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HUMAN FACTORS: TENERIFE REVISITED

John McCreary
Michael Pollard
Kenneth Stevenson
and
Marc B. Wilson
University of Maryland Eastern Shore
Princess Anne, MD

ABSTRACT

This case study is a human factors analysis of the aircraft collision which occurred at the Los Rodeos airport in Tenerife, on the Canary Islands. The collision between two 747 jumbo jets cost the lives of 583 people. This collision is an example of how large scale disasters result from errors made by people in crucial circumstances and illustrates the potentially devastating consequences of ineffective human and organizational behavior. This paper focuses on three areas that were the major contributing factors in the accident: stress, small group communication under stress, and small group dynamics. An analysis of the accident in each of these areas determined what measures can be taken to prevent catastrophes of this nature from reoccurring (reengineering for improvement).

INTRODUCTION

In March 1977, two 747 aircraft, one KLM and one Pan Am, both bound for Las Palmas in the Canary Islands, were temporarily diverted to Tenerife because the Las Palmas airport had been closed by a terrorist bomb explosion. The KLM flight landed at Tenerife first and its passengers were deplaned. The Pan Am flight landed 45 minutes later but its passengers remained on board. The airport at Las Palmas reopened 15 minutes later. The Pan Am aircraft was immediately ready to depart for Las Palmas but was parked behind the KLM and could not depart until the KLM aircraft taxied for takeoff. More than two hours passed before the KLM refueled, re-boarded the passengers, and was ready for takeoff.

Clouds and fog made visibility very poor, as low as 300 meters, so the controllers in the tower and the crews of both aircraft were completely dependent on their radios for information on runway positions. The tower instructed the KLM to taxi down the takeoff runway, turn around, and wait for further instructions. The Pan Am was to follow behind the KLM on the takeoff runway, turn off at taxiway C3, and use a parallel runway for the rest of its taxi. After completing its turn around at the end of the runway, the KLM requested both takeoff and air traffic control's (ATC) clearance. The first officer of the KLM radioed, "The KLM 4805 is now ready for takeoff and we are awaiting our ATC clearance." The tower replied with the following ATC clearance, "KLM…you are cleared to line Papa Beacon, climb to…" While the KLM first officer was reading back the ATC clearance to the tower, the KLM captain released the brakes and said, "We gaan" (we go), and began the takeoff roll. After completing the ATC's read back, the first officer said either, "We are now —eh—taking off" or "We are now at takeoff." (The tapes of transmission were not clear.)

In a later statement, the tower controller said he understood the first officer's message to be, "We are at takeoff position." The controller replied in response, "Okay," then paused for two seconds and said, "Stand by for takeoff, I will call you." Meanwhile, in the Pan Am cockpit, the captain remarked that the KLM could possibly interpret the ATC clearance as takeoff clearance. So, immediately after the tower said "okay" and paused, the Pan Am first officer quickly responded, "We are still taxiing down the runway." This Pan Am message coincided with the end of the tower's instructions to the KLM to standby, which in the KLM cockpit caused a strong squeal. Both messages were barely intelligible in the KLM cockpit. The controller then told the Pan Am to report when clear of the runway and the Pan Am replied they would report when clear.

In the KLM cockpit, apparently only the flight engineer heard these last two messages leading to the following dialogue:

Engineer, "Is hij er neit af-dan?" (Is he not clear, then?)

Captain, "Wat zag je?" (What did you say?)

Engineer, "Is hij er niet af die Pan American?" (Is he not clear, that Pan American?)

Captain: "Jawal." (Yes)

The captain made this response quite emphatically. The planes collided about 13 seconds later.

