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CHEST Commentary

What Went Right

Lessons for the Intensivist From the Crew of US Airways Flight 1549

Lewis A. Eisen, MD, FCCP; and Richard H. Savel, MD

On January 15, 2009, US Airways Flight 1549 hit geese shortly after takeoff from LaGuardia Airport in New York City. Both engines lost power, and the crew quickly decided that the best action was an emergency landing in the Hudson River. Due to the crew's excellent performance, all 155 people aboard the flight survived. Intensivists can learn valuable lessons from the processes and outcome of this incident, including the importance of simulation training and checklists. By learning from the aviation industry, the intensivist can apply principles of crew resource management to reduce errors and improve patient safety. Additionally, by studying the impact of the mandated process-engineering applications within commercial aviation, intensivists and health-care systems can learn certain principles that, if adequately and thoughtfully applied, may seriously improve the art and science of health-care delivery at the bedside.

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Abbreviations: CRM = crew resource management; FAA = Federal Aviation Administration; NTSB = National Transportation Safety Board

On January 15, 2009, US Airways Flight 1549 hit geese shortly after takeoff from LaGuardia Airport (New York, NY), causing both engines to lose power. The first officer was controlling the aircraft. Captain Chesley Sullenberger took over control of the airplane and radio communications, and instructed the first officer to run an engine restart checklist, which was unsuccessful. Without engine power, Sullenberger determined that he was unable to reach either LaGuardia or Teterboro airport in New Jersey. The flight crew decided that an emergency landing in the Hudson River was necessary (Fig 1). Due to expert crew performance (Table 1), all 155 people aboard survived the 5-min flight (Table 2).[1,2]

Many people hailed the incident as miraculous. Others focused on the pilot's technical skill in landing the aircraft without engine power on the water, noting that he was an experienced glider pilot. Although it is undoubtedly technically difficult to land an airplane on water, the crew demonstrated important nontechnical skills ingrained from aviation training that may have been equally (if not more) important to the successful outcome. Many lessons can be learned from what went right on Flight 1549. This article discusses some of the important collaborative and training techniques the crew used and how the lessons learned can be applied to critical care.

Crew Resource Management

Analyses from airplane accidents[3,4] show that failures frequently are related to pilots' nontechnical and communications skills rather than to technical flying abilities or to aircraft malfunctions. To improve these skills, the aviation industry[5] has developed safety-training programs called *crew resource management* (CRM). All crew members of Flight

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FIGURE 1. The airplane in the Hudson River showing passengers evacuating onto the wings (from Consolidated Edison surveillance video).

1549 would have had annual training in CRM; in fact, Captain Sullenberger had made extensive academic study in this area.[6]

CRM, originally termed *cockpit resource management*, was developed in a workshop sponsored by the National Aeronautics and Space Administration in 1979.[7] Some principles were adapted from process engineering, which is the study of the design and operation of manufacturing processes. This workshop was a collaboration between the National Aeronautics and Space Administration and the aviation industry to research the cause of aviation accidents.[8] Air carriers at the meeting committed to developing training programs based on CRM principles in order to reduce error rates. United Airlines was the first airline company to establish a comprehensive CRM training program, having been stimulated to action by a crash in 1978, which the National Transportation Safety Board (NTSB) ruled as partly due to the captain's failure to accept input from junior crew members and the flight engineer's lack of assertiveness.[8] Due to the perceived success of these training programs, CRM has been adopted by other public institutions, such as the military, police, and firefighting.

