Chapter four

"Get this . . . on the ground"

It was December 28, 1978, and for the passengers on United flight 173, both Christmas and JFK airport were fading memories, their thoughts directed to Portland and the upcoming weekend. A little after 5 p.m., the flight called Portland approach for the first time, "We have the field in sight." The flight had departed from its stopover at Denver 2 hours and 18 minutes earlier with 189 souls on board, including a crew of eight. The DC-8 required about 32,000 pounds of fuel to fly from Denver to Portland, but the plane was filled like dad after the holidays with half again the amount of fuel needed, including the 45 extra minutes required by the Federal Aviation Administration (FAA) and 20 minutes of contingency fuel added by United Airlines.

As the landing gear lowered, the captain noted an unusual "thump, thump in sound and feel." The first officer noted the plane yawed to the right. Although the nose gear light was green, no such assurances glowed from the other landing gear indicator lights.

As United 173 moved toward Portland, Dr. Bob Helmreich, a young professor sat at his desk at the University of Texas, penning a paper for an upcoming conference sponsored by National Aeronatics and Space Administration (NASA) in cooperation with the airline industry. The paper was about the psychology of small groups. Helmreich had studied small groups in high-stress environments since his second year in graduate school at Yale, when he worked with the Navy's aquanauts in Project Sealab in the mid-1960s. Sealab was an effort to study how people worked in pressurized confined spaces on the ocean floor. A few years later, NASA would use these kinds of data to inform its decisions about the Apollo missions. Despite his youth, Helmreich had been known for years for his systematic observational approach to quantifying the behavior of operators under stress when United 173 called Portland approach.

At 5:12 p.m., Portland approach instructed United 173 to contact Portland tower for final landing instructions. However, the suspected problem with the landing gear led the captain to stay with approach control. At this point, the flight had a little over 13,000 pounds of fuel, enough to fly for, at most, 1 hour. Approach control sent the aircraft southeast of the airport so it could

stay in a holding pattern within 20 nautical miles (nm) of the airport while the problem was investigated. The crew discussed and performed the necessary checks; the visual indicators on the wings suggested that the gear was down and locked. Twenty-eight minutes from the time the captain notified Portland approach of the possible landing gear problem, he contacted United Airlines maintenance control center, explaining the suspected problem and the steps they had taken. He reported that he now had 7,000 pounds of fuel and intended to hold for another 15 or 20 minutes.

United San Francisco: okay, United 173... You estimate that you'll make a landing about 5 minutes past the hour. Is that okay?"
Captain: Ya, that's a good ball park. I'm not goanna hurry the girls. We got about 165 people on board...

At this point, United 173 had 30 minutes before it would run out of fuel.

Back in Austin, unaware of the peril of flight 173, Helmreich spent those 30 minutes writing about the effect of stress on small groups. Helmreich was no stranger to high-stress living. He not only experienced it personally as part of the U.S. blockade during the Cuban missile crisis, but also when he studied those aquanauts for his dissertation. He worked through the argument that, because attention narrows under stress (like focusing on the landing gear), additional tasks (like overseeing the preparation of the passenger cabin, monitoring fuel) make the situation especially dangerous if the tasks are taken on by the captain. Crew members become more dependent on the captain while the captain becomes less able to monitor the crew.

As if to illustrate Helmreich's point, the captain summoned the senior flight attendant to the cockpit and told her to prepare the passengers and the cabin for a possible abnormal landing.

5:46:52 First Officer [to Flight Engineer]: How much fuel we got ...?
Flight engineer: 5,000
5:48:54: First officer [to Captain]: ...what's the fuel show now ...?
Captain: 5
First officer: 5
Captain: That's about right; the feed pumps are starting to blink
Conversation about landing gear. Heading change from Portland approach. Traffic advisory.
5:50:20: Captain [to Flight engineer]: Give us a current card on weight. Figure about another 15 minutes.
First officer: 15 minutes?
Captain: Yeah, give us 3 or 4,000 pounds on top of zero fuel weight.
Flight engineer: Not enough. 15 minutes is gonna—really run us low on fuel here.
5:50:47: Flight engineer: Okay. Take 3 thousands pounds, two hundred and four.

