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FINAL REPORT

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"Operational Factors Influencing Pilots' Decision Making Under Risk"

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ABSTRACT

Objective: Two studies were conducted to examine pilots' responses to risk and the factors that influence their decisions. **Background**: Analyses of aviation accidents revealed a particular class of decision errors, called plan continuation errors, that involved decisions by flight crews to continue with their flight as planned despite evidence suggesting to change that plan. One explanation of these errors centers on pilots' decision frames; i.e., pilots stress economic losses resulting from a change and thus proceed as originally planned. Alternatively, pilots' plan continuation errors may reflect inadequate or inappropriate risk perception or assessment. **Methods**: 30 pilots from a major U.S. carrier, and 31 pilots from a national U.S. carrier participated in the research. Participants received two realistic decision scenarios involving decision dilemmas (safety vs. economy goals) and ambiguous and uncertain conditions. Participants were asked to verbalize their concerns and reasoning while deciding on how to proceed in each situation. Sessions were audiotaped and transcribed for content analysis. **Results**: Logistic regression analyses indicate that inappropriately optimistic risk assessment rather than a decision frame highlighting economic losses may be a dominant factor in pilots' plan continuation errors. Differences between the pilot groups concerned pilots' risk mitigation strategies and the consistency of their risk tolerance across situations. **Conclusions**: Our research highlights the importance of risk assessment in pilots' decisions to take or avoid a risk. Differences in pilots' risk assessment, moreover, were associated with the presence of ambiguous flight conditions.

Application: Implications of these findings for pilots' risk management training are discussed.

INTRODUCTION

Safe flight depends on effective decision making. While decision errors by flight crews are relatively infrequent in everyday flight, they tend to be more consequential than other types of errors, often resulting in unsafe aircraft states (Helmreich, Klinect, & Wilhelm, 2001). Improper crew decision making has been implicated in 68% of aircraft accidents occurring between 1978 and 1990 (NTSB, 1994). Three-quarters of these errors were subsequently classified as plan continuation errors; i.e., instances in which the crew decided to continue with a plan of action despite evidence suggesting that their original plan should be modified (Orasanu, Martin, & Davison, 2001). As an illustration of this type of decision error, consider the following accident description:

The charter flight departed Los Angeles International for Aspen-Pitkin County Airport (ASE), Aspen, Colorado, 41 minutes late, pushing the estimated arrival time at ASE to just 12 minutes before the airport's nighttime landing curfew. When the charter customer was informed about the possibility of a diversion, he became irate and stressed the importance of landing at ASE this evening. During the flight's initial descent, the crew was told that visibility at the airport was deteriorating and they heard three of the four aircraft ahead of them report conducting missed approaches. As the crew continued with the approach, they indicated that they had visual contact with the runway to the right of the aircraft. According to radar data, the airport was actually to the left of the airplane at that time. Shortly afterward, the airplane crashed into sloping terrain about 2,400 feet short of the runway threshold (NTSB, 2002).

Decision frames as a possible cause of pilots' plan-continuation errors

Why do pilots sometimes continue with a flight as planned even though this course of action carries a potential safety risk? One possible answer is based on prospect theory (Tversky & Kahneman, 1981) which states that people will accept or avoid some risk dependent on how they frame the outcomes associated with available options. If options are worded to highlight adverse consequences (i.e., lives lost), people tend to be risk seeking. That is, they are willing to adopt an uncertain option if it entails the possibility of no loss (e.g., "no one may die") rather than accept a moderate but sure loss (e.g., "1/3 of the affected population will die"). On the other hand, if the same options are framed as gains (i.e., they underscore the number of lives saved), then people are "risk averse" and prefer the moderate but sure gain ("2/3 of the affected population will be saved") to the gamble ("everybody may be saved").

Prospect theory thus suggests that accidents like the one in Aspen, Colorado, happen because pilots focus on the economic losses associated with available options while disregarding or at least de-emphasizing the safety benefits of a change in the flight plan. Accordingly, one might speculate that the pilots in the Aspen accident proceeded with the approach because this action entailed a chance of no economic loss: the customer would be satisfied and his continued business ensured. Diverting to another airport may not have been seen by the crew as a viable alternative since it would likely have entailed negative economic consequences: an irate customer and a future loss in revenues. A study by O'Hare and Smitheram (1995) examining the effect of framing on private pilots' weather-related decisions provides some support for this explanation. Pilots prompted to consider the safety benefits of a diversion were less likely to continue in deteriorating weather conditions than pilots who were reminded of the money and time already invested in the flight. However, no framing effects were observed when scenarios were described in neutral terms and prior to the experiment, pilots were asked to simply identify the decision frame that reflected their usual mind-set in aviation decisions.

