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IDENTIFYING ORGANIZATIONAL VULNERABILITIES IN SPACE OPERATIONS WITH COLLABORATIVE, TAILORED, ANONYMOUS SURVEYS

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ABSTRACT

Organizational problems have contributed to many aerospace accidents. Because of the unforgiving environment of aerospace, it is crucial to eliminate as many of these problems as possible. Collaborative, tailored, anonymous surveys can identify organizational problems early on. In this paper, we discuss how to develop this type of survey in space support environments, using as an example a survey with International Space Station (ISS) flight controllers. We then discuss some results of this survey to demonstrate how such a survey can identify organizational problems. Finally, we discuss ways in which the survey results were used to address problems and reduce risk.

1. INTRODUCTION

Organizational factors can affect system risk. In aviation, organizational factors have contributed to many aircraft accidents. Some of these organizational factors have been lack of training, time pressure, over-scheduling (and resulting fatigue), policies on resource management (fuel use), and faulty procedures (e.g., shift handovers in maintenance, check list procedures in the cockpit) [1].

Organizational factors have also contributed to spacecraft accidents. Some of these factors have been the lack of coordination between NASA and a non co-located contractor (Mars Climate Orbiter) [2]; lack of clearly defined roles and responsibilities (Titan IV/Milstar) [3]; inadequate documentation practices (Ariane 5) [4]; and the lack of communication channels for engineers who strongly hold a minority opinion (Challenger) [5]. Organizational factors were cited in the Columbia Accident Investigation Board (CAIB) Report [6] as contributing to the Columbia accident. One of the recommendations of this board was the necessity for

> . . .organizations committed to effective communication [to] seek avenues through which unidentified concerns and dissenting insights can be raised, so that weak signals are not lost in background noise. . . [These avenues] must mitigate the fear of retribution, and management and technical staff must pay attention. (p. 192)

One such avenue is collaborative, tailored, anonymous surveys. When administered at regular intervals, they can identify problems early on and provide communication channels for anonymous input. Hence they are a first step in reducing risk from organizational factors.

2. SURVEY EXAMPLE

In November of 2003, 191 ISS flight controllers completed an online survey, "Organizational Risk and Tool Development Survey." The purpose of the survey was to identify organizational risks that could endanger the program and to generate tools to reduce these risks and facilitate tasks. The survey was repeated this year, but the new data are not yet fully analyzed.

The ISS Flight Controller survey focused on four different organizational levels: organization-wide, flight team, discipline group (e.g. power, thermal, etc.), and individual. Additional sections of the survey determined the adequacy of documentation and software, and obstacles to work effectiveness. Finally, the flight controllers were asked to identify the three most serious organizational vulnerabilities and to offer suggestions.

3. SURVEY DEVELOPMENT AND ATTRIBUTES

Many different types of surveys and survey questions exist to address many different goals. The following are specific features and advantages of the ISS flight controller survey designed to identify organizational risk factors.

3.1 Based on Organizational Risk Literature

Many of the risk factors found in the organizational risk literature apply to space environments and can be used to develop survey items. (See especially the literature regarding High-Reliability Organizations—HROs) [7, 8], Generative Organizations [9], and Learning Organizations [10].) A summary of the literature on safety culture in high-risk organizations was commissioned as part of constructing the ISS Flight Controller Survey [11].

3.2 Supported and Administered by Knowledgeable Outsiders

Experts from outside a domain are more likely to be free from internal alignments, which enables the survey and findings to be accepted more readily by all parties. The first two authors on this paper are experts in aerospace system safety and, although they are affiliated with NASA, they are not from operational centers.

3.3 Scientifically Valid

Constructing a scientifically valid survey requires specialized knowledge. For example, one needs to know how to select participants, organize topics, phrase questions, examine response consistency, and choose and use appropriate analysis techniques. Such a survey can provide valid and reliable results on which decisions can be based.

3.4 Collaborative

Since facilitating communication is a goal, it is important to collaborate on the survey with both management and future respondents. The survey taken by ISS flight controllers was modified by Mission Operations Directorate (MOD) management to elicit information they needed. It was further modified by the flight controllers to communicate their concerns to management. Hence, the survey was truly *collaborative* and facilitated communication within MOD.

