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Technological Solutions to Human Error and How They Can Kill You: Understanding the Boeing 737 Max Products Liability Litigation

W. Bradley Wendel
Cornell University Law School

TECHNOLOGICAL SOLUTIONS TO HUMAN ERROR AND HOW THEY CAN KILL YOU: UNDERSTANDING THE BOEING 737 MAX PRODUCTS LIABILITY LITIGATION

W. Bradley Wendel*

I. INTRODUCTION

TECHNOLOGY OFTEN promises increased safety in the form of reduction of human errors. One of the major arguments for the move to semiautonomous and "driverless" cars is the expected significant reduction in road accidents caused by driver carelessness. This evolving technology may be outrunning the development of legal principles that apply to the interaction between sometimes careless users and machines with design features intended to mitigate the risks resulting from human error. Products liability analysis tends to focus either on a product's design or user carelessness.[1] In the context of a product's use, there is a dynamic relationship between technological solutions to risks and human behavior. The attempt to design out a persis-

* Associate Dean for Academic Affairs and Professor of Law, Cornell Law School. The author is grateful for comments from Valerie Hans, Ian Kysel, and Jeff Rachlinski, and to Gily Leshed and David St. George for helpful pointers to some of the major works on human–computer interactions in aviation. Thanks also to participants in a Cornell Law School faculty workshop for helpful comments. He also gratefully acknowledges the research funding provided by the Judge Albert Conway Memorial Fund for Legal Research, established by the William C. and Joyce C. O'Neil Charitable Trust to honor the memory of Judge Conway, Chief Judge of the New York State Court of Appeals from 1954 to 1959, and his son, Hewitt A. Conway, a member of the Cornell Law School Class of 1949. This Article is dedicated to the author's friend, former colleague, and mentor Jim Henderson, who along with Aaron Twerski, is largely responsible for the rigor and elegance of modern products liability law.

[1] *See generally, e.g.*, Kenneth S. Abraham & Robert L. Rabin, *Automated Vehicles and Manufacturer Responsibility for Accidents: A New Legal Regime for a New Era*, 105 Va. L. Rev. 127 (2019). In fairness to Abraham and Rabin's excellent article, they address the liability landscape for manufacturers of fully autonomous vehicles and do not consider the issues relating to human–machine interactions in semiautonomous cars.

tent pattern of accidents caused by human error can lead to a new, perhaps unanticipated, and possibly even more dangerous pattern of accidents caused or exacerbated by the technology. For this reason, it is essential that products liability law proceed from a systems approach, not considering product design and user error in isolation. A systems approach to risk management sees safety as an emergent property resulting from the interaction between users and machines and their environment.[2] It also focuses on the risks associated with latent errors—those made by product designers and engineers seeking to foresee the actions of human users, though sometimes introducing new and unanticipated dangers.[3]

This Article argues that a systems approach to accidents involving technologically advanced products, taking into account the relationship between product design and foreseeable carelessness by users, is essential to ensuring that the law of products liability does not have a negative impact on the underlying goals of this area of law, including the promotion of increased user safety, innovation in product design, and the affordability of useful products. It is not a reformist project, however, because to a significant extent, the modern law of products liability builds in elements of systems thinking. For example, the design-defect standard considers the comparative benefits to product safety of both a potential redesign of the product and the user's ability to avoid the danger by the use of reasonable care. It also takes into account the possibility of providing additional warnings and instructions to users as an alternative to requiring a redesign of the product. Existing doctrines of comparative fault and apportionment of liability recognize that manufacturers and users share responsibility for safety, and that user carelessness may in some cases be a risk that requires the manufacturer to adopt a redesign or provide additional information. In short, the legal

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[2] *See generally, e.g.*, SIDNEY DEKKER, THE FIELD GUIDE TO UNDERSTANDING HUMAN ERROR (2006); DON NORMAN, THE DESIGN OF EVERYDAY THINGS (rev. ed. 2013); CHARLES PERROW, NORMAL ACCIDENTS: LIVING WITH HIGH-RISK TECHNOLOGIES (1984); EDWARD TENNER, WHY THINGS BITE BACK: TECHNOLOGY AND THE REVENGE OF UNINTENDED CONSEQUENCES (1996). The focus here is on systems thinking in the field of accidents and risk reduction. It should not be confused with other systems theories used in legal scholarship. *See generally, e.g.*, Tamara Belinfanti & Lynn Stout, *Contested Visions: The Value of Systems Theory for Corporate Law*, 166 U. PA. L. REV. 579 (2018); Henry E. Smith, *Systems Theory: Emergent Private Law*, *in* OXFORD HANDBOOK OF NEW PRIVATE LAW (Andrew Gold et al. eds., forthcoming 2019).

[3] *See* JAMES REASON, HUMAN ERROR 173–216 (1990).

framework is already well designed to incorporate a systems approach into the analysis of accidents involving interactions of humans and machines, as long as courts and lawyers understand it correctly.

The Article uses, as a case study, two accidents involving a recent variation on a tried-and-true product design—the Boeing 737 Max jetliner. The Max design incorporated a design feature intended to prevent accidents caused by a pernicious observed pattern of human error. When it failed to function as intended, the result was disaster. Should the blame for these accidents be placed on the manufacturer for flaws in the design of what was intended as a safety feature? Or should the flight crews be blamed for failing to handle an anomaly that they were trained to deal with? Although the principal claim of this Article is that products liability law must incorporate systems thinking in order to deal correctly with situations like this, the Article also considers how these accidents should be analyzed under existing law. Addressing an accident allegedly caused by both design and warnings deficiencies and user error requires care with doctrines such as risk–utility balancing, superseding causation, and comparative fault. After explaining the cause of the 737 Max accidents in Section II, the Article explains in Section III how modern products liability law will deal with the litigation against Boeing. Some of the design and warnings claims are relatively straightforward, but others implicate the subtler issues arising out of Boeing's efforts to design technological solutions to stubbornly persistent patterns of flight-crew errors in commercial aviation. Section IV takes up the importance of a systems perspective on risks involving the interaction between fallible humans and the safety features of products intended to protect against human error.

II. THE 737 MAX ACCIDENTS

On October 29, 2018, Lion Air Flight 610 crashed into the Java Sea shortly after departure from Jakarta, Indonesia. Soon after takeoff, the flight crew reported control problems and requested a return to the airport.[4] They finally lost control after struggling for almost ten minutes to resist what seemed to be the

[4] *See* Mika Gröndahl et al., *In 12 Minutes, Everything Went Wrong: How the Pilots of Lion Air Flight 610 Lost Control*, N.Y. TIMES (Dec. 26, 2018), https://www.nytimes.com/interactive/2018/12/26/world/asia/lion-air-crash-12-minutes.html [https://perma.cc/BL6K-GZNT].

airplane's irresistible compulsion to enter a nosedive.[5] Then on March 10, 2019, Ethiopian Airlines Flight 302 went down under very similar circumstances—the flight crew reported a problem with the flight controls, requested a return to the airport, and crashed soon thereafter in a steep nose-down attitude.[6] Both flights were operated by Boeing's 737 Max jetliner.[7] Designed to compete with the fuel-efficient Airbus A320neo,[8] the 737 Max is an incremental change to the ubiquitous 737 NG, itself a reengineered version of a venerable design that first entered airline service in 1968.[9]

Although final accident reports have not yet been released, both accidents almost certainly involve a feature of the 737 Max called Maneuvering Characteristics Augmentation System (MCAS).[10] MCAS is a "flight control law."[11] Modern jetliners, like the 737 and its competitor from Airbus, the A320, do not have strictly direct, unmediated connections between the flight controls and the external control surfaces (ailerons, rudders, elevators, and spoilers). Rather, computers translate control inputs from the crew into movements of the control surfaces. This arrangement is sometimes referred to as "fly by wire," although flight control systems answering to that description vary consid-

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[5] *See* Dominic Gates, *Pilots Struggled Against Boeing's 737 MAX Control System on Doomed Lion Air Flight*, SEATTLE TIMES (Nov. 28, 2018), https://www.seattletimes.com/business/boeing-aerospace/black-box-data-reveals-lion-air-pilots-struggle-against-boeings-737-max-flight-control-system [https://perma.cc/4LM4-EA8N].

[6] *See* Hadra Ahmed et al., *Ethiopian Airlines Pilots Followed Boeing's Safety Procedures Before Crash, Report Shows*, N.Y. TIMES (Apr. 4, 2019), https://www.nytimes.com/2019/04/04/world/asia/ethiopia-crash-boeing.html [https://perma.cc/AB2G-BZ7R].

[7] *See id.*

[8] *See* Jon Ostrower, *The World Pulls the Andon Cord on the 737 Max*, AIR CURRENT (Mar. 12, 2019), https://theaircurrent.com/aviation-safety/the-world-pulls-the-andon-cord-on-the-737-max/ [https://perma.cc/QT3Y-TJ7E].

[9] *See* Jack Nicas & Julie Creswell, *Boeing's 737 Max: 1960s Design, 1990s Computing Power and Paper Manuals*, N.Y. TIMES (Apr. 8, 2019), https://www.nytimes.com/2019/04/08/business/boeing-737-max-.html [https://perma.cc/H9LM-3R3J].

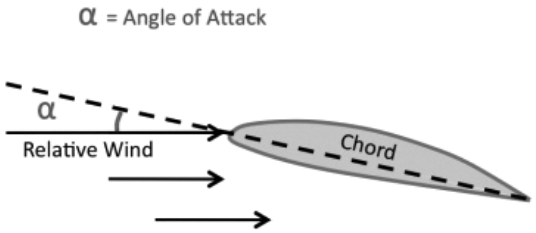
[10] I have tried to keep the use of aviation acronyms and jargon to a minimum, without oversimplifying or distorting the points to be made. Any discussion of the 737 Max design and these accidents is going to require the use of some specialized lingo, such as MCAS and angle of attack, but hopefully the relevance of these details will become apparent in the discussion of the applicable law. I will try to confine the real down-in-the-weeds aeronautics discussions to the footnotes.

[11] Sean Broderick et al., *The Boeing 737 MAX MCAS Explained*, AVIATION WK. & SPACE TECH. (Mar. 20, 2019), https://aviationweek.com/commercial-aviation/boeing-737-max-mcas-explained [https://perma.cc/S3D3-M45W].

erably.[12] Airbus and Boeing aircraft have different flight control laws.[13] The control laws are complex, multilayered, and somewhat counterintuitive on Airbus aircraft, while Boeing's laws more or less correspond to basic, old-school control inputs—pull back on the yoke, the nose points up; push forward on the yoke, the nose points down.[14] However, even on Boeing aircraft, there are a few built-in interventions, designed in for operational or safety reasons, and MCAS is a significant one.[15]

The purpose of MCAS is to prevent an inadvertent aerodynamic stall during certain, relatively unusual flight conditions. To non-pilots, the word "stall" may suggest something wrong with the aircraft's engines. (My children, who are learning to drive stick-shift, frequently stall the car in that sense.) An aerodynamic stall, on the other hand, occurs when the wing exceeds its critical angle of attack. Angle of attack (AOA) is the angle between the chord line (the straight line connecting the leading and trailing edges of the wing) and the relative wind.[16]

Figure 1



Exceeding the critical angle of attack causes the airflow around the wing to separate and create such an excess of drag over lift that the wing can no longer function to keep the airplane on the desired flight path. The result is a loss of control if

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[12] *See* Mac McClellan, *Can Boeing Trust Pilots?*, AIR FACTS (Mar. 11, 2019), https://airfactsjournal.com/2019/03/can-boeing-trust-pilots [https://perma.cc/YZ6X-DT2J].

[13] *See, e.g.*, Brian Palmer, *Boeing vs. Airbus*, SLATE (July 11, 2011), https://slate.com/news-and-politics/2011/07/do-pilots-have-a-preference-between-boeing-and-airbus.html [https://perma.cc/S3D3-M45W].

[14] *See id.*

[15] Yaw damping to prevent Dutch roll is a more familiar intervention in the flight control system and is part of every modern jetliner. *See* Bjorn Fehrm, *Boeing's Automatic Trim for the 737 MAX Was Not Disclosed to the Pilots*, LEEHAM NEWS (Nov. 14, 2018), https://leehamnews.com/2018/11/14/boeings-automatic-trim-for-the-737-max-was-not-disclosed-to-the-pilots [https://perma.cc/43TN-UWG9]. Leeham News is a respected aviation industry blog.

[16] *See* H.H. HURT, JR., AERODYNAMICS FOR NAVAL AVIATORS 22 (rev. ed. 1965).

the incipient stall is not corrected. AOA is not the same as deck angle, which is the angle between the longitudinal axis of the airplane and the ground. As every aeronautical textbook will tell you, an airplane can stall at any flight attitude—what matters is AOA.[17] Importantly, while every wing has a constant critical AOA, the wing will stall at different airspeeds depending on the weight of the aircraft, the load on the wings, the use of flaps, and other factors.[18] Pilots of most civilian aircraft use airspeed as a rough proxy for AOA because the latter parameter is not displayed directly, but strictly speaking, it is incorrect to talk about a wing stalling at a particular airspeed.[19]

Although not stalling is pretty much the most basic task in flying, several recent airline accidents involved the failure of the flight crew to recognize and recover from an inadvertent stall. Most prominently, the crash of Air France Flight 447 in the South Atlantic resulted from the flying pilot's incorrect response to a temporary loss of airspeed data and the failure of the three-person crew to recognize that the A330 airliner was descending in a fully developed stall.[20] The crash of Colgan Flight 3407 on arrival to Buffalo, New York, was also caused by a stall—this one resulting from the failure of the crew to add power after leveling off on a descent into the airport with the autopilot set to capture and hold a preset altitude, and the crew's subsequent bungling of what should have been a simple recovery.[21]

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[17] *See, e.g.*, WOLFGANG LANGEWIESCHE, STICK AND RUDDER: AN EXPLANATION OF THE ART OF FLYING 18–24 (1944). I recently experienced a stall in a nearly vertical dive coming out of a loop during aerobatics training.

[18] *See id.* at 18–21.

[19] *See* FED. AVIATION ADMIN., FAA-H-8083-38, AIRPLANE FLYING HANDBOOK 4-2–4-13 (2016), https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/airplane_handbook/media/airplane_flying_handbook.pdf [https://perma.cc/UGS9-QLNQ].

[20] *See* William Langewiesche, *The Human Factor*, VANITY FAIR (Oct. 2014), https://www.vanityfair.com/news/business/2014/10/air-france-flight-447-crash [https://perma.cc/B38D-83WY]. Langewiesche is a pilot and aviation journalist and the son of Wolfgang, the author of STICK AND RUDDER; his article is by far the best popular account of the Air France 447 accident. If it has a weakness, it is that it makes the actions of the flight crew seem utterly inexplicable. For a more technical analysis of the accident, written by an A330 training captain for a U.S. airline, which explains if not excuses the performance of the flight crew, see BILL PALMER, UNDERSTANDING AIR FRANCE 447 (2013). *See also* ROGER RAPOPORT & SHEM MALMQUIST, ANGLE OF ATTACK: AIR FRANCE 447 AND THE FUTURE OF AVIATION SAFETY (2017).

[21] *See generally* NAT'L TRANSP. SAFETY BD., NTSC/AAR-1010, AIRCRAFT ACCIDENT REPORT: LOSS OF CONTROL ON APPROACH, COLGAN AIR, INC. OPERATING AS CONTINENTAL CONNECTION FLIGHT 3407, BOMBARDIER DHC-8-400, N200WQ, CLARENCE

In order to realize the benefit of larger, more fuel-efficient CFM LEAP engines, the 737 Max design situated the engines slightly farther forward and higher as compared with the previous 737 NG.[22] The result of the new engine placement on the Max was that, in conditions of an accelerating, banking flight, an increase in thrust by the flight crew could cause a pitch-up tendency, leading to an angle of attack dangerously close to the critical angle.[23] Boeing could have informed airline customers

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CENTER, NEW YORK, FEBRUARY 12, 2009 (2010), https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1001.pdf [https://perma.cc/YES7-HD9N]. One of the first things an instructor made me do as part of my transition training to a highly automated aircraft is replicate the Colgan 3407 scenario with the autopilot and recover the resulting stall. It is a non-event if done properly.

[22] *See* Jack Nicas et al., *New Evidence in Ethiopian 737 Crash Points to Connection to Earlier Disaster*, N.Y. TIMES (Mar. 15, 2019), https://www.nytimes.com/2019/03/15/business/boeing-ethiopian-crash.html [https://perma.cc/2ET9-WE8B]; Gregory Travis, *How the Boeing 737 Max Disaster Looks to a Software Developer*, IEEE SPECTRUM (Apr. 18, 2019), https://spectrum.ieee.org/aerospace/aviation/how-the-boeing-737-max-disaster-looks-to-a-software-developer [https://perma.cc/J7PG-6DHB]. "NG" stands for "Next Generation" and includes the 737-600, -700, -800, and -900 series aircraft. If you have flown in the last ten years on a 737 with Southwest, United, Delta, or American, it was almost certainly an NG.

[23] Travis, *supra* note 22. Another way to put the point is to say that the 737 Max exhibited less longitudinal stability than the predecessor 737 NG. Longitudinal stability refers to the tendency of a properly trimmed aircraft to return to the flight condition it was trimmed for if temporarily disturbed. *See* NAT'L AERONAUTICS & SPACE ADMIN., IS-97/08-DFRC-WUT, INFORMATION SUMMARY: WIND-UP TURN (1997), https://www.scribd.com/document/53095046/NASA-Information-Summaries-Wind-Up-Turn [https://perma.cc/DA8R-EZML] (last visited Oct. 31, 2019). The Federal Aviation Administration (FAA) certification standards for transport-category aircraft specify as follows, under the heading of "Stall characteristics":

> It must be possible to produce and to correct roll and yaw by unreversed use of the aileron and rudder controls, up to the time the airplane is stalled. *No abnormal nose-up pitching may occur.* The longitudinal control force must be positive up to and throughout the stall. In addition, it must be possible to promptly prevent stalling and to recover from a stall by normal use of the controls.

14 C.F.R. § 25.203(a) (1995) (emphasis added). Furthermore, the certification standards specify a stable stick-force curve throughout various regimes of flight. *See* 14 C.F.R. § 25.175(a) (2004). Stick force refers to the force pilots feel in the flight controls when they attempt to move the airplane from the flight path it is trimmed for. *See* McClellan, *supra* note 12. As described in a well-reported article, the challenge for Boeing engineers was to keep the stick-force curve smooth throughout a test maneuver designed to determine the longitudinal stability of the aircraft in a maneuver that would almost never be encountered in normal airline operations (a steep descending turn during which the pilots keep the airspeed constant, which requires constantly increasing the angle of attack). *See* Dominic Gates & Mike Baker, *The Inside Story of MCAS: How Boeing's 737 MAX System Gained Power and Lost Safeguards*, SEATTLE TIMES (June 22, 2018), https://

of this difference in handling between the NG and the Max, and the airlines could have trained their flight crews to anticipate the pitch-up and compensate with forward pressure on the yoke. The company was keen, however, to market the Max as requiring no additional training for flight crews because it handled exactly like the NG.[24] It particularly wanted to avoid requiring pilots to undergo time-consuming simulator training before transitioning from the NG to the Max.[25] Boeing's solution was therefore to incorporate MCAS—a software-based modification to the airplane's flight control laws that automatically trims the nose down to prevent exceeding a specified angle of attack in unusual flight attitudes, including both high-speed and low-speed banking turns.[26]

"Trim" in this case refers to the angle at which the horizontal stabilizer—part of the tail of the aircraft—is set.[27] On large airline jets, the stabilizer can be angled up or down to cause the nose to go down or up, respectively, which is referred to as the pitch attitude of the aircraft. Pitch trim is constantly being adjusted during flight, either by the flight crew or by the flight management computer. Pilots can change the pitch trim with either an electrical switch under the pilot's thumb on the control yoke or a manual wheel on either side of the center pedestal. MCAS was designed to operate in the background by adding some nose-down trim when the crew was hand-flying the plane (i.e., not on autopilot) and approaching the critical angle of attack.[28] It therefore supplemented existing stall-warning and pre-

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www.seattletimes.com/seattle-news/times-watchdog/the-inside-story-of-mcas-how-boeings-737-max-system-gained-power-and-lost-safeguards/ [https://perma.cc/RQB8-AT3S].