{aircraft was 18 nm south of the airport in a turn to the NE}
Captain instructed Flight engineer to tell United in Portland that 173 would land with 4000 lbs of fuel. Captain responded affirmatively to landing at 6:05.
Approach descent completed.
5:56:53: First officer: How much fuel you got now?
Flight engineer: 4000 lbs, 1000 in each tank
5:57:30 to 6:00:50 Captain and First officer discuss upcoming abnormal landing.
Report to cockpit that cabin will be ready in another 2 or 3 minutes
{aircraft was 5 nm SE of the airport vectoring to a SW heading}

Helmreich's address to the NASA conference argued that suboptimal management of human resources in the cockpit can have tragic consequences. The industry had to move beyond thinking of pilot error to thinking of crew errors. That meant moving past thinking of technical errors to thinking of communication errors.

Helmreich's aquanauts from years earlier lived on the ocean floor, dropped in water a degree or two away from being ice, where aptly named scorpion fish surrounded the alien intruders from the surface who had to forgo their normal oxygen, toxic at these pressures, to inhale heliox (a mixture of 90% helium and 10% oxygen). In this stressful other-world, Helmreich found that performance correlated positively with the amount of conversation among the team, even when the conversations were back at base, not diving. Interestingly, conversations back to friends and relatives on the surface correlated negatively with performance. The more in-group communication and the less out-group communication, the better the aquanauts performed.

If Helmreich were right, leadership style, crew dynamics, and personality would all be important to the safety of the flying public. Even the culture within the cockpit, the "captain is the captain" mentality, would matter. Until then, no one had argued that entire crews, not an individual, should be the unit of study—crews under high workload, crews in crisis.

6:02:22: Flight engineer: We got about 3 on the fuel and that's it.
Captain: Okay. On touchdown, if the gear folds or something really jumps the track, get those boost pumps off so that … you might even get the valves open.
6:02:44: First officer [to Portland approach]: … It'll be our intention, in about 5 minutes, to land on two eight left. …
6:03:14: Captain [to Portland approach]: They've about finished in the cabin. I'd guess about another three, four or five minutes.
{Aircraft was 8 nm S of the airport on a SW heading}
6:03:23: Captain [to Portland approach]: (We've got) about 4,000, well make it 3,000, pounds of fuel. You can add to that 172 plus 6 lap infants.
6:03:38 to 6:06:10 the flight deck crew prepares for abnormal landing.

6:06:19 Flight attendant [to Captain]: Well, I think we're ready.
{Aircraft was 17 nm S of the airport on a SW heading}
6:06:40: Captain: Okay. We're going to go in now. We should be landing in about five minutes.
First officer [to Captain]: I think you just lost number 1
[To Flight engineer]: better get some cross feeds open there or something
6:06:46: First officer [to Captain]: We're going to lose an engine...
Captain: Why?
First officer: We're losing an engine.
Captain: Why?
First officer: Fuel

At 6:07:12 the captain made the first request for a clearance since the landing gear problem. United 173 was 19 nm SSW of the airport. The last minutes of communication follow:

Flight engineer: We're going to lose number 3 in a minute, too.
It's showing zero.
Captain: You got 1000 pounds, you got to.
Flight engineer: 5000 in there, but we lost it.
Captain: Alright.
Flight engineer: Are you getting it back?
First officer: No number 4. You got that cross feed open?
Flight engineer: No, I haven't got it open. Which one?
Captain: Open I both—get some fuel in there. Got some fuel pressure?
Flight engineer: Yes, sir.
Captain: Rotation. Now she's coming. Okay, watch one and two. We're showing down to zero or a 1000.
Flight engineer: Yeah...
Captain: On number 1?
Flight engineer: Right.
Flight officer: Still not getting it.
Captain: Well, open all four cross feeds.
Flight engineer: All four?
Captain: Yeah.
Flight officer: Alright, now it's coming. It's going to be—on approach though.
Unknown voice: Yeah.
Captain: You got to keep 'me running...
Flight engineer: Yes, sir.
First officer: Get this . . . on the ground.
Flight engineer: Yeah, it's showing not very much more fuel.
We're down to one on the totalizer. Number two is empty.