Table 1—*Members of US Airways Flight 1549 Crew*

Names	Position	Length of Service, yr
Chesley Sullenberger III	Captain	29
Jeffrey Skiles	First officer	23
Donna Dent	Flight attendant	26
Doreen Welsh	Flight attendant	38
Sheila Dail	Flight attendant	28

Table 2—*Timeline of Events*

Time	Event
1524:54	Tower cleared flight 1549 for takeoff
1525:51	Pilot informs control tower that they were at 700 ft
1527:01	Radar detected that 1549 hit primary targets
1527:36	Pilot, "Ah, this is Cactus 1539 hit birds, we lost thrust in both engines. We're turning back towards LaGuardia"
1527:49	Controller advised LaGuardia to stop departures
1528:05	Controller, "Cactus 1529, if we can get it to you do you want to try to land runway one three?"
1528:11	Pilot, "We're unable. We may end up in the Hudson"
1528:50	Pilot, "I am not sure if we can make any runway. Oh, what's over to our right anything in New Jersey; maybe Teterboro"
1529:02	Controller, "Do you want to try and go to Teterboro"
1529:03	Pilot, "Yes"
1529:25	Pilot, "We can't do it"
1529:28	Pilot, "We're going to be in the Hudson"
1530:30	Touchdown in Hudson River

Times are eastern standard time (add 5 h for Greenwich mean time). Based on NTSB senior official Kathryn O. Higgins's account and based on a transcript of the communication.[1,2,50]

The principles of CRM[9] include maintaining team structure and climate, applying problem-solving strategies, communicating with the team, executing plans, and managing workload while improving team skills. Pilots are hired and assessed not only for technical skills, but also for skills in CRM, including managing team function. Errors are dealt with nonpunitively and are seen as opportunities to improve performance.[10] Table 3 compares the key principles of CRM with examples from the crew of Flight 1549 and an idealized response to a cardiac arrest.

An article by Martin et al,[6] coauthored by Captain Sullenberger, reviewed the factors associated with major airplane accidents. A common decisional error the authors identified is called "plan continuation error" (an example of a fixation error). Pilots involved in major accidents often failed to consider all available options and would persist in their original plan when unexpected threats arose. In CRM training, pilots are instructed to project the likelihood of the success of various options and consider the disadvantages of a particular plan before implementing it.[6]

Intensivists are prone to plan continuation error as well. A common error made in "can't ventilate, can't intubate" situations, for example, is to persist in standard endotracheal intubation attempts while the patient desaturates. Intensivists who are aware of CRM principles would quickly choose a backup option instead. Similarly, the intensivist would not make more than two attempts at central venous catheterization at one site as the complication rate is

Table 3—*Critical Steps for Dealing With an Emergency Based on CRM, Using the Examples of Flight 1549 and an Idealized Response to a Cardiac Arrest*

Steps	Flight 1549	Cardiac Arrest
Identify an emergency	"Hit birds, we lost thrust in both engines"	Responder identifies absence of pulse
Declare an emergency	"Mayday"*	Responder calls a code
Declare leadership role	"My aircraft"	"I am the code leader"
Assume the command position	Sullenberger assumes primary flight control	Code leader positions self at head of bed
Gather necessary equipment	Equipment in cockpit is in optimal standardized position	Get bag valve mask, hook oxygen up to wall, turn on oxygen, set up suction, place intubation tray at head of bed, get code cart
Set the scene	Instruments are ideally placed for ease of use	Drop all side rails, lower bed, push bed away from wall, place backboard under patient
Assign roles and responsibilities	Captain, copilot, and three flight attendants	Code leader, cardiac arrest team, nurses, respiratory therapists
Maintain chain of command	Captain, copilot, three flight attendants	Code leader, cardiac arrest team, nurses, respiratory therapists
Callback orders	Sullenberger, "My aircraft" Skiles, "Your aircraft"	Code leader, "Epinephrine 1 mg IV push" Nurse, "Epinephrine 1 mg IV push given"
Use the command voice	"Brace for impact"	Code leader should speak in clear, authoritative voice
Avoid air commands	"Cactus 1549 New York departure radar contact climb and maintain one five thousand"	Code leader, "Nurse Jones, charge to 200 joules"
Avoid nonpertinent communication	"We're gonna be in the Hudson"	Any conversation not directly related to response to cardiac arrest will impair performance
Monitor team function	Unable to assess from transcript	Code leader, "Slow down, you are bagging too fast"
Accept feedback	Unable to assess from transcript	Nurse, "Doctor Smith, I think that is vtach and we should shock it" Code leader, "I agree, Nurse Jones, charge to 200 joules"