[24] *See* James Glanz et al., *After a Lion Air 737 Max Crashed in October, Questions About the Plane Arose*, N.Y. TIMES (Feb. 3, 2019), https://www.nytimes.com/2019/02/03/world/asia/lion-air-plane-crash-pilots.html [https://perma.cc/JE2Z-QQHD].

[25] Some reporting indicates that Boeing had agreed to give Southwest Airlines, a long-time purchaser of large numbers of 737 aircraft, a rebate of $1 million per plane if the Max required additional simulator training for crews already qualified on the NG. *See* Gates & Baker, *supra* note 23.

[26] *See id.*; Fehrm, *supra* note 15; Jack Nicas et al., *Boeing Built Deadly Assumptions into 737 MAX, Blind to a Late Design Change*, N.Y. TIMES (June 1, 2019), https://www.nytimes.com/2019/06/01/business/boeing-737-max-crash.html [https://perma.cc/YU4F-CTFT].

[27] *See* FED. AVIATION ADMIN., FAA-H-8083-25B, PILOT'S HANDBOOK OF AERONAUTICAL KNOWLEDGE 3-6 (2016), https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/pilot_handbook.pdf [https://perma.cc/HWP5-FDRW].

[28] *See* Broderick et al., *supra* note 11.

vention systems but, significantly, did so in the background, not observed or controlled in any way by the pilots.[29] *Voilà*, an updated 737 that flew just like the familiar NG, without the need for expensive flight-crew retraining.[30]

Of course, any electrical system can malfunction. That observation is not limited to software-driven control systems like MCAS but to any electrical connection between flight controls and control surfaces. Pilots have always known about, and are trained to deal with, a problem known as trim runaway (or a stabilizer runaway). For a variety of reasons, an electric pitch-trim system may go haywire and command excessive nose-up or nose-down trim attitudes. The procedure for dealing with a trim runaway is simple and committed to memory by flight crews—disable the electrical pitch-trim system, leaving only the manual wheels on the center console for making trim changes, while also not allowing the airspeed to get too high, which would make manual retrimming difficult or impossible.[31] Significantly, the very same plane that crashed the next day as Lion Air 610 experienced a trim runaway on its inbound flight to Jakarta.[32] A company pilot riding in the jumpseat correctly diagnosed the problem, the crew shut off the electric trim, and the plane landed safely.[33] Journalist (and pilot) James Fallows reported on at least four incidents in which pilots for U.S. airlines dealt with

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[29] *See* Gates & Baker, *supra* note 23.

[30] *See id.*

[31] *See* James Glanz et al., *What the Lion Air Pilots May Have Needed to Do to Avoid a Crash*, N.Y. TIMES (Nov. 16, 2018), https://www.nytimes.com/interactive/2018/11/16/world/asia/lion-air-crash-cockpit.html [https://perma.cc/P6JB-MFNV]; Ted Reed, *United Pilot Leader Says Boeing 737Max and 727 Runaway Trim Recovery Procedures Are Similar*, FORBES (Nov. 17, 2018), https://www.forbes.com/sites/tedreed/2018/11/17/united-pilot-leader-says-boeing-737max-and-727-auto-stall-recovery-systems-are-similar/#7cfb91b5f0f0 [https://perma.cc/66LG-D55Z]. The electric pitch-trim system is taken out of the loop using two STAB TRIM CUT-OUT switches located on the center pedestal, between the captain's and first officer's seats. *See* Mike Baker & Dominic Gates, *Boeing Altered Key Switches in 737 MAX Cockpit, Limiting Ability to Shut Off MCAS*, SEATTLE TIMES (May 10, 2019), https://www.seattletimes.com/business/boeing-aerospace/boeing-altered-key-switches-in-737-max-cockpit-limiting-ability-to-shut-off-mcas/ [https://perma.cc/KW8A-TLNX] (last updated May 14, 2019). The runaway trim procedure is a memory item, meaning it is performed without reference to checklists, because it must be executed quickly.

[32] *See* Alan Levin & Harry Suhartono, *Pilot Who Hitched a Ride Saved Lion Air 737 Day Before Deadly Crash*, BLOOMBERG BUS. (Mar. 20, 2019), https://www.bloomberg.com/news/articles/2019-03-19/how-an-extra-man-in-cockpit-saved-a-737-max-that-later-crashed [https://perma.cc/82E5-MF3X].

[33] *See id.*

unexpected MCAS activations or other pitch-trim issues without difficulty.[34] It would thus appear that any additional risk introduced into the 737 Max design by the inclusion of MCAS was mitigated by procedures already trained and practiced by flight crews operating the 737 NG.[35]

Nevertheless, preliminary reports on the Lion Air 610 and Ethiopian Airlines 302 accidents suggest that both involved a sudden, rapid, un-commanded nose-down trim input likely resulting from erroneous air data received by the flight management computer (which includes the MCAS control laws).[36] The relevant data pertains to the airplane's AOA and comes from at least one of two sensors or vanes on either side of the nose of the plane.[37] There is some evidence that a bird strike may have damaged the AOA sensor on the Ethiopian Airlines flight,[38] and the AOA sensor on the Lion Air accident aircraft had been replaced in the days preceding the accident but was still performing incorrectly.[39] Regardless of the reason for the failures of the

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[34] James Fallows, *Here's What Was on the Record About Problems with the 737 Max*, ATLANTIC (Mar. 13, 2019), https://www.theatlantic.com/notes/2019/03/heres-what-was-on-the-record-about-problems-with-the-737-max/584791/ [https://perma.cc/EQ5R-H2TP].

[35] That is the view taken by William Langewiesche, the aviation journalist and pilot who unequivocally blamed pilot error for both the Lion Air and Ethiopian Airlines crashes. *See* William Langewiesche, *What Really Brought Down the 737 Max?*, N.Y. TIMES MAG. (Sept. 18, 2019), https://www.nytimes.com/2019/09/18/magazine/boeing-737-max-crashes.html [https://perma.cc/4T7C-9M7Q] (last updated Oct. 29, 2019). His conclusion is damning:

> What we had in the two downed airplanes was a textbook failure of airmanship. In broad daylight, these pilots couldn't decipher a variant of a simple runaway trim, and they ended up flying too fast at low altitude, neglecting to throttle back and leading their passengers over an aerodynamic edge into oblivion. They were the deciding factor here—not the MCAS, not the Max.

Id.

[36] *See* Todd C. Frankel, *Sensor Cited as Potential Factor in Boeing Crashes Draws Scrutiny*, WASH. POST (Mar. 17, 2019), https://www.washingtonpost.com/business/economy/sensor-cited-as-potential-factor-in-boeing-crashes-draws-scrutiny/2019/03/17/5ecf0b0e-4682-11e9-aaf8-4512a6fe3439_story.html [https://perma.cc/3LDW-GWE5].

[37] *See id.*

[38] *See* Leslie Josephs, *US Aviation Officials Think a Bird Strike Was Factor in 737 Max Crash*, CNBC (May 21, 2019), https://www.cnbc.com/2019/05/21/boeing-shares-rise-after-report-that-a-bird-strike-may-have-caused-737-max-crash.html [https://perma.cc/CFJ9-CNHD].

[39] Firdaus Hashim, *Angle-of-Attack Sensor Replaced Before 737 Max Crash*, FLIGHTGLOBAL (Nov. 8, 2018), https://www.flightglobal.com/news/articles/angle-of-attack-sensor-replaced-before-737-max-crash-453455/ [https://perma.cc/4KTV-8VFG].

AOA sensors, the big problem is that the MCAS flight control laws took into account air data from only one of the two available AOA sensors, rather than comparing data from both.[40] Unreliable AOA data had the potential to trigger the nose-down trim input from the MCAS system, even though the airplane's pitch attitude was normal.[41] It seems inexplicable now that Boeing would have incorporated a single point of failure into the MCAS design. However, Boeing concluded that the single AOA sensor was sufficient in light of two factors: (1) the limitation of MCAS to operation in very unusual flight regimes (high-speed and low-speed banking turns); and (2) the assumption that flight crews would deal promptly (within three seconds) and correctly with any pitch-trim anomalies caused by erroneous MCAS operation.[42] Apparently, however, the crew of Ethiopian Airlines 302 did employ the procedure of cutting off the electric pitch trim but were still unable to recover.[43] Subsequent tests in a 737 simulator suggest that the MCAS system was aggressive enough to place the aircraft so severely out of trim that a recovery was impossible using back pressure on the yoke and the manual trim wheel, due to aerodynamic forces at high airspeeds.[44]

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[40] *See* Gates & Baker, *supra* note 23.

[41] *See id.*

[42] *See id.* (noting that Boeing calculated the probability of a hazardous MCAS failure as 1 in 223 trillion flight hours).

[43] *See* Ahmed et al., *supra* note 6.

[44] *See* Dominic Gates, *Why Boeing's Emergency Directions May Have Failed to Save 737 Max*, SEATTLE TIMES (Apr. 8, 2019), https://www.seattletimes.com/business/boeing-aerospace/boeings-emergency-procedure-for-737-max-may-have-failed-on-ethiopian-flight [https://perma.cc/9D9X-VVY8]. Widely read aviation blogger and airline pilot Patrick Smith summarizes the analysis of the cockpit voice recorder and flight data recorder data that indicate the crew took appropriate corrective action but were thwarted by an aerodynamic effect that makes it impossible to move the manual trim wheel while holding back pressure on the yoke. *See* Patrick Smith, *Ethiopian, Lion Air, and the 737 Max*, ASK THE PILOT, https://www.askthepilot.com/ethiopian-737max-crash [https://perma.cc/45QA-79SM] (last updated Oct. 25, 2019); *see also* Ahmed et al., *supra* note 6. The only way to counteract this effect would be to relax back pressure, thus relieving aerodynamic process on the stabilizer, while simultaneously rolling in lots of nose-up trim. Smith rightly calls this an extremely counterintuitive response. *See* Smith, *supra*. Apparently, this procedure was part of first-generation (pre-NG) 737 flight manuals and training but has not been trained or referred to in standard operating procedures for decades. *See* Gates, *Why Boeing's Emergency Directions May Have Failed*, *supra* (noting that an Australian pilot had posted and discussed the "roller coaster" technique from a 1982 manual). A subsequent article by Dominic Gates, a long-time aviation journalist in Boeing's home town (until very recently), reports that a U.S.-based airline crew tried the roller coaster technique in a simula-

The U.S. Federal Aviation Administration (FAA) grounded the 737 Max soon after the Ethiopian accident, following similar action by aviation authorities in other countries.[45] The aircraft remains out of service worldwide as of October 2019 and is not expected to reenter service until later in the year at the earliest.[46] Boeing has announced several design changes to the aircraft, including incorporating air data from both AOA sensors into the operation of MCAS and limiting the nose-down trim the system can force against contrary actions by the flight crew.[47]

III. BOEING'S EXPOSURE UNDER MODERN PRODUCTS LIABILITY LAW

A number of lawsuits have already been filed against Boeing, and more are sure to follow, alleging faults—"defects" in products liability parlance—in the design of the 737 Max or in the warnings and instructions provided to airline training departments and flight crews. The complaints cite a number of doctri-

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tor and was able to recover, but they lost 8,000 feet of altitude in the process; Ethiopian Airlines 302 was never more than 8,000 feet above ground level. *See* Dominic Gates, *How Much Was Pilot Error a Factor in the Boeing 737 Max Crashes?*, SEATTLE TIMES (May 15, 2019), https://www.seattletimes.com/business/boeing-aerospace/how-much-was-pilot-error-a-factor-in-the-boeing-737-max-crashes [https://perma.cc/WD7A-44LA]; *see also* Sean Broderick, *Ethiopian MAX Crash Simulator Scenario Stuns Pilots*, AVIATION DAILY (May 10, 2019), https://aviationweek.com/commercial-aviation/ethiopian-max-crash-simulator-scenario-stuns-pilots [https://perma.cc/8LKV-TRN5].

[45] *See* Thomas Kaplan et al., *Boeing Planes Are Grounded in U.S. After Days of Pressure*, N.Y. TIMES (Mar. 13, 2019), https://www.nytimes.com/2019/03/13/business/canada-737-max.html [https://perma.cc/2RG4-7RWC]; Luz Lazo et al., *Investigators Find 2nd Piece of Key Evidence in Crash of Boeing 737 Max 8 in Ethiopia*, WASH. POST (Mar. 15, 2019), https://www.washingtonpost.com/world/africa/french-start-analysis-ethiopian-airlines-black-boxes-as-new-evidence-appears/2019/03/15/87770e8c-468f-11e9-94ab-d2dda3c0df52_story.html [https://perma.cc/VBM8-8JRF].

[46] *See* Leslie Josephs, *Costs Pile Up for Airlines as Boeing 737 Max Grounding Enters Eighth Month*, CNBC (Oct. 13, 2019), https://www.cnbc.com/2019/10/13/boeing-737-max-grounding-enters-eighth-month-driving-up-airline-costs.html [https://perma.cc/KEB8-ZXYJ]; Andrew Tangel et al., *Trials Near for Boeing 737 MAX Fix*, WALL ST. J. (June 16, 2019), https://www.wsj.com/articles/boeing-ceo-promises-greater-transparency-on-737-max-11560697321 [https://perma.cc/66JC-25YF]. A significant unknown is whether additional simulator training will be required for 737 Max crews. There is currently only one Max simulator in North America, owned by Air Canada. *See* Patti Waldmeir et al., *Return to Service of Boeing 737 Max Could Depend on Pilot Training*, FIN. TIMES (May 28, 2019), https://www.ft.com/content/a7dd933a-7e5c-11e9-81d2-f785092ab560 [https://perma.cc/FCA5-N6AV].

[47] *See* Gates & Baker, *supra* note 23.

nal bases for liability, including negligence, strict liability, and breach of implied warranty.[48] As discussed below, in modern products liability law, following the Restatement (Third) of Torts: Products Liability, these claims should be understood functionally as alleging one of three types of defects—manufacturing, design, or instructions or warnings.[49] The currently prevalent risk–utility test compares the existing product, and the information provided with it, to a hypothetical redesigned product or information that should have been provided. If the failure to incorporate the design change or to provide the additional warnings renders the product not reasonably safe, the manufacturer is liable.[50] The question is therefore whether the 737 Max, as delivered, was defective, and whether the design and information changes contemplated by Boeing will render the aircraft reasonably safe going forward.

It took a while for courts to work this out, but it is now well understood that a products liability action seeks to hold the manufacturer to a standard of reasonableness in the design and provision of information (i.e., instructions and warnings).[51] An early California Supreme Court opinion insisted that the cause of action for a defective product should not burden the plaintiff with an element that "rings of negligence."[52] But the court also recognized that the manufacturer should not be held absolutely liable, as an insurer of product users.[53] The effort to walk the tightrope between avoiding a test that rings of negligence and avoiding imposing absolute liability preoccupied courts in the early decades of the development of products liability law. For example, cases arose where safety technology advanced between the time of manufacture of the product and the occurrence of

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[48] *See, e.g.*, Complaint at 9–18, Abdalla v. Boeing Co., No. 1:19-cv-04162 (N.D. Ill. June 20, 2019); Complaint at 13–16, Soegiyono v. Boeing Co., No. 1:19-cv-03415 (N.D. Ill. May 21, 2019); Complaint at 48–62, Vdovic v. Boeing Co., No. 2:19-cv-01455-DCN (D.S.C. May 17, 2019); Complaint at 48–62, Thugge v. Boeing Co., No. 2:19-cv-01443-DCN (D.S.C. May 17, 2019); Complaint at 11–16, K'Obien v. Boeing Co., No. 1:19-cv-03285 (N.D. Ill. May 15, 2019); Complaint at 11–16, Kondaveeti v. Boeing Co., No. 1:19-cv-02597 (N.D. Ill. Apr. 17, 2019); Complaint at 18–26, Debets v. Boeing Co., No. 1:19-cv-02170 (N.D. Ill. Mar. 28, 2019).

[49] RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. n (AM. LAW INST. 1998).

[50] *See id.* § 2 cmt. a.

[51] *Id.*

[52] Cronin v. J.B.E. Olson Corp., 501 P.2d 1153, 1162 (Cal. 1972).

[53] *See id.* at 1162.

the accident.[54] If liability was truly strict for design defects, the manufacturer should be liable, even if it acted reasonably.[55] Courts tended to reject this conclusion, however.[56] The belief that liability for defective products must be strict also tied courts into knots when they attempted to work out the relevance of user misconduct—is it possible to compare user negligence and strict products liability?[57] Modern courts are much more comfortable admitting that the test for design defect and inadequate instructions or warnings is conceptually similar to negligence, although with some distinctive features.[58]

A. Design Defect

Modern products liability law begins with section 402A of the Restatement (Second) of Torts, which purported to create a rule of strict tort liability for anyone who "sells any product in a defective condition unreasonably dangerous to the user or consumer."[59] Many of the first generation of products liability cases involved what is now known as a manufacturing defect, in which the particular product that caused injury had deviated, usually as a result of some glitch in the production process, from the manufacturer's specifications for the product.[60] Those cases are relatively easy to conceptualize as strict liability; the manufacturer's liability flows from nothing more than the sale of a product departing from its intended design, where the departure

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[54] *See* Restatement (Third) of Torts: Prods. Liab. § 2 reporters' note cmt. d (II)(A).

[55] *See id.* § 2 cmt. a.

[56] *See, e.g.*, Boatland of Houston, Inc. v. Bailey, 609 S.W.2d 743, 748–50 (Tex. 1980).

[57] *See, e.g.*, Murray v. Fairbanks Morse, 610 F.2d 149, 155–58 (3d Cir. 1979).

[58] *See, e.g.*, Webb v. Navistar Int'l Transp. Corp., 692 A.2d 343, 351 (Vt. 1996).

[59] Restatement (Second) of Torts § 402A(1) (Am. Law Inst. 1965). The development of strict liability in tort occurred in parallel with the elaboration of the alternative doctrinal basis of implied warranties of merchantability in contract law. *See* Henningsen v. Bloomfield Motors, Inc., 161 A.2d 69, 76–84 (N.J. 1960). Breach of implied warranty eventually was folded into the generic cause of action for defective products, which sounds primarily in tort. *See* Restatement (Third) of Torts: Prods. Liab. § 2 cmts. n, r. Contract-based recovery for design defect is still an important fallback theory of liability in a few special cases, particularly for claims for pure economic losses. *See* East River S.S. Corp. v. Transamerica Delaval, Inc., 476 U.S. 858, 870–73 (1986). For the most part, however, a design-defect claim is handled as a matter of tort law, under the Third Restatement's risk–utility test. *See* discussion *infra* section III.A.1.

