

CULTURE AND ERROR IN SPACE: IMPLICATIONS FROM ANALOG ENVIRONMENTS

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ABSTRACT

An ongoing study investigating national, organizational, and professional cultures in aviation and medicine is described. Survey data from 26 nations on five continents show highly significant national differences regarding appropriate relationships between leaders and followers, in group versus individual orientation, and in values regarding adherence to rules and procedures. These findings replicate earlier research on dimensions of national culture. Data collected also isolate significant operational issues in multi-national flight crews. While there are no better or worse cultures, these cultural differences have operational implications for the way crews function in an international space environment. The positive professional cultures of pilots and physicians exhibit a high liking for the job and professional pride. However, a negative component was also identified characterized by a sense of personal invulnerability regarding the effects of stress and fatigue on performance. This misperception of personal invulnerability has operational implications such as failures in teamwork and increased probability of error. A second component of the research examines team error in operational environments. From observational data collected during normal flight operations, new models of threat and error and their management were developed that can be generalized to operations in space and other socio-technological domains. Five categories of crew error are defined and their relationship to training programs in team performance, known generically as Crew Resource Management is described. The relevance of these data for future space flight is discussed.

Future missions in the International Space Station (ISS) will be directed by a multinational organization and will involve crews from differing disciplinary backgrounds and national cultures. Crew performance in space can be viewed in terms of an *input-process-outcome* model as shown in Figure 1, which is derived from investigations of pilot performance in aviation (2).

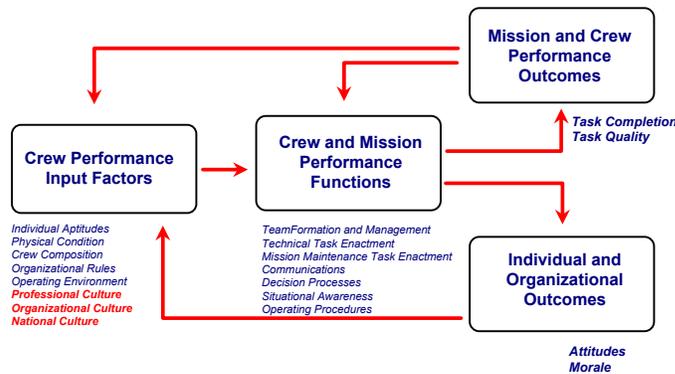


Figure 1. A model of astronaut team performance.

The model shows multiple input factors including national, organizational, and professional cultures as well as individual attributes including personality and physical condition, team composition, procedures, and the operating environment. Input factors influence the processes, both technical and interpersonal, required for mission accomplishment. These, in turn, determine outcomes. Outcomes consist of technical task fulfillment, individual job satisfaction, and crew morale. The model is iterative in that both processes and outcomes influence subsequent inputs and

processes. Of concern here is the importance of cultural factors as determinants of processes and outcomes.

Culture Defined and Measured

Culture has been defined as ‘the software of the mind’ by the Dutch psychologist, Geert Hofstede (8). More technically, culture consists of the shared norms, values, and practices associated with a nation, organization, or profession. In a study that ultimately involved more than fifty countries, Hofstede surveyed employees of a large, multi-national corporation and derived four distinctive dimensions of national culture. His work is the most cited cross-cultural research and remains the benchmark for multi-national investigations. However, the basic work was conducted in the 1970s and published in 1980 and it could be argued that, with increasing globalization of organizations and travel, national differences in values and attitudes are diminishing and becoming irrelevant. In a large project at the University of Texas, Helmreich and Merritt and their colleagues (4) developed new measures of culture that incorporated Hofstede’s survey and administered them to more than 8,000 pilots in 26 countries.¹ The survey contains items that are directly related to the aviation domain, that are conceptually related to Hofstede’s dimensions, and have been validated as predictors of pilot performance (3). The results show highly significant differences as a function of national culture demonstrating, thus demonstrating the enduring importance of national culture.

Aviation is one of the analog environments from which parallels to space have been drawn. If national cultural factors in aviation have implications for crew effectiveness, consideration of their possible impact on ISS crews is warranted.