Stress

Stress and its effect on human and organizational behavior are major factors in the Tenerife collision. According to Holroyd and Lazarus (1982) psychological stress involves "a judgement that environment and/or internal demands tax or exceed the individual's resources for managing them" (p. 22). Among the demands facing the KLM crew were delays caused by terrorists at their destination airport, difficult and uncertain weather conditions, and strictly enforced flight and duty time limits that were nearing expiration. The Pan Am crew faced the same environmental conditions and, although they were not near the limits of their duty time, they had been working for 11 hours and were being unnecessarily delayed by the KLM plane. The Spanish controllers in the tower were dealing with much larger planes that usual and a heavier than normal traffic volume. In addition, the controllers were working in English, a less familiar second language. Demands such as these disrupt cognitive processes, decrease alertness and diminish judgement. George (1986, p. 542) outlined the following specific effects of stress on the performance of complex tasks:

1. Impaired attention and perception
    a. Important aspects of the situation may escape scrutiny
    b. Conflicting values and interest may be overlooked
    c. Range of perceived alternatives is likely to narrow, but not necessarily to the best option
    d. Search for relevant options tend to be dominated by past experience; the tendency to fall back on familiar solutions that have worked in the past, whether or not they are appropriate to present situations
2. Increased cognitive rigidity
    a. Impaired ability to improvise; reduced creativity
    b. Reduced receptivity to information that challenges existing beliefs
    c. Increased stereotypic thinking
    d. Reduced tolerance for ambiguity leading to cutoff of information search and premature decision
3. Shortened and narrowed perspective
    a. Less attention to longer range considerations and consequences of actions
    b. Less attention to side effects of options
4. Shifting the burden to the opponent (another)
    a. Belief that one's options are quite limited
    b. Belief that the opponent (another) has it within his power to prevent impending disaster

Many if not all of these effects were present at Tenerife. The KLM captain apparently did not even consider the possibility that the Pan Am was still on the runway. He cut off the ambiguity presented by the engineer and made a premature decision. He did not choose the better option of waiting a few more seconds versus taking off quickly.

Regression

Weick (1993) theorized that the key to understanding Tenerife may lie in the principle of stress causing regression to first learned responses. This means that in stressful situations, people regress or behave in ways or patterns they learned first. The KLM pilot had been an instructor for more than 10 years and had been flying routes again for only a short time. The significance of this is that in flight simulation training, instructors act as controllers and issue takeoff instruction. Regression by the KLM pilot to the behavior patterns of an instructor would explain his taking off before the tower gave takeoff clearance. The KLM co-pilot and flight engineer may have been intimidated by the seniority and prestige of the captain and regressed to overly subordinate behavior by not raising the issue of the take off clearance and presence of the Pan Am more emphatically. Weick also observed possible regression on the part of the Pan Am pilot who wanted to stay off the active runway. Instead of trying to negotiate this with the Spanish controller, the Pan Am crew chose simply to follow the controller's instructions.

Performance

Research shows an inverted U-curve relationship between stress and performance (Hermann & Hermann, 1975 as referenced in 't Hart, Rosenthal, & Kouzim, 1993). Increasing stress to a certain point can lead to an increase in performance, but beyond that threshold point, increasing stress leads to diminished performance. Although the shape of the curve will vary from individual to individual and from task to task, this general curvilinear shape can be said to describe the effect of stress on individual performance in many situations. Research on groups, however, has shown a more linear relationship between stress and performance. In other words, effectively functioning groups perform better as stress increases.

Small Group Communication Under Stress

Communication problems in stress and crisis-prone, highly mechanistic groups are clearly evident twice in the Tenerife air disaster. First, during the KLM preparation for takeoff and even after releasing the brakes, the KLM co-pilot knew that the aircraft had not been given permission to take off by air traffic control. However, at no point does the co-pilot perform his duty to prevent the illegal takeoff. Second, although the KLM flight engineer had strong suspicions that the Pan Am jet was still taxiing on the active runway, he failed to make his suspicions clear to the captain.

These communications failings are not isolated incidents attributable solely to the flight officer's unwillingness to speak or act on these concerns. It is highly probable that, given the same group dynamics, even "perfect" flight officers would again follow the same behavior patterns. In fact, in January 1994, the U.S. National Transportation Safety Board (NTSB) report on the analysis of 37 major air transport disasters between 1978 and 1990 concluded that nearly 50 percent (17 of 37) accidents were caused by a failure of the first officer to properly monitor and challenge a captain's decision (Inside DOT & Transportation Week, 1994).