[60] *See, e.g.*, Escola v. Coca Cola Bottling Co., 150 P.2d 436, 441–44 (Cal. 1944); MacPherson v. Buick Motor Co., 111 N.E. 1050, 1051 (N.Y. 1916).

renders the product unreasonably dangerous.[61] The much more difficult issue arises where the plaintiff alleges that the manufacturer's specifications are themselves "defective." As the California Supreme Court observed, in an important early case, "[a] defect may emerge from the mind of the designer as well as from the hand of the workman."[62] If the claim is that the design itself is faulty, however, the issue is what baseline should be used to determine if there is a deviation from an appropriate design.[63] The baseline has to be a hypothetical design that should have been employed but was not.[64] And, the evaluation of a design defect relative to that baseline inevitably involves balancing the risk of the existing design with the disutility involved in any redesign that would eliminate or mitigate the risk.[65] The Second Restatement's language of "defective condition *unreasonably* dangerous" thus suggested a test that is strict liability in theory but negligence in application.[66]

Early efforts to address the design-defect issue picked up on a comment to section 402A of the Second Restatement, which said that a product is unreasonably dangerous if it is "dangerous to an extent beyond that which would be contemplated by the ordinary consumer who purchases it, with the ordinary knowledge common to the community as to its characteristics."[67] The so-called consumer expectations test worked well enough for everyday products with safety aspects that are easily understandable.[68] A chef's knife is not defective in design just because it can take off a user's fingertip. The danger of the knife is exactly that which would be contemplated by a reasonable consumer.[69] It

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[61] RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmts. a, c.

[62] Cronin v. J.B.E. Olson Corp., 501 P.2d 1153, 1162 (Cal. 1972).

[63] RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmts. a, d.

[64] *Id.* § 2 cmt. d.

[65] *Id.*

[66] *See* RESTATEMENT (SECOND) OF TORTS § 402A cmt. i (AM. LAW INST. 1965) (emphasis added).

[67] *Id.*

[68] RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 reporters' note cmt. d (II)(D).

[69] One subtle aspect of this analysis is that the obviousness of the danger cannot, by itself, yield the conclusion that there is no defect in the design of the product. Some early cases followed the so-called patent danger rule, under which the obviousness of a defect was an absolute defense. *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. d & reporters' note cmt. d (IV)(C). Modern caselaw almost uniformly rejects the per se aspect of the patent danger rule, while considering the obviousness of a danger as a factor to be taken into account in risk–utility balancing. *See id.* The chef's knife is not defective in design, not be-

soon became apparent to courts, however, that a test referring to the expectations of ordinary consumers was useless to evaluate the design of complex products or to deal with tradeoffs between the safety and utility of a product.[70] As the Oregon Supreme Court recognized in an influential case, an ordinary consumer would expect a pickup truck to be able to run over a rock of one or two inches diameter on the road but probably has no expectation regarding a six or eight inch rock.[71] Then, in one of the handful of most important decisions in the development of products liability law, the California Supreme Court limited the consumer expectations test to situations in which everyday experience would be sufficient to permit the trier of fact to infer that the product failed to perform as a reasonable consumer would expect.[72] In a case involving a product of any real complexity, the plaintiff's burden of production includes introducing sufficient evidence from which a reasonable trier of fact can conclude that the manufacturer erred in its balance of competing product design considerations.[73] Specifically, the jury must be instructed that it should consider whether the product's design embodies "excessive preventable danger."[74] This is known as the risk–utility test. It has come to be the decisive majority approach in state courts,[75] and it is the exclusive test (with

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cause the danger is open and obvious, but because there is no way to mitigate the risk without undermining the utility of the product or transforming it into a different product altogether, such as a mandoline.

[70] *See* Heaton v. Ford Motor Co., 435 P.2d 806, 808–09 (Or. 1967).

[71] *See id.* at 809–10.

[72] *See* Soule v. General Motors Corp., 882 P.2d 298, 308–10 (Cal. 1994).

[73] *See id.* at 308.

[74] *Id.* at 308 (citing Barker v. Lull Eng'g Co., 573 P.2d 443, 454 (Cal. 1978)).

[75] *See* James A. Henderson, Jr. & Aaron D. Twerski, *Achieving Consensus on Defective Product Design*, 83 CORNELL L. REV. 867, 887 (1998). South Carolina and Illinois, where most of the products liability lawsuits against Boeing have been filed, both follow the risk–utility test. *See* Branham v. Ford Motor Co., 701 S.E.2d 5, 14 (S.C. 2010); Mikolajczyk v. Ford Motor Co., 901 N.E.2d 329, 352 (Ill. 2008). Illinois has an oddball procedure in which if either the plaintiff or the defendant seeks jury instructions on risk–utility factors, the court will give them. *See Mikolajczyk*, 901 N.E.2d at 352–53. Since it is almost inevitable that one side will prefer the risk–utility approach, the Illinois procedure creates a de facto exclusive risk–utility test, while claiming to also recognize the alternate consumer expectations test. *See id.* Aaron Twerski has recently argued that even states claiming to adhere to the consumer expectations test are de facto risk–utility jurisdictions because plaintiffs' lawyers, wishing to avoid losing on summary judgment, inevitably introduce evidence of a reasonable alternative design and are prepared to argue their theory of defect on risk–utility considerations. *See* Aaron D. Twerski, An Essay on the Quieting of Products Liability Law 5, 12 n.63 (n.d.) (unpublished manuscript) (on file with author).

a few exceptions not relevant to this discussion) employed by the Restatement (Third) of Torts: Products Liability.[76]

As its name suggests, the risk–utility test comes full circle, from the supposed innovation of strict liability for defective products represented by the Second Restatement's influential section 402A, to the use of ordinary negligence principles to analyze design defects and information (warnings and instructions) deficiencies.[77] The benefits of a proposed redesign are compared with the existing product design, and at root, the test is simply whether, from the point of view of a reasonable person, the redesign represents a better net balance of safety, cost, and other factors bearing on the utility of the product.[78] This is a negligence test in substance. The only sense in which the modern law of design defect retains aspects of strict liability is in its focus on the product itself, rather than the conduct of engineers, executives, and other agents of the manufacturer.[79] In practice, this is often a distinction without a difference. During investigation and discovery, the plaintiffs generally learn information pertaining to the manufacturer's decision-making process and can show that the defendant's agents acted unreasonably by making unreasonable risk–utility tradeoffs. This kind of proof is not necessary, however, and the plaintiff may make out a prima facie case of liability for design defect entirely by introducing evidence of a feasible alternative design (almost always using one or more expert witnesses).[80] Whatever evidence emerges in discovery about the conduct of Boeing engineers or managers, the jury considers only whether the plaintiff's proposed alternative design is a reasonable alternative design, with reasonableness being evaluated along the lines of conventional negligence analysis. To the extent evidence about the conduct of Boeing agents bears on the reasonableness of the alternative design, it is relevant and may be admitted, but it is not necessary for the plaintiff's claim to survive summary judg-

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[76] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2(b) (AM. LAW INST. 1998).

[77] *See* Sheila L. Birnbaum, *Unmasking the Test for Design Defect: From Negligence [to Warranty] to Strict Liability to Negligence*, 33 VAND. L. REV. 539, 613–15 (1980). *See generally* Henderson & Twerski, *Achieving Consensus on Defective Product Design*, *supra* note 75.

[78] RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. d.

[79] *See, e.g.*, Garrett v. Hamilton Standard Controls, Inc., 850 F.2d 253, 257–58 (5th Cir. 1998) (interpreting Texas law); *cf.* Davis v. Globe Mach. Mfg. Co., 684 P.2d 692, 696 (Wash. 1984).

[80] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. f.

ment.[81] In that sense, and in that sense only, the design-defect test retains a flavor of strict liability. At its conceptual heart, however, it is a negligence analysis.[82]

1. The Third Restatement Design-Defect Analysis

The key to the Third Restatement risk–utility analysis is proof of a reasonable alternative design (RAD), which proceeds in this way: the plaintiff introduces evidence that some sort of redesign of the product was technologically and economically feasible at the time of the sale of the product.[83] The jury is then instructed that it should consider whether the plaintiff's proposed redesign is a RAD. A product is defective in design if the manufacturer's failure to incorporate a RAD renders the product not reasonably safe.[84] It is an analytic point that the jury's determination that a proposed redesign is a RAD entails the conclusion that the product is defective in design. The Third Restatement test requires the trier of fact to balance the relative advantages and disadvantages of the product as designed, compared with the plaintiff's proposed alternative.[85] In doing so, it considers a number of factors, including the severity and likelihood of foreseeable risks associated with the product as designed, and the likely impact of the proposed redesign on production costs; product longevity, usability, aesthetics, and maintenance; and expectations consumers have regarding the product's performance and safety aspects.[86] An influential law review article, from which the Third Restatement test was drawn, boils the test down to the following consideration: "The manufacturer's ability to eliminate the unsafe character of the product without impairing its usefulness or making it too expensive to maintain its utility."[87]

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[81] *See id.* § 2 cmt. n.

[82] True strict liability exists for manufacturing defects where the particular product that caused the plaintiff's harm departed from its intended design. *See id.* § 2(a). Nothing that has been reported about the Lion Air 610 and Ethiopian Airlines 302 accidents suggests that they were caused by a deviation from the intended design rather than by features of the design itself.

[83] *Id.* § 2 cmt. f.

[84] *Id.*

[85] *See id.*

[86] *Id.*

[87] *See* John W. Wade, *On the Nature of Strict Tort Liability for Products*, 44 MISS. L.J. 825, 837 (1973).

Manufacturers are therefore not in any meaningful sense subject to a strict liability rule for design defects.[88]

The determination that a redesign is or is not a RAD is not simply a comparison of the dollar cost of the added safety feature and the expected savings in accident costs.[89] It is conceptually similar to the famous Hand formula for assessing the defendant's conduct under the negligence standard ($B < PL$),[90] but the analysis of the costs to the manufacturer and the consumer is structured by the factors in comment f to section 2 of the Third Restatement.[91] The economic cost of the redesign is one factor, but more important is the impact of the redesign on the utility the user receives from the product.[92] For example, safety guards and "deadman" switches on power tools are not all that expensive to include with a product, but they interfere to some extent with the usefulness of the product. Anyone who has had to restart a lawnmower after letting go of the handle to remove a stick or rock has cursed that safety feature, but the added safety resulting from inclusion of the deadman switch is probably worth it, notwithstanding the hassle. A redesign may yield additional safety, but if at some point the redesigned product becomes a big enough headache for the user, a safety feature may not be a RAD.[93] The comparison between the existing design and the proposed redesign, to determine whether the latter is a RAD, is undertaken from the point of view of the reasonable person.[94] Thus, all of the familiar issues in connection with the negligence standard pertaining to the values and perspective of the reasonable person are fully applicable to the analysis of a design defect.

It also matters whether the redesign does better at avoiding the risk than a reasonably careful user. Although most states do

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[88] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. a; David G. Owen, *Defectiveness Restated: Exploding the "Strict" Products Liability Myth*, 1996 U. ILL. L. REV. 743, 785 (1996) ("the very idea that liability in these central contexts [of design and warnings claims] is 'strict' has been viewed increasingly as a myth.").

[89] *See generally* David G. Owen, *Toward a Proper Test for Design Defectiveness: "Micro-Balancing" Costs and Benefits*, 75 TEX. L. REV. 1661 (1997).

[90] *See* United States v. Carroll Towing Co., 159 F.2d 169, 173 (2d Cir. 1947). *B* represents the burden of taking precautions, *P* stands for the probability of the harm occurring, and *L* represents the severity of the injury—a party is liable where *B* is less than *P* multiplied by *L*. *Id.*

[91] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. f.

[92] *See id.*

[93] *See id.*

[94] *See id.* § 2 cmt. d.

not use disappointment of consumer expectations as a stand-alone test for design defect, expectations of users regarding the product's performance and the risks associated with its use may be taken into account in determining whether a proposed redesign is a RAD—that is, whether the existing design is defective.[95] A hazard need not necessarily be designed out of a product if its users are already aware of the risk and are in a better position than the manufacturer to take precautions to avoid it.[96] On the flip side, evidence of user carelessness is not necessarily restricted to consideration of the issue of comparative fault as an affirmative defense. It could be the case that the manufacturer should have foreseen certain careless behavior and redesigned the product to make it safer in light of the risk produced by the interaction of the product and foreseeably careless users.[97] One could say, for example, that users of hairdryers should be careful not to use these products in the bathtub (obviously) or with standing water on the floor (maybe less obvious). Nevertheless, a hairdryer manufacturer that did not include the RAD of a ground-fault circuit interrupt switch may be liable for a design defect.[98]

This point is worth careful attention in connection with the 737 Max design because the MCAS system was designed as an alternative to the usual approach of relying on training, crew discipline, and basic airmanship.[99] Recall that MCAS was in-

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[95] *See id.* § 2 cmt. g.

[96] *See id.* § 2 reporters' note cmt. a.

[97] *See id.* § 2 cmt. p.

[98] Would a warning be sufficient to avoid liability? (Everyone is familiar with warning stickers on hairdryers cautioning against use near water.) This issue will be discussed in more depth in connection with warnings below, but the short answer is that if a RAD is available, the manufacturer may not warn its way out of liability. *See id.* § 2 cmt. *l*, illus. 14. The longer answer is that determining whether a redesign is a RAD may require considering the relative efficacy of a redesign and enhanced warnings and instructions. *See, e.g.*, Uniroyal Goodrich Tire Co. v. Martinez, 977 S.W.2d 328, 335–37 (Tex. 1998).

[99] There is no gender-neutral term in widespread use that captures the same meaning as "airmanship," defined by the FAA as:

> [A] broad term that includes a sound knowledge of and experience with the principles of flight, the knowledge, experience, and ability to operate an airplane with competence and precision both on the ground and in the air, and the application of sound judgment that results in optimal operational safety and efficiency.

FED. AVIATION ADMIN., AIRPLANE FLYING HANDBOOK, *supra* note 19, at 1-1. Cognitive psychologist James Reason uses the term "professionalism," noting it is what pilots refer to as airmanship, to denote "a capacity to see the broader picture, to think ahead and to draw upon a wide range of knowledge and experience so as to

tended to operate only when the flight crew had gotten into a situation they probably should not be in, of a significant bank angle during either a nose-high, relatively slow flight or a steep, descending turn. The only intended effect of MCAS was to ensure that the angle of attack did not increase any further with an addition of power. A well-trained crew could accomplish the same goal with standardly trained, unusual attitude recovery procedures.[100] On the other hand, as shown by the Air France 447 and Colgan 3407 accidents, some professional crews have revealed an alarming inability to recognize and recover from a developing stall, even with the assistance of technology such as flight directors and stick pushers and shakers.[101] However, the Air France and Colgan accidents are generally regarded in the aviation community as the result of shocking incompetence.[102] No airplane can be made impossible to crash by a crew determined to do its worst, and some risks are not worth it to design out. Again, by "worth it," the Third Restatement does not refer to purely dollars-and-cents considerations. The question is, what is the optimal mix of safety precautions, considering both technological solutions and reasonable care by human operators? Importantly, even though potential user error is involved, the foreseeability of human error is not only considered in connection with the affirmative defense of comparative fault but also must be taken into account when considering whether a RAD is

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perform demanding work safely, elegantly and effectively." JAMES REASON, THE HUMAN CONTRIBUTION: UNSAFE ACTS, ACCIDENTS AND HEROIC RECOVERIES 161 (2008).

[100] As an aerodynamics textbook for pilots of airliners blandly states, "It is highly unlikely that anyone with sufficient experience to be an airline captain would inadvertently stall the aircraft." JIM WEBB & BILLY WALKER, FLY THE WING 93 (Blackwell Publishing 3d ed. 2006) (1971).

[101] *See* Nicola Clark, *When Disaster Threatens, Instinct Can Be a Pilot's Enemy*, N.Y. TIMES (Nov. 20, 2011), https://www.nytimes.com/2011/11/21/world/europe/when-disaster-threatens-instinct-can-be-a-pilots-enemy.html [https://perma.cc/4HNR-QMWW].

[102] *See id. But see generally* PALMER, *supra* note 20, at 61–62 (making a case that some aspects of the Airbus A330 flight control system and primary flight display could have confused the crew). I am not aware of any claim that Colgan 3407 was anything other than astonishingly poor airmanship by the crew. The late and highly respected aviation writer Dick Collins provided a balanced overview of the cause of the accident and the congressional response of mandating an air transport pilot (ATP) certificate for airline first officers as well as captains. *See* Richard Collins, *A Double Tragedy: Colgan Air Flight 3407*, AIR FACTS (Mar. 28, 2014), https://airfactsjournal.com/2014/03/double-tragedy-colgan-air-flight-3407 [https://perma.cc/2922-W42C].

available that would mitigate the risk caused by foreseeable carelessness.[103]

There is a certain irony in the 737 Max design. MCAS was required to enhance the airplane's longitudinal stability only in corners of the flight envelope that a professional airline crew should not be in at all. Thus, the presence of MCAS tacitly assumes the foreseeability of pilot error in getting into an excessively banked turn near the critical angle of attack. At the same time, however, Boeing assessed the likelihood of a hazardous condition caused by an inadvertent operation of MCAS as 1 in 223 trillion flight hours, and this estimate was based, in part, on the assumption that pilots would recognize and correct a trim runaway within three seconds.[104] It therefore appears that MCAS is a design feature intended to counteract the foreseeable human error of ordinary pilots, but the assessment of the risk posed by this design feature is based on the skill and performance that could be expected only from test pilots under controlled conditions, not the chaos of a failure in the real world, with the resulting cacophony of warning horns and stick shakers.[105]

Another important aspect of the story of the 737 Max is that Boeing may have been able to avoid what has become a fiasco for the company by simply informing the operators of the aircraft about the pitch-up tendency associated with the new engines. The company was concerned, however, that requiring extensive "differences training" for crews transitioning from the NG to the Max would diminish the latter's marketability.[106] The issue of whether Boeing's silence about the presence of MCAS constitutes a failure to warn will be considered below in section III.B. It appears, however, that decision makers at the company may have unnecessarily boxed themselves in by committing to make the Max fly as much like the NG as possible.[107] If the company had frankly informed airline purchasers that the Max had slightly different handling characteristics that needed to be

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[103] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmts. a, f.

[104] *See* Gates & Baker, *supra* note 23.

[105] *See id.*

[106] *See id.* "Differences training" is the term used for required training for pilots who already hold a type rating on an aircraft and are transitioning to a variant of that aircraft. *See* David Learmount, *'Differences Training' Under Scrutiny After 737 Max Crashes*, FLIGHTGLOBAL (May 24, 2019), https://www.flightglobal.com/news/articles/analysis-differences-training-under-scrutiny-afte-458276 [https://perma.cc/9XD9-S8EJ].

[107] *See* Learmount, *supra* note 106.

taken into account by flight crews, it may not have needed this modification to the aircraft's control laws. Boeing apparently assumed that a crew someplace would eventually screw up and stall the redesigned 737, choosing to adopt the technological solution of MCAS operating in the background without disclosure to airlines.

2. Design Issues in the 737 Max as Delivered

The optimal balance of reliance on human care and automated solutions to human carelessness is very much an open question in products liability law. It will be faced again, not only in aviation but also in contexts such as semiautonomous vehicles, which still require some driver monitoring. Section IV of this Article will return to this interesting and subtle problem. The analysis of Boeing's liability for the 737 Max design can avoid some of those deep conceptual issues, however, because some of its design decisions are difficult to defend in hindsight.[108] The good news for Boeing is that these design flaws can be corrected and the 737 Max returned to service. The bad news, of course, is that it is exposed to significant liability judgments stemming from the Ethiopian Airlines 302 and Lion Air 610 accidents.

a. Relying on One of Two AOA Sensors

It is a fundamental principle of aircraft design, and of engineering generally, that single points of failure are to be avoided whenever possible.[109] The design of the MCAS system took AOA data from only one of two available sensors.[110] As a result, if one

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[108] *Cf.* Jon Ostrower, *Boeing Details Changes to MCAS and Training for 737 Max*, AIR CURRENT (Mar. 27, 2019), https://theaircurrent.com/aviation-safety/boeing-details-changes-to-mcas-for-737-max/ [https://perma.cc/JS4B-HHB8].

