradition of prioritizing engineering became subsumed by a culture of corporate managerialism, which prioritized supply-chain efficiency and treated jetliners as a typical commodity. By most accounts, this culture shift began with the company's 1997 takeover of McDonnell Douglas;[2] was exemplified by its 2001 decision to relocate its corporate headquarters from Seattle to Chicago, 1,700 miles away from where it builds its jetliners; and was fiercely resisted by its engineers, who even went on strike to protest the changes (Tkacik 2019; Useem 2019).

In grappling with Boeing's relationship to incentives in this matter, it is also worth noting that the relationship between economics and reliability in civil aviation has itself evolved. It is important not to overstate this. To the extent that the company can be said to have subordinated reliability to short-term profit, then it is almost certainly still true to say that it acted against its own economic interests (witness the outsized costs of the MAX debacle, outlined previously). But the balance of that calculation has undoubtedly shifted in recent years.

The principal cause of this shift is the changing nature of competition. Chapter 10 argued that one of the conditions that has long underpinned the extreme reliability of jetliners was a competitive market that makes airframers extremely vulnerable to reputational damage. Yet the exposure of airframers to market competition has diminished significantly in recent decades. There are two basic reasons for this. One is that decades of consolidation and competition have winnowed the industry to the point where there are now far fewer competitive airframers than there were thirty or forty years ago. Really, there are just two in the wide-body market—Airbus and Boeing—both of which are protected from bankruptcy by the fact that they are increasingly seen as vital regional assets. The other is that maintenance and training considerations have increasingly locked airlines into exclusive relationships with one of those airframers (Chokshi 2020). In combination, these trends have meaningfully reduced the market's tendency to severely punish airframers for unreliability. Insofar as Boeing is weathering the MAX crisis, for instance, it is largely because most of its customers have strong incentives to stay with the company for reasons pertaining to maintenance and training arrangements, and because the market understands that the US federal government is unlikely to allow Boeing to go bankrupt.

In this respect, therefore, the MAX accidents might best be understood as the exception that tests the rule. They still testify to the fact that airframers are economically incentivized to prioritize reliability over short-term profits, even if they also remind us of the imperfect sway that those incentives exert on airframers' decision-making.

The industry's long-term economic incentives aren't infallibly determinative of its safety choices, therefore, but they still usually prevail. And should we be tempted to doubt this, the industry's relationship with crash survivability reaffirms the point.

## 11.3 CRASH SURVIVABILITY

### LOST SURVIVORS

In her 2014 farewell speech at the National Press Club, Deborah Hersman, the departing chair of the NTSB, lamented that a "great disappointment" of her ten-year tenure at the agency was that child-safety seats were yet to be required on commercial jetliners (Jansen 2014). The NTSB investigates US aviation accidents to determine their causes, but when it comes to remedial action, the agency only has the power to make recommendations. Under Hersman, it had repeatedly appealed the FAA to mandate that airlines carry child-safety seats, with its experts believing that the measure would save lives. It was not alone in this view. Demands for such seats had been gathering steam for decades, drawing in a wide range of safety advocates. "Every single thing on [an] airplane, down to the coffee pots, are required to be properly restrained except children under the age of two," the president of the Association of Flight Attendants, Patricia Friend, told the *New York Times* in 2010, adding, "It's just physically impossible, no matter how much a parent loves that child, given deceleration forces of an aircraft in a crash, to hold onto that child" (Higgins 2010). By broad assent, however, the regulator had repeatedly stalled on the issue.

The frustration of safety advocates over child-safety seats is interesting because it is illustrative of a much broader set of tensions around crash survivability (sometimes referred to as "crashworthiness" or simply "survivability") in civil aviation. There is an old adage, usually credited to the American baseball player "Satchel" Paige, that "airplanes may kill you, but they ain't likely to hurt you." The line is intuitive but misinformed. Jetliner crashes involve attempted landings or aborted takeoffs far more often than catastrophic explosions or meteoric plummets, and, as a result, most have injuries and survivors. Contrary to Paige's aphorism, in fact, airplanes are considerably more likely to hurt you than to kill you. Of 53,000 people involved in accidents involving US air carriers between 1983 and 2000, 51,207 of them—96.6 percent—survived (Fiorino 2009).

