DESIGN-INDUCED ERRORS IN COMPUTER SYSTEMS

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I. INTRODUCTION: NORTHWEST FLIGHT 255

Northwest Airlines Flight 255 departed from the gate at 8:32 p.m. on August 16, 1987. One hundred forty-nine passengers and six crewmembers were on board.[1] The crew of Flight 255 had previously landed at Detroit Metropolitan Wayne County Airport[2] to disembark several passengers and to board new passengers for the continuing flight.[3] The next scheduled stop was Phoenix, Arizona.[4] Santa Ana, California was its final destination.[5]

Flight 255 taxied out on to the runway and awaited clearance for takeoff:

> At 2042:11,[6] the local controller cleared flight 255 to taxi into position on runway 3C and to hold. He told the flight there would be a 3-minute delay in order to get the required "in-trail separation behind traffic just departing." At 2044:04, flight 255 was cleared for takeoff.
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> The CVR [Cockpit Voice Recorder] recording showed that engine power began increasing at 2044:21 . . . and that the first officer called 100 knots at 2044:45.6. At 2044:57.7, the first officer called "Rotate," and, at 2045:05.1, the stall warning stick shaker activated and continued operating until the CVR recording ended. At 2045:09.1, 2045:11.4, 2045:14.3, and, 2045:17.1, the aural tone and voice warnings of the supplemental stall recognition system (SSRS) also activated. Between 2044:01 and 2045:05.6, the CVR recording did not contain any sound of the takeoff warning system indicating that the airplane was not configured properly for takeoff.
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> After flight 255 became airborne it began rolling to the left and right. Witnesses estimated that the bank angles during the rolls varied

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1. NATIONAL TRANSPORTATION SAFETY BOARD, BUREAU OF ACCIDENT INVESTIGATION, AIRCRAFT ACCIDENT REPORT—NORTHWEST AIRLINES, INC., MCDONNELL DOUGLAS DC-9-82, N312RC, DETROIT METROPOLITAN WAYNE COUNTY AIRPORT, ROMULUS, MICHIGAN, AUG. 16, 1987, at 1 (1988) [hereinafter NORTHWEST ACCIDENT REPORT].
2. *Id.*
3. *Id.*
4. *Id.*
5. *Id.*
6. Times are represented in military time. For example, 2042:11 is equivalent to 8:42:11 p.m.

from 15° to 90°. Some witnesses stated that the airplane wings leveled briefly and then banked to the left just before the left wing hit a light pole in a rental car lot. Most witnesses did not see fire on the airplane until it was over the rental car lot. The first officer of the Northwest airplane parked on taxiway "A" testified that flight 255 was intact until the left wing struck the light pole in the auto rental car lot. After the wing struck the pole, he saw what appeared to be "a four-to five-foot chunk of the wing section . . ." fall from the airplane. He did not see any fire on the airplane until after it struck the light pole and then he saw "an orange flame. . . ." emanating from the left wing tip section.

After impacting the light pole, flight 255 continued to roll to the left, continued across the car lot, struck a light pole in a second rental car lot, and struck the side wall of the roof of the auto rental facility in the second rental car lot. Witnesses stated that the airplane was in a 90° left-wing-down attitude when it struck the roof and that it continued rolling and was still rolling to the left when it impacted the ground on a road outside the airport boundary. The airplane continued to slide along the road, struck a railroad embankment, and disintegrated as it slid along the ground. Fires erupted in airplane components scattered along the wreckage path. Three occupied vehicles on the road and numerous vacant vehicles in the auto rental parking lot along the airplane's path were destroyed by impact forces and or fire.[7]

Of the 149 passengers who remained on Flight 255, the accident killed all but 1, a 4-year-old child[8] who suffered serious injuries.[9] All 6 crewmembers were killed as well.[10] On the ground 2 people were killed,[11] 1 suffered serious injuries[12] and 4 suffered minor injuries.[13]

The National Traffic Safety Board (NTSB) Accident Report discussed the professional experience of the two pilots:

The Captain.—The 57-year-old captain was hired originally by West Coast Airlines on October 3, 1955. . . . During his 31 years [of commercial airline service], the captain [had flown] seven different [commercial] airplanes ranging from the McDonnell Douglas DC-3 to the Boeing 757 (B-757).

. . . .

Virtually all of the interviewed first officers and other captains who had flown with the captain described him as a competent and capable pilot. . . . One first officer stated that the captain had a reputation "as a strict, by-the-book pilot who would not tolerate any deviation from standard procedures."

7. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 3-4.
8. *Id.* at 4.
9. *Id.*
10. *Id.*
11. *Id.*
12. *Id.*
13. *Id.*

> . . . .
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> *The First Officer.*—The 35-year-old first officer was hired by North Central Airlines in May 1979. . . .
>
> . . . . Other captains who recently had flown with the first officer described his ability and performance in favorable terms.
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> The first officer's supervisors stated that they had not had any personal or professional problems with him.[14]

The NTSB ACCIDENT REPORT concludes:

> [T]he probable cause of the accident was the flightcrew's failure to use the taxi checklist to ensure that the flaps and slats were extended for takeoff. Contributing to the accident was the absence of electrical power to the airplane takeoff warning system which thus did not warn the flightcrew that the airplane was not configured properly for takeoff. The reason for the absence of electrical power could not be determined.[15]

The NTSB is the regulatory agency charged with the dual role of investigating transportation accidents and acting as the federal watchdog for transportation safety.[16] The Board made a thorough investigation of the accident and declared that the probable cause of Flight 255's demise was pilot error.[17] This Note discusses the legal ramifications of concluding that this was solely pilot error as opposed to pilot error induced by faulty airplane design.

If one accepts the NTSB's conclusion that the probable cause of this accident was pilot error alone, the fault shifts away from the aircraft manufacturer. However, the airplane system design and the circumstances of this accident do not entirely support such a shift:

> While a repeated error due to carelessness or negligence, and possibly even poor judgement, may be considered the act of a fool, these are not the only kinds of error made by man. Errors such as those which have been induced by poorly designed equipment or procedures may result from a person reacting in a perfectly natural and normal manner to the situation presented to him.[18]

Thus, placing the blame on the human operator where the operator has acted in a perfectly normal manner serves to continue the pattern of error. This follows from the fact that the true cause of the error is the situation, not the person making the error. The NTSB's conclusion focuses on the mistakes the pilots of Flight 255 made rather than why the pilots made these mistakes. In doing this, the NTSB shifts attention

14. *Id.* at 5-6.

15. *Id.* at v.

16. NATIONAL TRANSPORTATION SAFETY BOARD, 1987 ANNUAL REPORT TO CONGRESS 1 (1988) [hereinafter NTSB ANNUAL REPORT].

17. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 56.

18. F. HAWKINS, HUMAN FACTORS IN FLIGHT 25 (1987) [hereinafter HAWKINS].

away from design problems that will continue to induce error.[19]

With the increased complexity and automation of commercial aviation[20] and other types of accident sensitive industries,[21] society can not continue to shift the blame to the human operator. The human operator is only a part of the system being operated. Society can not expect the human operator to make up for the deficiencies of the system. In fact, the system's greatest deficiencies arise from the limitations of the human operator. While talented, the operator's talents are finite. To be successful, a well designed "man-machine" system must take advantage of the human operator's talents and augment any deficiencies.[22]

This Note will focus on the area of "man-machine" systems design or human factors engineering. In general, the field of human factors engineering seeks to design a working environment that conforms to an individual's physical, mental, and perceptual limitations. This Note will discuss how this area of engineering undermines the traditional notion of human culpability associated with error. Unlike the legal and industrial communities which have historically blamed the operator for committing errors, the human factors engineer assumes that the error resulted from an improperly designed machine component.

To introduce this concept of human factors, the Note begins with a brief history of the use of human factors in industry and in the courts; it then applies the principals of human factors to the Northwest accident both from a design standpoint and as part of a legal analysis.

The entire analysis assumes that the pilots of Flight 255 made errors. However, two question are asked: (1) Could the machine component of the man-machine system involved have been easily designed so that, as a whole, the man-machine system performed more reliably? and (2) If the manufacturer could have so designed the machine component, should the manufacturer-designer be legally liable for a defective design when the man-machine system fails?

The three goals of this Note are: (1) to inform the reader of human factors design methods and how to use them during product design, (2) to urge the courts to expand the scope of the designer's responsibility to include not only the machine component but also the human component of the man-machine system where the operator errs in a reasonably foreseeable manner, and (3) to encourage express judicial use of a human factors analysis to determine whether the designer should have

19. *Id.* at 27.

20. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 55.

21. NTSB ANNUAL REPORT, *supra* note 16, at 25.

22. This Note is primarily concerned with man-machine systems where the machine is capable of taking over some of the cognitive functions of the operator. Although other systems are discussed, the focus will be on machine components capable of performing at least minimal logic functions.

foreseen the particular human error which led to the injury. To some extent, the legal system has already accomplished the second goal. However, given the increased use of computers in man-machine systems, and the consequent reduction in costs to a designer of preventing foreseeable human error, courts should consider a wider sphere of potential human error and require that designers create man-machine systems which are less vulnerable to such error.

II. HUMAN FACTORS IN DESIGN

A. History

The human factors engineering field developed during World War II "in response to the increased complexity of the machines of war (tanks, aircraft, . . . and ships) . . . . [The] stimulus for the development of the field was the fact that machine complexity was outstripping the capacity of the available [human operator] to operate and maintain the machines with reasonable safety and maximum efficiency."[23] Early efforts focused on personnel selection and training. "These attempts failed to reduce injuries and accidents. . . . [It became clear that] something had to be done to modify the machinery to accommodate the human beings."[24]

B. Human Factors as an Industry Standard

Even though human factors engineering was developed as early as the 1940's, it has not received widespread societal acceptance. It has, however, been used and refined in academe, private and public industry, and the defense industry.

> [A] number of Ph.D. programs in human factors [have been formed], most notably the ones at Ohio State University, the University of Michigan, and the University of Illinois. The first graduates of these programs appeared in 1949 and 1950 and went to work in defense-related industry and government. . . . [T]he First National Meeting of the Human Factors Society [met] in 1957, and was attended by 90 persons. . . . In 1977 the society membership was over 1,800."[25]

Researchers in these and other academic programs, as well as in the defense industry, have developed standards and practices for human factors. Where applicable, the Department of Defense has adopted

23. Bliss, *Defective Product Design—Role of Human Factors*, 18 Proof Fact 2d 117, 125 (1979) [hereinafter Bliss].

24. Messina, *The Human Factors Expert*, Trial Law. Q., Feb. 15, 1983, at 56 [hereinafter Messina].

25. Bliss, *supra* note 23, at 126. Since 1977, membership in the Human Factors Society has grown to approximately 5,000. Wiener, *From the President*, Hum. Factors Soc'y Bull., Apr. 1989, at 4.

human factors system design concepts as part of a normal government "Request for Proposal" or "Design Specification."[26] Furthermore, this human factors development work has resulted in the creation of a Military Standard (MIL STD) on the subject.[27]

In private industry, human factors standards are "being incorporated into the standards of such groups as the Society of Automotive Engineering . . . [and in such works as] the *Human Engineering Guide to Equipment Design* by H. Van Cott and R. Kinkade, published in 1972."[28] In the commercial aviation manufacturing industry, the Federal Aviation Administration (FAA) has incorporated human factors design standards into Federal Aviation Regulation (FAR) Part 25 "Airworthiness Standards: Transport Category Airplanes."[29] An aircraft manufacturer must meet these regulations together with their associated "Advisory Circulars" before the FAA will certify a new aircraft or aircraft component design.[30]

C. JUDICIAL APPLICATIONS

Although human factors as a discipline of engineering design has been around for at least forty-five years, the courts have only recently begun to consider it in determining liability.[31] The earliest cases focused on injury to the operator resulting from inadequate safety features to protect the operator from moving parts,[32] unguarded power switches,[33] normal or reasonably anticipated use,[34] and from reasonable human error in using the machine.[35] These cases involved industrial

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26. *See* BMY v. United States, 693 F. Supp. 1232 (D.D.C. 1988) (human factors design plans considered in making contract award); *In re* Johnson Controls, 82-1 B.C.A. (CCH) ¶ 15,779 (Apr. 28, 1982) ("proposal shall describe in detail use of man-machine interface and human engineering factors"); *In re* Systems & Computer Information, Inc., 78-1 B.C.A. (CCH) ¶ 12,946 (Nov. 23, 1977) (request for proposal required emphasis on "recognized principles of human engineering and reliability to the highest degree"); *In re* Avco Corporation, Avco Electronics Division, 76-1 B.C.A. (CCH) ¶ 11,736 (Sept. 30, 1975) (compliance with MIL STD 803A-1, "Human Engineering Design Criteria for Aerospace Systems and Equipment," required under specification).