[109] *See* Chris Woodyard, *Boeing's 'Single Point Failure': Why Was There No Backup System on 737 Max Jet?*, USA TODAY (Apr. 6, 2019), https://www.usatoday.com/story/news/nation/2019/04/06/boeings-737-max-8-jet-mystery-why-there-no-backup-system/3378703002/ [https://perma.cc/FM73-YFMR].

[110] *See* Nicas et al., *Boeing Built Deadly Assumptions Into 737 MAX*, *supra* note 26. That article also reports that MCAS initially was designed to trigger only in certain high-speed, accelerated maneuvers. *Id.* It therefore relied on two data points—AOA and acceleration (G-force). *Id.* Once MCAS was adapted to prevent stalls in a different flight regime, e.g., of slow, climbing flight, the G-force trigger was removed from MCAS, leaving only the single AOA sensor as the source of data. *Id.* Software engineer and pilot Gregory Travis raises the interesting point that an additional source of AOA data is the eyeballs of the flying pilot, who can look at outside visual references (or at the attitude indicator during instrument flight conditions) and verify that the airplane's pitch attitude is not excessively

sensor fed erroneous data to the flight-control system, the computer might react in a way the crew did not anticipate. Under the Third Restatement design-defect analysis, a plaintiff suing Boeing for losses resulting from the Lion Air 610 or Ethiopian Airlines 302 accidents would have the burden of establishing that relying on AOA data from both sensors was a RAD. The sensor is already there, so the economic cost is practically zero.[111] The risks presented by relying on only one sensor are entirely foreseeable.[112] A bird strike could disable a sensor (as is believed to have occurred to Ethiopian 302), it could be affected by ice or other weather conditions (the beginning of the accident chain of Air France 447), or the sensor could malfunction for other reasons.[113] Other factors in the design-defect analysis are the effect of the redesign on the utility of the product.[114] For example, the reliance on two sensors creates the possibility of mismatches between the left- and right-side AOA indications. This seems like it might happen, but it could be addressed by requiring agreement between the two before the AOA protections of MCAS will kick in. An additional disutility is the requirement of replacing or repairing a faulty sensor. Boeing wanted to keep the system as simple as possible so that its airline customer would not be forced to ground a plane for required maintenance if it would still be safe to operate it with one AOA sensor.[115]

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high. *See* Travis, *supra* note 22. The pilot should properly be considered part of the system maintaining a safe AOA, but MCAS by design takes the pilot out of the system. *See id.*

[111] *Cf.* Gates & Baker, *supra* note 23.

[112] For example, a similar problem, although in this case with one of two radio altimeters instead of AOA sensors, was the initial cause that started the chain of events leading to the crash of Turkish Airlines Flight 1951. *See* DUTCH SAFETY BD., CRASHED DURING APPROACH, BOEING 737-800, NEAR AMSTERDAM SCHIPHOL AIRPORT, 25 FEBRUARY 2009, at 48 (May 2010), https://www.onderzoeksraad.nl/en/page/1182/turkish-airlines-crashed-during-approach-boeing-737-800-amsterdam [https://perma.cc/Y3T8-A6L5].

[113] *See, e.g.*, Alan Levin & Ryan Beene, *Sensors Linked to Boeing 737 Crashes Vulnerable to Failure*, BLOOMBERG BUS. (Apr. 11, 2019), https://www.bloomberg.com/news/articles/2019-04-11/sensors-linked-to-737-crashes-vulnerable-to-failure-data-show [https://perma.cc/AB6K-KGDN].

[114] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. f (AM. LAW INST. 1998).

[115] *See* Gates & Baker, *supra* note 23; Alison Sider & Andy Pasztor, *Boeing Official Played Down Scenario that May Have Doomed Ethiopian Jet*, WALL ST. J. (May 21, 2019), https://www.wsj.com/articles/boeing-official-played-down-scenario-that-may-have-doomed-ethiopian-jet-11558439651 [https://perma.cc/M5WK-Z6PX].

Alternatively, or in addition, the flight crew should be warned when the two AOA sensors do not agree with each other. In fact, Boeing had already designed in the capability of alerting flight crews to a disagreement among AOA sensors but decided that this indication would be enabled only for customers who had purchased the optional feature of an AOA indication on the primary flight display.[116] Some reporting has made this sound like a cover-up by Boeing or an effort to squeeze more money out of purchasers by charging for an optional feature that should have been made part of the baseline product.[117] However, most civilian aircraft do not display AOA directly even though the data are used by the flight management computer.[118] Flight crews would have to be trained to interpret AOA indications and integrate that information into their scan, which already includes airspeed, glidepath, and lateral guidance. In an attention-getting scenario like a sudden pitch down, the instinct of most airline pilots would not be to take a look at indicated AOA but to

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[116] *See* Jamie Freed & Eric M. Johnson, *Optional Warning Light Could Have Aided Lion Air Engineers Before Crash: Experts*, REUTERS (Nov. 30, 2018), https://www.reuters.com/article/us-indonesia-crash-boeing-aoa/optional-warning-light-could-have-aided-lion-air-engineers-before-crash-experts-idUSKCN1NZ0QL [https://perma.cc/R2KL-W49N].

[117] *See, e.g.*, Hiroko Tabuchi & David Gelles, *Doomed Boeing Jets Lacked 2 Safety Features that Company Sold Only as Extras*, N.Y. TIMES (Mar. 21, 2019), https://www.nytimes.com/2019/03/21/business/boeing-safety-features-charge.html [https://perma.cc/FU4X-DYX] ("As the pilots of the doomed Boeing jets in Ethiopia and Indonesia fought to control their planes, they lacked two notable safety features in their cockpits. One reason: Boeing charged extra for them."); Nick Zazulia, *Boeing Knew the AOA Disagree Alert on the 737 MAX Didn't Work—And Said Nothing*, AVIATION TODAY (May 6, 2019), https://www.aviationtoday.com/2019/05/06/boeing-angle-of-attack-disagree-alert/ [https://perma.cc/2JB3-LL3U].

[118] A Boeing publication notes:

> AOA can be used for many indications on the flight deck to improve flight crew awareness of airplane state relative to performance limits. Dedicated AOA indicators have been used on military aircraft for many years, but this form of display has not been used often on commercial airplanes. On Boeing models currently in production, AOA is used to drive stall warning (stick shaker), stall margin information on airspeed indicators, and the pitch limit indicator (PLI) on the primary attitude displays. AOA information is combined with other data and displayed as an integral part of flight deck displays.

John E. Cashman et al., *Operational Use of Angle of Attack on Modern Commercial Jet Airplanes*, AERO, Oct. 2000, at 10, 12, http://www.boeing.com/commercial/aeromagazine/aero_12/aoa.pdf [https://perma.cc/PNE5-HWFM].

pull back to establish the desired pitch attitude, looking at either the attitude indicator or external visual references.

Boeing's decision to make an AOA display available as an option makes sense, not from the point of view of corporate greed, but as rightly deferring a risk–utility decision to purchasers. An airline's flight operations and training departments would have to reach a considered decision about whether to integrate AOA information into standardized procedures. An interesting wrinkle in the design-defect analysis using the risk–utility test is that there may be two versions of a product—call them Option A and Option B—one of which includes a safety feature that may be omitted under certain circumstances without unreasonably reducing the safety aspects of the product. Option B is not a RAD for Option A, or vice versa, as long as the purchaser is aware of the optional safety feature and knowledgeable about the risk–utility trade-offs involving it.[119] Again, the dollar cost of the safety feature is not by itself dispositive of the risk–utility analysis. In a well-known case, a state police department purchased bulletproof vests that offered less than full coverage for users' bodies.[120] It did so not to save money but because troopers preferred vests that were cooler and offered more freedom of movement.[121] The full-coverage vest was available as an option, but it was not a RAD for the model purchased by the state police.[122] Similarly, the lack of a direct indication of AOA is not a design defect even though an option to display AOA is available.

However, Boeing's silence about the presence and operation of MCAS should be considered in conjunction with a variation on this theory of liability. Some reporting on the 737 Max has focused on the absence of a warning that the two AOA sensors are disagreeing with each other.[123] The trouble is, even if the

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[119] *See, e.g.*, Scarangella v. Thomas Built Buses, Inc., 717 N.E.2d 679, 681–83 (N.Y. 1999) (school bus is not defective in design for lack of an audible backup alert because there are circumstances—including the purchaser's situation of operating a crowded bus yard in a residential neighborhood—in which the safety feature's disutility would outweigh its utility).

[120] Linegar v. Armour of Am., Inc., 909 F.2d 1150, 1151 (8th Cir. 1990). This case is the basis for illustration 10 to section 2 of the Third Restatement on risk–utility analysis. *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. f, illus. 10 (AM. LAW INST. 1998).

[121] *See Linegar*, 909 F.2d at 1154–55.

[122] *See id.*

[123] *See, e.g.*, Tripti Lahiri, *Boeing Has a Puzzling Explanation for Why a "Standalone" Warning Signal Didn't Work*, QUARTZ (Apr. 30, 2019), https://

crew received an "AOA Disagree" warning, the significance of that warning would not be apparent unless they had also been told that a sudden change in pitch trim might be commanded by a flight control law based on indications of a high AOA. Boeing recently (and correctly) stated in a press release:

> Air speed, attitude, altitude, vertical speed, heading and engine power settings are the primary parameters the flight crews use to safely operate the airplane in normal flight. Stick shaker and the pitch limit indicator are the primary features used for the operation of the airplane at elevated angles of attack. All recommended pilot actions, checklists, and training are based upon these primary indicators. Neither the angle of attack indicator nor the AOA Disagree alert are necessary for the safe operation of the airplane. They provide supplemental information only, and have never been considered safety features on commercial jet transport airplanes.[124]

Airline crews are trained to rely on airspeed, attitude, power setting, etc., rather than angle of attack. Thus, an AOA Disagree indication would not by itself convey the information that something having an immediate impact on the safe operation of the aircraft was possible. The alert would be significant only in the context of previous training about the existence of MCAS, which Boeing sought to avoid.

Again, the company painted itself into a corner by trying to design the Max to fly like the NG while also seeking to circumvent the requirement of differences training for crews transitioning to the Max. Now that every pilot in the world has heard of MCAS, the AOA Disagree alert is much more meaningful, and it should be a required feature of the design of the aircraft. It will continue to be important, however, for the company to think about a way to make the warning salient and trigger the right reaction. Over-warning and unhelpful presentation of warnings are already well-recognized problems in flight deck de-

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qz.com/1608362/boeing-says-it-didnt-deactivate-standalone-aoa-safety-alert [https://perma.cc/LKZ7-NLPK].

[124] Press Release, Boeing, Boeing Statement on AOA Disagree Alert (May 5, 2019), https://boeing.mediaroom.com/news-releases-statements?item=130431 [https://perma.cc/N9F5-SJJ5]. Boeing CEO Dennis Muilenburg has insisted—rightly, I believe—in public comments that the AOA Disagree alert is an issue separate from MCAS. *See* Joe Anselmo & Graham Warwick, *Boeing Chief Dennis Muilenburg Talks MAX, NMA, 777X and Automation*, AVIATION WK. & SPACE TECH. (June 14, 2019), http://aviationweek.com/paris-airshow-2019/boeing-chief-dennis-muilenburg-talks-max-nma-777x-and-automation [https://perma.cc/7UBU-N3SL].

sign, and pilots attempting to sort through a barrage of warnings take the wrong corrective action in many cases.[125]

b. Aggressive and Repeated Trim Inputs

A design change during the development of MCAS made the system much more assertive. While earlier versions had the capability of changing the stabilizer trim angle by a maximum of 0.6 degrees in 10 seconds, the system was subsequently redesigned to allow trim changes of up to 2.5 degrees in 10 seconds.[126] What is worse, on previous 737 aircraft, pulling back against a nose-down trim input would have had the effect of stopping the trim.[127] It is a natural reaction to pull back in response to an unexpected pitch down, but MCAS fought that reaction by aggressively reasserting the nose-down trim input.[128] The much stronger, more assertive version of MCAS on the Ethiopian Airlines and Lion Air aircraft seems obviously defective in design, but Boeing may have an argument to raise in defense of its engineering decisions.

Descriptions of the Ethiopian Airlines crew battling against MCAS run amok sound like a real-world version of HAL, the murderous computer in *2001: A Space Odyssey*. The flying pilot was pulling back on the control yoke and trying to trim nose-up. Why would the flight control system not let him? It seems perverse to incorporate flight control laws that run counter to instinctive inputs on the controls by pilots. One must keep in mind, however, that Boeing designed the 737 Max flight control system after accidents such as Air France 447, in which the flying pilot incorrectly (and inexplicably) held the stick full back in a deep stall for over three minutes.[129] The determined nose-down

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[125] *See* SIDNEY W.A. DEKKER, TEN QUESTIONS ABOUT HUMAN ERROR: A NEW VIEW OF HUMAN FACTORS AND SYSTEM SAFETY 152–54 (2005).

[126] *See* Nicas et al., *Boeing Built Deadly Assumptions into 737 MAX*, *supra* note 26.

[127] *See* Gates & Baker, *supra* note 23. Accident investigator and Boeing 777 captain Shem Malmquist writes:

> It is standard in the Boeing aircraft that the stabilizer trim can be stopped by moving the control column in the opposite direction. Aircraft designers assume that no pilot would intentionally trim the aircraft nose up while also pushing forward on the controls to pitch the aircraft down or vice versa.

Shem Malmquist, *The AOA Problem – What We Can Do About It*, AIRLINE SAFETY BLOG (Nov. 19, 2018), https://airlinesafety.blog/2018/11/19/the-aoa-problem-what-we-can-do-about-it/ [https://perma.cc/NT95-M553].

[128] *See* Gates & Baker, *supra* note 23.

[129] *See* WEBB & WALKER, *supra* note 100, at 99 ("It would be absolutely unthinkable for a pilot to pull back on the elevator from an extreme stalled attitude").

inputs made by MCAS were a feature, not a bug, of the system, relative to the foreseeable risk created by the human–machine interaction.[130] Previous accidents had shown that even professional flight crews do the wrong thing—perhaps due to psychological effects, such as the startle reflex and narrowing of focus, or perhaps due to a lack of training in high-altitude stall recognition and recovery. From the point of view of Boeing engineers, the foreseeable risk to be taken into account when designing the flight-control system of the 737 Max included the risk that pilots will fight existing stall-prevention systems, including stall warnings, stick shakers, and stick pushers.

The Third Restatement design-defect analysis is a risk–utility test. That means the assessment of whether there is a design defect related to MCAS depends to a significant extent on a precise specification of the risk the design is intended to prevent or mitigate. A systems approach to this analysis sees the risk as a property of the interaction between airplanes and flight crews in the aggregate. Arguably the feature of aggressive, repeated nose-down trim inputs was not a mistake made by the designers of the system but a response to prior accidents—and also to the fact that an increasing number of jetliners were being purchased and operated in the developing world. While airlines in many developed countries have long relied on the military and a robust civil aviation sector to provide basic training to pilots, there is a much smaller pool of already trained pilots in many parts of the developing world.[131] Boeing and its major competitor Airbus

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[130] *See* Travis, *supra* note 22 (observing that "not letting the pilot regain control by pulling back on the column was an explicit design decision.").

[131] It is important not to overgeneralize the training and competence of flight crews in the developing world. The captain of Ethiopian Airlines 302 was a high-time pilot and, by all accounts, a very proficient aviator. *See* Maggie Fick, *Youngest Captain, Loving Son: Ethiopian Pilots Honored in Death*, REUTERS (Mar. 20, 2019), https://www.reuters.com/article/us-ethiopia-airplane-pilots/youngest-captain-loving-son-ethiopian-pilots-honored-in-death-idUSKCN1R11LV [https://perma.cc/7VYP-554G]. However, his first officer is reported to have had only about 200 hours of total flying time, which is astonishingly low. *See* Christine Negroni, *Ethiopian Airlines, with a Tradition of Training Pilots, Wants to Become Africa's Leading Carrier*, N.Y. TIMES (Mar. 12, 2019), https://www.nytimes.com/2019/03/12/business/ethiopian-airline-crash-school.html [https://perma.cc/2RW5-KSGB]. Air France is a major Western European carrier that draws pilots from the French Air Force as well as the civilian aviation sector, but it experienced one of the most egregious incidents of pilot error in recent years. The pilot flying at the time of the crash of Air France 447 was a relatively inexperienced relief pilot, but the captain and first officer had significant flying experience. *See* Langewiesche, *The Human Factor*, *supra* note 20. What can be said in general, however, is that commercial airliner manufacturers are operating under

have made determined efforts to sell more aircraft in countries like Indonesia that are experiencing a booming demand for air travel but which are behind North America and Western Europe in producing trained flight crews.[132] Increasing reliance on automation to mitigate risks associated with deficient airmanship is a strategy employed across aviation generally. Ironically, however, Boeing considered the likelihood of a prompt, correct response to a trim runaway as one of the safeguards protecting against the possibility of an accident caused by an inadvertent MCAS operation.[133] Boeing's risk–utility analysis may have been hampered by these two inconsistent mindsets regarding the possibility of crew error. MCAS was designed to reduce the likelihood of accidents caused by poor airmanship, but Boeing's evaluation of the expected accident costs of the system depended on unrealistic assumptions about the performance of the average airline crew.

It makes no sense to think about the risk–utility balance of a product as designed—for example, the 737 Max with MCAS—without taking into account what is known about users of the product, their expectations of its performance, their training and experience, and the types of errors to which they are susceptible. However, the interaction between user performance and product safety goes both ways. It is clear that a product can incorporate safety features that mitigate risks created by foreseeable user errors. Pilots may sometimes get slow and too close to the stall margin; a rattle from the stick shaker will prevent the situation from developing into an actual loss of control. Perhaps less obviously, the presence of a safety feature may lead to complacency or inattention by users or erosion of user skills, which may increase the likelihood of a different type of risk.[134] This is

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the assumption that a growth area in their industry will be in parts of the world in which aircrew training standards, in the aggregate, are not what they are in the developed world.

[132] *See* Eric Lipton et al., *Diplomats Help Push Sales of Jetliners on the Global Market*, N.Y. TIMES (Jan. 2, 2011), https://www.nytimes.com/2011/01/03/business/03wikileaks-boeing.html [https://perma.cc/PV99-FZM6].

[133] *See* Gates & Baker, *supra* note 23; Nicas et al., *Boeing Built Deadly Assumptions into 737 MAX*, *supra* note 26 (quoting a Boeing vice president as telling a meeting of American Airlines pilots that MCAS is not a single point of failure system because "the function and the trained pilot work side by side and are part of the system").

[134] American Airlines training captain Warren VanderBurgh coined the term "Children of the Magenta Line" to describe automation-dependent pilots who had, mostly at the urging of airline training departments, become overly dependent on automation. *See* Editorial, *How to End Automation Dependency*, AVIATION WK. & SPACE TECH. (July 19, 2013), http://aviationweek.com/commercial-avia-

the phenomenon of systems accidents, in which the dynamic interaction between the safety features designed into a complex product and the experience of users over time with the product combine in unpredictable ways, complicating the manufacturer's risk–utility analysis.