*Cockpit recorder has Sullenberger declaring, "Mayday," but it is not on the air-to-ground communications transcript, possibly due to the button for communication not being pressed at the time.[2]

increased. Instead, he or she would choose another site or allow another operator to attempt the procedure.[11,12] Luckily for the passengers of Flight 1549, Sullenberger did not persist in his original plan to return to LaGuardia but, instead, quickly cycled through the available options before deciding to land in the river.[1,2]

CRM identifies many other classes of errors (Table 4). The Flight 1549 crew avoided violations and procedural errors by following established protocols assiduously. The crew avoided communication errors by use of the command voice and calling back important communiqués. Skill-based, knowledge-based, resource-based, and decisional errors were avoided due to the simulation training the crew had undergone and the many hours of flying they had logged.[6,10]

The importance of effective leadership in the outcome of Flight 1549 deserves special mention. In addition to dealing with errors, an effective team leader is responsible for managing information, equipment, and people. During an emergency response, the team leader must assign roles for all staff members present and dismiss unnecessary personnel. Without effective leadership, emergency response can be chaotic and haphazard. In most hospital ICU practice, team coordination occurs in the ICU; however, during disaster management, the team coordinator and the communication hub may be off site. Leadership errors by the crew of Flight 1549 were avoided due to the clear establishment of command by Sullenberger and the callback by the first officer. When Sullenberger gave the order, "Brace for impact," the flight attendants chanted repeatedly, "Brace, heads down, stay down," and the passengers maintained brace position. Although only one person can be in charge, the other team members can still demonstrate leadership. One flight attendant closed a door opened by a passenger to stop water from entering, and all flight attendants led their passengers to safety after the evacuation order from Sullenberger.[1,2]

Although traditionally errors are believed to be caused by a particular person, CRM calls for the study of team function. In medicine, some people believe that bad things happen to bad people and that focusing on an individual's negligence or lack of skill will eliminate all errors.[13,14] A review of emergency department risk management cases found that 43% of errors were due to problematic team coordination.[15] The methods of grading teamwork in medical settings have been validated.[16] CRM dic-

Table 4—*Error Classification System From CRM Principles*

Error Type	Definition	Example
Violation	Subject consciously decides not to follow procedures	Failure to call, "Time out," before inserting central venous catheter
Procedural error	Subject executes procedures incorrectly or does not follow prescribed procedures	Insufficiently large sterile field during central venous catheter insertion
Communication error	Information is not exchanged properly between two subjects	Medication dose misheard during a verbal order
Skill-based error	Subject lacks proficiency in performance of a task. The action made was not what was intended	Accidental esophageal intubation due to subject's lack of practice on a simulator of the technical skill of endotracheal intubation
Decisional error	Subject makes a decision that is unnecessarily risky	Proceeding with direct laryngoscopy and intubation attempt without adequate time for preoxygenation because the subject believes that it will be easy
Knowledge-based error	Subject lacks education or information on how to perform a task or solve a problem	An incorrect dose of digoxin ordered for a patient with rapid atrial fibrillation
Resource management error	Subject fails to assign and distribute tasks among crew members, overloads crew members, or fails to organize equipment in the most effective way	Failure to assign a particular person to administer medication during a cardiac arrest
Systems operation error	Subject mishandles important patient safety or monitoring systems	Permanently silencing a ventilator alarm because it "beeps too much"
Leadership error	Subject fails to establish leadership role or effective team control	Code leader failing to announce leadership role so that team lacks sense of direction, and response is chaotic
Monitoring or challenging error	Subject fails to monitor or challenge an error made by another team member	Medical student not challenging an operator inserting a central venous catheter while not wearing a mask
Situational awareness error	Subject fails to be aware of environmental cues critical for decision making	Being unaware that the patient has desaturated to 80% during an endotracheal intubation attempt

Table was Adapted from Martin et al[6] and Helmreich.[10]

tates that all people make errors. By focusing on the latent failures inherent in systems, the probability of error commission is diminished.[14] CRM principles are ideal for medical emergencies because they are time limited, have complex and multiple sources of information, include multiple players, involve rapidly changing situations, and have high-stakes outcomes.[4,9]

Unlike members of the aviation industry, hospital ICU staff members have many incorrect attitudes about errors. When surveyed, 30% of ICU staff members denied that they committed errors. Additionally, the majority of ICU physicians reported that fatigue, personal problems, and emergencies did not affect clinical performance. Although only 3% of ICU staff members believed that junior team members should not question senior team members,[17] other studies[18,19] have shown that team members and team leaders have varying opinions about the effectiveness of communication.