27. *Id.*

28. Bliss, *supra* note 23, at 131.

29. *See* W. WOODSON, HUMAN FACTORS DESIGN HANDBOOK 175-85 (1981).

30. 2 S. SPEISER & C. KRAUSE, AVIATION TORT LAW 480 (1978) [hereinafter SPEISER & KRAUSE].

31. Wallace & Key, *Human Factors Experts: Their Use and Admissibility in Modern Litigation*, FOR DEF., Dec. 1984, at 16 [hereinafter Wallace & Key].

32. Keiner & Keiner, *Human Factors on Trial*, N.Y.L.J., Sept. 12, 1984, at 6, col. 1 [hereinafter Keiner & Keiner].

33. *Id.* at 6, col. 3.

34. *See* Bliss, *supra* note 23, at 143.

35. Keiner & Keiner, *supra* note 32, at 6, col. 4.

machinery[36] and consumer items such as snow blowers[37] and lawn mowers.[38]

Human factors engineering has been implicitly adopted where the law no longer shields the manufacturer from liability for patent defects. A New York court adopted this view when it held that a plaintiff must act only with "that degree of reasonable care. . .required under the circumstances."[39] Thus, where a machine design presents open and obvious dangers, the law holds the human operator to a reasonable standard only. When the operator acts reasonably and the machinery still injures him, "something [should have been] done to modify the machinery to accommodate the human being[]."[40]

At least one court has applied human factors principals to a complex system analogous to those systems found in aviation. In *Silkwood v. Kerr-McGee Corp*,[41] the plaintiff sought to recover for the health effects which were likely to develop after she discovered that her apartment had been contaminated with plutonium from her employer's plant.[42] She had not intentionally removed the plutonium,[43] but rather it had been allowed to escape from the plant due to inadequate safety precautions taken by the employer.[44] The dissent noted that the defendant plutonium plant had "not [been] designed to satisfy the most simple principles of human factors engineering. The facility was cramped. The plant did not incorporate sufficient safety systems, such as 'state of the art' alarm systems, leak detectors, air monitoring systems, and welded gaskets, into its design."[45] A "state of the art" plant would employ complex systems for control and monitoring of the plants' processing operation.[46] Apparently, the dissent felt that human factors design concepts required that the system designer incorporate such complex systems into the plant design to ensure that plant operators could maintain reasonable employee and public safety.

The foregoing case law recognizes human factors implicitly and explicitly. These and other cases often involve mechanical systems where

36. Micallef v. Miehle Co., 384 N.Y.S.2d 115 (1976) (plaintiff injured by unguarded printing press); *see also* Keiner & Keiner, *supra* note 32, at 6, col. 1 (plaintiff injured by cardboard box stamper).

37. Keiner & Keiner, *supra* note 32, at 6, col. 3.

38. *Id.* at 6, cols. 3-4 (champagne bottles and motorcycles were also involved).

39. *Micallef*, 384 N.Y.S.2d at 122.

40. Messina, *supra* note 24, at 56.

41. 769 F.2d 1451 (10th Cir. 1985), *cert. denied*, 476 U.S. 1104 (1986).

42. *Id.* at 1451.

43. *Id.* at 1464.

44. *Id.* at 1456.

45. *Id.* at 1468-69.

46. *Cf.* A. CHAPANIS, MAN-MACHINE ENGINEERING 26, 27 (1965) (discussing automated control and monitoring of an oil refinery).

the designer has ignored the most basic of human factors engineering principles.[47] In holding the designer responsible for the operator's misuse, the courts acknowledge the injured operator's unfamiliarity with the equipment; they acknowledge the operator's lack of appreciation of the danger associated with the machine's misuse; and, they recognize that easy and identifiable safeguards could have prevented the injury.[48]

III. HUMAN FACTORS ANALYSIS OF NORTHWEST FLIGHT 255

Human factors engineering embodies a premise that a more error free system can or "could have been designed initially and reasonably according to known human factors principles."[49] The techniques for performing a human factors analysis include:

- Task Analyses as part of the design process.
- Good human engineering of controls, displays and workspace.
- Hazard Integration Analyses using mockups and simulators which should be a continuing part of the design process.
- Job Hazard Analyses wherein typical operational people are used in a real world situation in a last phase effort before releasing a system for general use.
- Accident/Incident Investigation to assess whether the assumptions made during design were valid.[50]

A. The Task Analysis

The task analysis consists of performing a detailed analysis of everything a man-machine system must do to execute a certain task or

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47. The *Silkwood* case differs from the other examples. In *Silkwood*, the injury was not due to any action by the operator. Rather, the injury was caused by the designer's failure to control the escape of hazardous plutonium into the environment. It is excerpted here to highlight the judicial recognition of human factors as a discipline.

48. R. D. Huchingson, New Horizons for Human Factors in Design 226 (1981) [hereinafter Huchingson]. Some of these recognized safeguards are as follows:

- Design equipment so that it is physically improbable that the worker would do something that would hurt herself or himself. . . . Examples are:
  - A rotary blade that will not start unless a guard is in place.
  - Interlocks that prevent operation unless the worker's appendages are in a safe position.
    - A classic illustration is a forming press for shaping metals, which requires two controls to start it so one hand cannot be inadvertently under the press.

. . . .

- Cover or guard all moving parts of machinery that could cut a worker or fly off.

. . . .

- Label hazards clearly and conspicuously.

Id.

49. Miller, *The Design-Induced Part of the Human Error Problem in Aviation*, 42 J. AIR L. & COM. 119, 130 (1976) [hereinafter Miller].

50. *Id.*

function.[51] The task analysis must:

> detail[] specifically what things have to be done by the operator and by the machine and when they have to be done and in what sequence, in order for the man-machine system to get the job done properly *and safely*. . . . If the system has not yet been designed, the task analysis provides the basis for designing into the machine the functions which it performs best, . . . leaving it to the operator to do the things which the person can do better. . . .[52]

Determining the allocation of tasks between man and machine should be the first step in the human factors design analysis.[53] This may be the easiest way to eliminate human error:

> One possible way to handle the problem of human error in a particular task is to take the task away from man altogether and give it to the machine or the computer. While there will still be scope for human error in controlling the machine or programming the computer, the execution of the original task will be free from the effects of human fallibility.[54]

As a general principal, humans should be given the tasks which they do best and machines should be given the tasks which they do best. For example, man is poor at tasks which require a large amount of vigilance. Vigilance is the ability to perform a task "requiring [the operator] to monitor or detect brief, low intensity and infrequently occurring events over long periods [of time]."[55] A classic example of a task requiring a high degree of vigilance is the monitoring of radar where there is very little activity within the range of the screen.[56]

Other areas where individuals are more prone to err include: tasks requiring use of short-term memory,[57] and tasks requiring routine and repetitive operations.[58] The latter tasks create boredom and cause a loss of motivation. This, in turn, increases the incidence of errors.[59] Thus, the designer should allocate these tasks to the machine.

On the other hand, there are some tasks which are more appropriate for human operators than for machines. A machine is "less adaptable" to novel circumstances and less reliable for certain tasks.[60] When a machine breaks down it usually does so abruptly and totally, while a human's breakdown is typically in the form of a lapse which is not as

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51. Bliss, *supra* note 23, at 129.
52. *Id.* at 129-30 (emphasis in original).
53. *See* HAWKINS, *supra* note 18, at 40.
54. *Id.*
55. *Id.* at 41.
56. *Id.*
57. *Id.*
58. *Id.* at 42.
59. *Id.*
60. *Id.*

severe or abrupt.[61]

The following discussion applies these basic concepts of task analysis to the Northwest Flight. Such an analysis is done the same way during an accident as it is during the design stage.[62] However, the source for the details of the task are different. Whereas, the task analysis for design requires the human factors engineer to predict the normal sequence of events which will occur during operation, the task analysis of an accident requires the human factors engineer to reconstruct the sequence of events leading up to the accident by thinking in terms of:

> (1) what the man-machine system was doing and, within that context, (2) what the operator (or victim) was trying to accomplish, (3) what he did that led directly to the accident, and (4) how the machine design may have contributed to the accident by assisting him, encouraging him, or cooperating with him in engaging in behavior leading to the accident. The human factors expert's approach to the analysis of an accident is the same as his approach to a design problem: What is the machine capable of doing, what can be done with it, and where, if at all, are the areas where the design of the machine can *contribute* to the occurrence of an accident?[63]

By focusing on the circumstances at the time the pilots made the critical error, a human factors investigator can do a task analysis of Flight 255. To begin with, the critical error occurred at a time when the crew had other responsibilities. They had to establish radio contact with Air Traffic Control (ATC) and taxi through congested ramp areas.[64] The latter task required sequencing with other taxiing airplanes.[65] Furthermore, the crew had to receive additional ground control instructions.[66]

Beyond these normal tasks, the pilots of Flight 255 had other distracting circumstances to deal with:

> The flight was operating behind schedule with the crew facing a curfew problem for their arrival in Santa Ana [owing to a noise abatement requirement]. Weather in the local area could have caused further delay if [a threatening] storm arrived before their departure. There were reports of windshear by other crews and [other] windshear advisories. [There had been a] runway change [requiring] the first officer to [refer to] the takeoff performance manual.[67]

In the face of these distracting circumstances, the flightcrew was also supposed to have completed the entire TAXI checklist. However,

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61. *Id.*
62. Bliss, *supra* note 23, at 131.
63. *Id.* at 130-31 (emphasis in original).
64. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 58.
65. *Id.*
66. *Id.*
67. *Id.* at 58-59.

they never performed this task. The crew's failure to begin and complete the TAXI checklist was the critical error which led to the mishap.[68] The aircraft designer intended that the flightcrew review this checklist during taxi and prior to each takeoff. The first item on the checklist required both pilots "to check and verify orally that the flaps and slats[69] were positioned correctly [for takeoff]."[70]

The NTSB concluded that the distractions during taxiing may have caused the flightcrew to fail to perform the checklist.[71] The NTSB offered the following explanation:

> Since the TAXI checklist was almost always performed early in the taxi operation, it is possible that the flightcrews become conditioned to having completed the checklist by the time the flight has taxied for more than a few minutes. If there are interruptions and the checklist has not been initiated normally, when the airplane reaches a point in the taxi where the TAXI checklist typically has been completed, it is possible that the flightcrew will believe that the checklist was completed.
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> .... [During flight 255's taxi the flightcrew had to attend to matters which required] almost a 2-minute digression from matters relevant to the checklist. By this time the airplane's location on the airport was such that the external cues and references available to the flightcrew were not those normally associated with the initiation of the TAXI checklist at Detroit-Metro. In fact, with reference to the time of taxi and the airplane's location, the flightcrew had progressed into a frame of reference where the TAXI checklist would have been completed. Since no further action was taken concerning any other TAXI checklist items, the Safety Board believes that by this time, the flightcrew thought the checklist had been completed.[72]

Thus, the NTSB reconstructed what the man-machine system was doing during the critical period. Specifically, it pieced together the operator's actions leading up to the accident in order to determine what the operator was trying to accomplish preceding the accident. Apparently the NTSB satisfied itself that the flightcrew did not perform its function.