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Flight engineer: We've lost two engines, guys.
Captain: They're all going. We can't make Troutdale (small airport on final approach to Portland).
First officer: We can't make anything.
Captain [to First officer]: Okay. Declare a mayday.
18:13:50: First officer: Portland tower, United one seventy three heavy, Mayday. We're—the engines are flaming out. We're not going to be able to make the airport.

At 6:15 p.m., 3 days before New Year's Eve, the dying United flight crashed 6 miles East Southeast of the airport into suburban Portland, cutting a swath 1,554-feet long and 285-feet wide. The flight engineer, senior flight attendant, and 8 passengers lost their lives. Another 21 people were seriously injured. The aircraft and two unoccupied homes were destroyed.

Helmreich continued his talk with a prophetic wager, not without a tinge of irony. The prediction would ultimately be confirmed in the analysis of the United crash: "I would bet a tank of gas that a significant number of communication breakdowns can be observed under high workload and emergency situations." In fact, the National Transportation Safety Board (NTSB) conclusion indicated that the United 173 crashed with empty tanks of gas because the crew did not communicate effectively about the lack of fuel (see Fig. 4.1).

NTSB analysis would reveal that the landing gear problem was caused by corrosion in the gear, which in turn caused the right main landing gear to fall free. The rapid fall disabled the microswitch for the indicator in the cockpit. Because the left and right landing gear descended at different times, the drag from the right gear caused the temporary yaw that the first officer noticed. Failure to give the flight attendant a time limit to prepare the cabin,

Figure 4.1 The aftermath of Flight 173. It is generally agreed that poor crew resource management was contributory to the crash. The lack of fire damage is due to the absence of fuel at the time of the crash.

as the airline operations manual states, probably failed to convey the correct sense of urgency.

The NTSB attributed the crash to the captain's failure to respond to the fuel state and to the crew's fuel state advisories. The captain was instead focused on the possible landing gear problem and abnormal landing procedure. Contributory was the crew's failure to understand the consequences of the fuel state or to communicate those consequences to the captain effectively.

The board recommended

> Issue an operations bulletin to all air carrier operations inspectors directing them to urge their assigned operators to ensure that their flightcrews are indoctrinated in principles of flightdeck resource management, with particular emphasis on the merits of participative management for captains and assertiveness training for other cockpit crewmembers (NTSB, 1979).

Helmreich had finished writing his talk for the NASA workshop. In hindsight, researchers would look at the workshop as the first conference on cockpit resource management, what is called today crew resource management (CRM). United 173 would, in hindsight, be viewed as the flight that began CRM. In fact, it began in late December both in the interactions of the crew of United 173 and in the mind of Bob Helmreich.

The chief pilot for Texas International (now Continental), J. V. Sclifo, had heard Helmreich's presentation. Helmreich had not proven his position, but he had made a compelling case that made sense on the face of it. Proof would require observations of flight crews. Helmreich knew it. Sclifo knew it.

Sclifo moved toward the podium to congratulate Helmreich on his presentation and, ultimately, to offer valuable help. He gave Dr. Helmreich and his Texas team jump seat access to Texas International Airline (TI) flights. With this kind of access, the human factors researchers from Texas could watch intact flight crews interact in real-world situations. Jump seat access to other airlines followed.

Some of the many jump seat rides are forever etched in memory: Helmreich sat in the jump seat as the aircraft began its takeoff roll. The captain had yet to deploy flaps. Fifty knots, 60 knots, 70. Rotation would occur around 120, and then it would be too late for flaps. Helmreich knew they needed flaps. Should he speak? Would you? After all, he was the guest. 80 knots. Finally, at 90, the copilot said, "Captain, do you want flaps?" resulting in an aborted take-off, but the avoidance of a not uncommon cause of crashes. In another observation flight, the captain of a 727 turned onto the wrong one of two parallel runways, one with another 727 already on it. A final example occurred

on a 747 that had pushed back waiting for taxi instructions to begin its flight from Kennedy to Asia. It was a nasty night. The middle of winter. Foggy. Air traffic control (ATC) broke the silence. The ground controller had given a long, complicated set of taxi instructions. The aircraft began to taxi and then stopped in the dark soup of Long Island's weather. After what seemed like minutes, the captain turned to the jumpseat and asked, "Do you know where we are? I can't ask ATC."