National Culture and Crew Performance

Two correlated dimensions of national culture identified by Hofstede (8) have particular relevance for aviation, Individualism-Collectivism (IC) and Power Distance (PD). Those from individualistic, low PD cultures tend to focus on the self, autonomy, and personal gain while those from collectivist; high PD cultures show great concern for the group and harmonious relationships and deference to leaders. A third, relevant dimension has been isolated in our research and labeled Rules and Order (5). It is conceptually similar to Hofstede’s Uncertainty Avoidance dimension. Those high on this attribute believe that rules should not be broken, that written procedures are needed for all situations, and that strict time limits should be observed. Rules and Order has proved to yield large and highly statistically significant differences across national cultures. Many Asian cultures are found at the rule oriented end of the continuum while the United States and members of the British Empire define the other end with much lower concern for rules and adherence to procedures.

These dimensions of national culture have clear relevance for flight operations (5). In the cockpit environment, IC can influence group climate and the commitment of members to group harmony and positive interaction. PD defines how junior crewmembers relate to the captain and is reflected in the way information is shared, including the willingness of subordinates to speak up with critical information. PD is also reflected in the style of leadership imposed, ranging from autocratic to democratic. Those from high PD cultures are more accepting of a directive or

¹ The sample of nations continues to grow, with 26 the number of countries at the time of writing. Most of the original cross-cultural comparisons were based on 21 countries.

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autocratic leadership style while low PD individuals prefer a more consultative style in which the leader solicits inputs and shares his or her mental model with other crewmembers. The Rules and Order dimension is manifested in the degree of adherence to regulations and Standard Operating Procedures (SOPs) shown by individuals and crews.

One of the unexpected findings in our cross-cultural study was a highly significant relationship between national culture and attitudes about automation (14). In addition to measuring cultural issues, the survey contained fifteen questions dealing with liking for automation and attitudes regarding its use. Data from pilots of highly automated aircraft were collected from 5,800 respondents in twelve countries. Items assessed included whether one should always use the automation, concern over losing individual skills, perceived freedom in use, and overall preference for automation. National differences were significant at $p < .001$ level on all items and the range of endorsement for each item across nations was very large, averaging 48% across all items. Selected items are shown in Table 1. The conclusion that these differences reflect *national* difference was supported by comparing the magnitude of within and between culture differences. This analysis showed that the range of agreement across nations was almost four times larger than the range of agreement within the same culture.

Item	Chi Square	% Range
Should always use automation	252.5	49-100%
Concerned with losing personal skill	173.7	19 - 73%
Feel free to select level of use	86.9	48 - 91%
Prefer automation	309.9	34-100%

Table 1. Range of agreement with statements about automation across countries among pilots of advanced aircraft.

National culture has been implicated as a contributory factor in analyses of air crashes (1). In one accident, the unwillingness of junior crew to speak up to alert the captain to a critical fuel condition was identified, along with the crew's acceptance of long delays from air traffic control.

The situation becomes more complex when multi-cultural teams must work together. Crews composed of individuals from highly divergent cultures offer many opportunities for misunderstanding and conflict. In surveys conducted at airlines with a multi-cultural pilot force, we included open-ended questions asking respondents to describe what was most satisfying and what was most frustrating about working in a cross-cultural work environment (5). A number of positive aspects of multi-national work were identified. Many reported that people try harder to make sure others know what they are doing and to verbalize decisions fully. These behaviors were seen as improving communications and safety. Another common theme was stricter adherence to SOPs in multi-national crews to reduce the possibility of misunderstanding. On the negative side, many frustrations were reported, the most frequent being difficulties in communication and the associated effort required to be understood. Power issues were also a source of frustration, particularly for those accustomed to a flatter authority structure. Social isolation based on culture was also reported as a source of discontent. Overall, multicultural work activities were seen as challenging, sometimes rewarding, but often frustrating.

No national culture is optimal for productivity and safety. Cultures that value harmony and teamwork may also endorse autocratic leadership and inhibit input from juniors. Pilots in cultures that do not value adherence to SOPs highly may be more creative in dealing with novel situations not covered by procedures. In contrast, pilots with a strong belief in strict adherence to rules may have more difficulty in dealing with unforeseen emergencies. Because cultural values are so deeply ingrained, it is unlikely that exhortation, edict, or generic training programs can modify them. The challenge is to develop organizational initiatives that congruent with the culture.