Of accidents that do produce casualties, moreover, studies have found that upward of 80 percent are potentially "survivable," in the sense that "the crash impact does not exceed human tolerances" (NAS 1980, 9; see also Fiorino 2009; Shanahan 2004; FAA 2016; ETSC 1996). In these accidents, the majority of the fatalities often result from potentially mitigable hazards: evacuation delays, unrestrained impacts, smoke inhalation, fires, cabin missiles, and other incidents. In principle at least, each of these fatalities represents a life that might have been saved if jetliners been designed differently.

It is in this counterfactual pool of "lost survivors"—individuals who might have lived but did not—that critics looking for shortcomings or scandals in civil airframe design and regulation have found their most tractable arguments. As we have seen, the aviation industry will go to impressive lengths to reduce the likelihood of a catastrophic accident even marginally, and yet it often seems far less proactive in its efforts to mitigate the human costs of accidents. Relative to reliability at least, survivability does not appear to be a priority for modern civil aviation.

## SAFETY SECOND

As with the claim that Boeing cut corners on the MAX, the claim that civil airframers often fail to prioritize survivability over profit is difficult to deny. FAA-funded studies have concluded that airframers are often unwilling spend more than the minimum required when it comes to survivability measures, even if very modest increases of expenditure promise substantial safety benefits (e.g., Cannon and Zimmermann 1985, 60).

It is true that modern jetliners are, to some extent, designed for survivability. Cabin interiors, for example, are configured to allow passengers to evacuate inside ninety seconds with minimum illumination and half the usable exits blocked. Fuselage doors are designed to open in conditions of extreme icing. Furnishings are designed to be fire resistant. Emergency slides double as life rafts. Seats are equipped with flotation devices and quick-release lap belts and are rigged to withstand strong dynamic forces. Most of these features came relatively late to jetliners, however, and often only after protracted struggles that pitted safety advocates like the NTSB against airframers, operators, and, in many cases, the FAA itself (Anderson 2011; Saba 1983; Bruce and Draper 1970; Nader and Smith 1994; Weir 2000; Perrow 1999).

Examples of these struggles around survivability abound. Perrow (1999, 163–164), for instance, describes a long-running fight to mandate that cabin address systems be equipped with backup power so that the crew can still instruct passengers if the electrical system is damaged. By his account, a series of fatal accidents involving failed address systems and delayed evacuations led to a decade-long lobbying effort by the NTSB to have the FAA require retrofits, each estimated to cost between $500 and $5,000 per aircraft. He tells a similar story about the structural integrity of cabin furnishings, arguing that regulators and manufacturers rebuffed clamorous concerns about outdated and inadequate impact standards for years, while accidents repeatedly tore seats from fuselages (Perrow 1999, 164–165; see also Saba 1983).

Rules governing the flammability of cabin furnishings became a particularly chronic source of contention, with safety advocates pitted against regulators and manufacturers. Three out of four people who died in “survivable” crashes in the years leading up to 2004 were killed by fire, smoke, or toxic fumes (Nader and Smith 1994). A major factor in these deaths was that cabin interiors were full of synthetic materials that, when heated, produced deadly and disorienting gases, such as phosgene and hydrogen cyanide. Alternative materials with reduced fire toxicity were available, but they were slightly heavier and more expensive, so manufacturers resisted efforts to mandate their use (Weir 2000; Perrow 1999). The FAA began studying aviation combustion toxicology in 1972, on the recommendation of the NTSB, and quickly came to the conclusion that cabin materials were producing toxic fumes.[3] However, it wasn't until 2008—a full thirty-six years later—that the regulator issued its first mandatory guidance on passenger cabin smoke protection (FAA 2008b).