Pilots' risk perception and assessment as possible causes of plan continuation errors

An alternative explanation of pilots' plan continuation errors reflects recent work on decision making in real world contexts that emphasizes the active role of decision makers in interpreting environmental cues prior to selecting a course of action (Endsley, 2000; Huber, 1997; Montgomery, 1994). In contrast to prospect theory's emphasis on the end point of the decision process and its assumption of known risks, this explanation centers on the pre-decisional phase and examines how initial risk appraisal influences subsequent decisions. While subjects in framing studies receive a well-defined problem (e.g., an unknown Asian disease striking 600 people), many real world problems do not come as neatly packaged. Instead, prior to deciding on how best to respond to a risk, people first have to acknowledge that they face an event that is potentially threatening. Risk appraisal further entails judging the seriousness and the likelihood of a negative outcome (Yates & Stone, 1992). This account of risk taking behavior suggests that pilots' plan continuation errors are the result of inappropriate risk perception or assessment. That is, pilots may continue with a flight as planned because they miss or misinterpret relevant cues in the environment and thus fail to perceive the potential threat associated with this course of action. Or, they may erroneously assume that a threat is not really serious or is unlikely to lead to a negative outcome. Problems of this kind were idenrified in several studies investigating factors underlying private pilots' decisions to continue into hazardous airspace. Pilots who opted to stay with their original flight plan were more likely to have missed significant changes in the flight environment (Muthard & Wickens, 2002), and were found to report greater optimism about weather conditions than pilots who decided to divert (Wiegmann, Goh, & O'Hare, 2002). Both inadequate risk perception and risk assessment may also have been factors in the Aspen accident. As evident in the cockpit voice recording, the pilots mistook lights to the right of the airport as runway lights leading them to believe that they could see the airfield and by implication that the weather conditions had improved. In addition, they apparently focused more on the one aircraft that had landed successfully before them than on the three previous aircraft that had discontinued their approaches.

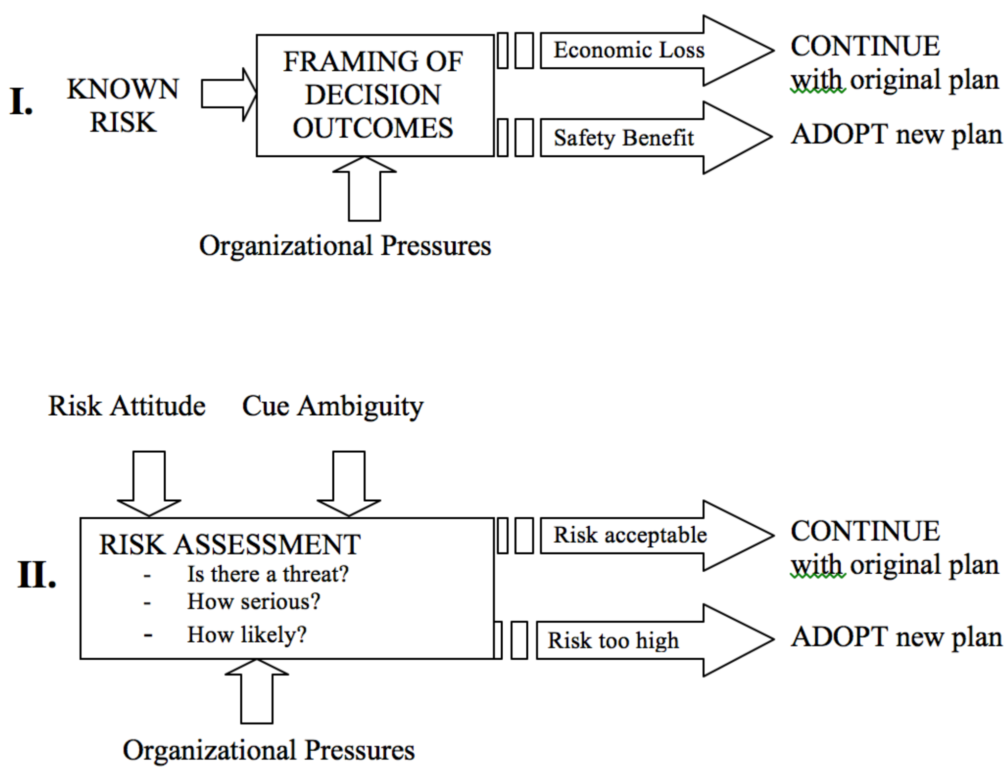

Figure 1. Alternative explanations of pilots' risky decisions (I) in terms of their decision frames, and (II) based on their risk perception and assessment.

The alternative explanations of pilots' risk taking behavior and their implications are summarized in Figure 1. As shown in the top half (I), the framing perspective maintains that all pilots have a common understanding of the nature and seriousness of the threats, but prefer different options depending on whether they focus on safety benefits or economic losses. In contrast, the risk assessment perspective (II) maintains that pilots who avoid or accept some risk differ in their problem understanding, i.e., in their attention to safety-related cues in the flight environment and in their judgments of the severity of safety threats.

Factors influencing pilots' risk perception and assessment

Pilots' risk perception or assessment may be influenced by individual factors, such as familiarity and experience with a threat as well as attitude toward risk and personal beliefs concerning competence and control (Slovic, 1987; Yates & Stone, 1992). While there has been little empirical support for the notion of a risk taking personality, attitudes toward risk were found to be fairly consistent within specific domains, such as business, health, or recreational activities, and to influence perception of risk in these domains accordingly (Weber, Blais, & Betz, 2002). For instance, Sitkin and Weingart (1995) observed that subjects who reported higher levels of risk propensity perceived less situational risk and were thus more inclined to accept a risky proposition than subjects who reported lower levels of risk propensity. Optimistic risk assessment, moreover, may also reflect overconfidence in one's abilities to control the risk (Goh & Wiegmann, 2001; Wilson & Fallshore, 2001).