Organizational Culture

Organizations can function within a national culture or can extend across national boundaries. Organizational norms can either be in harmony or at odds with national culture. An organization's culture reflects its attitudes and policies regarding punishment of those who commit errors, the openness of communications between management and flightcrew, and the level of trust between individuals and senior management. Organizational culture also influences norms regarding adherence to regulations and procedures. Using perceptions of management's safety concerns as a benchmark, large and highly significant differences in organizational culture are seen, even in an industry that is heavily regulated. For example, in one airline, 84% agreed with the item 'Management never compromises safety for profit,' while in another, only 12% endorsed the item.

Organizational climate, manifested in members' morale and affect toward the organization, is a function of both the organizational culture and individuals' liking for their jobs. Similar variability is shown on these measures. In the airline where management was seen as committed to safety, 97% reported that they were proud to work for the organization, while in the second, only 26% did. Morale was equally labile. In the first organization, 87% agreed that their morale was high, contrasted with 3% in the second. Culture and the climate are separate but related determinants of processes and outcomes in organizational endeavors. Culture and climate necessarily have an impact on the way people work and their effectiveness.

Organizational culture has been identified as a causal factor in aviation accidents (11). The U.S. National Transportation Safety Board has singled out management for allowing a culture of non-compliance with procedures that can lead to fatal error. Recent investigations concentrate on organizational attributes that serve as precursors of disaster.

Professional Culture

The third cultural determinant of outcomes is professional or disciplinary culture. Many professions such as aviation and medicine have strong cultures and develop their own norms and values along with recognizable physical characteristics such as uniforms or badges. The ongoing research at the University of Texas has examined the professional culture of both pilots and doctors (5). The positive aspects of professional culture are shown in strong motivation to do well and a in a high level of professional pride. Doctors and pilots are self-selected members of elite professions and have expended great effort to achieve their current status.

There is also a negative component of professional culture that is manifested in a sense of personal invulnerability. We have found that the majority of pilots and doctors agree that their decision making is as good in emergencies as normal situations, that their performance is not affected by personal problems, and that their performance is not hindered by working with less experienced team members. Comparative data from pilots in 22 countries and doctors in four

countries are shown in Figure 2. While the positive aspects of professional culture undoubtedly contribute to aviation's splendid safety record, the 'macho' attitude of invulnerability can lead to risk taking, failure to rely on fellow crewmembers, and a variety of team-based errors.

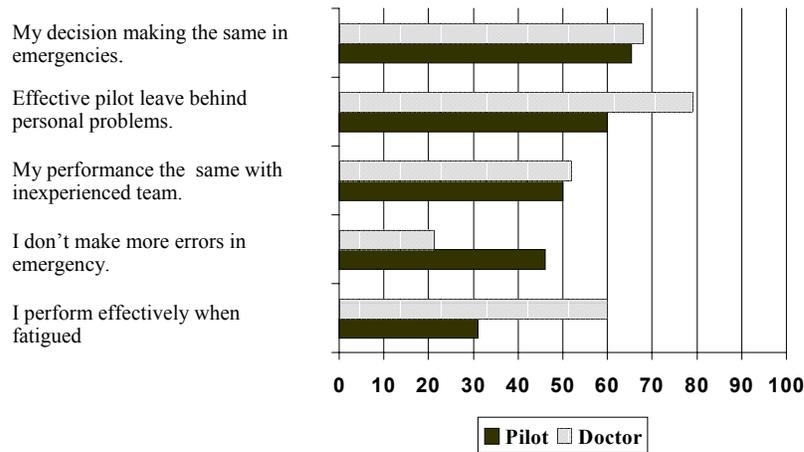


Figure 2. Percentage of pilots and doctors endorsing unrealistic attitudes about personal capabilities

Error in Aviation

Human error is a critical factor in aviation and other socio-technical endeavors such as space flight and medicine. NASA research in the 1970s demonstrated that crew-based error is involved in at least two-thirds of air crashes (2).² The aviation community responded to these findings by developing team training programs that are known as Crew Resource Management (CRM). This training has evolved in the last two decades and the latest programs focus explicitly on specific behaviors that are error countermeasures (5,6). Issues associated with national, professional, and organizational culture are conceptually relevant to crew error (7). However, before cultural factors can be incorporated in programs to manage error, it is essential to have empirical data on the nature and extent of error in normal operations and a model of error avoidance and response that can bring order to the data.