However, the NTSB did not recognize or perform the fourth step in the human factors task analysis. This step requires the human factors expert to determine how the machine design might have contributed to the accident. In this case, the machine at issue was the entire airplane.

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68. *Id.* at 56.

69. The flaps are on the trailing edge and the slats are on the leading edge of an aircraft's wings. They provide the additional lift required for slower aircraft speeds during takeoff and landing.

70. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 56.

71. *Id.* at 58.

72. *Id.*

The airplane piloted by the crew of Flight 255 was designed to allow an experienced pilot to place the airplane's throttles at takeoff power and proceed down the runway with all systems apparently operating normally whether or not the pilots had met a critical requirement for takeoff. This design contributed to the accident; it let the flightcrew make a critical error.

As previously discussed, the first step in a human factors design is to allocate tasks between the individual and the machine. A human factors engineer expects a flightcrew to have failures in short-term memory which may cause members of the crew to forget that the TAXI checklist is not complete. This short-term memory loss, along with a lack of motivation is expected by the human factors engineer because of the repetitive nature of the task. As a result, a human factors engineer would not be surprised by the fact that the flightcrew did not exactly follow the prescribed call and response procedure for performing the checklist. Notwithstanding this, the NTSB concluded that any flightcrew which does not complete the TAXI checklist precisely as required before every takeoff compromises the "entire structure which was designed to support"[73] safe operation of the airplane.

A good human factors designer would have allocated the task of confirming that the pilots correctly positioned the flaps and slats to the machine. A computer functions very well as a system monitor in situations requiring repetitive tasks and short-term memory. Apparently, the designer did consider and implement such an allocation on board Flight 255. The airplane was equipped with a takeoff warning system,[74] itself a part of a larger system known as the Central Aural Warning System (CAWS) which was capable of monitoring whether the pilots had properly configured the airplane for takeoff:

> The DC-9-82's central aural warning system (CAWS) provides distinctive aural (horn, "C" chord, chime, and bell sounds) and vocal (electronically-generated system identification words) indications when potentially unsafe operating conditions, unsafe airplane configurations, or system malfunctions exist. Each voice message is preceded by an associated warning tone. The voice message is cycled with a 1-second aural tone, followed by a 1-second voice message identifying the unsafe configuration, condition, or malfunction for the duration of the warning period.[75]

Within the CAWS:

> The takeoff warning system . . . is programmed to provide a modulating horn for 1 second, followed by a voice warning identifying the system or systems, control or controls not properly configured for takeoff.

73. *Id.* at 57.
74. *Id.* at 13.
75. *Id.* at 12.

> Thus, if the slats are not set for takeoff and the slat takeoff light is not illuminated, the warning system will state the word "slats"; if the flap handle is not in agreement with the value set in the flap window of the takeoff condition computer, the warning system will state the word "flaps;" . . . If more than one out-of-configuration condition exist[s], the voice warning will identify, in turn, each out-of-configuration control.[76]

This system would normally serve to warn the flightcrew that it had not successfully completed the checklist.[77] Unfortunately for the crew and passengers of Flight 255, the "CAWS unit's takeoff warning system was inoperative and, therefore, did not warn the flightcrew that the airplane was not configured properly for takeoff."[78] A power failure to one of the power inputs to the CAWS caused the failure of the takeoff warning system.[79] As explained below, the manufacturer could have prevented this result through good human factors engineering.

B. Hazard Integration Analyses

A hazard integration analyses requires the use of mock-ups and simulators as part of the design process.[80] A human factors engineer uses these mock-ups of the system to test the acceptability of the design. Ultimately, a full-scale mock-up may be linked to a simulation computer. The simulation computer drives the mock-up allowing experienced pilots to fly various flight scenarios. The human factors engineer monitors the performance of this man-machine system, including the pilots' performance, to uncover any latent or unexpected problems or reactions.

The FAA requires such validation procedures as part of the normal certification process for a new system. The validation procedures serve to demonstrate the accuracy of the failure mode and effects analysis (FMEA) which must be done prior to each certification.[81] Such a FMEA was done for the CAWS:

> During the development of the CAWS for certification by the FAA, McDonnell Douglas and the FAA conducted [a FMEA] of the system. The FMEA analyzed the types of possible system failures, how the failures could be detected, and the results of the failures. Severity of the hazards to flight resulting from these failures were [sic] categorized into four classes: Class I - Safe; Class II - Marginal; Class III - Critical; and, Class IV - Catastrophic. Also, the FMEA evaluated whether the airplane could be dispatched [(takeoff)] with a particular component or

76. *Id.* at 13.
77. *Id.* at 67.
78. *Id.*
79. *Id.* at 53.
80. Miller, *supra* note 49, at 130.
81. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 14.

system inoperative. The failure of the entire CAWS and the failure of just the takeoff warning channel of the CAWS were [each] classified as a Class I risk. The FMEA stated that the airplane should not be dispatched with an inoperative CAWS, but it could be dispatched with the takeoff warning channel inoperative.[82]

With each increase in the class of failure, FAA regulations impose a stronger burden on the designer to reduce the risk of failure. For example, a Class IV or catastrophic failure cannot occur at a rate greater than 1 x 10[su'-9'], or one in one billion. In contrast, a Class I failure can occur at a rate of 1 x 10[su'-5'], or one in one hundred thousand.[83] Design and manufacturing costs increase with every decrease in the required failure rate. A high class rating in a flight system usually calls for complex and expensive system self-monitoring and system redundancy. Clearly, in a competitive market, obtaining the lowest hazard classification is most desirable.[84]

For the CAWS system on the DC-9-82, the original FMEA certified by the FAA classified the type of failure experienced by Flight 255 as Class I, or "safe." There were several justifications offered by the designer and the FAA for this classification:

> With regard to the takeoff warning channel, the FMEA stated that the loss of the input . . . power supply . . . will cause the CAWS fail lights to illuminate. The director of the McDonnell Douglas Flight Guidance and Controls Design Engineering Department and a supervisory aerospace engineer in the Systems and Equipment Branch at the FAA Aircraft Certification Branch . . . testified [that] this statement [in the FMEA] was erroneous.
>
> . . . .
>
> The FAA supervisory aerospace engineer also testified that the FMEA would have been approved even if it had portrayed correctly that the loss of the . . . input power [to the CAWS] would not illuminate the CAWS fail lights, "because it's a non-essential system. There's [sic] other means by which the pilot can verify the event that's causing that warning or would cause the warning had it not failed. There's [sic] other means by which he would normally check his airplane."
>
> Finally, with regard to the cockpit CAWS fail light, the McDonnell Douglas director of Flight Guidance and Controls Design Engineering

82. *Id.*

83. Federal Aviation Administration, Advisory Circular No. 25-1309-1A, System Design & Analysis ¶ 7(d), ¶ 10(b) (June 21, 1988) (defining catastrophic, major, and minor failures) [hereinafter FAA Adv. Cir. No. 25-1309-1A]; Telephone interview with Harry Wassinger, Supervisor of Electronic Flight Control Section, Systems, and Equipment Branch, Los Angeles Aircraft Certification Office, Federal Aviation Administration (Nov. 3, 1989) (describing how McDonnell Douglas adopted the Class I through IV failure classification scheme to correspond to the three FAA failure classifications and the four European (JAA) failure classifications).

84. *See* Hawkins, *supra* note 18, at 258.

testified that the light was installed as a maintenance aid and that "if the crew had any squawks about the [CAWS], if there weren't [sic] a light, [maintenance personnel] would have to climb around the avionics compartment and first off run through the tests on the front of the [CAWS unit] and see if there was a fault light . . . . We thought it would be an aid to the maintenance of the airplane to put a light in the overhead which would indicate the computer had failed[.] . . . [T]he flightcrew could write it up . . . if the light were [sic] on . . . and the maintenance crew would know where to go." He testified that this was the reason that the CAWS unit monitors only its internal components.[85]

The CAWS design philosophy adopted by McDonnell Douglas and accepted by the FAA showed little evidence of a human factors fault integration analysis, although such an analysis may have been done. The FAA felt that if the CAWS failed there still existed sufficient "means by which the pilot could verify the event that's causing [the] warning or would cause the warning."[86] Essentially, the FAA believed that the pilots of Flight 255 could have discovered such an event independent of the CAWS warning.[87] Yet, an accurate simulation in a mock-up would probably have shown how wrong this belief was.

The FAA's conclusion that the pilots could have used other means to detect the failure also ignores the phenomenon of "automatic complacency."[88] Automatic complacency occurs when automation in the cockpit becomes so reliable that it generates a complacency on the part of the flightcrew.[89] In other words, the flightcrew relies on the automatic systems to such a degree that they become lax in their attention to the primary flight instruments.[90] A professor of management science testifying before the NTSB referred to this as the "primary backup inversion where the primary system, which is the human and human vigilance, becomes the backup system, and the backup system, the machine, becomes the primary."[91] As an example, the professor cited the altitude alerting system which:

during climb or descent, is programmed to provide an alert to the flightcrew 700 feet above or below the inserted level off altitude. Virtually all air carriers procedures require the nonflying pilot to provide

85. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 14-15.

86. *Id.* at 14.

87. *Id.*

88. NATIONAL TRANSPORTATION SAFETY BOARD, BUREAU OF ACCIDENT INVESTIGATION, AIRCRAFT ACCIDENT REPORT—SCANDINAVIAN AIRLINES SYSTEM, FLIGHT 901, MCDONNELL DOUGLAS DC-10-30, JOHN F. KENNEDY INTERNATIONAL AIRPORT, JAMAICA, NEW YORK, FEB. 28, 1984, at 79 (1984) [hereinafter SCANDINAVIAN ACCIDENT REPORT].

89. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 44.