In a survey of organizational behavior (OB) studies on crisis decision making, 't Hart, et al. (1993) found that members of mechanistic group structures work very will together until the group is forced to respond to an outside stress. During a crisis, three different communication patterns evolve:

1. Instead of the group's normal "bureaucratic prescripts of multi-layered and highly differentiated patterns of decision making", 't Hart et al. found that the patterns of decision making become *highly centralized*. In the case of the KLM airliner, the pilot responded to the stresses of time and weather by literally shutting all other players, including the ATC officers, out of his decisionmaking loop.
2. 't Hart et al. found that a profound form of Janis' groupthink hypothesis sets in during a crisis. "Criticism, dissent and mutual recrimination literally must wait until the crisis is over." Influenced by mechanistic-group behavior, the crew of the KLM airliner understood they had to be quiet and let the pilot, their sole decision maker, concentrate on decisionmaking. In fact, criticism of any form was either ignored or rejected by the KLM pilot. In a similar study focusing on group cognition, Schneider , Angelmar & Reinhold (1993) found (like Janis) that in certain types of task environments, different interpretations of the same events (seen as covert judgement) can generate similar overt behavior (group agreement).
3. 't Hart et al. found that inexperienced participants are often shut out of the centralized decisionmaking process. The principal players in the team will confer only with the most skillful, most trusted and most powerful co-players.

The inexperienced KLM co-pilot was on this first flight as a co-pilot. If the co-pilot had been seen as an equally experienced professional, the KLM captain may have included his views in the decision making process and taken his judgement into account. Lack of co-pilot experience is also cited by the NTSB in their previously mentioned 1994 study of major aircraft accidents. The median flying time of those co-pilots was 419 hours, or slightly less that three-quarters of a year's experience.

A linguistic analysis of the KLM co-pilot's conversations, as recorded on the aircraft's cockpit-voice recorder brings forth further data supporting the above hypothesis. The analysis found that the KLM co-pilot used "devices of mitigation" (such as phrasing statements as questions) and hedged statements with qualifications in order to soften the effects of his requests (Weick, 1993). Presumably knowing that his comments were out of line, the KLM co-pilot kept his suspicions to himself and when speaking used speech devices which were less likely to rile the captain.

Small Group Dynamics

French and Raven (1968) suggested that there are five bases of power: (1) reward, (2) coercive, (3) legitimate, (4) expert, and (5) referent. In the KLM case, the pilot certainly had expert power, a significant amount of legitimate power, and vestiges of referent power. His referent power came from the fact that the pilot had recently given the co-pilot a check ride and could possible do so again in the future.

Each person possesses certain characteristics or properties which carry value for other people. For example, a majority of out society may value wealth or material possessions while some people may place a greater value on personal characteristics such as friendliness or honesty. A powerful person is one who possesses one or more properties that are valued by others. Naturally, the greater amount of highly valued properties (in this case knowledge and experience) a group member has, the more potential influence the person may have over a group. In this incident, the KLM pilot exercised his expert power quite forcefully. The co-pilot and flight engineer yielded to the influence of the pilot despite the reservations each held. Neither one so much as even challenged the decision of the pilot. They undoubtedly behaved this way because of the established credibility of the KLM pilot and a desire to maintain group cohesion.

Cohesion

The more cohesive a group, the greater the influence the group may have on an individual. That is, the more cohesive the group, the more pressure can be brought to bear on an individual. In response, the individual may conform by changing original behaviors or attitudes or may reject group pressure by psychologically reinforcing an original position. In the latter case, one can expect greater rigidity and strength in the position as a means of defending it form outside pressures.

To summarize the group dynamics and the inflexible stance of the captain, the KLM crew was under stress not simply from a job performance perspective; they were very close to exceeding restrictions for flight duty as a crew. The captain had the job of taking care of his crew and himself. The co-pilot and flight engineer trusted the captain's judgement because of his experience level. It can be concluded from the interactions that took place in the cockpit of the KLM that the co-pilot and flight engineer chose to maintain group cohesion rather than challenge the captain. Their unwillingness to challenge the decision of a superior contributed to the Tenerife disaster.

Reengineering for Improvement

Instead of charting a path for improvement, the NTSB has recommended to the Federal Aviation Administration (FAA) that the FAA issue regulations to airlines that require captains to be receptive to challenges from co-pilots and further require that the co-pilots have sufficient experience to be able to challenge the captains (Inside DOT and Transportation Week, Jan 1994). It will most likely take a long time for these regulations to impact on the human factors which they are trying to address.