The University of Texas project has developed a methodology to collect data during normal flight operations called the Line Operational Safety Audit (LOSA, 10). LOSA uses expert observers riding in the cockpit to collect data about crew behavior and situational factors. Observations are conducted under strict non-jeopardy conditions; thus no crews are at risk for

² Early investigations tended to focus on the crew as the sole causal factor. Today, of course, we realize that almost all accidents are system accidents as discussed by Helmreich & Foushee (1) and Reason (10,11).

observed actions.³ Observers code observed threats to safety and how they are addressed, errors and their management, and specific behaviors that have been associated with accidents and incidents (and that form the basis for contemporary CRM training). Data are collected using the University of Texas Line/LOS Error Checklist (4). Eight audits including over 3,500 flights have been completed. However, only the three most recent have focused directly on error and error management. These three LOSA projects were conducted both in the U.S. and in international operations and involved two U.S. and one non-U.S. airline. While errors committed during training are routinely studied, LOSA data are unique in capturing actual practices in the operational environment, including violations of procedures.

A Model of Flightcrew Error Management

Operationally, flight crew error is defined as *action or inaction that leads to deviation from crew or organizational intentions or expectations* (6). The definition classifies five types of error: **1) Intentional non-compliance errors** or conscious violations of SOPs or regulations. Examples include omitting required briefings or checklists; **2) Procedural errors** in which the intention is correct but the execution flawed. These include the usual slips, lapses, and mistakes such as incorrect data entries or flying the wrong heading; **3) Communication errors** that occur when information is incorrectly transmitted or interpreted. Examples include incorrect readback to ATC or communicating wrong heading to the other pilot; **4) Proficiency errors** that indicate a lack of knowledge or stick and rudder skill; and **5) Operational decision errors** in which crews make a discretionary decision not covered by procedures that unnecessarily increases risk. Examples include extreme maneuvers on approach, choosing to fly into adverse weather, or over-reliance on automation. The error management model is shown graphically in Figure 3

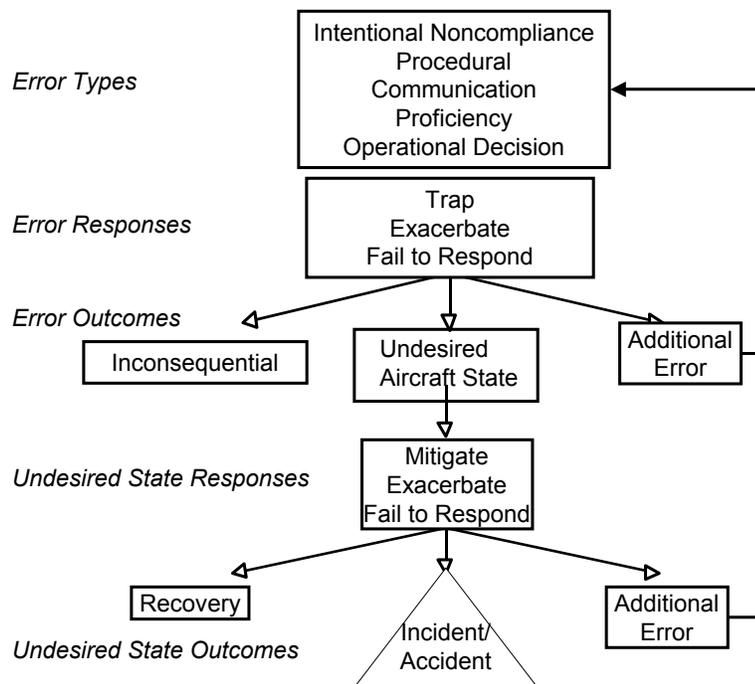


Figure 3. A model of flightcrew error.