A notorious accident illustrating this interaction between technology and human error is the crash of Asiana Flight 214 at San Francisco International Airport on July 6, 2013.[135] The flight crew was preoccupied with getting the aircraft down on the proper glidepath, using the flight management system for an automated approach, and failed to notice an alarming decrease in airspeed; the airplane crashed into the seawall short of the runway.[136] Significantly, the weather could not have been more benign and would have been suitable for a hand-flown approach.[137] The National Transportation Safety Board (NTSB) found that most Asiana crews did not hand-fly above 1,000 feet on approach and landing.[138] The airline "emphasized the full use of all automation and did not encourage manual flight during line operations."[139] As a result, there is a risk that pilots will become rusty in basic skills:

> By manually flying only the last 1,000 ft of an approach, pilots do not get to experience the necessary control inputs and feedback performance of the airplane that takes place in climbs, descents, turns, accelerations, decelerations, and configuration changes and do not develop or maintain an ability to "stay ahead" of the airplane, meaning the ability to anticipate the airplane's performance.[140]

The airline encouraged the use of automation because it believed it would increase safety, and in many respects, it probably did. But it led to the unintended consequences of eroding the

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tion/editorial-how-end-automation-dependency [https://perma.cc/4JM5-BSVU] (citing Captain VanderBurgh's "famous lecture" on the paradox of automation); *see also* Chuck Cali, *Masters of the Magenta – The Real Story*, AIR FACTS (July 13, 2016), https://airfactsjournal.com/2016/07/masters-of-the-magenta/ [https://perma.cc/G5KY-MVA8].

[135] *See generally* NAT'L TRANSP. SAFETY BD., NTSB/AAR-14/01, ACCIDENT REPORT: DESCENT BELOW VISUAL GLIDEPATH AND IMPACT WITH SEAWALL, ASIANA AIRLINES FLIGHT 214, BOEING 777-200ER, HL7742, SAN FRANCISCO, CALIFORNIA, JULY 6, 2013 (2014), https://dms.ntsb.gov/public/55000-55499/55433/563979.pdf [https://perma.cc/GYG5-ZNL7] [hereinafter ASIANA 214 REPORT].

[136] *See id.* at xi–xii.

[137] *See id.* at 30.

[138] *Id.* at 62–63.

[139] *Id.* at 102.

[140] *Id.* at 104.

ability of pilots to recognize and recover from an unstable situation.[141]

A dissenting member of the NTSB referred to Asiana 214 as a systems accident.[142] It is true that the crew failed to monitor airspeed, but that is because they had come to rely on the airplane's automation to provide airspeed control. As the dissenter argued, "insufficient flight crew monitoring of airspeed during the approach resulted, in part, from expectancy, increased workload, and automation overreliance."[143] In other words, a narrow causal focus on flight-crew error would fail to pick up the contributing factor of reliance on automation that led to the laxness in monitoring airspeed. Granted, the flying pilot misunderstood the operation of the autothrottles in the automation mode he had selected in order to expedite the descent, and granted, he and other crew members failed to keep a close eye on airspeed throughout the approach.[144] These are mistakes, and serious ones, but the crucial insight of systems thinking is these are not independent of the existence of automation and the foreseeable effect of automation usage on human skill and performance. The considerable safety advantages offered by flight deck automation may have the seemingly perverse but entirely foreseeable result of increasing the likelihood and gravity of other types of risks.

Evaluation of the 737 Max design is therefore not a simple matter of approving or disapproving of increasing levels of automation. There are feedback effects that must be taken into account. Without MCAS, a crew might have gotten slow in a climbing turn, added power without sufficient offsetting forward pressure on the yoke, and stalled the airplane as a result. The addition of MCAS mitigated that stall risk but created a new source of potential trim runaways. Mitigating that increased trim risk might have been a simple matter of retaining the behavior of the 737 NG, in which pulling back would stop nose-down trim. But the Air France 447 and Colgan 3407 accidents showed

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[141] The NTSB observed that the FAA has "acknowledged that autoflight systems are useful tools for pilots and have improved safety and workload management but cautioned that continuous use of autoflight systems could lead to degradation of the pilot's ability to quickly recover the aircraft from an undesired state." *Id.* at 74.

[142] *Id.* at 139 (NTSB member Robert L. Sumwalt concurring in part and dissenting in part, statement filed on July 1, 2014).

[143] *Id.*

[144] *See id.* at 126 (report's findings).

that crews confronted by a sudden unexpected anomaly might react inappropriately by fighting the automated systems that already existed to prevent a stall. Something more intrusive and aggressive might be needed to mitigate the risk of resisting automated systems, but a system that intervenes too vigorously creates its own characteristic risks—those that manifested in the Lion Air 610 and Ethiopian Airlines 302 accidents. The 737 Max will eventually return to service with a kinder, gentler MCAS. Boeing CEO Dennis Muilenburg has publicly committed to modifications including a single activation of MCAS, not a repeated activation that will fight repeated control inputs by the flight crew.[145] In effect, this is a design change that restores some of the traditional trust placed by manufacturers in the competence of pilots.

One hopes that there will not be an accident in the future that could have been prevented by the older, more aggressive MCAS.[146] However, the interaction between human error and the technological means of mitigating it is dynamic and unpredictable. The analysis of design defect needs to take this interaction into account. The right approach is not blind deference to manufacturers' risk–utility calculations but appreciation of the challenge of employing technological solutions to human error, which themselves can lead to new types of errors.

3. Relevance of FAA Approval of the Max Design

A great deal of reporting in the popular media has focused on the seemingly cozy relationship between Boeing and the FAA,

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[145] *See* Anselmo & Warwick, *supra* note 124; Scott McCartney, *Inside the Effort to Fix the Troubled Boeing 737 MAX*, WALL ST. J. (June 5, 2019), https://www.wsj.com/articles/testing-the-fix-for-the-troubled-737-max-11559772634 [https://perma.cc/8UTB-AHT2].

[146] Jeff Rachlinski suggested to me the possibility that Boeing may be "damned if it does, damned if it doesn't"—i.e., that it may be liable in an accident scenario in which a less-intrusive version of MCAS failed to override the incorrect control inputs of the flight crew—shows that liability may in fact be strict for certain products. He mentioned *Dawson v. Chrysler Corp.*, 630 F.2d 950, 957–59, 962 (3d Cir. 1980), in which a car manufacturer was held liable for a design that incorporated insufficient side-impact protection, even though the reason was to provide additional protection against the much more common scenario of a rear-impact collision. Is liability not strict in this case, if the jury is permitted to find the manufacturer liable even though it made the right risk–utility tradeoff, taking into account both side and rear impacts? The answer, I think, is that *Dawson* should be seen as a cautionary tale, and that courts should be somewhat reluctant to send cases to juries, or to allow jury verdicts to stand, where this type of iterated liability is a substantial possibility.

which is responsible for certifying aircraft designs as airworthy.[147] Unsurprisingly, the regulations defining the requirements for certification are complex and require the submission of reams of engineering data.[148] It is unrealistic to believe that a federal agency could afford to attract and retain engineering staff in all of the subdisciplines required to evaluate the compliance of a design with airworthiness standards. The FAA therefore recognizes Designated Engineering Representatives (DER), who may be employed by the manufacturer, to approve technical data on behalf of the FAA.[149] In general, conformity with federal or state safety regulations is not a defense to a design or warnings claim.[150] Compliance is some evidence that can be taken into account by the trier of fact, but it is not dispositive of the issue.[151] This is different from a defense based on preemption of state common law standards by federal regulations, although the arguments could be raised at the same time in a suitable case.[152] It reflects the traditional view that government-mandated standards are only a floor of safety, and that courts

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[147] *See, e.g.*, Dominic Gates, *Flawed Analysis, Failed Oversight: How Boeing, FAA Certified the Suspect 737 MAX Flight Control System*, SEATTLE TIMES (Mar. 21, 2019), https://www.seattletimes.com/business/boeing-aerospace/failed-certification-faa-missed-safety-issues-in-the-737-max-system-implicated-in-the-lion-air-crash [https://perma.cc/VM4M-SKJR]; Natalie Kitroeff et al., *The Roots of Boeing's 737 Max Crisis: A Regulator Relaxes Its Oversight*, N.Y. TIMES (July 27, 2019), https://www.nytimes.com/2019/07/27/business/boeing-737-max-faa.html [https://perma.cc/8M47-7YES]. It should be noted that the same issue would arise for a design certified by Airbus, Embraer, or Bombardier. There is nothing specific to Boeing's relationship with the FAA, as opposed to the certification process in general, that is suspicious. *See* Kitroeff et al., *supra*.

[148] *Aircraft Certification*, FED. AVIATION ADMIN., https://www.faa.gov/licenses_certificates/aircraft_certification/ [https://perma.cc/TRM7-JY9H] (last modified May 23, 2019).

[149] *See* 14 C.F.R. § 183.29 (1989); *see also* Fed. Aviation Admin., Order 8110.37F, Designated Engineering Representative Handbook 2-1–2-9 (2017), https://www.faa.gov/documentLibrary/media/Order/FAA_Order_8110.37F.pdf [https://perma.cc/3XGL-2XQB].

[150] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 4(b) (AM. LAW INST. 1998).

[151] *See id.*

[152] *See, e.g.*, Wyeth v. Levine, 555 U.S. 555, 559–73 (2009) (failure-to-warn products liability case considering both compliance with regulatory standards and federal preemption); Wilson v. Piper Aircraft Corp., 577 P.2d 1322, 1332 (Or. 1978) (Linde, J., concurring) (explaining the difference between these doctrines); *see also* Robert L. Rabin, *Reassessing Regulatory Compliance*, 88 GEO. L.J. 2049, 2053–60 (2000) (distinguishing the analytically similar but distinct doctrines of preemption and regulatory compliance).

may apply the common law defect standard in a way that requires manufacturers to do more than the minimum.

In some cases, however, the trial court may conclude that a regulatory standard is both a floor and a ceiling—that is, that the regulator got it just right, so that a product in compliance with the regulation should be deemed non-defective as a matter of law. As a comment to the Third Restatement emphasizes, however, this should be an unusual occurrence:

> Such a conclusion may be appropriate when the safety statute or regulation was promulgated recently, thus supplying currency to the standard therein established; when the specific standard addresses the very issue of product design or warning presented in the case before the court; and when the court is confident that the deliberative process by which the safety standard was established was full, fair, and thorough and reflected substantial expertise.[153]

The argument for a regulatory compliance defense would be, quite simply, considerations of comparative institutional competence.[154] Who is more likely to know whether the risk of an inadvertent MCAS deployment is adequately mitigated by existing flight-crew training in dealing with trim runaways—the FAA or a jury applying the design-defect and RAD standard? In the similarly complex field of toxic torts, involving issues of medicine, pharmacology, and epidemiology, courts have gotten it badly wrong in cases involving products such as the anti-morning-sickness pill Bendectin and silicone breast implants.[155] But of course one can also cite numerous examples of capture of regulatory agencies by powerful actors in the industries they regulate.[156] The backstop of potential tort liability is necessary to ensure that manufacturers cannot lobby or use the revolving door of em-

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[153] RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 4 cmt. e. The Restatement comment does not mention another consideration that may be the most significant—namely, whether the regulation was aimed at establishing a minimum standard or striking the optimal risk–benefit analysis. *See* Richard B. Stewart, *Regulatory Compliance Preclusion of Tort Liability: Limiting the Dual-Track System*, 88 GEO. L.J. 2167, 2173 (2000).

[154] *See, e.g.*, Peter Huber, *Safety and the Second Best: The Hazards of Public Risk Management in the Courts*, 85 COLUM. L. REV. 277, 334–35 (1985); W. Kip Viscusi et al., *Deterring Inefficient Pharmaceutical Litigation: An Economic Rationale for the FDA Regulatory Compliance Defense*, 24 SETON HALL L. REV. 1437, 1447–48 (1994).

[155] *See* Rabin, *supra* note 152, at 2061–64.

[156] *See* Teresa Moran Schwartz, *The Role of Federal Safety Regulations in Products Liability Actions*, 41 VAND. L. REV. 1121, 1147–52 (1988).

ployment between industry and government to beat back safety regulations that would prove too costly.

In the case of the 737 Max, there is considerable evidence suggesting not invidious corruption or even regulatory capture; rather, the FAA was simply overwhelmed by the task of reviewing the design of complex aircraft systems and had little choice but to defer to Boeing engineers.[157] The DER system is premised on the inability of the FAA to attract and retain qualified engineers in all of the subdisciplines involved in certifying a transport-category jetliner—engines, electronics, flight analysis, structural, and systems and equipment engineering.[158] The sometimes maligned dual-track system, in which manufacturers must obtain government approval and then face the possibility of *ex post* scrutiny of their design decisions by juries in the wake of an accident, may actually be functional in a context in which the regulator will inevitably be outmatched by the resources available to the manufacturer. Incentives to "pencil whip" test data or otherwise take shortcuts in the regulatory compliance process are mitigated by the possibility that documents revealed in discovery in a civil lawsuit could expose decisions that would be difficult to defend before a jury. Criticism of the civil jury system for lack of expertise are mostly well-taken, but conducting the certification process in the shadow of potential jury adjudication may not be a bad second-best system, in comparison with the hypothetical (but unattainable) system in which a regulator like the FAA had access to all the engineering talent that would be required to make reliable risk–benefit determinations. In any event, Boeing's assertion of a regulatory compliance defense will almost certainly be unsuccessful in light of the evidence of the departure of the process from the ideal of a "full, fair, and thorough" consideration.[159]

B. Information Defects: Inadequate Warnings and Instructions

The information-defect standard of the Third Restatement is unabashedly a negligence rule.[160] The manufacturer is liable if

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[157] *See* Gates & Baker, *supra* note 23; Kitroeff et al., *supra* note 147.

[158] *See* Fed. Aviation Admin., Designated Engineering Representative Handbook, *supra* note 149, at 2-1.

[159] *See supra* note 153 and accompanying text.

[160] *See* James A. Henderson, Jr. & Aaron D. Twerski, *Doctrinal Collapse in Products Liability: The Empty Shell of Failure to Warn*, 65 N.Y.U. L. Rev. 265, 269–70 (1990).

the foreseeable risks of a product "could have been reduced or avoided by the provision of reasonable instructions or warnings."[161] The reasonableness standard asks simply whether the information provided by the manufacturer was adequate to inform a user of the nature of an unknown hazard and the means available to avoid or mitigate that risk.[162] No warning need be given if the danger would be open and obvious to a reasonable user,[163] but no one could seriously contend that pilots would know of the presence of a flight control law that is supposed to operate in the background. The issue in the litigation will therefore be whether a reasonable manufacturer would have provided information about the presence of MCAS operating in the background as part of the 737 Max flight control laws. As we will see, the systems approach to accidents involving the interaction between users and product safety features is inescapable in the analysis of failure-to-warn claims.

1. Interaction Between Warnings and Design Analysis

Assume a risk associated with the interaction between a product and its users. Now assume there are two options for reducing that risk: redesigning the product to incorporate a safety feature or giving warnings to users about the risk and information on how to avoid it. In a frequently cited case, a city sanitation worker lost a foot to the powerful hydraulic press on the back of a garbage truck.[164] The manufacturer argued that obviousness was an implicit warning about the danger of getting the user's foot caught in the press.[165] However, the plaintiff pointed out that several redesigns were available that would have kept the user's foot at a safe distance from the press when it was operating (for example, a switch might have been located at a sufficient distance from the press that it would be impossible to get too close to it).[166] The Massachusetts Supreme Judicial Court wrote:

> An adequate warning may reduce the likelihood of injury to the user of a product in some cases. We decline, however, to adopt any rule which permits a manufacturer or designer to discharge

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[161] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2(c) (AM. LAW INST. 1998).

[162] *See id.* § 2 cmt. i.

[163] *Id.* § 2 cmt. j.

[164] Uloth v. City Tank Corp., 384 N.E.2d 1188, 1189 (Mass. 1978).

[165] *Id.* at 1191.

[166] *See id.*

> its total responsibility to workers by simply warning of the dangers of a product. . . .
>
> . . . .
>
> . . . If a slight change in design would prevent serious, perhaps fatal, injury, the designer may not avoid liability by simply warning of the possible injury.[167]

This case appears to state a clear priority principle, i.e., that design changes are required before warnings will serve to avoid the manufacturer's liability. But notice an important qualification on that rule lurking in the passage quoted above—"[i]f a *slight* change in design would prevent serious . . . injury."[168] It may be the case that avoiding or mitigating a risk would require an extensive design change or at least one that is greater than "slight."

The best way to understand the priority principle is that if a RAD is available, the manufacturer must adopt it and may not simply warn its way out of liability. The tricky aspect of this way of understanding the interaction between design and warnings is that the possibility of eliminating or reducing the risk with a suitable warning is *itself* a factor in the analysis of whether a redesign is a RAD.[169] Putting it in terms made prominent by Guido Calabresi, who is the cheaper cost-avoider: (1) the manufacturer, by means of a redesign; or (2) a suitably well-informed user?[170] It could be the case that additional safety features are not as effective as relying on the exercise of reasonable care by users. In that case, the proposed redesign would not be a RAD. An important refinement on the Calabresi analysis, as applied to products liability, is that the costs to be avoided include the disutility to users of the redesign.[171] It is possible to imagine all kinds of redesigns that increase safety but at an unacceptable cost in terms of reducing the utility of the product to its users. A BB gun, for example, could be made safer by shooting only soft projectiles, not metal balls, but then it would be a lot less fun. A reasonable balance between manufacturer and user responsibility might therefore be to require the manufacturer to warn users to wear eye protection (if that risk is not open and obvious) but to allow it to continue using the design that shoots metal balls.

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[167] *Id.* at 1192.

[168] *See id.*

[169] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. f (AM. LAW INST. 1998).

[170] *See* GUIDO CALABRESI, THE COSTS OF ACCIDENTS: A LEGAL AND ECONOMIC ANALYSIS 244–65 (1970).

[171] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. f.

The MCAS design feature was intended to mitigate a risk that was introduced by the manufacturer into the design of the 737 Max.[172] It is important not to read the priority principle as necessarily *mandating* a design change in this case. It may have been sufficient to provide a reasonable warning of the slightly increased risk of an inadvertent stall created by the size and placement of the engines on the Max, as distinct from the 737 NG. (Boeing may now wish it had done just that). Determining whether some design change like MCAS is required takes the analysis back to the concept of the RAD. Boeing had to determine *ex ante* whether the 737 Max would have a design defect related to the placement of the engines and thus an increased likelihood of a stall in certain flight regimes. Doing so requires thinking about the possibility of a redesign like MCAS and asking whether the redesign would be a RAD. The answer may be negative if the redesign introduced disutilities that outweigh the reduction in expected accident losses. The insight of a systems approach to this issue is that the risk–utility comparison may refer to multiple risks arising from different sources, yet they are linked to each other. The introduction of MCAS reduces the risk of inadvertent stalls, which is already fairly low for the most part due to training, good airmanship, and commitment to following standard procedures. The reduction in stall risk, however, is associated with a heightened risk of trim runaway. The likelihood of an accident related to this risk can also be mitigated by training, airmanship, and following standard procedures. However, doing so may require the provision of additional information by the manufacturer about the operation of the safety feature. Thus, we must consider Boeing's liability for failure to provide warnings and instructions concerning MCAS.

2. Information-Defect Claims Related to MCAS

The duty of the manufacturer regarding information (warnings and instructions) is simple to state: It must provide instructions and warnings that are reasonably adequate to inform product users of an unknown risk and to take steps to avoid or mitigate that risk.[173] What is reasonable, however, varies according to a number of factors, including the skill and experience of

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[172] *See* Broderick et al., *supra* note 11.

[173] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2(c) & cmt. i.

users and the severity of the unknown risk.[174] Liability should not be imposed for failure to warn of trivial risks, and much of the reason for this limitation is the concern for swamping information about serious risks in a sea of warnings about inconsequential hazards. It is easy to find examples of silly warnings attached to everyday products.[175] Many manufacturers apparently regard the cost of providing additional warnings as trivial and a rational safeguard against the possibility of a failure-to-warn claim. In theory, a plaintiff might be able to establish that he or she overlooked a warning of an unknown, serious hazard because it was part of a long list of warnings for known or minor risks. As much as courts talk about the problem of "warnings clutter,"[176] however, I am not aware of any successful claim for damages based on this type of theory. Over-warning therefore seems likely to continue to be the strategy employed by manufacturers.