The subjective nature of risk perception and assessment is heightened in the aviation environment where pilots routinely make decisions based on incomplete, vague, or conflicting information about current and future states of the environment (Orasanu, Martin, & Davison, 2001). Ambiguous cues and uncertain conditions may impede pilots' risk perception and assessment, ultimately leading to decisions that in hindsight turn out to be ill chosen. When crucial information is missing, when conflicting cues are present, or when conditions are rapidly changing, pilots may continue with their current course of action because they do not “see” sufficient information to tell them a change is warranted. Indeed, an analysis of weather –related incidents involving commercial pilots revealed that plan continuations errors were frequently associated with cue ambiguity (Bernhard, Orasanu, Tada & Schwartz, 2003).

In addition to individual factors and environmental conditions, commercial pilots’ perception and assessment of a safety threat may also be influenced by organizational pressures relating to company productivity, economics, and safety culture. For example, companies may emphasize fuel economy and getting passengers to their destinations rather than diverting, thus inadvertently sending mixed messages to their pilots concerning the relative importance of safety versus productivity. Mixed messages create goal conflicts for flight crews that are difficult to resolve. In a risk survey pilots reported that their most difficult decisions were those in which safety was pit against economic or passenger considerations (Orasanu, Davison, & Fischer, 2001). The presence of organizational pressures, in turn, may render pilots’ risk perception and assessment vulnerable to biased information processing resulting in risky actions, at times with fatal consequences as in the Aspen accident. While trying to accommodate organizational goals such as customer satisfaction, pilots may underestimate the seriousness of a safety threat and continue with their flight as planned.

As shown in Figure 1, organizational pressures may also play a role in establishing decision frames (Part I). In this context organizational pressures are assumed not to bias pilots' risk perception and assessment, but instead to influence how they think about available options. Specifically, organizational pressures may highlight the economic implications of available options: deviations from the original flight plan will lead to sure economic losses that ought to be avoided. Adherence to the original flight plan, in contrast, would be judged favorably as this course of action promises no economic loss.

Predictions

The present research was conducted to examine commercial pilots' decision making in ambiguous problem situations that involved a decision dilemma between flight safety and economic pressures. While past research addressed risky decisions by private pilots and usually assessed their cognitions after a decision was made, our study involved commercial transport pilots and recorded their thoughts during the decision process. We focused on commercial pilots because they routinely make decisions that require them to balance multiple goals and risks, most notably flight safety and economic considerations. Our research goal was to determine whether risk averse or risk tolerant decisions are the result of distinct decision frames or reflect differences in pilots' perceptions and assessment of potential threats to flight safety. Unlike past research that presented subjects with options highlighting their associated gains or losses, we examined whether in the course of deciding on how to proceed with a flight, pilots frame potential decision outcomes as gains or losses, and whether their self-generated decision frames predict their final decisions. We hypothesized that if pilots focus on the negative economic implications associated with a change in plan, they will ultimately decide to continue with the flight as planned – thus favoring the riskier option. If they stress the safety benefits of available options, they will opt for a change of plan because this course of action will ensure flight safety. On the other hand, if pilots' decisions are motivated by differences in risk perception and assessment, we hypothesized that all pilots – irrespective of their final decision—will be concerned about flight safety. However, risk averse pilots will consider the threat to flight safety as more serious than risk taking pilots.

METHOD

Participants

Thirty pilots (13 captains and 17 first officers) from a major U.S. carrier, and 31 pilots (15 captains and 16 first offices) from a national U.S. carrier volunteered to participate in the research. Volunteers were recruited via flyers posted on bulletin boards at airlines' training and operations centers, and were paid for their participation. The study was conducted in accordance with the ethical principles prescribed by the American Psychological Association (1992) for research involving human subjects; the experimental procedure and consent form were approved by the Institutional Review Boards at the Georgia Institute of Technology and NASA Ames Research Center.

Pilots from the major carrier were significantly older ($F(1,53) = 16.54$, $p = .000$) and more experienced in Part 121 (commercial air transport) operations ($F(1,52) = 12.91$, $p = .001$) than pilots form the national carrier[1]; however both age and experience effects varied by crew position ($F(1,53) = 12.94$, $p = .001$; $F(1,52) = 16.93$, $p = .000$, respectively). While the captain groups differed in terms of age ($M_{\text{Major}} = 53.38$, $SD_{\text{Major}} = 4.41$; $M_{\text{National}} = 42.50$, $SD_{\text{National}} = 6.05$; $F(1,25) = 28.18$, $p = .000$) and time (in hours) in

[1] One captain and three first officers did not indicate their age. Two captains and three first officers did not specify their professional experience.

Part 121 operations (M_{Major} = 16,930.77, SD_{Major} = 5,908.66; $M_{National}$ = 8,900; $SD_{National}$ = 3,928; $F(1,24) = 16.65$, $p = .000$), no significant differences were observed between first officers with respect to their age (M_{Major} = 38.67, SD_{Major} = 4.97; $M_{National}$ = 38; $SD_{National}$ = 5.76; $F(1,28) = .12$; *ns*) or experience (M_{Major} = 6,362.5, SD_{Major} = 2,477.6; $M_{National}$ = 6,907.14, $SD_{National}$ = 2,608.11; $F(1,28) = .34$; *ns*).

Materials

Two realistic decision scenarios were created involving decision dilemmas aggravated by ambiguous conditions and uncertain outcomes. In both scenarios, continuing with the original plan posed a threat to flight safety. However, if the original plan were successful, it would also bring economic and productivity gains (i.e., customer satisfaction and undisrupted flight operations, saving the company money). On the other hand, changing the original plan would increase the margin of safety, but would also involve economic and productivity losses.