90. SCANDINAVIAN ACCIDENT REPORT, *supra* note 88, at 79.

91. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 44.

a 1,000 (foot)-to-go alert call to the pilot flying the airplane when climbing or descending. [The professor] testified that "it doesn't work that way. So what do you see on climbing or descending? The pilot will sit there . . . until the altitude reminder sounds (and then) say 'a thousand to go.' That's the primary backup inversion. He has used a backup system to human vigilance and made it the primary system and then he reacts."[92]

Other examples of automatic complacency include:

In an automatic approach, a bend on the Glide Path at 500 ft caused a very marked pitch down, resulting in an excessive sink rate. The pilot, though fully aware of the situation, did not react until the situation was so critical that a very low pull up had to be made.[93]

[Also], [i]n July, 1987, a Delta L-1011 flew 60 miles off course and nearly hit a Continental 747, probably because the flight crew entered the wrong data in the computer-navigation system.[94]

[Finally, in 1985], a China Airlines 747 dropped 30,000 feet with a series of gut-churning rolls in less than 2 minutes, as the horrified pilots fought to regain control. NTSB experts who recreated the twisting dive on computers are convinced that the tired pilots relied on the autopilot to fly the plane with one engine out of service, and that when they switched the autopilot off, the plane overcorrected.[95]

In investigating Flight 255, the NTSB dismissed the occurrence of automatic complacency. The Board concluded that there was "no indication that the flightcrew's failure to configure the airplane for takeoff was attributable to their reliance on an automated system which would warn them of their omission [to set the flaps and slats for takeoff]."[96] The NTSB arrived at this conclusion despite evidence that some Northwest flightcrews had "used the takeoff warning system to check their airplane configuration while taxiing out for takeoff."[97] Apparently, these flightcrews had only been using the takeoff warning system to make fine adjustments in the airplane's trim.[98] The NTSB found the flightcrew's practice was done to avoid the occurrence of a takeoff warning at the time of takeoff which would lead to further delays of departure.[99] Despite the NTSB's findings, the potential for backup inversion clearly exists on the DC-9-82. The aircraft designer should have

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92. *Id.*

93. SCANDINAVIAN ACCIDENT REPORT, *supra* note 88, at 79.

94. *High Tech and Human Error Above the Clouds*, U.S. News & World Rep., Jan. 23, 1989, at 8.

95. *Id.*

96. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 64.

97. *Id.*

98. *Id.*

99. *Id.*

acknowledged and accounted for this phenomenon in designing the CAWS.

In sum, the aircraft designer could have used the hazard integration analysis, as developed and verified in a simulated working environment, to predict the degree of actual use of the TAXI checklist procedure. Similarly, the aircraft designer could have used the hazard integration analysis to demonstrate the potential undesired use of the takeoff warning system as a primary indicator of the configuration of the airplane.

Besides performing a hazard integration analysis, another means to limit the effect of pilot error is through good human engineering of controls, displays, and workspaces.

C. Good Human Engineering of Controls, Displays, and Workspaces

The flightcrew's ability to pilot an airplane successfully is "dependent to a considerable extent on the design, layout and interpretation of displays and controls."[100] A display must be easily visible and well lit to be useful.[101] The same is true of controls.[102]

On Flight 255 there were several displays and controls which could have helped the pilots determine that they had not extended the flaps and slats. In a DC-9-82 the flap and slat control (the flap handle) is on the right side of the control pedestal.[103] To view this location, the captain must look down and to the right approximately 35° from his forward field of vision. The indicators that display the current position of the flaps and slats are on the lower right side of the center instrument panel almost directly forward of the flap handle.[104] To view this location, the captain must look down and to the right approximately 20° from his forward field of vision. Both the flap handle and the flap and slat indicators are in an area that is outside of, or on the perimeter of, the areas the flightcrew normally monitor during takeoff.[105] As a result, during the takeoff of Flight 255, the flap handle and position indicators could not have alerted the flightcrew of their improper takeoff configuration.

In contrast, had the CAWS aural warnings been operative, they would have notified the pilots that the airplane was not in proper takeoff configuration. At the very least, if the CAWS fail lights had illuminated, their location on the overhead cockpit annunciator panel, in the

100. Hawkins, *supra* note 18, at 16.
101. *Id.* at 228.
102. *Id.*
103. Northwest Accident Report, *supra* note 1, at 7.
104. *Id.* at 8.
105. *Id.* at 56.

area the flightcrew normally monitors during takeoff, would have signaled the pilots that they were in trouble.[106] Unfortunately, the CAWS fail lights did not illuminate because there had been no internal failure of the CAWS unit[107] on board Flight 255.[108] Instead, the unit had suffered only a loss of power to one of its power inputs;[109] a failure for which the designer-manufacturer provided no cockpit indication.[110]

After performing this partial human factors design analysis, the designer would probably conclude that the only way to avoid the type of error which occurred on Flight 255 would be to stress to the flightcrew the importance of relying on the taxi checklist. However, a human factors engineer would most likely conclude that forcing the crew to rely on a taxi checklist is a bad idea because it improperly allocates tasks between the individual and the machine.

D. Job Hazard Analyses

Before releasing a system for general use, a good human factors analysis requires that a human factors engineer monitor the system in operation with typical personnel.[111] This task is very similar to the mockup and simulator work done during the hazard integration analysis, but it has much higher fidelity to the expected operational environment. However, due to safety considerations, the human factors engineer cannot analyze the extremes of this operational environment in an actual airplane.[112]

Under current FAA certification procedures, pilots from both the manufacturer and the FAA thoroughly test new systems. Some test pilots are unfamiliar with the new system and, consequently, are able to provide information on how the general user, who is also unfamiliar with the system, will perform. Comments and feedback sometimes require designers to modify the system.[113]

As with all systems, the CAWS and flap and slat systems underwent this type of flight test program before certification. However, the thoroughness of the test program was determined by the hazard classification assigned to the CAWS failure.[114] Because the approved FMEA

106. *Id.* at 14.
107. *Id.* at 14, 29.
108. *Id.* at 28.
109. *Id.* at 53.
110. *Id.* at 64.
111. Miller, *supra* note 49, at 130.
112. *See* Chapanis & Van Cott, *Human Engineering Tests and Evaluations*, in HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN 701, 725 (H. Van Cott & R. Kinkade rev. ed. 1972).
113. *But see* HAWKINS, *supra* note 18, at 258.
114. *See supra* text accompanying note 82.

classified a loss of input power to the CAWS as "safe," the thoroughness of the test program was probably limited. If the designer had adequately performed the hazard integration analysis and determined the correct hazard classification, a more thorough flight test program would have been conducted and may have revealed this human factors design problem.

E. Accident and Incident Investigation

The complete human factors analysis does not end after release of the system. A complex system involving a human, a machine, or both, is very likely to have latent defects. Exhaustive testing of these systems to account for all possible inputs would be impossible and unnecessary. Instead, the designer should test the system's performance based on his knowledge of its structure, goals, and anticipated performance. Such testing will catch a number of defects, including most of the critical defects. Remaining defects, which occur after the system has gone into general use, should be investigated by the designer and incorporated into an improved design.

The human factors engineer must also thoroughly investigate whenever there has been a system failure where the complete or contributing cause is thought to be pilot error. Even when pilot error is not alleged, the human factors engineer should be part of the investigative team since a better human factors design may have aided the pilot in overcoming the system deficiency attributed to the machine.

The NTSB and McDonnell Douglas investigated Flight 255 to determine the cause of the accident. McDonnell Douglas's recommendations for system improvements are not available to the public. However, the NTSB's recommendations to the FAA are available. These recommendations are as follows:

> Require the modification of the DC-9-80 series airplanes to illuminate the existing [CAWS] fail light on the overhead annunciator panel in the event of CAWS input circuit power loss so that the airplane conforms to the original certification configuration.
>
> . . . .
>
> Develop and disseminate guidelines for the design of central aural warning systems to include a determination of the warning to be provided, the criticality of the provided warning, and the degree of system self-monitoring.
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> . . . .
>
> Require that all [commercial airline] operators and principle operations inspectors emphasize the importance of disciplined application of standard operating procedures and, in particular, emphasize rigorous adherence to prescribed checklist procedures.
>
> . . . .

> Convene a human performance research group of personnel from the National Aeronautics and Space Administration, industry, and pilot groups to determine if there is any type or method of presenting a checklist which produces better performance on the part of user personnel.[115]

The designer must feed these recommendations, along with the recommendations of its own investigators, back into the human factors design process in order to prevent a similar tragedy in the future.

In the case of Flight 255, the NTSB concluded that pilot error was the probable cause of the accident with power failure of the CAWS as a contributing cause. Legally, who should be liable? Should the pilots be held responsible even though they behaved in a predictable manner based upon a well-defined and studied environment? Or, should the court hold the equipment designer responsible because it has the background and resources to foresee and prevent the consequences of this human error?

The author is aware of the existence of human factors personnel, departments, and expertise within the aviation industry. He is also aware of the frustration felt by those in the field of human factors whose concerns go unaddressed because management is focusing on traditional engineering methods and profit margins.[116] Taking the extra step to build mock-ups and simulators to test designs at an early stage requires time, planning, and money. All of these are in short supply in the commercial design and manufacturing world.[117] As a result, human factors recommendations come late in the design stage, when it is easiest to test the man-machine interface but hardest to change the design.[118]

The FAA has the power to prevent any new system, or old system, from flying.[119] However, economic and market pressure on the manufacturer to meet rigid engineering and delivery deadlines often forces the FAA to back down from a strong safety stance.[120] While the NTSB

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115. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 68. Note that while the NTSB still recommends improving on the checklist performance aspect of the man-machine system, they clearly recognize the importance of the role of the machine and the limitations of the individual.

116. HAWKINS, *supra* note 18, at 314, 316.

117. *Id.* at 12, 314.

118. *Id.* at 258, 314.

119. 49 U.S.C.S. § 1348 n.10 (Law. Co-op 1981).

120. *Compare* O'Lone, *New Certifications Pose FAA Challenge*, AVIATION WK. & SPACE TECH., Dec. 1, 1980, at 43 (discussing conflict between the FAA's safety expectations and the manufacturer's cost and deadline constraints) *with Was FAA Lax on Cargo-Door Hazards?*, Wash. Post, Apr. 23, 1989, at A11, col.1 (discussing how the FAA made a "gentlemen's agreement" with the manufacturer not to order changes required to improve safety) *and* PR Newswire, Aug. 26, 1980 (discussing Airline Pilots Association's alle-

can not force changes, it can make recommendations for studies and new regulations.[121] Ultimately, it may be reaction to accidents such as Flight 255 which will be most effective in promoting progress in this area.

The balance of this Note will discuss an alternative way to encourage better man-machine system design.

IV. HUMAN FACTORS IN THE LEGAL ANALYSIS

Most litigation of commercial aviation disasters is settled out of court.[122] While litigants in these cases may advance evidence of human factors engineering design principals to support their positions, it is unclear how successful such evidence would be at trial. The cases cited in this Note provide some insight as to the potential merit of evidence of human factors where the victim has made errors resulting in injury to himself or others. However, most of these cases do not advance new legal theories. Instead, they either accept evidence supported by human factors principals directly or, more frequently, implicitly. The courts then apply existing legal doctrines to this evidence. For example, the courts may apply traditional negligence,[123] contract, or products liability theories. This Note focuses on the use of human factors under theories of products liability and contract.

Cases where courts have applied human factors principles often involve mechanical systems where easy and recognized safeguards could have prevented the injury.[124] In these cases, the courts consider available safeguards, as well as the injured operator's lack of familiarity with

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gations that manufacturers were "improperly influenc[ing], dominat[ing], and control[ling] the aircraft certification process").

121. 49 C.F.R. § 800.3 (1988).