In light of this observation, it is telling that Boeing chose to say nothing about the presence and operation of MCAS, which (according to the plaintiffs) presents a risk that even well-trained flight crews are unlikely to be aware of. Boeing's response is that pilots already trained on 737 NG aircraft, and for that matter of any transport-category jet, can be expected to know of the risk of a trim runaway and have committed the procedure for dealing with the problem to memory.[177] But some of the features of the integration of MCAS with the flight control system of the 737 Max may present hazards that a reasonable pilot may not be aware of. One of the plaintiffs' strongest failure-to-warn arguments will relate to the difference in behavior between the NG and the Max when the pilot pulls back on the yoke in response to nose-down trim. The two aircraft designs differ in the way they interact with the flight crew.[178] Put simply, the NG allows the pilot to override the nose-down trim input, while the Max assumes the pilot's back pressure on the yoke is

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[174] *See id.* § 2 cmt. i.

[175] Examples include: a sticker on a baby stroller warning, "Remove child before folding"; a brass fishing lure with a three-pronged hook on the end with a label indicating, "Harmful if swallowed"; or a cardboard car sunshield completely covering the windshield that warns, "Do not drive with sunshield in place."

[176] *See, e.g.*, Cotton v. Buckeye Gas Prods. Co., 840 F.2d 935, 937–39 (D.C. Cir. 1988); Broussard v. Continental Oil Co., 433 So. 2d 354, 358 (La. Ct. App. 1983).

[177] *See* Gates & Baker, *supra* note 23. During the flight test and certification process for the 737 Max, Boeing assumed that a crew would recognize and deal appropriately with a trim runaway within three seconds. *See id.*

[178] Fehrm, *supra* note 15.

itself a problem to be corrected by aggressive nose-down trim.[179] Pilots who became accustomed to dealing with uncommanded trim inputs by simply holding back pressure against the trim would likely not realize that, instead of shutting off, the automatic nose-down trim would only become more determined to follow the logic of its programming. More drastic action is required, and pilots have no way of knowing this.

Soon after the Lion Air 610 accident, the FAA issued an Emergency Airworthiness Directive (AD),[180] requiring 737 Max operators to add details to the trim runaway procedure spelled out in the existing Aircraft Flight Manual (AFM). The new language specifically alerts crews to the operation of MCAS: "Note: The 737-8/-9 [i.e., the Max] uses a Flight Control Computer command of pitch trim to improve longitudinal handling characteristics. In the event of erroneous Angle of Attack (AOA) input, the pitch-trim system can trim the stabilizer nose down in increments lasting up to 10 seconds."[181] It then directs pilots to use the existing runaway trim procedure, including pulling the STAB TRIM CUTOUT switches, but it emphasizes that higher-than-usual control forces may be necessary and also advises that pilots may need to use nose-up trim to bring the aerodynamic forces under control.[182] In other words, this may be something more than the garden-variety trim runaway.

The dollar cost of adding this warning is trivial, and there is no issue of warnings clutter when the additional information would be added to an already lengthy and detailed AFM. So why did Boeing avoid providing this information from the beginning? The answer, again, is related to its marketing strategy of selling the 737 Max as capable of being flown by crews type rated on the 737 NG, without extensive differences training. Admitting the existence of MCAS—disclosed in the language of the AD as "a Flight Control Computer command of pitch trim to improve longitudinal handling characteristics"[183]—would have prompted questions from airlines about the functioning of this

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[179] *See id.*

[180] FED. AVIATION ADMIN., (AD) 2018-23-51, EMERGENCY AIRWORTHINESS DIRECTIVE (Nov. 7, 2018), https://www.faa.gov/aircraft/air_cert/continued_operation/ad/type_pub/type_emerg [https://perma.cc/29JG-SYA6] (final rule proposed at 83 Fed. Reg. 63,561 (Dec. 11, 2018)).

[181] *Id.* at 4.

[182] *See id.* See also the discussion of the "roller coaster" recovery technique, *supra* note 44.

[183] FED. AVIATION ADMIN., EMERGENCY AIRWORTHINESS DIRECTIVE, *supra* note 180, at 4.

system and the need for additional simulator training. Boeing apparently assumed that pilots would react to any pitch trim anomaly by using the STAB TRIM CUTOUT switches, not by holding pressure on the control yoke against the trim.[184] The trouble is, the design for the existing 737 NG aircraft permitted the "pull against trim" work-around, and pilots became familiar with it.[185] It may not have been the approved procedure in the AFM, but it is certainly not unusual for pilot folklore to include unofficial procedures for accomplishing tasks.

The failure-to-warn test is doctrinally and conceptually no different from ordinary negligence analysis. The question is whether a reasonable person in the manufacturer's position would have provided the warning. There is a tacit question lying behind the reasonableness analysis, namely whether to permit the consideration of purely self-interested reasons for acting. In a sense, Boeing did act reasonably if one considers the reported fact that it was obligated to pay customers $1 million per airplane sold if airlines had to provide supplemental training for 737 Max crews.[186] Surely a reasonable person would want to avoid a financial penalty that sizeable. It is clear from an economic approach to negligence that the reasonable person standard is indifferent between costs to the manufacturer and expected accident losses.[187] Even at common law, however, there is arguably no requirement that the reasonable person act altruistically. The leading American mid-twentieth century torts treatise—i.e., before the rise of law and economics—quoted approvingly from a 1927 law review article stating that, applying negligence analysis, "an actor 'is permitted . . . to condemn the interests of others to his own use to the extent that he is permitted to act without liability although knowing that his conduct involves a substantial chance of injuring persons or property of others.' "[188] In a straightforward Hand formula analysis, if the likelihood of an inadvertent MCAS response outside its intended range of operation is as small as Boeing thought it was, it might have considered the "*PL*" term of the formula to be con-

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[184] *See* Fehrm, *supra* note 15.

[185] *See id.*

[186] *See* Gates & Baker, *supra* note 23.

[187] *See, e.g.*, Richard A. Posner, *A Theory of Negligence*, 1 J. LEGAL STUD. 29, 33–34 (1972).

[188] 3 FOWLER V. HARPER ET AL., THE LAW OF TORTS § 16.4, at 395 (2d ed. 1986) (quoting Warren A. Seavey, *Negligence – Subjective or Objective?*, 41 HARV. L. REV. 1, 8 n.7 (1927)).

siderably less than the $1 million per airplane it stood to lose if it disclosed the existence of the system to purchasers.[189] Although this approach to negligence analysis has its critics,[190] it is close enough to the conventional wisdom that Boeing cannot necessarily be considered greedy or heartless for considering its own potential economic losses in connection with the information about MCAS. Having said that, however, there is no requirement that a jury perform the kind of impartial economic cost–benefit analysis recommended by Posner and his ilk.[191] A jury may well decide that a reasonable person would have provided this information.

Boeing's further defense to a failure-to-warn claim will likely be that if the pilots of Lion Air 610 and Ethiopian Airlines 302 had promptly done what the AFM instructed them to do, they would have disabled MCAS and stopped the nose-down trim inputs before the plane's airspeed increased to the point that a recovery was impossible. This is not an argument on the duty or standard of care for warnings. There is no question that Boeing had a duty to warn and should have provided reasonably adequate information about the MCAS-related risk and how to mitigate it. Rather, the argument pertains to causation, which presents subtle issues in many products liability cases, particularly those involving systems accidents. The failure to provide information about MCAS did have a causal connection to the accident, but at least in the case of Lion Air 610, the accident would not have occurred without the failure of the flight crew to follow the procedure specified in the AFM.[192] This means causal responsibility is shared between the manufacturer and user, and it must be apportioned by the trier of fact.

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189 *See supra* notes 89–90 and accompanying text.

190 *See, e.g.*, Leslie Bender, *A Lawyer's Primer on Feminist Theory and Tort*, 38 J. LEGAL EDUC. 3, 31 (1988). *See generally* MAYO MORAN, RETHINKING THE REASONABLE PERSON: AN EGALITARIAN RECONSTRUCTION OF THE OBJECTIVE STANDARD (2003).

191 *See* Stephen G. Gilles, *The Invisible Hand Formula*, 80 VA. L. REV. 1015, 1045–46 (1994).

192 Although the final accident report is not yet available, some reporting based on the cockpit voice recorder (CVR) recovered from the wreckage of Ethiopian Airlines 302 suggests that the crew promptly cut out the stabilizer trim and attempted to manually retrim nose up. *See* Ahmed et al., *supra* note 6. If these reports are accurate, it may be that MCAS is defective in design because its nose-down trim inputs were so aggressive that there is no conceivable way for the crew to override the system before the airspeed got too high to preclude manually retrimming.

C. Causation, Superseding Causation, and the Relevance of User Error

Products liability claims are subject to the same factual and legal (proximate) causation requirements as ordinary negligence claims.[193] The conceptual confusion discussed above, resulting from occasional stubborn insistence that products liability claims are "really" strict liability, has sometimes caused courts to introduce new terminology and draw unwarranted distinctions, e.g., between "proximate" and "producing" cause.[194] But once all of the language and categories are parsed carefully, it turns out that the causation analysis is just the same as the familiar negligence approach. First, the plaintiff must show that "but for" the product defect—whether the manufacturer's failure to adopt a RAD (design defect) or the manufacturer's provision of inadequate warnings or instructions—the accident more likely than not would not have occurred.[195] Where there are multiple causes, the "but for" requirement changes to an analysis of whether each individual cause was a substantial factor in bringing about the accident.[196] As long as the accident would not have occurred without any particular event, each event is *a* cause, even if not *the* cause.[197] Second, the plaintiff must show legal causation, in the sense that the accident that occurred is of a type that, considered *ex ante*, would have required the adoption of a RAD or the provision of additional warnings and instructions.[198] There are many cases in which the defendant might argue a lack of proximate cause because the harm that occurred was not "within the risk" that required a different design or information from the manufacturer. There is no plausible argument along these lines in connection with the 737 Max. The risk requiring the adoption of a RAD is exactly the risk that manifested itself in the Lion Air 610 and Ethiopian Airlines 302

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193 *See* Restatement (Third) of Torts: Prods. Liab. § 15 (Am. Law Inst. 1998) ("Whether a product defect caused harm to persons or property is determined by the prevailing rules and principles governing causation in tort."). The familiar proximate cause analysis now goes under the heading of "Scope of Liability" in the Restatement (Third) of Torts: Liab. for Physical and Emotional Harm § 29 (Am. Law Inst. 2010). I expect the old, familiar term to hang on for a long time with lawyers and judges, however.

194 *See, e.g.*, Union Pump Co. v. Allbritton, 898 S.W.2d 773, 775 (Tex. 1995).

195 *See* Restatement (Third) of Torts: Liab. for Physical and Emotional Harm § 26 cmt. b.

196 *See id.* § 27 & cmt. b.

197 *See id.* § 26 cmt. d.

198 *See* Restatement (Third) of Torts: Prods. Liab. § 16 cmt. b.

accidents—loss of control resulting from a sudden, uncommanded control input.

The claims of an overly aggressive and undisclosed MCAS are causally connected in the right way to engineering and marketing decisions made by the manufacturer. But other claims may fail on factual causation. For example, some of the complaints filed in connection with these accidents cite the absence of the "AOA Disagree" warning light as a defect in the product.[199] Under the circumstances of either accident, where the crews were confronted with an unexpected and dramatic nose-down pitch attitude, even if they had been warned of a disagreement between the two AOA sensors, that information would be irrelevant to solving the immediate problem unless they had also been informed previously about the operation of MCAS and its reliance on AOA data. In other words, a claim based solely on the absence of the AOA Disagree light as the theory of defect would fail for a lack of evidence of factual causation.[200]

Non-lawyers sometimes misunderstand causation and believe that if one event was a causal factor, then other potentially responsible parties are off the hook. Boeing's stock price briefly went up when news reports indicated that a bird strike may have disabled the captain's side AOA sensor on the Ethiopian 302 accident aircraft.[201] If these reports were accurate, it would be true in a sense the bird strike "caused" the accident, but so did: (1) the choice by engineers to trigger the operation of MCAS based on data from only one AOA sensor; (2) the failure of the flight crew to recognize the runaway trim and cut out the electric pitch trim in a timely fashion; and (3) Boeing's decision not to inform pilots about the existence of MCAS, which might have made them a little less likely than they otherwise might have been to recognize and resolve the runaway trim. If investors thought the news about the bird strike somehow absolved Boeing of a causal role in the accident, they failed to understand the doctrine of concurrent causation. The unfortunate bird, the crew, and the manufacturer all made causal contributions to the accident. It may even have been necessary for all of them to oc-

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[199] *See, e.g.*, Complaint at 28–29, Vdovic v. Boeing Co., No. 2:19-cv-01455-DCN (D.S.C. May 17, 2019); Complaint at 7, K'Obien v. Boeing Co., No. 1:19-cv-03285 (N.D. Ill. May 15, 2019).

[200] *See* RESTATEMENT (THIRD) OF TORTS: LIAB. FOR PHYSICAL AND EMOTIONAL HARM § 26 cmt. g.

[201] *See* Josephs, *US Aviation Officials Think a Bird Strike Was Factor in 737 Max Crash*, *supra* note 38.

cur.[202] In aviation, the phenomenon of jointly necessary causes is often referred to as the "Swiss cheese" model of accidents—all the holes in slices of Swiss cheese need to line up for the hole to go all the way through, so preventing an accident is often a matter of taking only one of several jointly necessary causes out of the event.[203] For liability purposes, anyone responsible for a slice of the cheese may be liable to the plaintiff; the trier of fact will apportion percentages of responsibility on the basis of a number of factors.[204]

As is well known, tort liability evolved from a regime in which one actor was deemed *the* cause of a mishap, through the development of comparative fault, to one in which multiple parties can be assigned percentage shares of liability based on the jury's assessment of their comparative responsibility.[205] Courts applying traditional all-or-nothing contributory negligence principles expressed the firm resolution not to diminish the plaintiff's responsibility by assigning some liability to the defendant.[206] Of course, the flip side was also the case—by assigning all the liability to the contributorily negligent plaintiff, the defendant was off the hook entirely. Starting with the leading California Supreme Court case *Li v. Yellow Cab Co.*,[207] courts began to recognize that multiple parties could bear responsibility simultaneously for an accident. Unlike some of the innovations of the 1960s tort revolution, comparative fault caught on almost everywhere, and now the great majority of U.S. jurisdictions instruct the factfinder to apportion liability between the plaintiff and defendant or defendants, and among joint tortfeasors.[208] Obviously there is no possibility of finding the plaintiffs—the relatives of passengers killed in the Lion Air 610 and Ethiopian Airlines 302 crashes—contributorily negligent. The relevant apportionment of responsibility will be between the jointly liable

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[202] *See* RESTATEMENT (THIRD) OF TORTS: LIAB. FOR PHYSICAL AND EMOTIONAL HARM § 26 cmt. e.

[203] *See* REASON, THE HUMAN CONTRIBUTION, *supra* note 99, at 95–103.

[204] *See* RESTATEMENT (THIRD) OF TORTS: APPORTIONMENT OF LIAB. § 8 (AM. LAW INST. 2000).

[205] *See id.*

[206] *See, e.g.*, Butterfield v. Forrester (1809) 103 Eng. Rep. 926 (casebook classic stating that "[o]ne person being in fault will not dispense with another's using ordinary care for himself.").

[207] 32 P.2d 1226, 1243 (Cal. 1975).

[208] *See* RESTATEMENT (THIRD) OF TORTS: APPORTIONMENT OF LIAB. § 7 reporters' note cmt. a. *See generally* Robert D. Cooter & Thomas S. Ulen, *An Economic Case for Comparative Negligence*, 61 N.Y.U. L. REV. 1067 (1986).

tortfeasors of Boeing, possibly component parts suppliers, and the airlines vicariously for the negligence (if any) of their employees.

It may be the case that pilots who immediately recognized the unexpected pitch down as a trim runaway and pulled the STAB TRIM CUTOUT switches could have recovered from the erroneous MCAS deployment. It is always important, however, to remember that reasonable care, for the purposes of comparative fault analysis, does not require performance at the very highest level.[209] When confronted by a sudden and unexpected emergency, recovery may require some combination of skill, training, discipline, teamwork, leadership, and pure dumb luck.[210] A jury may properly be reluctant to conclude that the Lion Air 610 and Ethiopian Airlines 302 crews fell below the applicable standard of care. Even if they did, however, the result would only be to assign some percentage of responsibility to them (and vicariously to their employers), not to exonerate Boeing altogether for liability for design defect or failure to warn. Similarly, superseding causation functions in products liability law just as in negligence.[211] A subsequent event does not break the causal chain and absolve the manufacturer from responsibility for a design defect or failure to warn if that subsequent event is one of the risks that required a redesign or better information, respec-

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[209] *See* RESTATEMENT (SECOND) OF TORTS §§ 283, 464 & cmt. f (AM. LAW INST. 1965).

[210] *See* REASON, THE HUMAN CONTRIBUTION, *supra* note 99, at 221–36 (analyzing in detail several near-catastrophes prevented or at least mitigated by extraordinary human responses). Applying Reason's analysis to US Airways Flight 1549, the so-called "Miracle on the Hudson," it is certainly the case that the captain and first officer were well-trained, highly experienced, and worked well together in dealing with the emergency. *See* Patrick Smith, *The Heroics of Captain Sully and the "Miracle on the Hudson,"* ASK THE PILOT, https://www.askthepilot.com/question-answers/sully-and-heroics/ [https://perma.cc/8HJJ-7ASK] (last visited Oct. 30, 2019). There is still an element of luck, however, in that the loss of both engines occurred during daylight hours, with good visibility, within gliding distance of a suitable (but unusual) landing site, and a flotilla of boats already on the scene to rescue the occupants. *See id.* As airline pilot and widely read aviation blogger Patrick Smith observes, while conceding Captain Sullenberger's excellent decision making and coordination with First Officer Jeff Skiles, "[h]ad the engines quit on a day with low visibility, or over a crowded part of the city beyond gliding distance to the river, the result was going to be an all-out catastrophe. No amount of skill would matter." *Id.*

[211] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 15 reporters' note cmt. a (AM. LAW INST. 1998).

tively.[212] Even on the assumption that one of the accident crews was blameworthy, in the sense of falling below the standard of care for professional aviators for not recognizing or reacting quickly enough to the trim runaway, their negligence in no way supersedes Boeing's liability because one of the risks that required the company to strike the right risk–utility balance regarding MCAS is the risk that the stall-prevention system will activate at an inappropriate time, requiring flight-crew intervention. In proximate causation terms (of which the analysis of superseding cause is a part), the possibility of an erroneous human reaction is "within the risk" that requires the adoption of a RAD or the provision of adequate warnings and instructions.

The term "misuse" has taken on a kind of talismanic quality for manufacturers who seek to use the plaintiff's misuse of a product as a complete defense. The Third Restatement recognizes that misuse is one of those terms in tort law, like assumption of risk, that is susceptible to a wide range of meaning.[213] The manufacturer's duty is to design the product and provide information in light of its foreseeable uses. If the user does something so bizarre with the product that no reasonable manufacturer could have foreseen it, there is no duty to design around or provide warnings concerning the risk thereby created.[214] That is one sense of misuse, akin to implied primary assumption of risk.[215] It would be unusual to encounter this sense of misuse in connection with the design of a complex product presenting many opportunities for foreseeable misuse. In aviation, these would include slipups such as taking off with incorrect flap settings, forgetting to put down the gear for landing, or letting the airspeed decay and stalling the aircraft. But a more ordinary sense of misuse, in the sense of failure to use reasonable care, may well be one of the risks that the manufacturer is obligated to foresee and safeguard against, either with a RAD or adequate warnings. Misuse in that sense would be like implied secondary assumption of risk and would be simply another fac-

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[212] *See* RESTATEMENT (THIRD) OF TORTS: LIAB. FOR PHYSICAL AND EMOTIONAL HARM § 34 (AM. LAW INST. 2010); RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 16 cmt. b.