3.5 Tailored

We have found that the more the survey is tailored to the specific domain, the more useful the information it will yield. Therefore, it is helpful for the survey designer to become familiar with the domain through standard ethnographic techniques of observation and interviews. For example, we know that inadequate documentation has been implicated in previous aerospace accidents (e.g., Ariane 5 [4]). Therefore, to tailor the survey to MOD, survey items were developed requesting information on the adequacy of *specific* documents within MOD.

3.6 Enables New Issues to Emerge

It is important to ask respondents to state in their own words what they perceive as the most important organizational vulnerabilities in their environment, what the consequences might be, and what they would suggest to remedy these vulnerabilities. There are two advantages to including these questions on the survey. First, they allow new concerns to percolate up, concerns that might not have been tapped by the interviews used to develop the surveys. Second, they enable one to assess the relative importance of the organizational vulnerabilities that have been rated earlier in the survey.

Another way to enable other issues to emerge is by providing space in the survey for free text comments after the rating statements. Doing so also contributes to a fuller understanding of what the ratings mean. In the ISS Flight Controller Survey, space for such comments was provided in every section.

3.7 Provides a Communication Channel for Safety of Flight Issues

The supreme example of allowing for other issues to emerge, especially just before a flight, is to include a question as to whether there are any safety of flight issues. This was included on the repeat survey for the flight controllers, and all responses to this question were promptly relayed to those in knowledgeable management positions. A question of this type provides an opportunity for direct, immediate, and anonymous communication between those closest to the mission and those in management positions.

3.8 Involves Multiple Levels

Risk factors can be identified at multiple levels of an organization and can exert their effects at higher or lower levels. It is important to address organization-wide, team-level, and individual-level risks in a survey. Obviously, management decisions made at the organizational level influence the operational effectiveness of both teams and individuals.

3.9 Assesses Decision Factors

In addition to organizational structure, factors such as schedule, cost, and pressure from governmental bodies have been shown to play an important role in decisions that have contributed to spacecraft accidents. In both the Challenger and Columbia investigations, it was determined that schedule concerns overrode safety concerns. One way to ascertain the prevalence of this pattern in ongoing missions is to ask respondents to rate how often they think various factors play a role in upper management decisions, as shown in Figure 1.

When upper management makes decisions about the mission, how often do you think the following factors play a role?

	Never	-	-	-	Always
Crew safety					
Vehicle safety					
Science output					
Cost					
Schedule					
Contract negotiations					
Public opinion and support					
International cooperation					
Interpersonal conflict					
Influence from other governmental bodies					

Figure 1. Possible survey format for assessing the perceived frequency of various factors in decision making.

Respondents can be asked to rate how often these factors play a role both in upper management decisions and in their own decisions and recommendations. These data can be used to measure the extent to which schedule and other factors are perceived as playing a role at different organizational levels, how they change with time, and whether they are in alignment with management goals and safety considerations.

4. RESULTS OF THE ISS FLIGHT CONTROLLER SURVEY

4.1 Organizational Strengths

The survey results revealed many strengths in the organization, the most important of which was a strong safety culture. ISS flight controllers feel free to speak up about safety concerns. ISS flight controllers have positive attitudes towards their work and take pride in their jobs. They have good relationships with supervisors who are seen as accessible and who listen to what is said—which means there is a good flow of information from one level to the next. Flight teams are seen as performing very well. Individual discipline groups have many excellent, risk-reducing characteristics. Group members respect those who spot and elevate problems, support each other, and have good collaborations within their group and between groups. Discipline group meetings also have many risk-reducing characteristics. Flight controllers feel free to disagree and are confident that their own input is considered.

4.2. Vulnerabilities

The survey results revealed one area of critical vulnerability, and several areas which needed improvement.

The critical vulnerability was an over-reliance on human operators to work around malfunctioning software. At the time of the survey there were over 1,000 written workarounds (called Station Program Notes, or SPNs) to software problems, and flight controllers reported difficulties in remembering them. Flight controllers rated software issues as compromising ISS safety. When flight controllers were asked to list the three most serious organizational vulnerabilities, software workaround issues were listed most frequently and rated as being the most serious. This vulnerability was compounded by a structural difficulty in communication, since the boards which have responsibility for making decisions on software (the Avionics group) are in a different directorate than the flight controllers, as shown in Figure 2.