122. For example, Northwestern Airlines has already settled with the families of the victims of Flight 255. Nat'l L.J., Nov. 13, 1989, at 3, col. 1. McDonnell Douglas may also be moving toward settlement. *Id.*

123. Failure to design an adequate computer system which accounts for human deficiencies may constitute negligence. *See* Silkwood v. Kerr-McGee Corporation, 769 F.2d 1451, 1468-69 (10th Cir. 1985) (Doyle, J., dissenting) ("ordinary negligence principles" and "simple principles of human factors engineering" required that the defendant power plant owners install "state of the art alarm systems, leak detectors, [and] air monitoring systems"); *see also* Freed, *Legal Questions in a Computer Society*, in COMPUTERS AND LAW 32-33 (R. Freed 5th ed. 1976), ("[o]nce it [is] shown that a computer system [can overcome] the deficiencies of people in detecting hazards and avoiding harm and is economical and has been proven to work, failure to utilize such a system would constitute negligence"). *Compare* R. NIMMER, LAW OF COMPUTER TECHNOLOGY ¶ 7.09 (1985) [hereinafter NIMMER] (failure to use available computers which could prevent harm may constitute negligence) *and* The T.J. Hooper, 60 F.2d 737 (2d Cir. 1932) (failure to provide available radio equipment which could have prevented harm is negligence).

124. *See supra* note 48.

the equipment. The courts also consider whether the operator appreciated the danger associated with misusing the product.

Reported cases have not addressed situations where the necessary safeguards are not in widespread use or part of accepted safety guidelines. Nor have these reported cases addressed situations where the operator who misused the product was well-trained or a professional. These two issues combine to distinguish a legal analysis of Flight 255 and accidents such as Three-Mile Island and Chernobyl[125] from other accidents involving less sophisticated man-machine systems. Thus, two questions necessarily remain to be answered: (1) does the law obligate the designer to recognize and incorporate cost-effective safeguards into a product even though they are not legally required or in widespread use? and (2) does the law shield the operator from liability, notwithstanding his failure to perform according to his training, where both the need for the safeguard and the operator's lapse of professionalism could be foreseen through a human factors analysis?

A. Products Liability

Products liability acknowledges the characteristics of those products that are distributed, by the manufacturer, to "more than a single client."[126] These characteristics include: the customer's foreseeable reliance on the product's safe design, the designer's risk-spreading capability through pricing, and the user's difficulty in establishing the designer's negligence.[127] Where a manufacturer-designer fails to perform a human factors analysis in its design of a computer system, it is appropriate to apply products liability. The following analysis of Flight 255 addresses liability for failure to warn and for defective design.

1. *The Duty to Warn*

There are many cases involving products ranging from champagne bottles[128] to portable telephones[129] where courts have found inadequate warnings in de facto recognition of human factors.[130] The duty to warn requires the designer to warn the consumer of the dangerous propensities of a product in a way that will "persuade the trier of fact that the consumer should have heeded it."[131] Or, in the words of a human fac-

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125. HAWKINS, *supra* note 18, at 27.
126. NIMMER, *supra* note 123, ¶ 7.06(2)(a).
127. *Id.*
128. Keiner & Keiner, *supra* note 32, at 6, col. 3.
129. Schwartz, *Proposals for Products Liability Reform: A Theoretical Synthesis*, 97 YALE L.J. 353, 396 n.84 (1988) [hereinafter Schwartz].
130. Perlman, *Use of Human Factors in a Product Liability Case*, 1 AM. J. TRIAL ADVOC. 47, 48 (1978) [hereinafter Perlman].
131. Schwartz, *supra* note 129, at 396.

tors expert,

> An effective warning will answer the question: "Why should I obey?" The answer must be short, explicit, easily understood and powerful. Weak warnings do not work! . . . [For example,] O.S.H.A. requires all [cranes] to have a decal which states: "It is unlawful to operate crane booms within 10 feet of power lines." There is very little instruction or motivation in that warning. A more effective warning might read: "ELECTRICITY KILLS—People easily misjudge power line clearances with fatal results."[132]

The same duty to warn applies to the designer of integrated computer systems such as the one on board Flight 255. One way the designer could satisfy this duty to warn would be to affix placards, in clear view, in the cockpit area to warn the pilots of system limitations. A more efficient solution would be to use displays which would warn the pilots if an unsafe condition developed. This solution might include a computer driven display with real-time warning presentations to guide safe operation. The CAWS system normally provides such warnings to the operator. However, when such a system fails to give the proper warning, it should be analyzed by the court as a design defect.

2. *Defective Design*

There are several tests which may be used to determine whether the manufacturer defectively designed the man-machine system onboard Flight 255. These tests include: the consumer expectation test, the cost/benefit test, and the regulatory compliance test.[133]

a. *The expectation test*

Courts, in many states, have favored the use of the consumer expectation test.[134] "A product fails the test when it is less safe than is reasonable for consumers to expect . . . ."[135] The *Restatement (Second) of Torts*, section 402A, adopts this test; any manufacturer who sells a product which is unreasonably dangerous is liable for injuries suffered by the ultimate user or consumer.[136] 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 ordinary knowledge common to the community as to its characteristics."[137]

Because this test focuses on the expectations of the consumer, it follows that if a product injures the consumer, and the consumer was

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132. Messina, *supra* note 24, at 62-63.
133. Schwartz, *supra* note 129, at 384-88.
134. NIMMER, *supra* note 123, ¶ 7.06(2)(b).
135. Schwartz, *supra* note 129, at 387.
136. RESTATEMENT (SECOND) OF TORTS § 402A(1) (1977).
137. *Id.* comment i.

aware of the product's propensity for this type of injury, the manufacturer would not be liable. In other words, the product would not be viewed as unreasonably dangerous under section 402A, because it was as safe as the consumer expected.

Accepting this test for the moment, it is now necessary to inquire as to the expectations of the consumers aboard Flight 255 to determine whether the manufacturer should be held liable for the deaths of the passengers and flightcrew.

Generally, passengers are well aware of the risks of flying because aircraft disasters receive such widespread media attention. However, passengers are also aware of how remote the chance is that they will become a victim of such an accident.[138] Since passengers know the risk of air travel is relatively insignificant, a court, in attempting to ascertain a particular passenger's expectation, might limit its inquiry to the person's personal air travel experience and exposure to the media. The court might also take into account the fact that passengers are typically aware of industry regulation and safety standards. These factors, taken together, might persuade a court that the passengers of Flight 255 expected the flight to be safe and uneventful.

In ascertaining the expectations of the pilots of Flight 255, the court might consider the following: the captain of Flight 255 had been flying commercial aircraft for thirty-one years.[139] The first officer had been flying commercial aircraft for at least eight years.[140] The crew was more aware than the passengers of the regulatory requirements of their industry. The pilots had routinely used automatic systems to determine the airworthiness of their aircraft.[141] These factors, taken together, suggest that the pilots expected another routine flight.

The preceding discussion illustrates the uncertainty inherent in the consumer expectation test. This uncertainty has led to widespread criticism of the test;[142] it does not provide an objective and consistent standard. Where the odds of catastrophic failure are slight, the consumer may come to *expect* continued safe operation. The test "raises the question of what safety expectations are reasonable."[143] In the end, the court makes this determination by relying on other tests to determine reasonableness.[144] These other tests, the cost/benefit test and the regu-

138. In 1987, of the nearly 7,000,000 scheduled commercial carrier departures there were only 4 fatal accidents. This represents a little more than a 1-in-2,000,000 chance of a fatal accident. NTSB ANNUAL REPORT, *supra* note 16, at 53.

139. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 5.

140. *Id.*

141. *See supra* text accompanying notes 88-99.

142. NIMMER, *supra* note 123, ¶ 7.06(2)(b).

143. Schwartz, *supra* note 129, at 384-85.

144. *Id.* at 385.

latory compliance test, focus on the designer's choices in developing the product.[145]

b. The cost/benefit test

The cost/benefit test requires the manufacturer to design its product with a degree of care similar to that called for under a negligence standard.[146] This cost/benefit test could be applied to Flight 255 to determine if the manufacturer defectively designed the man-machine system thereby causing the accident. The question to be answered is whether the costs of performing a human factors design analysis on the DC-9-82, and incorporating the results, outweighed the benefits of such a program.

A 1979 draft of a proposed uniform products liability law incorporates the cost/benefit test:

> In order to determine that the product was unreasonably unsafe in design, the trier of fact must find . . . the likelihood that the product would cause the claimants harm . . . and the seriousness of those harms outweighed the burden on the manufacturer to design a product that would have prevented those harms [as well as] the adverse effects that alternative design would have on the usefulness of the product.[147]

Four questions must be considered by the court in determining whether the manufacturer has met this cost/benefit test. These questions are:

1. What is the current state of technology?[148]
2. What is the comparative cost and feasibility of alternative designs?[149]
3. What is the risk that the selected design will cause injury?[150] and
4. To what extent will a change in design have a negative impact on the characteristics that made the product a commercial success?[151]

The Current State of Technology. To determine the current state of technology, the court must consider two areas of technology: human factors and computer, control, and display, technology.

The aerospace industry has a well-developed understanding of the human component of the man-machine system. This is due, in part, to the fact that human factors has been in a constant state of refinement

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145. NIMMER, *supra* note 123, ¶ 7.06(2)(b).

146. *Id.*; *cf. id.* ¶ 7.06(2)(a) (where a designer only has one client, courts are likely to favor a negligence standard). *See also supra* note 123 and accompanying text.

147. MODEL UNIFORM PRODUCTS LIABILITY ACT § 104(b)(1), 44 Fed. Reg. 62,714, 62,724 (1979).

148. NIMMER, *supra* note 123, ¶ 7.06(2)(b).

149. *Id.*

150. Perlman, *supra* note 130, at 47; NIMMER, *supra* note 123, ¶ 7.06(2)(b).

151. NIMMER, *supra* note 123, ¶ 7.06(2)(b).

since World War II.[152] The concept has been set forth in texts and trade journals[153] and has been incorporated into the military and commercial contexts, successfully stretching man-machine performance capabilities.[154]

The computer, control, and display technology currently available is capable of exploiting the goals of good human factors design. For instance, the computer technology used in the CAWS system onboard the DC-9-82 could have provided warnings to the crew of failures in the flight system. This is evidenced by the fact that at the time of Flight 255's accident, if the CAWS failed internally, the system would cause an annunciator to illuminate in the cockpit.[155] The manufacturer testified that the only reason it included system monitoring in the CAWS was to expedite maintenance.[156] Nevertheless, the manufacturer could have designed the CAWS to monitor its input power to detect a failure.[157]

Thus, industry and academia have developed both the human factors technology and computer, control, and display technology necessary to prevent this type of accident.

The Comparative Cost and Feasibility of the Alternative Design. In determining the cost of an alternative airplane design which incorporates desired human factors principles, the court should look to the cost of incorporating the machine system technology into the airplane design,[158] as well as to the initial cost of performing a human factors analysis.[159]

Evidence suggests that it would not have been too costly to incorporate into the design of the DC-9-82 the machine system technology necessary to realize a human factors design which would have prevented the crash of Flight 255. After all, the CAWS was already designed to monitor the power input which failed and resulted in the crash.[160] It was only because the designer felt this information was not essential to safe operation that it chose to design the system so that this failure was not communicated to the pilots.[161] The feasibility of incorporating technology to communicate this failure to the pilots is further evidenced by the NTSB's recommendation that the CAWS system monitoring be al-

152. *See supra* text accompanying note 25.