³ In practice, members of the University of Texas project have trained observers from participating airlines and also University of Texas at Austin Human Factors Research Project: 249
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Three responses to crew error are identified: **1) Trap** – the error is detected and managed before it becomes consequential or leads to additional error; **2) Exacerbate** – the error is detected but the crew’s action or inaction leads to a negative outcome; **3) Fail to respond** – the crew fails to react to the error either because it is undetected or is ignored. Definition and classification of errors and responses are based on the observable process. There are three outcomes: **1) Inconsequential** – the error has no effect on the safe completion of the flight or was successfully countered by error management. This is the modal outcome, a fact that demonstrates the robust nature of the aviation system; **2) Undesired aircraft state** – the error results in the aircraft being in a condition that increases risk. This includes incorrect vertical or lateral navigation, unstable approaches, low fuel state, and hard or otherwise improper landings. A landing on the wrong runway, at the wrong airport, or in the wrong country would be classified as an undesired aircraft state. **3) Additional error** – the response to error, as we have noted, can result in an additional error that again initiates the cycle of response.

Undesired aircraft states can be *mitigated*, *exacerbated*, or the crew can fail to respond. For example, recognizing an unstable approach and going-around would mitigate the situation. Crew actions may exacerbate the situation, increasing the severity of the state and the level of risk. Just as with error response, there can also be a failure to respond to a situation. There are three possible resolutions of the undesired aircraft state: **1) Recovery** indicating that the risk has been eliminated; **2) Additional error** where the actions initiate a new cycle of error and management; and **3) crew-based incident or accident**.

The model aids analysis of all aspects of error, response, and outcome. The failure or success of defenses such as CRM behaviors can also be evaluated. Errors thus classified can be used both to guide organizational actions and to develop training.

Error in Flight

Examination of the aggregate data from the first three LOSAs in which error was measured is instructive (10). Errors were committed by 68% of the crews observed with a range of zero to fourteen and an average of 1.8 per flight. The distribution of error types is shown in Figure 4.



Figure 4. Distribution of error types in normal flight.

More than half of the errors observed were intentional non-compliance (or violations), with the second highest consisting of procedural. The high percentage of intentional non-compliance is alarming and will be discussed later. Procedural errors doubtless have multiple causes. They can result from the inherent limitations of humans accomplishing difficult tasks, often under high workload conditions or they may be an indication that procedures themselves are sub-optimal.

Of all the unintentional errors observed, 36% were trapped, 11% were exacerbated, and 53% elicited no response. Errors differ by types in whether or not they become consequential. By consequential, we mean action resulting in an additional error or an undesired aircraft state. While proficiency and operational decision errors are least common, they are much more likely to become consequential as shown in Table 2.

<i>Error Type</i>	<i>Consequential</i>
Intentional Noncompliance	2%
Procedural	23%
Communication	11%
Proficiency	69%
Decision	43%

Table 2. Percentage of each error type becoming consequential.

The Significance of Violations

The high proportion of intentional non-compliance errors found in the data dismayed both us and the management at collaborating airlines. Several points regarding these violations should be considered. First, as we have noted, there were very large differences between airlines and between fleets within airlines. Hence, one cannot generalize from these data to the frequency of violations in the global aviation system. This point is further emphasized by the fact that the three carriers included in the study all came from countries that scored low on commitment to rules, as measured by our Rules and Order scale (5). It would be incorrect to assume that pilots from other cultures, especially those high in adherence to procedures, would be equally cavalier in disregarding formal rules. On the other hand, the universal pilot belief in personal invulnerability may foster a general disregard for rules. The fact that many rules are broken does not imply that violating pilots have a death wish or have contempt for formal requirements. One must also consider the possibility that the proliferation of regulations may have created a contradictory, unwieldy, and inefficient operating environment that invites violations (11).