Faulty communication is a key area that CRM training can improve. Communication errors during airline flights led to the creation of CRM,[8] and poor communication causes at least 15% of hospital ICU errors.[20–22] Communication errors range from misreading a written order to cutting off input from team members. All team members should monitor team performance and feel empowered to speak out when threats to patient safety are observed. The team leader is obligated to acknowledge and act on any concerns that team members raise. According to one study,[23] hospital ICU nurses feel undervalued and are reminded of power differences by physicians. This hierarchical attitude tends to discourage appropriate communication and safety monitoring by nurses.

Another source of communication error is interruption. A high rate of interrupted communications occur in the hospital ICU,[20] which may lead to cognitive overload and cause errors by conflicting demands on the ICU practitioner's attention, time, and working memory.[24] Through CRM, pilots are taught methods of limiting and dealing with interruptions. Proven methods[25,26] of decreasing error rates in the hospital ICU that are at least partially due to communication are computer order entry and pharmacist presence on team rounds.

Ideally, errors should be avoided. If errors occur, they should be trapped before commission or the consequences of the errors mitigated (Fig 2). Hospital ICU team members should be trained and empowered to vocalize their concerns when they believe that an error is about to be committed. The team leader must be taught to assimilate team members' concerns and not to dismiss them. Group debriefing should occur after all medical emergencies to evaluate performance

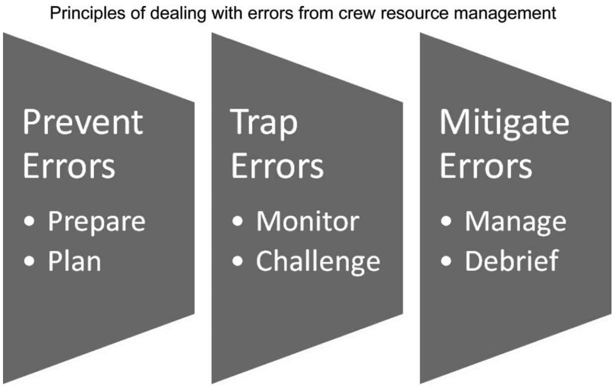

Figure 2. CRM principles of dealing with errors.

and learn from errors. Other methods for intercepting errors[10] include monitoring, cross-checking, reviewing, and plan modification.

The US aviation industry, in conjunction with the Federal Aviation Administration (FAA) and the NTSB, has implemented many changes to decrease the probability of error commission. The FAA regulates all aspects of civilian aviation, including safety promotion. The NTSB is responsible for investigating civil transport accidents. The aviation industry has independently made many safety advances, but only agency regulations have made the others. For example, because sleepiness is known to impair memory,[27] pilot work hours are limited. The effect of limiting work hours on errors in the hospital ICU also is evident.[28] Additionally, stress impairs memory and cognitive function; therefore, pilots are trained in stress mitigation techniques. Possibly as a result of stress, Captain Sullenberger and the air traffic controller occasionally misidentified Flight 1549 as 1539 or 1529. The FAA accounts for the possibility of similar errors by prohibiting flights with similar call signs to be in the same vicinity. Hospital ICU physicians should be vigilant about analogous errors, such as mixing up hydralazine and hydroxizine or writing an incorrect dosage. Systems should be in place such as callback, computer order entry, and decision support to limit the chances of error commission.