[213] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. p & reporters' note cmt. p.

[214] *See id.* § 2 cmt. p.

[215] *See* RESTATEMENT (SECOND) OF TORTS § 496C (AM. LAW INST. 1965).

tor to be taken into account by the trier of fact in apportioning responsibility among multiple actors.[216]

There is no viable defense of misuse or superseding causation to the most serious allegations of design defect and insufficient warnings. The flight-crew errors, if errors existed (and from some reports at least, the Ethiopian 302 crew did everything right),[217] are just the sort of possibility that requires getting the risk–utility balance right or providing adequate warnings or instructions. Provided that Boeing is prima facie liable on a design-defect or failure-to-warn theory, then the most it can expect by way of relief from liability is to have some responsibility apportioned to the airline, which is vicariously liable for the negligence of its employees. That is the case even if the Lion Air and Ethiopian Airlines crews had mishandled the emergency which, again, is not at all clear. However, the possibility of flight-crew error prompted or exacerbated by a design or information defect raises the question of how, exactly, the trier of fact should assign shares of responsibility. The Restatement (Third) of Torts: Apportionment of Liability offers the following set of factors for consideration:

> The nature of each person's risk-creating conduct includes such things as how unreasonable the conduct was under the circumstances, the extent to which the conduct failed to meet the applicable legal standard, the circumstances surrounding the conduct, each person's abilities and disabilities, and each person's awareness, intent, or indifference with respect to the risks.[218]

For example, a jury may conclude that even if the crew of one of the 737 Max accident aircraft did not handle the emergency in exactly the way they were supposed to, their conduct was not all that unreasonable under the circumstances. These circumstances include: (1) the sudden onset of the emergency; (2) its relatively unusual nature (compared with something that is practiced frequently in the simulator); (3) the fact that it was encountered at low altitude (giving them less time to work the problem); and (4) the Max design's removal of techniques that 737 NG pilots had learned to use in dealing with trim runaways. The jury may therefore apportion relatively little responsibility

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[216] *See* 62A AM. JUR. 2D *Products Liability* § 1267 (2019).

[217] *See supra* note 192.

[218] RESTATEMENT (THIRD) OF TORTS: APPORTIONMENT OF LIAB. § 8 cmt. c (AM. LAW INST. 2000).

to the flight crew, even though they may have fallen below the applicable standard of care. On the other side, Boeing's awareness of the risks and its attitude toward them may be a factor in a substantial apportionment of liability to the company.

D. Bottom Line

Assuming something like MCAS was necessary to ensure sufficient longitudinal stability to satisfy FAA certification standards for the 737 Max,[219] two available, technologically feasible design changes would have been RADs. These are: (1) relying on data from two AOA sensors; and (2) a single application of nose-down trim, not repeated inputs.[220] The first design feature would have reduced the risk an erroneous pitch down and the second would have prevented the system from fighting the flight crew. Note, however, that the second redesign would have somewhat reduced the utility of MCAS as an anti-stall system. It would still be necessary to rely on flight crews to recognize that they were approaching a stall and respond accordingly. There is no 100% technological solution available, at least with existing technology, to mitigate the risk of another Air France 447 or Colgan 3407 accident. Because a RAD is available, by definition, the 737 Max has a design defect for which Boeing is liable. Although evidence of the company making these changes will be inadmissible at trial to prove a defect,[221] it is useful for the purpose of analysis to observe what changes will be made to the aircraft's design before it reenters service.

The company is also very likely to be liable for the plaintiffs' warnings and information claims. Although the risk of trim runaways is already known, pilots needed to know that MCAS was not an ordinary trim runaway and could not be managed using work-around procedures that had been developed over time by 737 NG crews, and also that the aerodynamic forces involved in a recovery would be higher than expected. Even if a trier of fact concludes that the Lion Air and Ethiopian Airlines crews fell below the applicable standard of care—which seems unlikely due to the unusual nature of the MCAS activation as compared

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[219] *See* Gates & Baker, *supra* note 23.

[220] *See* discussion *supra* section III.A.2.a–b.

[221] *See* Fed. R. Evid. 407 (referring to liability for design and warnings defects, among other causes of action, which may not be proven through the introduction of evidence of subsequent remedial measures).

with ordinary trim runaways—their negligence would serve only as a damages-reducing factor, not a complete defense.

On the substantive law of products liability, Boeing is therefore looking at the possibility of substantial liability exposure resulting from these two accidents. It may be able to succeed in moving to dismiss on the grounds of *forum non conveniens*,[222] but the procedural aspects of the litigation are not the subject of this Article. The Montreal Convention governs the liability of the air carriers in the two 737 Max accidents in question, and it creates a rule of strict liability for injuries resulting from an accident.[223] However, the Convention permits the carriers to assert an action for contribution against Boeing.[224] Serious settlement negotiations will undoubtedly have to await the resolution of motions to dismiss and other jurisdictional maneuvering, but on the underlying law, there is little doubt that Boeing is facing liability for design defect and failure to warn.

IV. SYSTEMS THINKING AND SYSTEMS RISKS IN PRODUCTS LIABILITY LAW

Rapid advances in artificial intelligence research and progress in fields such as autonomous cars have created a sense that risks resulting from human error can be designed out of complex undertakings, including aviation. The attitude of *Wall Street Jour-*

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[222] *See, e.g.*, Lleras v. Excelaire Servs. Inc., 354 F. App'x 585, 587 (2d Cir. 2009) (dismissing for *forum non conveniens* in favor of Brazil in action arising out of collision between a business jet and an airliner over Brazil); *In re* Air Crash Over Mid-Atlantic on June 1, 2009, 760 F. Supp. 2d 832, 847 (N.D. Cal. 2010) (litigation arising out of Air France 447 accident dismissed on *forum non conveniens* grounds). The adequacy of the alternative forum—in this case, presumably, Ethiopia and Indonesia—is an element the defendant must establish in order to justify dismissal. *See In re Air Crash*, 760 F. Supp. 2d at 839. Interestingly, in an air crash case subject to the New Zealand Accident Compensation Commission (no fault) scheme, the Ninth Circuit concluded that the no-fault remedy was adequate, and New Zealand was a suitable alternative forum for the claim against an American manufacturer of avionics equipment and a Canadian aircraft manufacturer. *See* Lueck v. Sundstrand Corp., 236 F.3d 1137, 1141–43 (9th Cir. 2001). The controlling Supreme Court precedent is *Piper Aircraft Co. v. Reyno*, 454 U.S. 235 (1981).

[223] *See* Convention for the Unification of Certain Rules for International Carriage by Air art. 21, May 28, 1999, T.I.A.S. No. 13,083, 2242 U.N.T.S. 309.

[224] *See In re* Air Crash at Lexington, Ky., August 27, 2006, No. 5:06-CV-316-KSF, 2008 WL 440293, at *2–3 (E.D. Ky. Feb. 12, 2008) (applying Article 37 of the Montreal Convention and permitting the air carrier Comair to file third-party complaints for contribution).

nal opinion writer Holman Jenkins offers an optimistic view of the promise of technology:

> Passengers might never be ready to board a plane that doesn't have a human crew member, but that should not stop designers from asking whether planes wouldn't already be safer (as well as cheaper and simpler) if not required to be built around a system element ([aka] the pilot) whose memory and computational resources are far less than a laptop computer's.
>
> This is not to denigrate the skills and instincts of a great pilot, but notice that it's been a decade since the skills and instincts of the world's greatest chess masters have been able to beat a computer.[225]

To which the obvious response is that one thing computers cannot do is improvise a solution to a previously unimaginable problem, like Captain Chesley "Sully" Sullenberger's decision to land on the Hudson River, rather than trying to turn back to LaGuardia, when both engines failed after ingesting a flock of Canada geese in the climbout.[226] Whatever a computer would have done in that situation, it almost certainly would not have been to attempt a water landing on the Hudson, which turned out to be the only sensible option available.[227] Not every accident is Colgan 3407, where taking the human operator out of the loop seems in hindsight like a good idea, but then again, neither is every incident the "Miracle on the Hudson," where the surviving passengers are all thanking their lucky stars that it was a human flying the plane, not a computer. More to the point, the *Wall Street Journal* editorial displays a naïve confidence that a risk-mitigation strategy can be devised that relies either on increased competence by human operators or increasingly capable automation.[228] In all likelihood, the best risk-mitigation strategy is a combination of human and machine competence, but

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[225] Holman W. Jenkins, Jr., *Boeing vs. Pilots?*, WALL ST. J. (May 31, 2019), https://www.wsj.com/articles/boeing-vs-pilots-11559341016 [https://perma.cc/7ZMZ-UWV3].

[226] This is a point made by several letters in response to Jenkins's column. *See* Letters, *You Need a Human Pilot When the Airplane's Computers Fail*, WALL ST. J. (June 5, 2019), https://www.wsj.com/articles/you-need-a-human-pilot-when-the-airplanes-computers-fail-11559763986 [https://perma.cc/28UL-WYSF]; *see also* William Langewiesche, *Anatomy of a Miracle*, VANITY FAIR (May 5, 2009), https://www.vanityfair.com/culture/2009/06/us-airways-200906 [https://perma.cc/TKM7-AEFN].

[227] *See* Langewiesche, *Anatomy of a Miracle*, *supra* note 226 (giving a pilot's perspective on Captain Sullenberger's decision making).

[228] *See You Need a Human Pilot When the Airplane's Computers Fail*, *supra* note 226.

this strategy presents its own analytical challenges for tort and products liability law.

The 737 Max accidents underscore something that is well known in the aviation community but may not be appreciated by lawyers, namely that a mitigation technique, whether technological or human-centered, aimed at reducing a primary risk can create or exacerbate a distinctive type of secondary risk.[229] For example, some evidence was developed by the NTSB following the crash of Northwest Flight 255 at the Detroit Metropolitan Airport that flight crews had gotten into the habit of using a designed-in safety feature, i.e., the takeoff-configuration warning system, as a way of ensuring proper flap settings for takeoff instead of the proper procedure of using standardized flows and checklists.[230] The most direct cause of the accident was pilot error—the failure to set takeoff flaps and the failure to follow pretaxi and pre-departure checklists that required verification of the proper flap setting[231]—but the secondary risk that flight crews may get sloppy with procedures is foreseeable based on the inclusion of the takeoff-configuration warning system as a means of reducing the primary risk of incorrect takeoff flap settings.[232] (Returning to the Swiss cheese model of accidents, the warning system malfunctioned at the same time that a crew missed the flap setting on the pre-departure checklist—the holes of the cheese slices had to line up for the accident to occur.)[233]

A more complex and subtle example is the Air France 447 accident, in which a flight crew believed that a highly automated aircraft was "stall proof" and therefore the rapid descent it was experiencing could not have been the result of a stall.[234] It is true that the Airbus A330 incorporated advanced envelope pro-

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[229] *See* PERROW, *supra* note 2, at 132.

[230] *See* NAT'L TRANSP. SAFETY BD., NTSB/AAR-88/05, AIRCRAFT ACCIDENT REPORT: NORTHWEST AIRLINES, INC., MCDONNELL DOUGLAS DC-9-82, N312RC, DETROIT METROPOLITAN WAYNE COUNTY AIRPORT, ROMULUS, MICHIGAN, AUGUST 16, 1987, at 64 (1988). There was some evidence that the crew was having an "off day," and the first officer may have been distracted by other duties at the moment he ordinarily would have set the flaps for takeoff. *Id.* at 56–60. Be that as it may, this was still a pretty big mistake to make. Even in small planes, proper takeoff flap setting is one of those items on the "things that can kill you" mental checklist that every pilot learns to verify twice or three times prior to taking the runway for departure.

[231] *Id.* at 68.

[232] *See id.* at 64.

[233] *See supra* text accompanying note 203.

[234] *See* Langewiesche, *The Human Factor*, *supra* note 20.

tection systems designed to prevent pilots from getting anywhere close to the critical angle of attack of the wing. The trouble is that the protections afforded by those systems were lost when air data became unreliable due to in-flight icing. The important observation here is that by designing the primary risk of a stall out of the system, Airbus engineers may have increased a secondary risk of flight-crew complacency or inattention to basic principles of aeronautics.[235] If the crew had simply maintained a set pitch attitude and power setting, the plane would have flown out of the area of icing, the automated systems would have returned to their original functionality, and several hours later, everyone would have walked off the plane in Paris.[236] The surprising reaction of the crew to the momentary flight control anomaly was not truly unforeseeable; rather, it was the predictable result of the increasingly pervasive emphasis by manufacturers and airlines on technological solutions to risks associated with human–machine interactions.

Product-related risks arise out of the interaction between the product and the user's experience with it. This sounds like an obvious point, but lawyers sometimes focus only on risks as a property of the product without thinking about the safety aspects of the product in connection with the way it is typically used. The risk and utility aspects of a product's design, which determine whether a redesign is a RAD under section 2(b) of the Third Restatement,[237] are both features of the user's needs and expectations regarding the performance of the product. Over time, the experience of a number of users with the product may reveal either previously unknown risks or a pattern of errors in the use of the product that potentially call for a technological solution. The introduction of technology, including automating tasks formerly performed by humans, then creates new challenges for humans interacting with the product. Airline pilot and human-factors researcher Sidney Dekker rightly observes: "Increasing automation transforms hands-on operators into supervisory controllers, into managers of a suite of automated and other human resources. With their new work come new vulnerabilities, new error opportunities. With [ ] new interfaces . . . come new pathways to human–machine coordination

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[235] *See* PALMER, *supra* note 20, at 179–82.

[236] *See id.* at 160.

[237] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2(b) (AM. LAW INST. 1998).

breakdown."[238] Automation is only one type of defensive action against human error that can be employed by product designers. Alerts, such as the "AOA Disagree" indication or a takeoff-configuration warning horn, can also function to interrupt the link between human error and an accident. Designers and users can also rely on more direct means of reducing human error, such as training, supervision, following standardized procedures, cross-checking by other crew members, and the like.[239]

Given the availability of means of engineering out human error, a strong claim sounding in systems thinking would be Don Norman's assertion that there is really no such thing as human error, only bad design.[240] As he rightly observes, human errors fall into predictable patterns, and a product designer armed with information about the foreseeable types of errors likely to be made by users of their products should be able to improve the product's design to reduce the likelihood or mitigate the effect of the errors.[241] For example, many World War II-era airplanes had handles for the flaps and landing gear that were located close together, and both were topped with similarly shaped knobs.[242] Naturally, a careful pilot would intend to verify that she is selecting either the gear or flaps up or down, but it is predictable that in a busy phase of flight, the pilot might get distracted and grab the wrong handle, which could make things exciting.[243] This risk can be mitigated, however, by topping the flap handle with a wedge-shaped knob and the gear handle with

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[238] DEKKER, TEN QUESTIONS ABOUT HUMAN ERROR, *supra* note 125, at 152.

[239] *See, e.g.*, WEBB & WALKER, *supra* note 100, at 106 (claiming that, as compared with technological advances, "the stabilized approach," a requirement that is part of all airline standard operating procedures, "has saved more lives than any invention or innovation since aviation began.").

[240] NORMAN, *supra* note 2, at 162–69; *see also* SIDNEY DEKKER, JUST CULTURE: BALANCING SAFETY AND ACCOUNTABILITY 131 (2007) (contrasting the "old view," in which the cause of accidents was assumed to be the human involved, and the response was to "suspend, retrain, admonish, [or] charge him or her," with the new view that human error is a symptom of trouble within the system, not a cause).

[241] *See* NORMAN, *supra* note 2, at 167–68.

[242] DEKKER, TEN QUESTIONS ABOUT HUMAN ERROR, *supra* note 125, at 7; Paul M. Fitts & R.E. Jones, *Analysis of Factors Contributing to 460 "Pilot-Error" Experiences in Operating Aircraft Controls*, *in* SELECTED PAPERS ON HUMAN FACTORS IN THE DESIGN AND USE OF CONTROL SYSTEMS 332, 338–39 (H. Wallace Sinaiko ed., 1961).

[243] *See* Fitts & Jones, *supra* note 242, at 340–41. Bringing up the flaps immediately after takeoff, without sufficient airspeed, could lead to a stall and a crash if the stall is not immediately recovered. On the other hand, the landing gear are retracted shortly after takeoff, as soon as a positive rate of climb is established, to reduce drag and allow the plane to accelerate to its best climb speed.

a wheel-shaped knob, providing a tactile cue to the pilot.[244] This inexpensive, relatively unobtrusive design change could do more to mitigate risk than continuing to rely on pilots not to mess up. In the modern era, the emphasis on standardized procedures like flow patterns, callouts, checklists, and crew resource management take as given that a certain amount of inattention or sloppiness is residual in even the best, most well-intentioned pilots.

One downside of applying Norman's approach to products liability law is the loss of focus on the performance of human operators of complex systems. If there really is no such thing as human error, only an inadequate design, then the legal system could potentially fail to send liability signals to airlines that create the right incentives for training and supervision. A response to this possibility would, in theory, be to create an "acoustic separation" between the adjudication of liability and the training of pilots.[245] Going back to the Asiana 214 crash in San Francisco, it may be the case that the 777 autoflight system is unnecessarily complicated, and one could understand the crew being confused about the effect of the vertical mode they selected on the operation of the autothrottles.[246] A trier of fact apportioning responsibility between the airline and the manufacturer might accordingly reduce the share of fault assigned to the crew. However, the jury's reduction in the crew's share of responsibility would have the unfortunate effect of undercutting what should be a perfectly clear and unambiguous message sent to all pilots at all times: Watch your airspeed on approach! If they had kept that very basic principle in mind, the accident would not have occurred.

From the point of view of decision rules, addressed to a trier of fact, it makes sense to consider the way fallible humans respond when having to rapidly navigate a confusing interface with a machine. Trust in automation builds over time as human operators observe the automated systems performing appropriately; however, the result may be less effort devoted to monitoring. As Norman says, it makes no sense to merely blame human error and continue doing things the same way we have always done them if it is possible to redesign the product to mitigate

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[244] *See id.* at 340, 342.

[245] *See, e.g.*, Meir Dan-Cohen, *Decision Rules and Conduct Rules: On Acoustic Separation in Criminal Law*, 97 HARV. L. REV. 625, 631 (1983).

[246] *See supra* notes 135–44 and accompanying text.

the risk of human error.[247] Perhaps what is required is something like a "context-dependent low energy alerting system" to provide an additional line of defense in the event that the flight crew fails to notice rapidly decaying airspeed.[248] However, that perspective fails to capture an important commitment of pilots and airlines to striving continually for better performance. From the point of conduct rules, intended to influence the safety-related behavior of people in the real world, there should be no compromise on a fundamental aspect of airmanship like airspeed monitoring. It is drilled into the heads of pilots not to make excuses, not to abdicate safety-related judgments to someone else, and to cultivate a "buck stops here" attitude regarding safety. The automation is complicated? Too bad—take the time to figure it out, follow standard procedures exactly, and click off the automation and hand-fly if necessary. Systems thinking may lead to an erosion of this highly functional mindset.