These past fights over what became modern survivability standards are echoed today in numerous ongoing struggles. The contest over child-safety seat is a good example, but there are many other measures that safety advocates would like to see implemented. Aft-facing seats are among them. Decades of research has found that reversing the orientation of passenger seats would significantly reduce impact fatalities (FAA 2016; ETSC 1996; Snyder 1982; Cannon and Zimmermann 1985). (This is why military transport vehicles have seats in this configuration.) There are also calls for increasing the seat pitch and equipping cabins with passenger airbags and three-point seatbelts, all of which, it is argued, would reduce impact fatalities (Klesius 2009; Smith 2013). Fires, too, remain a prominent concern. Some safety advocates have lobbied for rules requiring that highly flammable oxygen canisters to be stored below cabin floors, where they would be better protected (Weir 2000, 85). Others have lobbied for jetliners to be equipped with smoke hoods (which have been compulsory on the FAA's own aircraft since 1967, and on most corporate jets and US military transport aircraft since the mid-1990s) (Weir 2000; ETSC 1996); and, to a lesser extent, for cabins to be fitted with sprinkler systems. There are even experts pushing for the use of low-flammability fuels, such as anti-misting kerosene or high-flashpoint kerosene (JP5/AVCAT), which are designed to limit fires and explosions in the event of an accident (Collins 1988; Collins and Pinch 1998; Weir 2000; ETSC 1996). All these measures would have saved lives in the past, but none looks likely to be implemented in the near future.

## REGULATION AND FINITISM

Much as with the 737-MAX, the industry's relationship to crash survivability appears to exemplify the claim that regulators are unable to police airframes effectively. In directly pitting the financial interests of airframers against the safety interests of the flying public, survivability measures should be an ideal candidate for regulatory intervention. It is notable, therefore, that in this context, regulators frequently find themselves at odds with safety advocates.

The frequent tensions between the NTSB and the FAA on matters pertaining to survivability speak revealingly to how the inherent ambiguities of engineering knowledge shape the regulator's relationship with the industry it oversees. Examined closely, these tensions do not suggest that the regulator is *unwilling* to defy airframers, so much as that it is often *unable* to do so. It may have taken the FAA decades to implement new fire toxicity regulations, for example, but over that period, it proposed numerous such rules, only to be forced to withdraw them when the industry contested its findings, pointing to uncertainties in the FAA's tests and demanding further studies (Smith 1981; Weir 2000; Perrow 1999).[4]

The uncertainties that airframers invoked to undermine the FAA's proposals were never indefensible, but this is the point. As we have seen, technological investigations—tests, models—always harbor defensible uncertainties, and determining the facts behind a technical question always requires interpretive work: a willingness to accommodate unanswered questions and overrule dissenting voices. Whenever airframers oppose an FAA technical ruling, therefore, they can always point to uncertainty to call for delay and further study. (This is a common tactic of powerful actors eager to maintain the status quo in a wide range of domains [see, e.g., Proctor 1991; Oreskes and Conway 2010].) And the regulator—beholden to a misleading but deeply institutionalized notion of technological positivism, which promises definitive answers to technological questions—is poorly able to deny such calls.

A parallel dynamic echoes in the stories of many other crash-survivability measures, with airframers frequently contesting the FAA's test results and demanding that regulation be postponed until further research has been done. The introduction of independently powered cabin warnings, for example, was delayed by controversies that lasted through the 1970s and into the 1980s (Perrow 1999, 164). The introduction of new standards for seat load factors came after an even longer period of debate: decades of disputed research that, by the 1980s, had the NTSB publicly questioning whether the FAA would ever accept the representativeness of its own test data (Perrow 1999, 165). This dynamic is even more evident in the stories of the many putative survivability measures that died in the laboratory, mired in perennially contested experiments. Studies of cabin sprinkler systems, for example, ran into complex questions about the dangers of steam (Weir 2000, 90). Studies of smoke hoods devolved into protracted debates about the validity of cabin evacuation tests (ETSC 1996; Weir 2000; Flight Safety Foundation 1994). Studies of aft-facing seating became bogged down in questions about impact dangers from underseat luggage (Cannon and Zimmermann 1985, 6). And studies of anti-misting kerosene were largely derailed by debates about engine flameouts (ETSC 1996, 26).