One scenario presented study participants with a decision dilemma at takeoff: As the aircraft moves up the takeoff queue, departure weather is deteriorating, and landing aircraft provide conflicting reports concerning windshear conditions. A commuter jet landing on the departure runway reports a loss of 15 knots, while a B-757 subsequently landing on the same runway experiences only a 10 knot loss and a B-747 landing on the parallel runway reports no loss of airspeed. In this situation pilots could decide to continue with takeoff although there was a possibility of windshear, or they could decide not to take any chances and delay their takeoff. This course of action would mean they would go to the end of a long line of aircraft waiting to depart, thereby delaying their departure even more (the flight already had been delayed for four hours due to poor weather at the destination). The second scenario involved a decision during approach to the destination airport: it is Christmas Eve, bad weather is delaying approaches, and a curfew is looming at the destination airport. This situation entailed productivity (getting passengers where they want to go on an important holiday), safety (possibly running out of fuel), and economic risks (accommodating passengers on later flights, loss of business due to passenger dissatisfaction).

Both scenarios consisted of an unfolding sequence of events reflecting progress over time. While the scenarios involved maximally five events, they could be shorter if a participant decided to delay departure in the Takeoff Scenario or to divert to an alternate airport in the Approach Scenario prior to the last event. At each point in the sequence, pilots could ask for more information than was presented in the event description, such as the current radar image or company input. The kind of information pilots may request was determined in a preliminary study involving six senior pilots affiliated with crew training at two major U.S. airlines. These senior pilots also helped in crafting the additional information so as to leave flight conditions ambiguous and uncertain.

Design and Procedure

Experimental material was administered in two different modes. In the study with pilots from the major carrier, experimental material was printed on flash cards and handed to study participants. The study with pilots from the national carrier involved computer presentation of the material. Except for the presentation mode, all material and instructions were identical in the two studies.

Participants were told that the scenarios progressed as a sequence of events; they were instructed to imagine they were the pilot flying, and to think aloud about their concerns and reasoning while they decided on how to proceed at each point in the evolving event. Instructions to participants followed the procedure outlined in Ericsson and Simon (1993) and specified that "[b]y 'think aloud' we mean that you say aloud everything that in a normal flight situation you would think or do silently. That is, say aloud everything that you are reading and thinking when you view each event description. Be as spontaneous as possible. Say aloud everything that you are considering: any concerns you have, any consideration, even details or sidetracks that may seem insignificant." Instructions also stated that if participants wanted to obtain more information than was included in an event description, they should say so. In the study involving flash cards, the researcher would then hand participants a card providing the requested information; in the computer-based version, the researcher would indicate which key (A through I) they needed to press. Once participants made a preliminary decision, all material relating to this event was removed and they were presented with a new card or webpage describing the event that followed from their decision. Sessions were audiotaped and later transcribed for content analysis. Participants received both scenarios; their order of presentation was counterbalanced. Prior to the experimental scenarios, participants had a training scenario to familiarize them with the materials and procedure.

Coding the Think-Aloud Protocols

The think-aloud protocols were segmented into idea units roughly corresponding to a sentence (main or subordinate clause) with a distinct topic or cognitive function (Hirokawa, 1983). For the Takeoff Scenario, eight topics were identified. Idea units were coded for reference to (a) the departure weather including winds, movement or location of storm cells, and intensity of rain, (b) reported or anticipated airspeed loss, (c) external pressures (i.e., four-hour delay, 20 aircraft in line waiting for takeoff, incurring further delay, passengers wanting to depart), (d) the operational environment (e.g., runway condition or length, departure path, time of day), (e) flight safety, (f) taking off (i.e., the possibility of taking off, takeoff procedures, or checklists), (g) delaying the departure, and (h) alternative courses of action such as changing the runway or departure path. Topics in the Approach Scenario concerned (a) the destination weather, (b) fuel on board (i.e., the aircraft's fuel status, consumption, or reserves), (c) external pressures (i.e., airport curfew, Christmas Eve, full flight, accommodating passengers), (d) the operational environment (i.e., runway length, spatial and global situational references), (e) the aircraft being in hold, the size of the holding pattern, or the duration of the hold, (f) flight safety, (g) the possibility of a diversion, the location of alternate airports, and their weather, and (h) the approach and landing at destination, plus required checklists.

Pilots' think-aloud protocols were coded both in terms of *what* they talked about and *how* they processed the information. Functional codes assigned to idea units reflected categories relevant to problem solving and decision making. These included requests for additional information about a particular topic (e.g., weather), status monitoring or review, situation evaluations (positive or negative), identification of conditions and limits for actions (e.g., wind speed and direction), contingency plans, intentions, and preliminary or final decisions. Definitions and examples for the functional codes are provided in Table 1.

Reliability of codes was established by the following procedure: For each scenario 25 percent of the protocols ending with the decision to continue the flight (= risk taking), and 25 percent of those ending with the decision to adopt the safer alternative were independently coded by two raters in terms of their content. Inter-rater reliabilities on the content codes for the Takeoff Scenario and Approach Scenario were 90.55 and 90.17 percent, respectively.