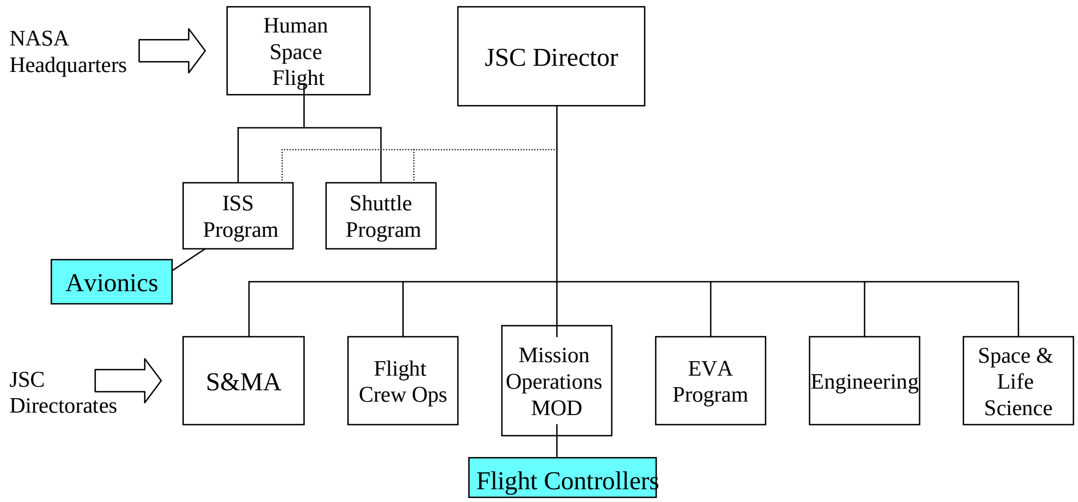

Figure 2. Simplified Johnson Space Center organization chart. (Not shown are offices such as Human Resources, Legal, Center Operations, etc.) Avionics is in a different directorate than the flight controllers.

In addition to the critical vulnerability described above, the survey identified the following areas as needing improvement: (1) ISS history, decisions, and rationales were not accessible. (2) There were inaccuracies in on-console documentation. (3) Better ISS system understanding on the part of flight controllers was needed. (4) Communication with international partners could be improved. (5) Finally, it was recommended that anonymous surveys be administered periodically to increase communication and to help forestall the development of critical vulnerabilities.

5. RESPONSE TO SURVEY RESULTS

For an operationally relevant survey to have an impact, results must be presented to the organization's managers and respondents. Findings are most likely to make a difference if they are given in a non-biased factual survey report. The report format aims to reduce defensiveness and to lay out the problems for all to work on. Also, the motivation to fix problems increases when they have been identified by a large group of people close to the spacecraft.

Figure 3 shows the survey timeline, along with the MOD-wide meetings held to address the issues identified by the survey.

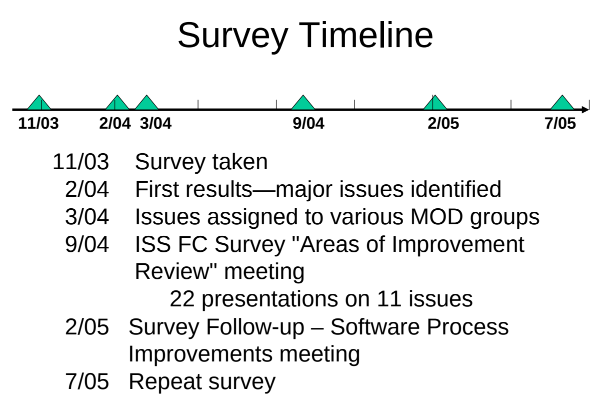

Figure 3. Survey timeline including two MOD-wide meetings to address the issues identified by the ISS Flight Controller Survey

As can be seen from the timeline, MOD devoted considerable time and resources to addressing the issues identified by the survey. Although substantial progress was made on many issues, due to space limitations we will discuss only the software workaround issue here.

5.1 Addressing the Problem of Software Workarounds

First, an effort has been made to reduce the number of software workarounds. As can be seen from Figure 4, the software workarounds, or SPNs, have been reduced by almost half. Even so, this leaves many workarounds in existence which continue to be problematic for the flight controllers. Nonetheless, the trend is certainly in the right direction. Reducing the number of SPNs by this amount has required considerable effort not only by Avionics, but also by the flight controllers in updating their procedures.

The other steps that have been taken are based on the two organizations' understanding of why the number of workarounds became so high.