Not all of these debates were wholly unwarranted, of course, and it is likely that some of the measures that died on drawing boards did so for good reasons, but collectively these stories paint a compelling picture of obstruction. (To quote one British accident investigator's candid take on survivability regulations: "The whole point of . . . commissioning research is to kick the issue into touch for a couple of years. Then the research comes back and they say the costs outweigh the benefits. By then, everybody has moved on and forgotten about the . . . original crash in the first place. It is a deliberate tactic. And it works." [Weir 2000, 98]). After all, the FAA has been able to move relatively quickly in matters pertaining to reliability. New bird-strike regulations, for instance, are routinely passed and revised despite their many unanswered questions. In principle, the industry could exploit the ambiguities of technological practice to delay or rebuff such measures—miring them in controversy, as it does survivability measures—but in practice this rarely happens. The industry treats survivability differently from reliability, in other words. And, as we will see, this distinction speaks convincingly to the primacy of economic incentives in shaping jetliner design decisions.

## SURVIVABILITY AND INCENTIVES

The history of airframers resisting survivability measures does not intuitively fit with every argument of the preceding chapters. This is because, while substantiating the claim that regulators are poorly positioned to police safety, it simultaneously seems to challenge the claim that economic incentives lead the industry to prioritize safety of its own accord. Considered carefully, however, the industry's adversarial relationship to survivability actually lends a lot of support to the idea that long-term economic incentives have underpinned its commitment to reliability.

To understand why this is the case, it helps to recall a distinction introduced in chapter 1, between reliability (defined as the "probability of a technology failing catastrophically") and safety (defined as the "probability of someone dying in a catastrophic technological failure"). Let us then add to this survivability: (defined as the "probability of someone surviving a catastrophic technological failure, should they experience one.") Now, as has been discussed, the terms reliability and safety are routinely conflated in civil aviation, but, by these definitions at least, safety encompasses more than just reliability. Jetliners are certainly safer if they crash less frequently—so more reliability means more safety (which is why the terms are often conflated)—but they are also safer if their crashes are less fatal. A more reliable jetliner might be a safer jetliner, in other words, but so is a more survivable jetliner.

While reliability and survivability both contribute to safety, however, the incentive structures around making jetliners unlikely to crash (reliability) differ markedly from those around making crashes less dangerous (survivability). The previous chapter outlined why the aviation industry is incentivized to pursue reliability. It argued that the industry pays a heavy price for accidents, especially those that can be tied directly to design choices or manufacturing practices. The same cannot be said about safety for its own sake, however, because even if catastrophic failures can cost the industry dearly, those costs do not scale proportionately with the number of deaths that arise from those failures.

For illustration of this disparity, consider that—from a purely legal, economic, or managerial perspective—it makes little material difference to the key institutional actors in civil aviation (airlines, airframers, or even regulators) if an accident incurs 80 fatalities or 280. The legal implications vary little in each case, not least because it is difficult to hold airlines or airframers accountable for not adopting survivability measures that regulators have not mandated. (And it is difficult to challenge regulators in the courts for not mandating specific survivability measures [Flight Safety Foundation 1994, 18]). The direct economic costs are also broadly equivalent in each case, liabilities for individual deaths being difficult to establish and rarely very punitive. As discussed previously, the real economic costs that jetliner accidents inflict on the industry primarily arise from the reputational damage that accidents cause, and history suggests that this damage correlates only loosely with the total number of fatalities. (Partly because any "lost survivors"—who might have been saved—are difficult to measure, so they tend to remain invisible.)

The upshot of this is that survivability measures, unlike reliability measures, are rarely cost effective from an airframer's standpoint, because the economic return on making jetliner accidents less dangerous is far less than on making accidents less frequent. [5] To understand this calculus it helps to recognize that survivability measures can be counterintuitively expensive, as the direct costs of developing, purchasing, and installing them are often overshadowed by indirect costs that are more opaque. Almost all such measures add weight, sometimes in nonobvious ways, which, as we have seen, can have considerable cost implications. (Aft-facing seats and three-point restraints do not weigh much themselves, for example. In the event of an impact, however, both would raise their occupants' center of gravity from the waist toward the shoulder, creating a leverage effect that would rip seats from the cabin floor without stronger, and therefore heavier, fixtures and structures [Cannon and Zimmermann 1985]). Other survivability measures impose costs by taking up valuable space. (Increasing seat pitch would lessen head impacts, for instance, but it would also decrease the number of seats that airframes can accommodate.) Airlines also fear that some measures—such as aft-facing seats or smoke hoods—would deter customers by disrupting their expectations and hinting at unwelcome possibilities (Cannon and Zimmermann 1985, 4; Snyder 1982).