Table 1. Definitions of Functional Codes and Examples from Pilots' Protocols

CATEGORY	**EXAMPLE**
INFORMATION GATHERING	
Re-reading of material	"Divert plus FAR is 8,000 pounds."
Queries	"And my radar looks like?"
STATUS MONITORING	
Observations	"still the same there." [= weather at alternate]
Non-evaluative interpretation or projection of conditions/events	"It could dissipate."
POSITIVE EVALUATION	
Optimistic interpretation or projection	"I am doing pretty good." "We've got 30 min. more fuel than we need."
NEGATIVE EVALUATION	
Pessimistic interpretation or projection	"The weather at the alternate is worse than what we are right now." "That's not enough to do 4 turns [in the holding pattern]."
CONSTRAINT	
Reference to issue that is of concern or limiting one's decision	"Want to make sure I have enough fuel." "but we have a window of about a 30 minute opportunity that we need to get in"
PLAN	
Reference to future action, contingency plans, planning for the worst case	"Once we get down to 8,000, we have to leave." "At this point we would do our procedure for delaying rotation, and so if we do have any type of shear on final, then we'll have this extra speed."
ACTION	
Statement of intention	"There are two on final, so I am gonna wait for the next one to come in."
Reference to Standard Operational Procedure	"We would do our published Missed Approach procedure."
DECISION	"So I continue downwind."

Functional coding was validated on the sample from the Approach Scenario as the functional codes were the same for both scenarios; but protocols for the Approach Scenario were generally longer ($M_{\text{idea units}}$ = 51.8, *SD* = 26.34) than those for the Takeoff Scenario ($M_{\text{idea units}}$ = 32.15, *SD* = 19.59), $F(1,53) = 54.56$, $p = .000$[2]. Inter-coder reliability for functional codes was 88.2 percent.

RESULTS

Pilots' decisions

The responses of four participants in the Takeoff Scenario, and of three participants in the Approach Scenario had to be excluded from our analyses due to technical problems or procedural errors. Table 2 displays the decision data for the remaining participants in the two scenarios. As can be seen, in the Takeoff Scenario most of the pilots (73.7%) indicated that they would depart although there was a chance of windshear, thus choosing the riskier option in terms of safety ($\chi^2(1, N = 57) = 12.79$, $p = .0003$). In contrast, no statistically significant preference for either course of action was observed in the Approach Scenario ($\chi(1, N = 58) = 1.10$, *ns*). Table 2 also shows that the majority of pilots who were risk taking in the Takeoff Scenario (76.2%) adopted precautionary steps such as full power on takeoff to reduce the effect of possible windshear (χ^2 $(1, N = 42) = 11.52$, $p = .0007$). In the Approach Scenario, strategies aimed at reducing the likelihood of fuel exhaustion were mentioned by half of the risk taking pilots (χ^2 $(1, N = 25) = .04$, *ns*); their strategies included requesting priority

[2] The data of seven participants were excluded from this analysis due to missing data.

handling on approach or asking for a closer alternate airport (to reduce fuel requirements for the current approach).

Table 2. Pilots' Decisions by Scenario and Carrier (Major versus National)

DECISION	**Pilots from Major Carrier**	**Pilots from National Carrier**	**TOTAL**
Takeoff Scenario			
- *Delay Departure*	10	5	**15**
- *Take Departure*			**42**
o w/ precaution	16	16	
o w/out precaution	2	8	
Approach Scenario			
- *Divert*	19	14	**33**
- *Continue*			**25**
o w/ precaution	8	4	
o w/out precaution	2	11	

Note. Table lists the number of pilots who selected a given course of action.

Factors influencing pilots' decisions

Pilots' age, crew position and airline affiliation

Logistic regression analyses were conducted to determine whether participants' age predicted their decisions (risk taking versus risk averse). According to the Wald criterion, no significant age effect was observed in either the Takeoff Scenario (z = .57, ns), or the Approach Scenario (z = .14, ns).

Chi-Square analyses indicated that pilots' decisions in the two scenarios did not differ by crew position or airline (Takeoff Scenario: (χ^2_{Airline} (1, N = 57) = 2.5, *ns*, and χ^2_{Position} (1, N = 57) = .64, *ns*; Approach Scenario: (χ^2_{Airline} (1, N = 58) = 1.76, *ns*, and

$\chi^2_{Position}$ (1, N = 58) = .41, *ns*). However, an airline effect was observed in pilots' use of mitigation strategies. Pilots from the major carrier who selected the riskier course of action were more likely than their colleagues from the national carrier to mention strategies they would use to control the safety risk. In the Takeoff Scenario, 89% of the risk taking pilots from the major carrier called for mitigation strategies as compared to 67% from the national carrier ($\chi^2(1, N = 42) = 2.80, p = .09$). In the Approach Scenario the respective percentages were 80% of major versus 27% of national pilots ($\chi^2(1, N = 25) = 6.84, p = .009$). Pilots from the two carriers also differed with respect to decision consistency on the two scenarios (i.e., consistently chose the safe or risky option, or were inconsistent in their decisions). While decision consistency was low for pilots from the major carrier (41%), it was considerably higher for pilots from the national carrier (63%; $\chi^2(2, N = 54) = 6.65, p = .04$), especially concerning risky decisions (19% and 51% for the major and national carrier, respectively).

Pilots' decision frames

In order to assess whether pilots' decisions were influenced by decision frames descriptive and logistic regression analyses were performed. In descriptive analyses we examined pilots' stated motivations for their final decision. According to prospect theory risk averse pilots should refer to flight safety and the safety benefits accruing from a change in plan (i.e., delay in departure in Takeoff Scenario, or diversion to alternate airport in Approach Scenario) while risk taking pilots should mention economic pressures and the economic costs (i.e., inconvenience to passengers, or future loss in revenues) associated with a change.