There are two improvement paths that the air transportation industry is pursuing: cockpit resource management training and improved technology. Both paths have been shown to lead to fewer human-factors related accidents, but both paths also choose not to alter the fundamental flaw - the cockpit crew's mechanistic group structure.

Crew Resource Management Training

It is currently assumed in the air transportation industry that training to overcome human-factors related failures, or crew resources management (CRM), will become a part of each airline's corporate culture. Currently, large airlines and aircraft manufacturers are slowly training each of their pilots.

Communication Training

Heine Caesar, manager of Lufthansa's operations inspections and safety division, told participants at the 1990 Flight Safety Foundation conference that "communication must be trained, especially in cultures where order and obedience are part of a normal daily life." Mr Caesar's recommendations included establishing precise crew coordination, promoting equal workloads and clear distribution of duties, and maintaining strict adherence to phraseology inside and outside the cockpit (Davis, 1990).

Stress Training

In addition to communication training, the air transport industry also promotes stress training as part of cockpit resource management. In 1988, a panel of experts, mostly psychologists from the American Psychological Association (APA), testified before the U.S. House of Representatives Committee on the Armed Services concerning the effects of stress on the military's mechanistic-structured groups. The panel testified that, although crews generally feel impervious to stress, if crews are made conscious of their vulnerability (through training) they can generally overcome the effects of stress. Specifically, the panel recommended that the military require that multiple people verify information and decisions to reduce the chance of error.

At about the same time the APA panel was testifying before the U.S. Congress, Aeromed, a Minneapolis-based company, added a new multimedia training kit to their "Medical Airworthiness" seminar series called "Aviation Stress Management." This series promised to help air crews realize the effects of stress in the cockpits, provided help in understanding the nature of human-stress response, and equipped air crews with stress management strategies.

Technology

Two different types of technological answers are available to the air transportation industry and each will yield significantly different results. First, airline manufacturers are investing heavily in cognitive science research to find effective human-systems interfaces that will allow machinery to better help humans think and solve problems. Second, however, is a technology that promises to change the management structure of the cockpit crew - remote cockpit management.

Remote Cockpit Management

Bernard Ziegler, Airbus Industries' senior vice-president of engineering and former chief pilot, reported in 1992 that communications technology is now advanced to the point that real-time digital data links of all aircraft data would be available to enable airlines to establish ground management sites to assist the captain and crew in routine and emergency aircraft management duties (Flight International, Sep 1992). The significance of this technology cannot be overstated. By introducing another layer of management (the ground control station), the pilot is thus removed from the rule of "boss" and becomes just another team player in a larger management system. Thus, the mechanistic flight dynamics, although still existent, are greatly mitigated in that the pilot will not be able to "override" ground control and is forced to maintain the bureaucratic, multi-layered decision-support system that is now most likely to be forgotten.

Conclusion

Aircraft crews are highly structured, mechanistic groups known to be capable of failures of communication and decision-making. The Tenerife air disaster is a clear example of that. Mechanistic groups typically perform very well as long as the tasks are fairly predictable and routine. However, during crisis situations, these trained responses tend to break down. Nowhere is this more evident than in the air transportation industry. Accidents due to equipment failures are now thought to constitute just three to five percent of all airline accidents. The remaining accidents are attributable solely to human error. Of the accidents attributed to human error, nearly three quarters of them are due to poor human communication.

The industry has recognized this problem for more that 20 years. The agenda for the 1974 Flight Safety Foundation and the 1975 International Air Transport Association meetings both identify human error as the "last frontier of aviation safety" and the industry has yet to conquer these problems. Just recently, the U.S. Federal Aviation Administration reported that more than 70 percent of the reports filed with the anonymous Air Safety Reporting System involve information transfer problems (Aviation Daily, 1990). In addition, authorities at the U.S. National Aeronautics and Space Administration's Ames Aerospace Human Factors Research Division also reports that up to 80 percent of all aircraft accidents are "due to a lack of adequate coordination or utilization of available resources (Cate, 1990).

Of course, statistics like these aren't very encouraging. We must continue looking for ways to reduce subjective decisions on the part of pilots. We can't take the human factor out unless we want a system that is completely rigid and inflexible. Research, study of lessons learned, and application of the knowledge gained will help reduce the chances of another Tenerife disaster in the future.

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