CRM can be adapted to hospital ICUs. Like airline crews, ICU teams are not fixed. Each day, different ICU staff members work together. However, important differences exist between the hospital ICU and the aviation industry; ICUs are less standardized in their physical layout than airplanes, and staffing is more variable. Despite these differences, when CRM is applied to emergencies, efficiency, and patient safety, team morale likely will improve.

Simulation Training

CRM and technical skills can be enhanced with the use of simulation training. High-fidelity simulators have been used in the aviation industry for many years.[9,29] Although the public, the aviation industry, and federal authorities do not question the validity of flight simulation, direct causality of improved passenger safety specifically due to simulation training has never been proven. In addition to formative training on simulators, airline pilots undergo yearly check flights on simulators to evaluate skill retention and prevent skill decay. Both the captain and the first officer of Flight 1549 had logged many hours on a cockpit simulator of the Airbus 320 aircraft they were piloting. They had practiced standard flights as well as emergency scenarios. Sullenberger had never experienced an engine failure in an actual flight, but he had experienced it on the flight simulator.

Both the substrate and the delivery of medical education are variables. Standard medical training consists of reading about medical conditions and observing senior colleagues treating patients. This training is limited by the random nature of medical encounters and assumes that senior colleagues are always good role models. Furthermore, patients may be placed at risk because learning and patient care occur simultaneously.[30]

A complementary, alternative method for medical education is simulation training. The use of simulated critical events, well debriefed, can occur either in the hospital ICU or in a simulation center environment.[31] Such a zero-risk environment allows practitioners to practice high-risk, low-frequency events without endangering patients. Errors can be allowed to occur and be studied. Complete team training can be done in realistic environments, with a formal debriefing period to address questions and concerns. Simulator-based competence can be demonstrated before treating patients.[31] Both technical skills and competence in teamwork can be assessed with standardized metric tools or checklists, providing for demonstration of proficiency.[16,31,32] An intriguing tool for objectively monitoring teamwork, the Communication and Team Skills assessment,[33] currently is undergoing statistical validation. Procedures that require frequent repetition before a safe level of performance is attained can be practiced repeatedly.[34] Whether full competency can be attained in many simulation systems and applications in parallel to aviation training systems is a subject of debate. Simulation is meant to complement, not replace, hours of actual clinical experience. A medical practitioner cannot be considered a master clinician after simulation training because the range of clinical situations and patients he or she may encounter is nearly infinite.

Deliberate practice using complex practical skills, realistic teams, and actual equipment improves familiarity with clinical scenarios.[30] Hospital ICU practitioners are among the most likely to benefit from simulation training given the grave consequences of medical errors in patients with critical illness. Although many studies[35,36] of simulation training have shown improved performance on human simulators, more recent studies[37,38] have shown that actual clinical practice improves. Simulator programs should be provided by highly skilled practitioners who are well grounded in education theory, including the concepts of contiguity and reinforcement.[39]

Intensivists can learn from the training and testing that pilots undergo. Each airline has its own FAA-approved training. Whenever a commercial airline pilot switches to a different airline or aircraft, additional training must be done, including simulation training on that particular airplane cockpit. Pilots start with ground school, which consists of 2 to 3 weeks of classes about the systems of a particular model. They then undergo cockpit procedures training to learn the location and operation of each switch, gauge, and button on the aircraft. Next, they undergo 2 weeks of flight simulator training in a full-motion room on hydraulic jacks that allow the simulator to move like a plane in flight. Pilots undergo training on a full range of emergencies, demonstrating team, technical, and process skills. Captain Sullenberger would have practiced two-engine failure several times. Pilots then undergo a check ride, a simulated flight test with an examiner, and spend 25 h flying with an instructor. The final flight test is called *line check*. Airline pilots are required to log 1,500 flight hours, with 250 h in command. Pilots complete proficiency training every 6 months and check rides every year. They cannot advance from one step of training to the next unless competency is validated. Finally, if deficiencies are noted during actual flights, pilots are brought back sooner for additional training.[40]

In many respects, medical training is less regimented. Medical personnel learn on the job about how to handle novel emergencies. A team may respond to cardiac arrest and use a defibrillator model that they have never encountered. The requirements for recurrent evaluation are considerably less rigorous as well. Because learned skills atrophy over time,[30,41] medical practitioners, like pilots, can benefit from frequent training and evaluation on simulators. Medical practitioners could be tested on simulations germane to their particular medical specialty as the American Board of Internal Medicine[42] does for interventional cardiology.