153. *See supra* text accompanying note 28.

154. *See generally*, HUCHINGSON, *supra* note 48, at 36-90 (discussing human capabilities and limitations).

155. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 14.

156. *See supra* text accompanying note 85.

157. *Id. See also supra* text accompanying notes 114-115.

158. *See supra* text accompanying note 84.

159. *See supra* text accompanying notes 116-118.

160. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 14.

161. *Id.*

tered to comport with the original FMEA.[162]

In so far as the initial cost of performing a human factors analysis is concerned, such costs would seem reasonable provided a human factors department existed within the company.[163] No doubt, the costs of additional human factors design work would increase the non-reoccurring costs of the final product. Nevertheless, it is the province of the manufacturer to make this cost trade-off determination. A minor increase in the cost of the product is not sufficient to risk serious injury to consumers.[164] The manufacturer of a commercial aircraft must balance these costs against the foreseeability of an accident.

The Foreseeability of Injury. A major problem faced by the manufacturer who tries to balance the costs and benefits of conducting a human factors analysis is the inability to determine the foreseeability of a given human error before the analysis is performed. The possible types of error that could be committed are only ascertainable after the designer has performed the task analysis. Furthermore, the designer cannot determine the overall risk of failure of the entire system, due to human error, unless a hazard integration analysis is done. Once the designer has completed these analyses, the cost of the program is immaterial, the designer has already spent the money. Thus, discovering the foreseeability of injury requires the performance of a human factors analysis and the assumption of the associated costs.

Human error in flight is foreseeable.[165] A human factors analysis merely isolates individual sources of error and identifies the resultant outcome of the error.

Affect of Design on Commercial Success. Once the manufacturer has identified an alternate human factors design, the next step is to determine how the alternate design will affect the product's commercial success. In the competitive world of aircraft manufacturing, cost is an important factor in the success of a product. However, with accident

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162. *See supra* text accompanying notes 114-115.

163. It is the author's experience that the particular aircraft manufacturer involved here has a human factors department available during the design phase. The degree to which this department's input is sought and incorporated during the design phase is, however, limited. The extent to which this department was involved during the development of the CAWS onboard Flight 255 is unknown.

164. The Ford Motor Company discovered this fact *after* its Pinto design became the subject of several high profile lawsuits resulting in substantial punitive damages. *See, e.g.*, Grimshaw v. Ford Motor Co., 119 Cal. App. 3d 757, 772-73, 174 Cal. Rptr. 348, 358 (1981).

165. The NTSB has documented repeated instances of pilot inattentiveness, misuse, inadvertence, complacency, misjudgment and forgetfulness. NATIONAL TRANSPORTATION SAFETY BOARD, BUREAU OF SAFETY PROGRAMS, ANNUAL REVIEW OF AIRCRAFT ACCIDENT DATA, U.S. GENERAL AVIATION CALENDAR YEAR 1986, at 86-148 (1988). In 1986, pilot error caused 83.8% of all aviation accidents. *Id.* at 20.

rates so low,[166] consumers rarely pay attention to who manufactured the plane in which they are flying. As a result, factors such as initial cost and operating cost are primary considerations for purchasing airlines. This makes it hard for the manufacturer to justify the cost of improved safety.

On the other hand, a single accident can have a grave impact on the manufacturer of that aircraft, especially if the media challenges the design of the aircraft. McDonnell Douglas' commercial aircraft business nearly came to a halt after a DC-10 crashed in 1979.[167] The media speculated that the accident was due to design failure. Thereafter, consumers avoided flights on the DC-10, and McDonnell Douglas saw most of its commercial aircraft orders and options dropped. If it were not for an Air Force order for 60 DC-10s, tanker/transport derivatives of the DC-10, and for the potential work on the C-17 military cargo plane, industry analysts at the time felt McDonnell Douglas' commercial aircraft plant would not have been able to remain open.[168] Structural problems in older Boeing aircraft have raised similar concerns at Boeing that bad press may arouse passenger fears and lead to equally disastrous results.[169]

As the foregoing suggests, the product designer is in the best position to determine the costs and benefits of alternative designs. A design would be deemed defective by the court if it did not satisfy the cost/benefit test or, in other words, if the manufacturer failed to avail itself of practical technology to prevent the foreseeable risk of human error.

c. *The regulatory compliance test*

The FAA has incorporated human factors standards into its regulations governing the commercial aviation manufacturing industry.[170] A manufacturer must satisfy these regulations, together with their associated "Advisory Circulars," before the FAA will certify a new aircraft's or aircraft component's design.[171] Even where the FAA has certified the aircraft, a court may determine that a product is defective or negligently designed if the manufacturer did not comply with these regulations.[172] In some states, failure to comply with these regulations is

166. *See supra* note 138.

167. Lee, *McDonnell Douglas' Planes Taking Off Again*, PUGET SOUND BUS. J., Mar. 11, 1985, at 1.

168. *Id.*

169. Vartabeelian, *Accidents Spotlight Issue of Boeing Quality Control*, L.A. Times, Feb. 26, 1989, at A1, col. 3.

170. *See supra* text accompanying note 30.

171. *Id.*

172. SPEISER & KRAUSE, *supra* note 30, at 557. *See* Elsworth v. Beech Aircraft Corp., 37 Cal. 3d 540, 547, 691 P.2d 630, 633, 208 Cal. Rptr. 874, 877 (1984)(the court instructed the

negligence per se.[173] Thus, where the FAA has incorporated human factors design principals into its regulations, or the supporting advisory circulars, these human factors standards may dictate the duty of care for the manufacturer under a negligence or products liability theory.

Regarding Flight 255, the NTSB accident report[174] did not indicate that the manufacturer had violated any regulations. The FAA had certified the entire airplane's design before release[175] and had witnessed or conducted the validation tests designed to verify the FMEA, which it approved as written.[176]

In sum, the manufacturer apparently satisfied the regulatory compliance test. However, regulatory compliance does not end the inquiry into the manufacturer's duty of care. The manufacturer must still exercise that duty of care required by the common law test for negligence or products liability.[177] Evidence of the manufacturer's failure to employ human factors analysis may still overcome evidence of regulatory compliance.

3. *Causation and the Pilots' Liability*

Even after a court has determined that the manufacturer defectively designed a product, the court must still decide if the defect proximately caused the injury,[178] or if other intervening or simultaneous causes were partly or wholly to blame.

If a manufacturer can successfully show that a superceding cause, independent of the defectively designed product, was responsible for the injury, the manufacturer may escape liability.[179]

With regard to Flight 255, the court is unlikely to consider the pilots' failure to perform the checklist a superceding cause given that the NTSB concluded that:[180] (1) the input failure was a contributing cause

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jury "that [it] must find [the manufacturer] negligent if [it] found the [FAA] regulations were violated and that the violations proximately caused decedents' injuries, unless [the manufacturer] justified its failure to comply").

173. Schwartz, *supra* note 129, at 388. SPEISER & KRAUSE, *supra* note 30, at 556.

174. NORTHWEST ACCIDENT REPORT, *supra* note 1.

175. 49 U.S.C.S. §§ 1423(b), 1423(c), 1430 (Law. Co-op. 1981).

176. NORTHWEST ACCIDENT REPORT, *supra* note 1, at 14.

177. Schwartz, *supra* note 129, at 389 n.72; SPEISER & KRAUSE, *supra* note 30, at 557. *See also* The T.J. Hooper, 60 F.2d 737 (2d Cir. 1932) (the existence of an industry custom and the absence of a violation of any statutes is an inadequate defense for lack of reasonable care).

178. Dimond v. Caterpillar Tractor Co., 65 Cal. App. 3d 173, 177, 134 Cal. Rptr. 895, 898 (1976).

179. *See* BLACK'S LAW DICTIONARY 201 (5th ed. 1979).

180. The finder of fact must come to its own conclusions from testimony and evidence presented to it. This does not include the NORTHWEST ACCIDENT REPORT. The NORTHWEST ACCIDENT REPORT may not "be admitted as evidence or used in any suit or action

and (2) the manufacturer could have designed the product to prevent this type of accident.[181] Instead, the court may consider the pilots' failure to perform the checklist, the failure of the CAWS input power, and the inadequacies of the CAWS design, to be concurrent causes of the accident. The basis for manufacturer liability for the inadequacies of the CAWS design was discussed previously. Alternatively, the manufacturer's liability may be established if the failure of the CAWS input power was due to a hardware failure arising from a design or manufacturing defect. In either case, the manufacturer's liability may be reduced or eliminated if the manufacturer can show that the pilots' misuse was a concurrent cause of the plaintiff's injuries.

For suits by a third party against the manufacturer, the manufacturer may be able to show that the way in which a consumer used the product was a concurrent cause of injury to the third party, and, therefore, the manufacturer and consumer should be viewed as direct and indivisible causes of the injury under a theory of joint causation.[182] In such a case, the court may hold the manufacturer and the consumer jointly and severally liable to the injured third party.[183]

In the case of Flight 255, there are at least three groups of plaintiffs who may file suit. First, representatives of the passengers' estates may sue the pilots' estates, the airline, and/or the manufacturer. Second, the representatives of the pilots' estates may sue the manufacturer. Finally, the airline may sue the manufacturer for direct and consequential economic losses arising from the accident.[184]

In order to hold the pilots and the manufacturer jointly and severally liable to the passengers' estates, the court must find concurrent negligence or proximate causation on the part of each defendant.[185]

Finally, if the manufacturer is sued by the user, the manufacturer can argue that the user's own negligence contributed to causing the accident.[186] Depending upon where the case is decided, the manufacturer may be able to reduce or eliminate its liability for the user's injury

for damages growing out of any matter mentioned in such reports." 49 C.F.R. § 835.2 (1975). Board employees, however, can testify as to their own factual findings provided the Accident Report is not used as a reference. *Id.* § 835.4.

181. NORTHWEST ACCIDENT REPORT, *supra* note 1, at v, 68.

182. Smith v. J.C. Penney Co., 269 Or. 643, 656-57, 525 P.2d 1299, 1305-06 (1974).

183. *Id.*

184. The latter suit is discussed in the contracts analysis, *infra* ¶ IV, B.

185. American Motorcycle Ass'n v. Superior Court, 20 Cal. 3d 578, 578 P.2d 899, 146 Cal. Rptr. 182 (1978). Joint and several liability also extends to co-defendants liable under a strict products liability standard. Smith v. J.C. Penney Co., 269 Or. 643, 656-57, 525 P.2d 1299, 1305-06 (1974).

186. Cousins v. Instrument Flyers, Inc., 58 A.D.2d 336, 396 N.Y.S.2d 655 (1977), *aff'd*, 44 N.Y.2d 698, 370 N.E.2d 914, 405 N.Y.S.2d 441.

based upon this contributory negligence theory.[187]

Analyzed in terms of Flight 255, it appears that if the manufacturer can successfully claim that the pilots were contributorily negligent in failing to perform the checklist, the manufacturer may be able to reduce or eliminate its liability.

To establish the pilots' negligence, for purposes of the foregoing legal theories, the court must find that the pilots either acted or failed to act in a way that breached the standard of due care.

a. The pilots' duty of care

The pilots of Flight 255 owed a duty of care to themselves and to their passengers. The pilots' breach of the duty owed themselves becomes important when the manufacturer pleads the defense of contributory negligence, while the breach of duty owed the passengers arises in lawsuits by the representatives of passengers' estates against the pilots' estates, the airline, and/or the manufacturer.