The need for acoustic separation may be overstated in this context, however. Boeing and its customer airlines have significant reputational interests of their own in maximizing safety. The Asiana 214 crew was widely ridiculed for stuffing up a visual approach in perfect weather. Two days after the accident and long before the NTSB report was released, recognizing the importance of public confidence in the company's safety, the airline's CEO had already committed to improving pilot training in basic hand-flying skills.[249] One function of products liability law is to send deterrent signals, but it is by no means the only source of incentives to improve safety. It is also not clear that a systems approach to evaluating liability would have the effect of exonerating the crew. The Third Restatement calls for the trier of fact to apportion responsibility according to factors such as "how unreasonable the conduct was under the circumstances, the extent to which the conduct failed to meet the applicable legal standard, the circumstances surrounding the conduct, [and] each person's abilities and disabilities."[250] Boeing could be expected to argue forcefully at trial that habitual overreliance on automa-

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[247] *See* NORMAN, *supra* note 2, at 162.

[248] *See* ASIANA 214 REPORT, *supra* note 135, at 130.

[249] *See, e.g.*, Ian Johnston, *Asiana Airline Chief Says It Plans to Improve Pilot Training After San Francisco Crash*, NBC NEWS (July 9, 2013), http://usnews.nbcnews.com/_news/2013/07/09/19370461-asiana-airline-chief-says-it-plans-to-improve-pilot-training-after-san-francisco-crash [https://perma.cc/4UNC-GLGT].

[250] RESTATEMENT (THIRD) OF TORTS: APPORTIONMENT OF LIAB. § 8 cmt. c (AM. LAW INST. 2000).

tion is itself conduct that falls below the applicable standard of care. The pilot flying in the Asiana 214 crash was reported to have said that he found visual approaches "very stressful" and was confused by the 777 autoflight system.[251] Apportionment rules permit the trier of fact to find the airline (vicariously) liable for the lion's share of damages in that case. But Norman's insight is still important. Systems thinking ensures that Boeing cannot simply write this accident off as caused by egregious pilot error. Each component of the system—the human and the machine—must be scrutinized to see whether it is possible to improve the way they work together. The NTSB recommended, among other things, that Boeing "develop enhanced 777 training that will improve flight-crew understanding of autothrottle modes and automatic activation system logic through improved documentation, courseware, and instructor training."[252] It made this recommendation notwithstanding its conclusion that the probable cause of the accident was

> the flight crew's mismanagement of the airplane's descent during the visual approach, the pilot flying's unintended deactivation of automatic airspeed control, the flight crew's inadequate monitoring of airspeed, and the flight crew's delayed execution of a go-around after they became aware that the airplane was below acceptable glidepath and airspeed tolerances.[253]

A weaker version of a systems approach yields a different and more general insight for products liability law dealing with human–machine interactions. To see the point, start with the standard economic analysis of contributory negligence.[254] On this approach, liability rules should be constructed that minimize the total social cost, in the form of the aggregate of precau-

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[251] Stephen Pope, *Asiana 214 Pilot Found Visual Approach 'Very Stressful,'* FLYING (Dec. 12, 2013), https://www.flyingmag.com/technique/accidents/asiana-214-pilot-found-visual-approach-very-stressful [https://perma.cc/NEV9-D2JQ]. The major takeaway for pilots from the famous "Children of the Magenta Line" video is that if you find yourself in a situation like the Asiana 214 crew—getting low and slow on short final—the *only* acceptable response is to click off the autopilot and autothrottles and make the plane do what you want it to do. *See How to End Automation Dependency*, *supra* note 134.

[252] NAT'L TRANSP. SAFETY BD., SAFETY RECOMMENDATION A-14-039, at 1 (July 16, 2014), https://www.ntsb.gov/safety/safety-recs/recletters/A-14-037-051.pdf [https://perma.cc/3NZW-BYLR].

[253] ASIANA 214 REPORT, *supra* note 135, at 129.

[254] *See generally* A. MITCHELL POLINKSY, AN INTRODUCTION TO LAW AND ECONOMICS 47–50 (3d ed. 2003); John Prather Brown, *Toward an Economic Theory of Liability*, 2 J. LEGAL STUD. 323 (1973); David Haddock & Christopher Curran, *An Economic Theory of Comparative Negligence*, 14 J. LEGAL STUD. 49 (1985).

tion costs by potential defendants (manufacturers, in products liability), precaution costs by potential plaintiffs (product users), and residual accident costs.[255] The standard model treats comparative negligence as a partial defense, in the sense of a liability-allocation rule, once the negligence of the defendant (a design or information defect in products liability litigation) and the failure of the plaintiff to use reasonable care have been established.[256] The economic case for comparative fault over contributory negligence, or vice versa, relies on the *ex ante* incentives created by either of those rules.[257] The key premise in the analysis is that the deviation by the defendant and the plaintiff from the applicable standard of care can be assessed independently by the court, so that each party potentially faces a penalty in the form of its share of the expected accident costs.[258] Only then can each party determine the marginal level of spending on accident prevention.

Complex systems involving interactions between machines and human operators pose a challenge to this model of *ex ante* incentive creation because of the dynamic relationship between, on the one hand, features of the product's design and information provided by the manufacturer that are sensitive to patterns of foreseeable user error, and on the other hand, user behavior that is shaped by the product's design and the information provided by the manufacturer. Something that starts out as a safety feature, and may be justified on efficiency grounds on that basis, may subsequently become a source of a new risk that is different in kind and greater in magnitude than the original risk to be mitigated. Go back to the example of Northwest 255.[259] There is a risk associated with the operation of any airline jet that an improper flap setting could cause a crash on takeoff. What risk-mitigation strategy should be adopted, thinking from the point of view of minimizing aggregate social costs? There are a couple of obvious options: (1) McDonnell-Douglas, the manufacturer of the MD-80 aircraft, could design a takeoff-configuration warning system that caused a horn to blare if a flight crew pushed up the power beyond a certain point with an improper flap setting; or (2) flight crews could use ordinary care by adhering to standard procedures and making disciplined use of checklists. Stan-

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[255] *See* Haddock & Curran, *supra* note 254, at 54–55.

[256] *Id.* at 56.

[257] *See id.* at 70.

[258] *See id.* at 56.

[259] *See supra* notes 230–32 and accompanying text.

dard economic analysis would consider the marginal costs of (1) and (2), and seek to establish liability rules that put the onus on the cheapest cost-avoider in the scenario. An armchair Calabresian least-cost-avoider analysis might emphasize the likelihood that even a well-intentioned crew could get interrupted in the middle of running a checklist and inadvertently skip a critical item. A takeoff-configuration warning system would mitigate this risk. The upshot in terms of liability rules would therefore be that the takeoff-configuration warning is a RAD, and an aircraft lacking that design feature is defective. Furthermore, a flight crew that missed the flap setting on the checklist would bear either no or a lesser share of the responsibility for the accident. But what about the phenomenon of crews becoming complacent and dependent on the takeoff-configuration warning? There is a lurking accident risk associated with the possibility of the failure of the warning system. That risk would ordinarily be relatively inconsequential because a crew using reasonable care would run all the necessary checklists and catch an improper flap setting. If the presence of the warning system tends to erode caretaking over time, however, the residual risk associated with failure of the warning system increases in magnitude.

A straightforward economic analysis of design defect and comparative fault has difficulty with dynamic effects such as automation dependency and complacency. Doctrinally, the problem is not one of causation;[260] rather, it is one of making the initial determination of whether the manufacturers or the users have deviated from the applicable standard of care. From the economic approach, each actor is expected to make a utility-maximizing tradeoff on the assumption that it will be required to internalize any residual accident costs. The problem of inaccurate adjudication of liability is well known in law and economics.[261] An actor may take excessive precautions in order to create a margin of error if it believes a fact finder is likely to err in assessing compliance with the standard of care.[262] Systems effects create an additional complication, however, by making expected accident costs into a moving target. A precaution taken by the manufacturer at time t_1 may be efficient in light of ex-

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[260] *Cf.* Maytal Gilboa, *Multiple Reasonable Behaviors Cases: The Problem of Causal Underdetermination in Tort Law*, 25 LEGAL THEORY 77, 87–88 (2019).

[261] *See, e.g.*, ROBERT COOTER & THOMAS ULEN, LAW AND ECONOMICS 316–20, 343–45 (3d ed. 2000).

[262] *See id.* at 320, 344.

pected user behavior at that time.[263] But it may have the effect of inducing riskier user behavior at time t_2 as users relax their own caretaking in reliance on the precaution. One might respond that the manufacturer must continuously reevaluate a product's design and may be required to adopt additional precautions at t_2 to take account of observed changes in user behavior. But by now, the manufacturer will be thinking, we have seen this movie, and whatever we do at t_2 is going to lead to some new and as-yet unanticipated risk at time t_3. How should the manufacturer perform the calculation of expected accident costs to determine whether an additional precaution is required under these circumstances?

It may be the case that, as Abraham and Rabin argue regarding autonomous vehicles, the concept of a RAD is so indeterminate that a negligence-based approach is no longer workable.[264] They advocate for a regime of absolute manufacturer liability—basically an insurance scheme—for all injuries resulting from autonomous vehicle accidents.[265] In the case of other highly complex products prone to system effects, a similar conclusion may be warranted, but it also may be the case that the liability regime is there already. In most of the cases of commercial aviation accidents in which automated systems and crew error are both causally involved, a plaintiff's design-defect claim would likely get past summary judgment, at which point the manufacturer would be motivated to settle. Moreover, as noted above in connection with the acoustic separation argument, the *ex ante* decision making of the manufacturer will already be dominated by reputational concerns and a genuine commitment to safety. The possibility of tort judgments is a factor in evaluating design changes such as MCAS, but manufacturers are already aiming at an accident rate of zero, rather than seeking an economically efficient level of precaution-taking. In its public statements about the 737 Max, Boeing has not sought to minimize its obligation to design the safest possible product, and all indications are that when it returns to service, the defects in the aircraft will have been rectified. Arguably the choice of liability rule is important here only as a decision rule, not a conduct rule.

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[263] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. a (AM. LAW INST. 1998).

[264] *See* Abraham & Rabin, *supra* note 1, at 144.

[265] *See id.* at 153–55.

The difficulty remains, however, with applying the decision rule that apportions liability between the manufacturer and airlines in systems accidents. The black letter law is clear that the conduct of both parties should be compared in terms of the extent of their deviation from the applicable standard of care.[266] With the standard of care being a moving target, this comparison may be difficult. As with many theoretical difficulties in tort law, however, it may be finessed in practice by simply instructing the jury to make the comparison based on the evidence in the record. Experts will have testified to the ways in which the design could have been improved and the flight crew could have performed better. Based on this testimony, the jury will come to a rough allocation of responsibility. This may be theoretically unsatisfying, but it rightly avoids the strong claim that there is no such thing as user error, only an inadequate design. To go back to James Reason's Swiss cheese metaphor, most systems accidents require the alignment of holes in many slices of cheese. The existing law of products liability and apportionment of responsibility establishes an imprecise legal approximation of the Swiss cheese model of accidents. Courts must take care, however, to craft jury instructions that focus the attention of jurors on the interaction between would-be safety features and foreseeable human error. Something that looks like an egregious instance of human error may, in fact, be an understandable adaptation to a design feature that was originally intended to enhance safety. In the case of the 737 Max, for example, flight crews may have become accustomed to the 737 NG work-around of holding back pressure on the yoke against a nose-down trim input. The resulting failure to follow the runaway trim checklist is therefore less of a deviation from the applicable standard of care than it initially appears. When assessing deviation from the applicable standard of care, a trier of fact should be informed that risks cannot be divided neatly into product defects and human error. Rather, these two sources of risk influence each other in complex ways. A properly instructed jury should be able to handle the task of allocating responsibility, particularly with the assistance of expert testimony that focuses on the interaction between products and users.

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[266] *See* RESTATEMENT (THIRD) OF TORTS: APPORTIONMENT OF LIAB. § 8 cmt. c (AM. LAW INST. 2000).

V. CONCLUSION

Here is a confident prediction: The 737 Max design will be modified, the airplane will return to service, and in a couple of years, no one will have a second thought, upon boarding a 737, about whether it is a Max or an NG. Boeing has already paid substantial amounts voluntarily to compensate families of the Lion Air 610 and Ethiopian Airlines 302 passengers,[267] and it will likely agree to hefty settlements if the U.S.-based products liability lawsuits are not dismissed on *forum non conveniens* or other grounds. It may have contractual agreements with purchasers, including airlines and leasing companies, entitling them to compensation for losses due to product defects.[268] The economic costs to the company will be significant, but considering the $60.7 billion in revenue of the Boeing Commercial Airplanes division in 2018,[269] one would expect that the company and its shareholders will do just fine. In the long-run perspective, these two accidents will be remembered as tragic and avoidable but not unprecedented in the history of commercial aviation.[270] Why, then, bother writing an article about the 737 Max?

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[267] *See* Dominic Gates & Steve Miletich, *Boeing's $100 Million Pledge for 737 MAX Crash Victims Sparks Criticism and Questions*, SEATTLE TIMES (July 3, 2019), https://www.seattletimes.com/business/boeing-aerospace/boeing-will-give-100-million-to-max-crash-victims-families-and-communities [https://perma.cc/KQ29-G9KS].

[268] Pure economic losses are not recoverable in tort actions alleging product defects and instead are handled by the Uniform Commercial Code. *See* East River S.S. Corp. v. Transamerica Delaval, Inc., 476 U.S. 858, 872–74 (1986); RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 21 cmt. a. American Airlines reportedly is looking at a $350 million loss in connection with the grounding of its 737 Max fleet. *See* Aaron Gregg & Douglas MacMillan, *American Airlines Expects to Lose $350 Million Because of 737 Max Grounding*, WASH. POST (Apr. 26, 2019), https://www.washingtonpost.com/business/2019/04/25/southwest-airlines-grapples-with-financial-fallout-boeing-max-grounding [https://perma.cc/4286-WZDZ].

[269] *See* Press Release, Boeing, Boeing Reports Record 2018 Results and Provides 2019 Guidance (Jan. 30, 2019), https://boeing.mediaroom.com/2019-01-30-Boeing-Reports-Record-2018-Results-and-Provides-2019-Guidance [https://perma.cc/HLX2-ZFZW].

[270] Other commercial airliners have suffered comparable rashes of accidents and regulatory scrutiny. The McDonnell Douglas DC-10 experienced three fatal crashes soon after its introduction into commercial service, prompting its grounding for design changes. It reentered service, however, and proved to be safe and reliable over its lifetime. *See, e.g.*, Tom Richardson, *Remembering the DC-10: End of an Era or Good Riddance?*, BBC NEWS (Feb. 24, 2014), https://www.bbc.com/news/uk-england-birmingham-26259236 [https://perma.cc/RNE2-4753]; *DC-10 Nicknames and Reputation – Was It Really that Dangerous?*, AIRWAYS MAG. (Feb. 21, 2014), https://airwaysmag.com/airlines/dc-10-nick-names [https://perma.cc/XJ9U-4GKA]. Boeing's 787 Dreamliner program was initially marred

The answer is that we will see many more design- and information-defect issues arising from human–machine interactions. For example, while automakers and technology companies predict the capability to deploy fully autonomous cars by 2020 or 2021,[271] for the next decade or so, it seems reasonable to predict that most technologically advanced vehicles will require some degree of human monitoring of the driving environment and their performance.[272] But there is considerable research showing that humans are terrible at the task of monitoring systems over long periods of time and intervening if necessary to prevent a hazardous situation from developing.[273] Somehow designers of semiautonomous vehicles will have to find ways of coping with human cognitive limitations and the foreseeable patterns of human error that result from them. The design-defect analysis of an accident involving a semiautonomous vehicle must there-

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by a series of electrical fires, resulting in the grounding of all 787s. *See, e.g.*, Umair Irfan, *How Lithium Ion Batteries Grounded the Dreamliner*, SCI. AM. (Dec. 18, 2014), https://www.scientificamerican.com/article/how-lithium-ion-batteries-grounded-the-dreamliner [https://perma.cc/7L56-LGDC]. After a modification to the battery design, the aircraft returned to service and has experienced (to the best of my knowledge) only one additional incident. *See* Christine Negroni, *Boeing Dreamliner's Lithium-Ion Battery Fails on United Flight to Paris*, FORBES (Dec. 1, 2017), https://www.forbes.com/sites/christinenegroni/2017/12/01/dreamliners-beleaguered-lithium-ion-battery-creates-problem-on-united-flight-to-paris/#33591e178513 [https://perma.cc/TW8T-RTQJ]. However, pilots still refer to the 787 as "Sparky."

[271] *See* Karen Hao, *The Three Challenges Keeping Cars from Being Fully Autonomous*, MIT TECH. REV. (Apr. 23, 2019), https://www.technologyreview.com/s/613399/the-three-challenges-keeping-cars-from-being-fully-autonomous/ [https://perma.cc/B5GF-Y7DB].

[272] The now-standard taxonomy of levels of automation was established by SAE International, and is based on "who does what, when." *See* U.S. DEP'T OF TRANSP., NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., FEDERAL AUTOMATED VEHICLES POLICY: ACCELERATING THE NEXT REVOLUTION IN ROADWAY SAFETY 9 (2016). SAE Level 5 is full autonomy with no expectation of driver intervention. *Id.* The two levels of high but not full automation are SAE Levels 3 and 4, defined respectively "as [Level 3] can both actually conduct some parts of the driving task and monitor the driving environment in some instances, but the human driver must be ready to take back control when the automated system requests" and Level 4 "can conduct the driving task and monitor the driving environment, and the human need not take back control, but the automated system can operate only in certain environments and under certain conditions." *Id.*

[273] THOMAS B. SHERIDAN, HUMANS AND AUTOMATION: SYSTEM DESIGN AND RESEARCH ISSUES 69–70 (2002).

fore consider the vehicle and the human as a system, with each component playing a role in risk creation and mitigation.[274]

More generally, the 737 Max accidents illustrate the limits of technological utopianism. It is undoubtedly true that replacing human pilots (or drivers, in the case of autonomous vehicles)[275] with automated systems has the potential to reduce the risk of certain types of accidents. But automation tends to create different, offsetting risks, as well as foreclosing the possibility of accident avoidance through human creativity and improvisation. The aggregate balance of risk and utility may very well be in favor of increasing automation. The analysis of product defects and comparative fault proceeds at the margin, however, and any given innovation in technology must be assessed for its net contribution to the utility of the product, including its safety aspects. This analysis, in turn, must take into account the ways in which humans interact with the technology and adapt to its presence, sometimes in ways that are detrimental to safety. Systems thinking is familiar in commercial aviation, so the 737 Max accidents are a useful case study illustrating the linkage between human performance and the safety features of products. They show that safety is seldom a matter of focusing on the product or the user in isolation but must consider the dynamics of human–machine interaction. From that perspective, it is apparent that the training and evaluation of users must include a thorough understanding of the functioning of automated systems, and the design of products must take into account the foreseeable risks posed by human cognitive limitations. The existing law of products liability can take this interaction into account, but it is important for courts and scholars not to look at product design and human error in isolation, and to always consider them as elements of a system. The applicable standard of care for both manufacturers and users must be understood in relation to the other component of the system (human or machine), its capabilities and limitations, and the way in which risks and mitigation strategies interact. Systems accidents do not call

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[274] *See* Abraham & Rabin, *supra* note 1, at 140 (predicting that "driver 'takeover' will often be central to safe operation [of semiautonomous vehicles], and driver-takeover issues may be central in products liability litigation").

[275] The National Highway Traffic Safety Administration reports that 94% of automobile accidents are caused by human error or decision making. *See Automated Vehicles for Safety*, NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., https://www.nhtsa.gov/technology-innovation/automated-vehicles [https://perma.cc/EK6L-DEVW] (last visited Oct. 31, 2019).

for a wholesale reform of tort principles, but they do demand careful application by judges and juries who are sufficiently well informed about the limits of machine and human performance.