Table 3. Reasons and Implications Pilots Mentioned at their Final Decision

	DECISION IN TAKEOFF SCENARIO	
	Delay Departure (N=15) (= Risk Averse)	**Take Off (N=42)** (= Risk Taking)
REASONS		
Airspeed Loss	1	16
Location of Storm	1	3
• Airspeed Loss	1	11
• Cell Movement	0	1
Intensity	1	0
+ Airspeed Loss	1	2
+ Cell Location	0	1
Cell Movement	1	2
+ Airspeed Loss	0	2
+ Storm Intensity	4	0
+ Intensity + Airspeed	5	0
None	0	4
OUTCOMES		
Safety Implication of T/O		
Windshear/airspeed loss	7	13
Anticipates no problem	0	2
+ **Econ. Implication of Delay**	5	2
None	3	25

	DECISION IN APPROACH SCENARIO	
	Divert (N=33) (= Risk Averse)	**Continue Approach (N=25)** (=Risk Taking)
REASONS		
Fuel	20	9
Destination Weather	7	2
+ Fuel	2	6
Curfew	3	1
+ Fuel	1	7
OUTCOMES		
Safety Impl. if Continue		
Use reserve fuel	5	1
Might not be able to land	4	2
Might crash	1	0
Safety Impl. if Divert		
Uncertain weather	0	1
Economic Impl. if Divert		
Christmas Eve elsewhere	0	2
None	23	19

Note. Table lists number of pilots mentioning a given reason or implication.

Table 3 lists the issues pilots mentioned just prior to their final decision in the Takeoff Scenario. As can be seen, both risk averse and risk taking pilots referred to safety-related issues, albeit with different emphases. Most (67%) of the pilots who decided to delay the departure (= risk averse) focused on the movement of the thunderstorm ("coming closer," "fast moving") as well as on the intensity of the winds ("gusty") and the fact that loss of airspeed had been reported. In contrast, the majority (71.4%) of pilots who decided to take off (= risk taking) pointed to the fact that the thunderstorms were behind them, their departure path was clear, and the reported loss in airspeed was within limits and decreasing. Still, just as their risk averse colleagues, most risk taking pilots did anticipate that they could encounter windshear on takeoff. They explicitly mentioned this possibility and/or—as shown in Table 2—prepared for it. However, unlike their more cautious colleagues, risk taking pilots apparently thought that they would be able to control this safety threat. All but two of the pilots who chose to take off stated that they would use procedures specifically designed to mitigate the effect of windshear, such as delayed rotation, and increased takeoff speed.

Table 3 also summarizes pilots' final thoughts in the Approach Scenario. As can be seen, safety-related issues again dominated pilots' decision making. Most (78.9%) of the pilots who decided to divert (= risk averse) stated that they were "getting low on fuel" and/or that weather conditions at the destination airport were "pretty bad" and "unlikely to improve." Similarly, 72% of the pilots who decided to continue with the approach (= risk taking) focused on their fuel status and/or the destination weather; in addition, 24% of them considered the time constraint imposed by the curfew. As did their more cautious colleagues, most risk taking pilots indicated that "fuel [was] tight;" only three of them believed they had "enough fuel." However, risk taking pilots presented a different view of the destination weather than risk averse pilots insofar as they emphasized that conditions were above the minimum requirement for the approach. Implications associated with the decision alternatives –i.e., continuation of the approach or diversion to an alternate airport—were explicitly mentioned by about a third of the risk averse and a quarter of the risk taking pilots. Risk averse pilots predicted two negative consequences if they continued the approach: deliberate use of reserve fuel thus violating a government regulation, or the possibility of having to conduct another missed approach due to the poor weather conditions, thereby depleting their fuel resources. Similar concerns apparently motivated the behavior of risk taking pilots who mentioned strategies that would reduce fuel consumption on approach or reduce the required divert fuel. Two of these pilots explicitly stated the rationale for these strategies. Drawbacks of a diversion were addressed by three (= 12%) of the risk taking pilots; however, none concerned economic losses: one pilot worried that the alternate airport was not a good option because a weather front was forecast to move in, and two pilots mentioned that they would not be able to get to their destination that same day if they diverted, and they "just would have to celebrate Christmas Eve somewhere else."

In addition to these descriptive analyses, logistic regression analyses were conducted to examine whether different issues dominated pilots' thinking throughout a scenario and were associated with different decisions. According to prospect theory we hypothesized that the more frequently pilots mentioned safety-related issues during their decision making, the more likely they would be to adopt a change in plan as their final decision. Conversely, if economic considerations dominated pilots' thinking they should be more likely to stay with their current flight plan.

Table 4. Logistic Regression Results of Pilots' Decisions as a Function of Topics Addressed

TAKEOFF SCENARIO						
	-2Log Likelihood	*% correct predicted*	*Coefficient*	*Wald Statistic*	*Signif.*	*R*
1st Step	32.75	87.72				
DelayDep			-1.04	13.27	.0003	-.41
Constant			3.16	18.57	.0000	
APPROACH SCENARIO						
	-2Log Likelihood	*% correct predicted*	*Coefficient*	*Wald Statistic*	*Signif.*	*R*
1st Step	63.12	74.14				
Approach-Related			.26	9.69	.002	.31
Constant			-2.81	10.92	.001	
2nd Step	51.01	74.14				
Approach-Related			.56	11.55	.0007	.35
SafetyIssue			-.17	7.35	.007	-.26
Constant			-2.33	5.77	.02	