From jump seat observations, there followed research time in simulators. More details, more behavioral markers to look for in effective and ineffective crews. It became evident that there was reason to believe that problems in flight crews were real. But what to do about them? The NASA workshop had mobilized the airlines, and a variety of CRM courses had sprung up, with the first at United.

United Airlines launched the first comprehensive CRM program in 1981. Crews participated in a seminar, reflected on their management style, and practiced interpersonal skills in the simulator during simulations of a full flight from preflight briefing to landing and debriefing [a practice called Line-Oriented Flight Training (LOFT)]. The focus was on bringing to awareness issues affecting crew interactions, changing styles, and correcting problems—overassertive captains and underassertive junior officers.

Along with John Lauber, then senior scientist of the human factors program at NASA-Ames and the future first behavioral scientist on the NTSB, Helmreich ran a course on CRM for the check airmen for Texas TI. The offering at TI began with the results of the first full-mission simulation study run at NASA, which identified many issues in communication and decision making, as well as discussion of human factors issues in accidents. The course did not provide guidance for more effective cockpit management. Rather, it was, in today's terminology, a basic awareness program designed to sensitize the check airmen to the importance of the nontechnical aspects of effective cockpit management.

The next few years saw CRM spread to one airline after another. It was not always easy. Many pilots were resistant, and not everyone embraced this "psychobabble," this "charm school." Some aviators even seemed to get worse after CRM training. Some airlines thought it counter to their traditions and philosophy. For example, Delta said it was a captain's airline. CRM would erode the captain's authority, and that was an approach they didn't need or want.

In 1987, Delta Airlines experienced a number of embarrassing incidents, sufficient to attract the attention of the press, including a column in *Time*, entitled "A Case of Delta Blues." Of the six incidents investigated by the NTSB in 1987, five of them pointed to problems in CRM, including limited, misunderstood, or no communication among the crew. In mid-June, a Delta flight mistakenly acted on a takeoff clearance intended for a Southwest flight. Southwest 715 and Delta 314 started their takeoff rolls from opposite ends

of the same runway. The Southwest had reached takeoff speed and continued, while the Delta veered off onto a taxiway, narrowly avoiding a head-on collision.

On July 7, a disoriented captain landed a 737 destined for Lexington, Kentucky, at an airport in Frankfort, 17 miles away. Later that same month, a 767 landed on the wrong runway in Boston. The NTSB cited crew coordination and noted that "the Delta captain had a reputation for dominant behavior which tended to suppress others in the cockpit."

On August 2, an L-1011 landed in Atlanta, touching down three times and contacting the runway with the fuselage because of excessive flare (nose up) caused by the captain and the check airman both applying nose-up actions. The final incident occurred in December, when the captain of a 737 became disoriented at LAX after landing and reentered a runway, forcing a United flight to take off over the errant Delta aircraft. The first officer was completing the after-landing checklist at the time.

Delta not only rethought their opinion of CRM, they aggressively embraced it. Helmreich and Lauber, along with J. Richard Hackman, a social psychology professor at Harvard, developed an extensive 3-day CRM course for the airline. Things improved, leading Delta's vice president of flight operations to indicate to Helmreich's team that "things are going too well. We think we changed the culture, but need to validate it." Again, Helmreich and team found themselves in jump seats, flying Delta around the country, looking for behavioral markers of CRM, and relating them to overall crew performance, including errors. The Delta course dealt with specifics of flight operations and focused more on the team and cognition: situation awareness, team building, strategies, decision making, and so on.

So, as it turned out, Delta, "the captain's airline," would become a leader in the evaluation of CRM. In fact, there is now good evidence that programs which include repeated CRM training and practice of interpersonal skills work, although CRM does not necessarily reach everyone.