Although many violations may be committed with the good intention of increasing operational efficiency, organizations cannot and should not tolerate disregard for established procedures. There are several compelling reasons for this. One is, of course, that standardization of operations cannot be achieved with idiosyncratic adherence to procedures. There is also compelling evidence for the threat to safety associated with violations. First, a Flight Safety Foundation analysis of global approach and landing accidents found that more than 40% involved violations of SOPs (8). Second, analysis of LOSA data indicate that *those who commit intentional non-compliance errors commit 25% more errors of other types*. Although the percentage of violations that became consequential was low, it can be concluded that violators place flights at greater risk because of

their general propensity to err. Further analyses may give us greater insight into the nature of this relationship.

CRM as Countermeasures for Threat and Error

One of the most informative aspects of LOSA data is the ability to link threat recognition and error management with the specific behaviors that form the core of CRM training. These behaviors emerge very clearly in observer ratings of the actions taken by effective crews. Those who deal proactively with threat and error exhibit the following behaviors:

- **Active leadership**
- **Briefing known threats**
- **Asking questions, speaking up**
- **Decisions made and reviewed**
- **Operational plans clearly communicated**
- **Preparing/planning for threats**
- **Distributing workload and tasks**
- **Vigilance through monitoring and challenging**

The behaviors associated with effective and ineffective coping with threat and error have clear ties to national culture. The functioning of a work team, nature of communications among team members, and the quality of leadership are culturally determined. Professional and organizational cultures can influence the nature of these behaviors and their acceptance.

IMPLICATIONS FOR SPACE FLIGHT

Cultures

Data from the aviation environment indicate that culture plays an important role in both mono-cultural and multi-cultural work environments. Anecdotal data from space operations also suggest that culture will play a significant role in determining the effectiveness of International Space Station operations (personal communication). Based on earlier studies of national culture (4,7), large differences in Individualism, Power Distance, and Rules and Order can be anticipated among participating countries. These differences could impede teamwork in the demanding environment of space and on the ground during training and mission preparation.

Organizational factors are of particular concern because the ISS represents a joint endeavor involving multiple national programs that have their own histories and cultures. Professional cultures also contribute to a complex environment. Astronauts are an elite corps with a distinct and heroic professional culture that shares many of the attributes of the pilot culture. However, astronauts are also professionals with a distinguished record in scientific specialties and they bring with them the professional cultures of their disciplines. One of the challenges for mission planning is to ensure that professional issues do not short-circuit overall mission effectiveness.

Error

Error is an inevitable component of the human condition. In socio-technical environments such as space craft, the costs of error can be extremely high. As the aviation data suggest, well trained and qualified crews commit a variety of errors of differing types. The frequency of violations in a

highly proceduralized environment is a source of concern and could be a source of conflict within a crew when individuals from cultures with differing propensities for non-compliance work together. In the more autonomous environment of the ISS, a better understanding of error and its management could increase the likelihood of mission success. It is important to note that certain types of error (for example, operational decisions) are more likely to have adverse consequences.

There are strong cultural differences in attitudes about error (for example, shame) and highly divergent organizational attitudes regarding how to deal with error. Many organizations function with a 'blame and punish' culture that drives error underground and decreases the opportunity to develop organizational initiatives to reduce the likelihood of future error. Professional cultures may also inhibit sharing information about the sources of error and countermeasures employed.

The focus of CRM on error management offers a model for space operations. However, to be successful, any program must be based on data from its own environment rather than imported from another domain. The general approach, however, should be applicable in any demanding, team-based operational environment.

Challenges for Research

To have practical value for space operations, a number of research questions about culture and its influence need to be answered. The interplay among national, organizational, and professional cultures is conceptually complex and needs to be explored empirically in the environment of space operations. While further research in analog domains is needed, the ultimate data must come from the operational environment. Perhaps the greatest challenge will be to forge a successful organizational culture for this complex multi-cultural endeavor.

Relationships between error and culture need to be examined directly if effective error countermeasures are to be developed and deployed. To be effective this research needs to be supported by a strong organizational commitment to error management and an open and non-punitive approach to inadvertent error.

Long term, multinational operations in the ISS present a major challenge to behavioral science and will require in-depth investigation of areas that have been ignored in the past. The ultimate goal of developing an operational environment that harmonizes the cultures involved is doubtless attainable, but not without the visible commitment of participants and organizations.

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