Logistic regression analyses included as predictors the categorical variable 'Airline' plus the frequencies with which pilots talked about scenario-specific topics during their decision making. In the Takeoff Scenario these included references to 'External Pressures,' the 'Operational Environment,' and to a 'Delay in Departure.' References to safety-related topics (i.e., reported or anticipated airspeed loss, the departure weather, and flight safety) were combined into one predictor variable, called 'Safety Issues.' References to the takeoff or to specific aspects of the departure (e.g., departure briefing and change of runway or departure path) were merged into the predictor variable 'Takeoff-related Issues.' The analysis of the Approach Scenario proceeded similarly. All references to safety-related topics (i.e., fuel status, consumption and reserves, destination weather, or flight safety in general) were aggregated into the predictor variable 'Safety Issues;' references to the aircraft's hold were combined with references to the operational environment into a predictor variable of the same name. The predictors 'External Pressures,' 'Diversion-related Issues,' and ' Approach-related Issues' reflect the frequencies with which pilots referred to the corresponding topics.

Results of these analyses are summarized in Table 4 and indicate that inconsistent with prospect theory, risk averse and risk tolerant decisions were not significantly related to the frequency with which pilots mentioned safety-related issues or external pressures. Instead, their decisions in both scenarios were primarily determined by the extent to which they discussed available options. In the Takeoff Scenario pilots' final decision was predicted by the number of times they contemplated the possibility of taking a delay. As shown in Table 5, pilots who ultimately decided to do so, were more likely to mention this option while responding to events than those who chose to take off.

Similarly, pilots' decisions in the Approach Scenario reflected differences in how often pilots considered the possibility of landing at their destination and referred to matters related to the approach, such as the approach and landing checklist. As can be seen in Table 5, pilots who chose to continue with the approach addressed these issues more frequently than pilots who decided to divert. In addition to approach-related issues, safety-related talk was identified as a second predictor of pilots' decisions; however, only after the effect of the approach-related talk was partialed out. The inclusion of this predictor did not improve the predictive value of the simpler model suggesting only minor differences between pilots in their concern for fuel status and destination weather; moreover, in the opposite direction than predicted by prospect theory.

Table 5. Mean References to Scenario-Specific Topics by Risk Averse and Risk Taking Pilots during their Decision Making

	DECISION IN TAKEOFF SCENARIO	
	Delay Departure (=Risk Averse)	**Take Off** (= Risk Taking)
Safety Issues	22.13 *(2.64)*	16.57 *(1.73)*
External Pressures	2.00 *(0.59)*	1.05 *(0.25)*
Delay in Departure	1.87 *(0.45)*	0.45 *(0.12)*
Takeoff-Related Issues	6.67 *(1.37)*	6.10 *(0.71)*
Operational Environment	2.80 *(0.64)*	2.74 *(0.50)*
	DECISION IN THE APPROACH SCENARIO	
	Divert (= Risk Averse)	**Continue Approach** (= Risk Taking)
Safety Issues	21.55 *(1.94)*	22.60 *(2.62)*
External Pressures	3.36 *(0.66)*	5.72 *(0.94)*
Diversion-Related Issues	6.27 *(1.05)*	7.12 *(1.08)*
Approach-Related Issues	5.79 *(0.58)*	10.36 *(1.41)*
Operational Environment	8.73 *(0.92)*	10.28 *(1.34)*

Note. Numbers refer to mean numbers of idea units in protocols of risk averse and risk taking pilots that refer to a given topic. Italicized numbers in parentheses provide standard deviations.

Pilots' risk assessment.

In two logistic regression analyses we examined whether pilots' decisions were determined by their risk assessment. In particular we hypothesized that the more optimism (or the less pessimism) pilots expressed during their decision making, the more likely they were to choose the risky option. Conversely, few optimistic (or frequent pessimistic) assessments should be predictive of risk averse preferences.

Logistic regression analyses included the categorical variable ‘Airline’ in addition to the frequencies of decision-relevant cognitions in pilots’ protocols (see Table 1). The results of these analyses are summarized in Table 6, and indicate that in both scenarios, pilots’ evaluations were the strongest predictor of their final decisions. In the Takeoff Scenario their decisions were significantly related to the number of negative evaluations pilots provided during their decision making.

Table 6. Logistic Regression Results of Pilots’ Decisions as a Function of Decision-Relevant Cognitions

TAKEOFF SCENARIO						
	-2Log Likelihood	*% correct predicted*	*Coefficient*	*Wald Statistic*	*Signif.*	*R*
1st Step	44.84	84.21				
NegativeEval			-.44	10.82	.001	-.37
Constant			2.83	17.82	.0000	
APPROACH SCENARIO						
	-2Log Likelihood	*% correct predicted*	*Coefficient*	*Wald Statistic*	*Signif.*	*R*
1st Step	63.73	68.97				
PositiveEval			.31	9.17	.003	.30
Constant			-1.79	10.65	.001	
2nd Step	53.39	81.03				
PositiveEval			.49	10.18	.001	.32
NegativeEval			-.36	7.47	.006	-.26
Constant			-.97	2.29	.13	

As shown in Table 7, pilots who decided to delay the departure –thus favoring the safer course of action—had more negative things to say about the weather conditions and the reported airspeed loss than pilots who took the riskier option and continued with the departure. Similar results were obtained in the analysis of pilots’ protocols for the Approach Scenario. In this scenario, the number of positive evaluations during pilots’ decision making was the strongest predictor, followed by the number of negative evaluations. That is, pilots who ultimately decided to continue with the approach—thus favoring the riskier option—were likely to be both more optimistic and less pessimistic about the situation than pilots who preferred the safer option and decided to divert.