Although any airline can have a few crewmembers whose behavior does not change or improve with CRM training, overarching cultural influences can stack the deck for or against the effectiveness of CRM for an entire workforce. In other words, exporting CRM to other cultures is not easy. One Asian copilot said, "I'd rather die than question the captain." That airline ultimately flew a Boeing 747 into a mountain with the full cognizance of the junior crew. CRM can have success provided adaptations to the culture are made. One adaptation to the collective culture with great respect for authority was applied successfully: Ask the junior crew to imagine they are the elder son and, as such, have the responsibility to ensure that no dishonor comes to the father.

Courses evolved and extended the concept of crew beyond the cockpit; for example, some courses included joint cockpit–cabin crew training. In 1990, the FAA gave airlines greater flexibility in training in exchange for the requirement that CRM and interpersonal skills training be given and integrated

into technical training. In the FAA's advisory circular issued in 1998, it was explicitly stated that "CRM training focuses on situation awareness, communication skills, teamwork, task allocation, and decision making."

As the 20th century moved to a close, CRM, the pedagogy associated with it, and the methodologies used to gather data and evaluate it all continued to evolve. However, problems remained. Not every pilot believed in CRM, the courses differed significantly, and training had to be refreshed every 5 years or so. Some argued that a side effect was a loss of focus on error.

Helmreich sat in his office chatting with his colleague, Ashleigh Merrit, about a rationale for CRM that could be endorsed by all. CRM had been extended, but only in one way. It had been extended to think of the crew as the cockpit officers, the flight attendants, ATC specialists, and so on. However, and this was exciting, it had not been extended to include the environment, the events that precipitated the incidents that CRM was thought to help the crew handle. Bob and Ashleigh bantered back and forth, heading toward another generation of CRM:

> We need CRM because it helps the crew do their job better if they've had that training than if they haven't. But what exactly is that job? The job is NOT interacting well with your teammates. That's important to do the job, but it is not the job. The job is really to manage problems. Problems like threats from weather, equipment, other aircraft, and so on.
>
> And threats of their own making.
>
> Yes. Errors made by the crew become threats that they have to manage just like they have to manage problems not of their doing such as weather and mechanical breakdowns.
>
> So, crews do threat and error management. Once the error has been made or once the threat presents itself, the job is to move from the situation caused by the threat or the error to a safe situation, one without threats, one not caused by an error.
>
> There's no psychobabble in managing threats and errors. Any flight crew would see threat and error management as a respectable job, an honorable job. If having better team communication meant better threat and error management, then crews would see it as valuable.
>
> So, we have to do more than extend the concept of crew to include other aviation personnel; we must extend the concept of the cockpit to include the environmental events that impinge on it. We have to put the cockpit and the crew in context.

Helmreich and his team were getting good data on the crew. What was missing was capturing the context. Significant support would be needed to begin this innovative path. The support was ensured when the head of safety of Continental visited the lab in Austin. As he was pulling into the parking lot at the University of Texas (UT), one of his DC-9s was landing with its gear up.

Helmreich and the UT team revamped the entire observation protocol, developing the Line Operation Safety Audit, and did this in the context of a model of threat-and-error management. Many human factors researchers at the time were focused like a laser beam on the error. To Helmreich, the error was blood under the bridge: "Once you screwed up, how do you manage it?" You can manage it and make it inconsequential if it isn't already, an outcome that research suggests occurs about two thirds of the time. Or the error can lead directly to a high-risk state, like the wrong heading or altitude. One must now manage this high-risk state. Or, rarely, an error chain can begin, cascading into a disaster.

By 1985, six years after Helmreich spoke in San Francisco, CRM had become mandated by the FAA, and by 2005, the Line Operations Safety Audit was mandated in 186 countries by the International Civil Aviation Organization, the United Nations regulatory body for aviation. Although the idea of looking at cognitive and social aspects of teams swept dramatically through the aviation industry, it promises to sweep even more rapidly through health care, process control, and the oil industry. Thus, the interaction of the three men in the cockpit of United 173 in the winter of 1978 has evolved over almost three decades to expand from the cockpit crew to the team of professionals with a stake in the aircraft, and from merely the events within the cockpit to the threats and errors that impact it. Airlines and pilots seem to have moved from a skepticism and disdain for CRM to an acceptance of, and even an appreciation for, the human factor.