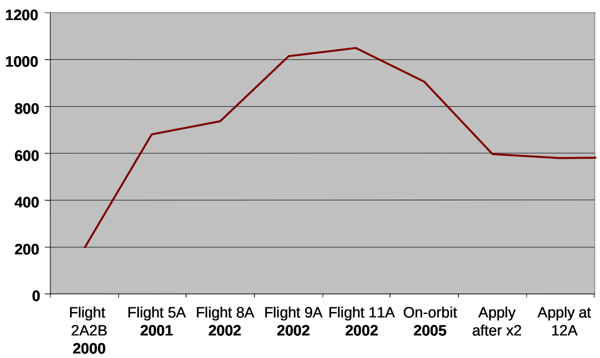

Figure 4. Number of SPNs since beginning of the ISS.

As can be seen in Figure 4, there was a sharp increase in the number of SPNs just before Flight 5A in February of 2001. During Flight 5A, the US Laboratory "Destiny" was installed on the ISS to provide initial US user capability. There was intense schedule pressure before 5A**,** and delays in the release of flight software by Avionics would have delayed the launch. Similarly, MOD was under schedule pressure before Flight 5A to certify flight controllers and to produce validated flight procedures. Software that did not function according to requirements adversely affected these goals. Hence, during this period the objectives of these two organizations were diametrically opposed, and the more the schedule pressure increased, the more their dealings became adversarial in nature. Hence the difficulty in communication was not only structural, due to being in different directorates, but was also based on the resentment that had built up during this period.

Once this was recognized, the basic strategy for the two organizations was not only to reduce SPNs, but also to improve communication and understanding at all levels. Accordingly, during 2004, Avionics and MOD examined their interfaces on the software deployment timeline and created additional interfaces, including new design reviews, new uplink planning, and new meetings to collaborate on how SPNs are incorporated into MOD procedures. Additionally, the two organizations set up weekly meetings between representatives of MOD and Avionics, and strengthened flight controller representation on Avionics Boards. To foster collaborative working relationships, an MOD-wide meeting was held to which Avionics representatives were invited. Additional "exchange programs" between the two organizations are planned.

6. BENEFIT OF SURVEY

The flight controllers worried about forgetting the SPNs, due to their large numbers. When asked at the end of the 2003 survey, "What worries you the most today?" the most frequent response involved external factors (such as loss of funding), but the next most frequent was that they would forget a software workaround. Although flight controllers felt the burden of remembering these workarounds, they were unable to communicate the weight of this burden, the extent to which it was shared by other flight controllers, and the risk it entailed to the ISS. The survey results effectively communicated this to all parties involved.

The prompt response of MOD, Avionics, and the ISS Program to the survey results shows the strong safety culture in these organizations. MOD's seeking information via a survey in and of itself showed a strong safety culture. The CAIB report stressed that seeking information is exactly what managers should do. All organizations involved have benefited from it. The head of MOD Systems Integration stated that

> The survey results brought us light years forward with regard to communicating and developing a working relationship between MOD and [Avionics].

7. FORWARD WORK

7.1 Repeat Surveys

Repeat surveys enable new issues to be brought forth to management. They also enable organizations to monitor past issues. For example, preliminary analysis of the ISS Flight Controller repeat survey indicates that despite progress on reducing SPNs and improving communication, flight controllers still rate these issues as serious. Hence efforts should continue to be made to address these issues.

Repeat surveys also help develop baselines for rating items so that positive and negative changes are apparent. It is especially valuable to do this for the decision factors described earlier such as schedule.

7.2 Organizational "Lessons Learned" Database

An ultimate goal would be to create a database of organizational "lessons learned" in aerospace environments. For example, it is apparent that schedule pressure creates conflict between certain groups. It is important to ascertain which groups these are. Identifying these groups and relevant pressures is the foundation for determining how this type of conflict can be prevented in the future or reduced once it occurs. It is important to learn what techniques have worked.

8. CONCLUSION

Organizational vulnerabilities have contributed to many spacecraft accidents. As missions grow in complexity, the bureaucracies that support them will also grow. As this happens, it is increasingly necessary to seek out information in a systematic way. A type of survey is described which can identify organizational vulnerabilities and facilitate communication in a space support domain. An example survey was described from ISS Mission Control at JSC. The organizational vulnerability identified by this survey was immediately addressed by all organizations involved, demonstrating a strong safety culture. Ultimately, these changes will result in increased safety for the International Space Station. Additionally, the organizations involved have provided a model for future space missions on how to reduce risk from organizational factors.

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