Despite the promise of simulation training, several problems have been identified. How can the entire hospital ICU staff be excused from clinical activities? Ideally, teams should train together as much as possible, with coverage by other staff. However, many skills can be practiced by crews (*eg*, two-person airway crew). Another problem is lack of buy-in. By making the scenario as realistic as possible, this problem usually can be overcome.

Checklists

Checklists have been used to enhance safety in the aviation industry for many years,[29,43] providing clear structure in complex environments.[43] Ground crew members routinely use preflight checklists to evaluate aircraft function, and the flight crew uses them once in the cockpit. Checklists ensure that all procedures are followed, eliminating reliance on the inherently fallible human memory.[44]

The crew of Flight 1549 used several other checklists to deal with the emergency. After the aircraft lost engine power, First Officer Jeffrey Skiles ran through an engine restart checklist. Although he was unsuccessful in restarting the engines, this action was critical. Because of the systematic nature by which different options were explored, Captain Sullenberger quickly reached the decision that restarting the engines would be impossible and that the only option was to land the airplane in the Hudson River.[2] After the airplane landed, Skiles ran through an evacuation checklist. Checklists are ideal for such rare occurrences when memory of the correct steps may be unreliable.

Completed by any member of the treating team or by a safety officer, checklists have been used to improve the quality of intensive care and have been shown[45] most recently to decrease the incidence of catheter-related bloodstream infections. A daily goals work sheet improves communication in the hospital ICU and decreases patient length of stay.[18,46] By formally writing important critical care goals, such as procedures, need for catheters, sedation, and nutritional plans, important issues are not overlooked. A hand-off checklist has been shown to improve the communication of critical information during simulations of nursing turnover.[47] This area is key for improvement because missing information has been implicated in many medical errors. Finally, a multinational study[48] showed the benefit of a surgical safety checklist, the use of which significantly decreased mortality and complications. Many items on this checklist could be adapted easily to create checklists for invasive procedures performed in the hospital ICU.

Table 5—*Institute of Medicine Strategy for Improving Patient Safety*

Establish a national focus to enhance the knowledge base about safety
Develop a mandatory error-reporting system and encourage health-care practitioners to develop and participate in voluntary reporting systems
Raise performance standards through the actions of oversight organizations, professional groups, and group purchasers of health care
Implement safety systems in health-care organizations to ensure safe practices, including simulation

The table was adapted from the Institute of Medicine "To Err is Human."[50]

Conclusion

The specific reasons why US Airways Flight 1549 had a successful outcome have been highlighted, and intensivists can learn several important lessons, yet the overarching message is that a hospital ICU staff must embrace a culture of safety. A checklist is useless if it is not used. Simulation training is ineffective if trainees do not buy in. Some hospital ICU staff members do not think about error prevention. Other self-regulatory experiments have been insufficient or nonsustained. Independent regulatory agencies, such as the Accreditation Council for Graduate Medical Education, the Joint Commission, and medical boards, should be more involved in error prevention training and analyzing medical "crashes." Like within the aviation industry, intensivists should partner with relevant independent agencies to improve safety; otherwise, reforms will have to be imposed by these agencies. A starting point would be to adopt the following safety recommendations from the Institute of Medicine (Table 5).[49,50]

The intensivist can learn many lessons from the successful outcome of Flight 1549. Intensivists should adhere to the principles of CRM when responding to emergencies. Checklists should be promulgated for use in multiple hospital ICU scenarios. Training should be done repeatedly on simulators for both common and rare ICU emergencies. Skill acquisition and skill maintenance should be taught and assessed. This combination of skills and training can help intensivists to remain as focused and prepared for any emergency as the crew of Flight 1549.

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