Perhaps the best evidence for the success of CRM comes from the pilots. Consider Captain Al Haynes and the often televised crash of United 232 at Sioux City (see Fig. 4.2). The flight lost all hydraulics, making control of the plane by conventional means, the ailerons, impossible. The crew flew and steered the crippled aircraft by using engine thrust. The coordination among the crew saved 184 of the 296 on board. Haynes attributes the success, in large part, to CRM: "I am firmly convinced that the best preparation we had is a program that United Airlines started in 1980 called Command Leadership Resource Management training." He continued, "It is now referred to as Cockpit Resource Management" (airdisaster.com).

CRM entered the aviation community like a karate chop, but what appeared to the rest of us as a rapid, illuminating change in aviation did not arrive to Helmreich as a moment of insight. To Helmreich, the creative idea to look at cognitive and social aspects of teams in the cockpit was simply a matter of following his interests into a new domain. What he

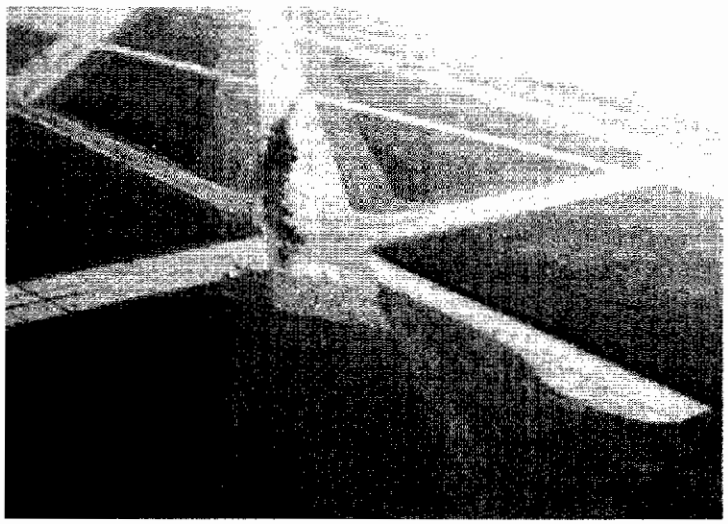

Figure 4.2 Although United 232 crashed, the fact that anyone survived was attributed to effective communication among the crew and with a pilot traveling as a passenger. The photo shows the aftermath of the landing.

learned on the ocean floor he taught to the men and women who fly far above it.

Lessons learned

Expanding from the individual outward to include the cognitive-social milieu of a complex industrial task is a critical lesson learned. Today, we understand that influences on individual performance come from teammates as well as higher order macroergonomic factors, including the company's philosophy, political pressures, and culture. Cognitive engineers have also developed markers that allow trained observers to distinguish a functioning teammate from a dysfunctional one, the skilled from the unskilled, the good from the bad. CRM is a prime example of how a demonstrable success can arise from good ideas taken from one domain and applied to another. Of course, it takes the appropriate human factors training in cognitive engineering for the researcher to recognize the good idea that can be transferred to the new situation, the markers in one industrial task that will be present in the other, and the countermeasure that can be exported from one culture to another. The expansion away from the individual proceeds along other dimensions as well, including to the environment, the task, and, most important, to other safety critical industries like health care.

Suggested readings

Helmreich, R. L., Merritt, A, C., & Wilhelm, J. A. (1999). The evolution of crew management training in commercial aviation. *International Journal of Aviation Psychology*, 9. 19 -32.

National Transportation Safety Board. (1979). *Aircraft Accident Report: United Airlines, Inc. Douglas DC-8-54, N8082U, Portland, Oregon, December 28, 1978 (NSB-AAR-79-7)*. Washington, DC: Author.

Reason, J. (1990). *Human error*. New York: Cambridge University Press.

Salas, E., & Fiore, S. (2004). *Team cognition*. Washington, DC: American Psychological Association.

Sexton, J. B., Thomas, E. J., & Helmreich, R. L. (2000). Error, stress, and teamwork in medicine and aviation: Cross sectional surveys. *British Medical Journal, 320*, 745–749.