The pilots' duty to themselves requires them to act with the same level of care as that exercised by a reasonably prudent person in similar circumstances,[188] while the pilots' duty of care to the passengers requires them to act in accordance with a malpractice standard.[189] When determining negligence of either sort, the court analyzes the pilots' behavior in accordance with the higher malpractice standard in order to account for the professional abilities of the pilots.[190]

Thus, the level of care pilots must exercise, for their own protection and for the protection of their passengers, is that of an ordinary prudent pilot with superior skills incident to professional training. Applying this standard to the pilots of Flight 255 raises the issue of whether the pilots breached their standard of care when they failed to perform the checklist.

b. Lowering the standard of care by acknowleging human factors

Several courts have concluded that a user's failure to exercise every

187. Sun Valley Airlines v. Avco-Lycoming Corp., 411 F. Supp. 598 (D.C. Idaho 1976).

188. Gyerman v. United States Lines Co., 7 Cal. 3d 488, 498 P.2d 1043, 102 Cal. Rptr. 795 (1972).

189. *See* W. KEETON, PROSSER AND KEETON ON TORTS § 32, at 185-86 (5th ed. 1984).

190. *Id. See also* RESTATEMENT (SECOND) OF TORTS §§ 289(b), 464 comment f (1965). The ordinary person standard for the duty of care which a professional pilot owes to himself and his passengers must be the same. In each case, the pilot must exercise the same level of care exercised by other pilots in like circumstances. Numerous contributory negligence cases in employee injury situations support this view. In such cases, the court considers an employee's specific knowledge of the dangers of the task, not just the knowledge of the reasonable person. *See, e.g.*, *Gyerman*, 7 Cal. 3d 488, 498 P.2d 1043, 102 Cal. Rptr. 795 (1972).

precaution, while operating equipment, does not necessarily mean that the user has fallen below the negligence standard of due care. In *Micallef v. Miehle Co.*,[191] the plaintiff was injured while trying to remove a foreign object from the plate of an operating printing press. Though the plaintiff conceded that he was well aware of the danger involved in trying to remove a foreign object while the machine was operating, shutting off the machine would have cost several hours in down-time. Moreover, this method of removing foreign objects had become the custom and usage of the trade.

After pointing out the various safety features which could have prevented plaintiff's injury, the court in *Micallef* rejected the patent danger rule which traditionally barred a plaintiff from recovering if the danger was shown to be open and obvious.[192] Instead, the court held:

> [A] manufacturer is obligated to exercise that degree of care in his plan or design so as to avoid any unreasonable risk of harm to anyone who is likely to be exposed to the danger when the product is used in the manner for which the product was intended, . . . as well as an unintended yet reasonably foreseeable use.
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> . . . .
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> That does not mean, however, that the obviousness of the danger as a factor in the ultimate injury is thereby eliminated, for it must be remembered that in actions for negligent design, the ordinary rules of negligence apply. . . . Rather, the openness and obviousness of the danger should be available to the defendant on the issue of whether plaintiff exercised that degree of care as was required under the circumstances.[193]

In an Ohio products liability case,[194] the jury awarded the plaintiff four million dollars for injuries suffered in a motorcycle accident.[195] The plaintiff "had forgotten to raise the kickstand, which was in a down position, when he made [a] turn, causing the motorcycle to go out of control and crash."[196] The plaintiff successfully argued that, "the manufacturer, Kawasaki, was aware that motorcyclists occasionally forget to raise the kickstands and that its contact with the road could cause loss of control."[197] Despite this knowledge, Kawasaki chose to equip the bike with the cheaper, non-automatic kickstand.[198] The jury apparently believed that this choice led to a defective design, thereby relieving

191. 384 N.Y.S.2d 115 (1976).

192. *Id.* at 122.

193. *Id.* at 121-22.

194. Keiner & Keiner, *supra* note 32, at 6, col. 4 (citing Beauregeard v. Rick Case Motors, Cuyahog County Court of Common Pleas (1983)).

195. *Id.*

196. *Id.*

197. *Id.*

198. *Id.*

plaintiff of any fault for his forgetfulness.[199]

Finally, in *Flynn v. City of New York*,[200] the court ruled that temporarily forgetting a known danger was no longer a valid defense to contributory negligence, but it could be considered when apportioning fault under comparative negligence.[201] In *Flynn*, the plaintiff suffered injuries when he fell into a hole in the sidewalk. The plaintiff acknowledged that he had seen the hole several times before the accident but that on the day of the accident he had forgotten it was there. In discussing how courts should handle "culpable conduct" on the part of the plaintiff, the court stated:

> [W]here the trier of fact finds negligence on the part of a defendant, it may then consider whether a plaintiff's failure to have kept a known danger in mind constituted conduct falling below the standard of a reasonably prudent person. If the trier of fact concludes that plaintiff's conduct did fall below that standard, it may then apportion the liability accordingly.[202]

Analyzing the situation of Flight 255, in light of the holdings in these cases, suggests that the crews' failure to perform the taxi checklist did not constitute a failure to exercise due care. Instead, as demonstrated by the human factors analysis performed after the accident, the pilots' forgetfulness was no greater than one would expect from a reasonably prudent pilot. Based upon their recommendations, the NTSB appears to share this view.[203] Thus, under the circumstances of Flight 255, a jury could correctly conclude that the designer, not the flightcrew, should be liable given the clear human factors shortcomings in its design.

c. *User negligence and the failure to warn*

The preceding discussion focused on an operator's liability based on contributory negligence when the equipment operated was defectively designed. A court may take a slightly different approach to determining an operators' liability for contributory negligence when the claim is based on a failure to warn. In such a case, the court will either find the warning to be sufficient to give the typical user notice of the risk, or defective because it fails to provide the user with adequate warning.[204] In cases where the latter is found to be true, courts reject contributory negligence as a defense because misuse could always be characterized as

199. *Id.*
200. 103 A.D.2d 98, 478 N.Y.S.2d 666 (1984).
201. *Id.* at 103, 478 N.Y.S.2d at 669.
202. *Id.*
203. *See supra* text accompanying note 115.
204. Schwartz, *supra* note 129, at 397.

contributory negligence.[205] Instead, courts will interpret reasonable victim misuse as being *directly caused* by inadequate warnings.[206]

In *Lenherr v. NRM Corp.*,[207] the court recognized that a manufacturer can significantly increase its ability to warn the user of dangers if it designs the product to provide real time warnings as dangers occur. In this case, the plaintiff was injured when the "squeegee" machine he was working with began operating and caught and injured his arm. The plaintiff was aware of an existing safety switch which would have prevented the machine from operating, but he failed to use it. Nevertheless, the court agreed with the human factors expert's determination that, despite the plaintiff's knowledge of the danger, the designer "overlooked human factors" and should have added warning bells and flashing lights to the design to further warn the plaintiff of an unsafe condition.[208]

Applying this rationale to the situation of Flight 255 suggests that even though the pilots knew they should complete the taxi checklist, they should not be considered contributorily negligent by the court for failing to do so because the manufacturer of the aircraft computer system failed to incorporate into the CAWS design a means of warning the pilots of their dangerous configuration.

The preceding discussion of causation and contributory negligence reviewed several approaches which a court might use to completely absolve the pilots of blame for the acts which occurred before the crash of Flight 255. Even where a court could not completely absolve the pilots of blame, most progressive jurisdictions would allow apportionment of fault during the original trial or in later suits for contribution.[209] As a result, if the plaintiff presents human factors evidence tending to relieve the pilots of blame, the manufacturer must counter with evidence demonstrating that human factors principals were, in fact, applied. In other words, the manufacturer must show that the design of the man-machine system was not unreasonably dangerous for its expected use. If the manufacturer fails to present this evidence, the plaintiff's human factors evidence may, at the very least, result in heavy apportionment

205. *Id.* at 397 n.87.

206. *Id.* (citing Moran v. Faberge, 273 Md. 538, 332 A.2d 11 (1975)).

207. 504 F. Supp. 165 (D. Kan. 1980).

208. *Id.* at 173.

209. Brown v. Keill, 224 Kan. 195, 203, 580 P.2d 867, 873-74 (1978); Dole v. Dow Chem. Co., 30 N.Y.2d 143, 282 N.E.2d 288 (1972); Safeway Stores, Inc. v. Nest-Kart, 21 Cal. 3d 322, 327-32, 579 P.2d 441, 443-46, 146 Cal. Rptr. 550, 552-55 (1978) (extending apportionment to two co-defendants, one under a strict products liability claim and the other under negligence); Flynn v. City of New York, 103 A.D.2d 98, 478 N.Y.S.2d 666 (1984) (for a discussion of the case, see *supra* text accompanying note 200).

of fault against the manufacturer.[210]

B. Contracts

Human factors analysis may allow Northwest Airlines to recover for the loss of its aircraft and foreseeable consequentials pursuant to the contractual theories of implied warranty of merchantability and implied warranty of fitness. A court may also extend recovery, under implied warranty theory, to injuries suffered by third parties such as the pilots or the passengers.

In most jurisdictions, Article 2 of the Uniform Commercial Code (U.C.C.) treats computer systems, consisting of hardware and software, as goods.[211] Jurisdictions which do not apply the U.C.C. to such products may still use it by analogy.[212]

Section 2-314 of the U.C.C. creates an implied warranty of merchantability for goods sold under a contract of sale unless the implied warranty is expressly excluded or modified.[213] This implied warranty requires that the goods meet the general standards of the trade and that they be fit for the buyer's ordinary purposes.[214] Section 2-315 creates an implied warranty of fitness for intended use where the seller, at the time of contracting, has reason to know the buyer's intended use.[215]

Section 2-314 applies to a computer system, such as an aviation system, designed and manufactured for a commercial aircraft and marketed generally.[216] Section 2-315 applies to a custom-designed computer system such as that used on a sailboat.[217] The design of the DC-9-82 would fall under section 2-314 since the manufacturer intended that the computer system installed in the aircraft be used for ordinary commercial aviation purposes. This analysis will, therefore, focus on section 2-314.

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210. Wallace & Key, *supra* note 31, at 19, 24 n.11.

211. *See e.g.*, Triangle Underwriters, Inc. v. Honeywell, Inc., 457 F. Supp. 765, 769 (E.D.N.Y. 1978), *aff'd in part, rev'd in part*, 604 F.2d 737 (2d Cir. 1979); Carl Beasley Ford, Inc. v. Burroughs Corp., 361 F. Supp. 325, 334 (E.D. Pa. 1973), *aff'd*, 493 F.2d 1400 (3d Cir. 1974).

212. *See* Samuel Black Co. v. Burroughs Corp., 33 U.C.C. Rep. Serv. (Callaghan) 954, 962 (D. Mass. 1981).

213. U.C.C. § 2-314 (1988). This analysis assumes the manufacturer/seller did not exclude or modify the implied warranty.

214. *Id.*

215. U.C.C. § 2-315 (1988).

216. U.C.C. § 2-315 comment 2 (1988) (discussion of the difference between a "particular purpose" and an "ordinary purpose").

217. *Id. See generally Hewlett Packard Co.: High-Tech Equipment to Aid Racing Yachts*, Bus. Wk., Sept. 2, 1988 (example of computer systems designed expecially for use on board the "New Zealand" for the America Cup Yacht Race).