Understood in this context, therefore, the civil aviation industry's reluctance to invest in survivability, as well as its resistance to regulations that would require it to do so, are easy to reconcile with the argument that its safety behavior is primarily guided by medium-term economic incentives. Indeed, the fact that its behavior is difficult to fault when viewed through the lens of reliability but looks rife with mundane institutional pathologies when viewed through the lens of survivability strongly supports this conclusion. The industry vigorously pursues reliability, we might say, because more reliable jetliners save it money, and it aggressively resists survivability because more survivable jetliners cost it money. Nobody would suggest that the individuals who work in civil aviation are indifferent to its human tragedies. But, as we have seen, individual sympathies have limited agency when it comes to shaping organizational behavior. Ultimately, profit drives airframe design decisions more than safety, and airframers have more control over those decisions than regulators do.

## 11.4 POSITIVIST PATHOLOGIES

### MOVING FORWARD

The stories of the 737-MAX and the industry's relationship to survivability are valuable in that they add nuance and substance to the argument that it is economic self-interest—more than rules, regulators, or good intentions—that polices the designs of modern jetliners. Both cleanly illustrate regulators' inability to effectively police jetliner designs, for example, and both, in different ways, speak to how economic imperatives act on airframers.

In this latter regard, the MAX is a cautionary tale that warns against simple narratives. It illustrates the pressure that competition exerts on technological decision-making, even when experienced organizations like Boeing are making choices about heavily regulated artifacts like jetliners. It demonstrates how that pressure can shape design deliberations, as well as the dangers that can arise from this dynamic. Ultimately, however, it shows why it is still a false economy for airframers to give in to these short-term incentives, even if their managers sometimes lose sight of this fact.

The industry's relationship to survivability, in turn, illustrates that the industry largely understands its incentives. Counterintuitively, perhaps, the resistance to making accidents more survivable speaks compellingly to the fact that economic incentives play a key role in shaping its design decisions. For how better to reconcile the great costs that airframers will shoulder in their efforts to make accidents less likely, on one hand, with their palpable reluctance to invest in making accidents less fatal, on the other, than by understanding that the incentives around these endeavors pull in opposite directions.

Note that examining these stories from this finitist, structuralist perspective offers insights that would not be apparent if they are viewed through a more conventional lens, wherein aviation safety is construed as governed by assessments and policed by regulators. Understood in this way, for example, the MAX crashes raise questions about the changing landscape of aviation economics. It suggests how decreasing competition in the industry, together with airlines' close relationships with specific airframers and Boeing's emergent status as "too important to fail," might all have underappreciated implications for future passenger safety (because they change the economic incentives around reliability). Survivability debates are similarly reconfigured. Seen from this perspective, for instance, laments about child-safety seats might be read less as a regulatory failing than as a reflection, again, of the incentive structures that shape the industry.

These insights, in turn, speak to ways in which the conventional, positivist understanding of aviation safety might itself be a source of danger. As we have seen in this discussion, for instance, the understanding that airframe designs are governed by rules and assessments hides the importance of structural incentives from the policymakers who police those incentives. Or take the industry's problematic relationship to survivability. One of the reasons why regulators and advocates have repeatedly struggled to force the industry's hand in this area is the pervasive but misleading idea that engineering tests should yield objective, definitive, and unambiguous results. Absent this positivist promise of certainty, endless appeals for "further study" to dispel lingering uncertainties would be less effective as a means of delaying or derailing proposed regulatory actions.

Civil aviation's hesitance over survivability has been broadly tolerable over the years because the industry's incentivized commitment to reliability has kept the absolute number of accidents so low: the rarity of plane crashes making the issue of surviving them less pressing. The fact that policymakers might be underappreciating the importance of competition is potentially more consequential, however. And, as we have seen, jetliners have some unique properties relative to other catastrophic technologies.

With that in mind, therefore, let us consider what other pathologies might arise from positivist misconceptions of engineering practice in civil aviation and beyond.

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