For the airline or other plaintiff to recover under a section 2-314 implied warranty of merchantability, it must "show not only the existence of the warranty but the fact that the warranty was broken and that the breach of the warranty was the proximate cause of the loss sustained."[218] Evidence of the care exercised by the designer-seller in the manufacture, processing or selection of the goods may serve as evidence as to whether the warranty was broken.[219]

Subsection (c) of section 2-314 is most applicable to design defects. This subsection provides that for goods to be merchantable they must be at least such as "are fit for the ordinary purposes for which such goods are used . . . ."[220] It is under this subsection that the court should make a human factors analysis to determine the degree to which a manufacturer must consider and incorporate human factors into a design to make the design fit for ordinary purposes. When using any product for ordinary purposes, the human operator will make, on average, between 1-in-100 and 1-in-1000 errors per attempt (i.e., per opportunity to make an error).[221] These error rates can "vary widely depending on the task and many other factors such as fatigue, sleep loss and motivation."[222] The manufacturer who sells a computer system for use in an aviation system would be in breach of the implied warranty of merchantability if it did not take these error rates into account in the design. The design must be fit for an aviation environment, including the known human error rate. To ensure that this is the case, the designer must utilize the same type of human factors design analysis illustrated with Flight 255.

Of course, an implied warranty analysis, like a torts analysis, runs into the obstacle of negligent user conduct. U.C.C. section 2-715(2)(b) allows consequential damages for the seller's breach of warranty only for "injury to person or property proximately resulting" from the breach.[223] In order for the breach to be the proximate cause of the injury, the buyer must not have negligently or knowingly intervened by failing to reasonably inspect the product before using it or by using the

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218. U.C.C. § 2-314 comment 13 (1988).

219. *Id.*

220. *Id.* § 2-314(c).

221. HAWKINS, *supra* note 18, at 27.

222. *Id.* For purposes of rough comparison of human to computer error rates, the FAA will approve an automatic landing system for very low visibility automatic-to-touchdown landings (i.e., landings without pilot intervention in bad weather) only when the designer has shown the system will not suffer a catastrophic failure more than once in one billion times. *Compare* FEDERAL AVIATION ADMINISTRATION, ADVISORY CIRCULAR NO. 120-28C, CRITERIA FOR APPROVAL OF CATEGORY III LANDING WEATHER MINIMA ¶ 7 (Mar. 9, 1984) (failure of the automatic landing system must be extremely improbable) *with* FAA ADV. CIR. NO. 25-1309-1A, *supra* note 83, at ¶ 10(b) (defining extremely improbable as 1×10^{-9} or less).

223. U.C.C. § 2-715(2)(b) (1988).

product even after discovering the defect.[224] Furthermore, the U.C.C. may also bar recovery when the user mishandles the goods or because of some other supervening cause.[225]

Courts have interpreted implied warranties to require the person injured to have acted with "that degree of care for his own safety that a reasonably prudent person would have exercised under the same circumstances . . . ."[226] This user care requirement would extend to the pilots and passengers of Flight 255, since the U.C.C. grants them no greater warranty than the airline.[227] Such a reasonableness standard is the same as that used in products liability.[228] It creates a negligence standard to govern the conduct of the airline, the pilots, and the passengers. Thus, a fact finder may use human factors analysis, under an implied warranty theory, just as in products liability analysis, to absolve these parties of any contributory negligence.[229]

Applying this contracts analysis to Flight 255, suggests that in order for the airline or other plaintiff to recover under the implied warranty of merchantability, the following must be shown (1) the existence of the warranty,[230] (2) the fact that the warranty was broken, and (3) breach of the warranty was the proximate cause of the loss sustained. Evidence that the airline manufacturer failed to incorporate known human factors principles and methods into its design serves to show that the warranty was broken. After all, use of such human factors principles and methods would have revealed the vulnerability of the DC-9-82 to the human error and system failure which led to the crash of Flight 255. The failure to use human factors principles would be evidence of the manufacturer's lack of care in selecting the proper goods.[231] Once again, the manufacturer has a duty to design goods under section 2-314 which "are fit for the ordinary purposes for which such goods are used."[232] Flight 255 was in the midst of normal operations when the

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224. U.C.C. §§ 2-314 comment 13, 2-715 comment 5. *See also* RESTATEMENT (SECOND) OF TORTS § 402A comment n (1966) (the user is contributorily negligent if he "voluntarily and unreasonably. . . encounter[s] a known risk. . . .").

225. *See* J. WHITE & R. SUMMERS, HANDBOOK OF THE LAW UNDER THE UNIFORM COMMERCIAL CODE § 11-8, at 413-14 (2d ed. 1980).

226. Codling v. Praglia, 345 N.Y.S.2d 461, 471, 298 N.E.2d 622, 629 (1973).

227. *See* U.C.C. § 2-318 comment 2 (1988). *See also infra* text acompanying notes 236-240 (privity discussion).

228. Preston v. Up-Right, Inc., 243 Cal. App. 2d 636, 642, 52 Cal. Rptr. 679, 684 (1966).

229. *Id. But cf.* Holt v. Stihl Inc., 449 F. Supp. 693 (E.D. Tenn. 1977) (split within and among jurisdictions as to the express use of contributory negligence as a defense in breach of warranty actions).

230. It is assumed, for purposes of this analysis, that the implied warranty exists. *See supra* text accompanying note 213.

231. U.C.C. § 2-314 comment 13 (1988).

232. *Id.* § 2-314.

man-machine system failed.

To determine whether the breach was the proximate cause of the accident, the court must ascertain whether the pilots of Flight 255 negligently or knowingly intervened by failing to reasonably inspect the aircraft before using it or by misusing the aircraft. These questions may be answered by a human factors analysis. Pursuant to such an analysis, the manufacturer has breached the implied warranty of merchantability where such a warranty existed and its breach was the proximate cause of the injury.[233] This will be true when (1) the manufacturer had "reason to know"[234] of the foreseeability and danger created by human error, (2) the manufacturer did not address violations of known human factors principles and methods and (3) the evidence shows the pilots acted above that standard of care which they owe themselves and their passengers.[235] In such a case, the court may award the airline damages for the loss of the aircraft and consequentials. Where non-economic damages are allowed, the court may also award damages to the pilots' estates and the passengers' estates.

Whether the court permits compensation to the pilots' estates or the passengers' estates under an implied warranty theory depends on how the court treats the issue of privity. Some courts restrict breach of implied warranty actions to situations where there is privity between the plaintiff and the defendant.[236] Where there is no privity, some courts have held that the law is more correct in treating recovery for injuries resulting from product defects under a theory of strict products liability.[237] In these jurisdictions, the pilots' and passengers' estates would not be able to bring an action for breach of an implied warranty.

Still other courts have rejected the privity requirement and allow non-contractual parties to recover under implied warranty.[238] The reasoning used by these courts is, however, very similar to that used by courts adhering to strict products liability.[239] As a result, the issue of privity is largely unimportant.[240] Where the law requires privity, the

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233. *Id.* § 2-314 comment 13.
234. *Id.* § 2-715 comment 2.
235. *Id.* § 2-314 comment 13.
236. Suffolk County v. Long Island Lighting Co., 728 F.2d 52, 63 (2d Cir. 1984)
237. Micallef v. Miehle, 384 N.Y.S.2d 115, 122 (1976) (citing several supporting cases).
238. RESTATEMENT (SECOND) OF TORTS § 402A comment m (1966).
239. *Id.*
240. Note also that where an implied warranty is treated under traditional contract theories, the U.C.C. allows the seller to exclude from the contract any implied warranty under § 2-316. U.C.C. § 2-316 (1988). This same exclusion would then transfer to the ultimate users under § 2-318 comment 2 of the U.C.C. *Id.* § 2-318 comment 2. In contrast, where the implied warranty is treated as analogous to strict products liability, the U.C.C. does not apply, and the implied warranty cannot be excluded. RESTATEMENT (SECOND) OF TORTS § 402A comment m (1966).

plaintiff can recover under strict products liability and where it does not, the theories and remedies available to the parties parallel strict products liability. Thus, whether an action is based on implied warranty, products liability, or both, the plaintiff-parties should always present evidence of a manufacturer's failure to incorporate human factors principles in order to convince the court to allow all the injured parties to recover.

V. CONCLUSION: TOWARD AN AWARENESS OF HUMAN FACTORS

Three Mile Isand, Chernobyl, and the crash of Flight 255 evidence the serious harm which can result from ignoring system designs which enhance the potential for human error.[241] The problem is that inadequate human factors designs such as that which led to the tragedy of Flight 255 could lead to even greater disasters for airports nestled in the midst of densely populated cities. Imagine a poorly designed plane veering out of control and crashing into a crowded office building or school because the pilot forgot to review a checklist.

Disasters such as these can and should be prevented. This Note has tried to explain how this may be done by acquainting the reader with the field of human factors engineering and by demonstrating how this field is attempting to increase the industry's understanding of the limitations of the operator and the need to account for these limitations in the design. In addition, this Note has attempted to educate management as to the liabilities they may face if they choose to ignore human factors technology. In this regard, the Note invites stronger action on the part of regulatory authorities, courts and the legal profession to meet the challenge of human error in the age of complex computer systems. As long as regulators and courts continue to shift the blame for tragic accidents from the designers of the system to the operator, accidents will continue to happen.

Finally, this Note hopes to encourage express judicial use of human factors analysis to determine whether the designer should have foreseen and safeguarded against the particular human error which led to the injury. Currently, the test for a defective design focuses on whether the product was unreasonably dangerous. To analyze a case under the current standard, courts look at the product as it currently exists. Even

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241. HAWKINS, *supra* note 18, at 27. By no means does this Note's focus on disaster sensitive industries imply that human factors design principles have no place in less critical products. For example, a poorly designed office system could just as easily form the basis of an implied warranty action to recover economic losses stemming from reasonably foreseeable misuse.

if a party provides human factors testimony, it usually goes to whether the design violates human factors principles.

In order for courts to truly accomplish the increase in product safety available through human factors design, the focus must shift from the product as it exists to the design method used by the designer. To determine liability when an accident occurs as a result of human error, the court should first ascertain whether the designer could have discovered, pursuant to a reasonable human factors analysis, the potential for the human error. If so, the next question would be whether the designer could have incorporated cost-effective safeguards which would have prevented or reduced the consequences of the human error. If the answer to both of these questions is yes, and the designer failed to implement the safeguards, then the designer should be held liable. Whether regulations require such safeguards, or whether the industry customarily uses such safeguards, is immaterial.

Furthermore, if the answer to these questions is yes, the question of the normal negligence (as opposed to gross negligence) of the operator is relevant only with regard to apportionment of damages because, but-for the designer's failure to perform a human factors analysis, the design would have accounted for the user's normal negligence. The question of the user's negligence turns on whether, under the circumstances, the user exercised that degree of care expected of a reasonably prudent person.

If the judicial system were to expressly recognize and use human factors design methods to evaluate the adequacy of a system design, this would do much to clarify and encourage safer designs of man-machine systems. Moreover, it would empower the private bar to implement and enforce the design methods, thereby reducing the current burden on regulatory agencies and the resultant conflicts between these agencies and the industries they monitor.

The NTSB's conclusion that pilot error caused Flight 255's crash does nothing to improve aviation safety. After all, no one can redesign the reasonably prudent pilot.

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