Table 7. Mean Number of Decision-Relevant Cognitions by Risk Averse and Risk Taking Pilots during their Decision Making in the Takeoff Scenario and the Approach Scenario

	DECISION IN TAKEOFF SCENARIO	
	Delay Departure (=Risk Averse)	**Take Off** (= Risk Taking)
Information Gathering	6.93 *(1.16)*	5.74 *(0.63)*
Status Monitoring	7.60 *(1.15)*	7.07 *(1.21)*
Positive Evaluation	2.67 *(0.41)*	4.52 *(0.65)*
Negative Evaluation	7.60 *(1.43)*	2.12 *(0.33)*
Constraint	6.80 *(1.41)*	3.17 *(0.43)*
Plan	3.00 *(0.64)*	3.19 *(0.42)*
Action	1.60 *(031)*	1.12 *(0.25)*
	DECISION IN THE APPROACH SCENARIO	
	Divert (= Risk Averse)	**Continue Approach** (= Risk Taking)
Information Gathering	11.45 *(1.42)*	12.52 *(1.67)*
Status Monitoring	12.06 *(1.36)*	12.24 *(2.10)*
Positive Evaluation	3.30 *(0.47)*	8.32 *(1.49)*
Negative Evaluation	5.27 *(0.63)*	3.44 *(0.54)*
Constraint	8.36 *(0.96)*	11.24 *(1.35)*
Plan	2.39 *(0.32)*	3.44 *(0.44)*
Action	1.97 *(0.32)*	3.16 *(0.67)*

Note. Numbers refer to mean number of idea units in protocols of risk averse and risk taking pilots that serve a given cognitive function. Italicized numbers in parentheses provide standard deviations.

DISCUSSION

The results of the present study suggest that inappropriately optimistic risk assessment rather than a decision frame that highlights economic losses may be a dominant factor in pilots' plan continuation errors. Pilots in the dynamic decision task were risk taking or risk averse depending on their evaluation of the situation. If their decisions had been the result of distinct decision frames, risk averse pilots should have focused on safety-related issues and emphasized the safety benefits of changing their flight plan while economic considerations and a concern for avoiding economic losses should have dominated the thinking of risk taking pilots.

Instead we observed that flight safety featured prominently in pilots' decision making, while economic pressures apparently did not influence their decisions. In both scenarios most pilots were aware of the safety risk and took steps to counter it. In addition to eliminating it altogether (e.g., by diverting to an alternate airport), they also "invented" solutions that went beyond the binary choice of "take it or leave it" typically presented to participants in framing studies. These novel solutions reflect pilots' attempts to take control of a risk and underscore the important role that risk management plays in real world decision making (Huber, 1997; Slovic, 1987).

Which risk management strategy pilots ultimately chose in each scenario reflected differences in their assessment of the safety risk. If pilots judged the safety threat to be "close to or beyond their comfort zone," they adopted a plan that would assure safety but might incur economic or productivity losses. On the other hand, if they judged the safety risk to be less serious, they modified their current plan to mitigate threats to flight safety while satisfying their company's economic and productivity goals. For example, they took precautions such as increasing takeoff speed to neutralize the effect of possible windshear, or they sought control over other factors in the situation, such as requesting priority handling to ensure that they would not become fuel critical. In both situations, pilots' normative model was to "go" (or continue) unless something occurred that surpassed a subjective threshold of safety. This kind of thinking is most vividly illustrated in statements such as, "Nothing has come up that would make me decide not to make the departure."

Differences between pilots' assessments of the safety risk were not significantly related to their experience levels or roles on the flight deck, as decisions did not vary by pilot age or crew position. Nor did we find evidence that individual differences in risk attitude influenced pilots' risk assessments, as pilots showed little consistency across scenarios in their preference for risky or risk averse options. Instead, differences in risk assessment apparently reflected the inherent ambiguity of the problem cues and the uncertainties concerning outcomes. Risk taking and risk averse pilots in both scenarios showed remarkably different interpretations of the "same" information. In the Approach Scenario pilots who decided to continue with the approach expressed more optimism about the conditions, the likelihood of landing at their original destination, and making the curfew than pilots who decided to divert. Similarly, those who decided to depart in the Takeoff Scenario evaluated the weather and airspeed loss more positively than did those who delayed the departure. "Risk-takers" in this scenario emphasized the fact that the weather was behind them, still 8 miles away, and that the departure path was clear. In addition, they focused on the quantity of airspeed loss, which they considered to be within limits, and interpreted the reported decrease in airspeed loss as an indication that weather conditions were improving. In contrast, pilots who delayed the takeoff were primarily concerned about the airspeed loss per se and took the variability in reported airspeed loss to indicate unstable winds. In line with this interpretation, they stressed the fact that the weather was getting closer. Since they assumed that they could not outrun the storm and that the winds were becoming unpredictable, they decided not to risk a takeoff but instead to wait for the weather to pass.

While our analyses did not reveal any differences between pilots from the two carriers in their decision processes, we did observe some differences in their decisions. Pilots from the major carrier seem to be more responsive to the specifics of a situation as their decisions varied across the scenarios. In contrast, pilots from the national carrier were more likely to select the same option across the two scenarios, usually the riskier one. In addition, they were less likely than their colleagues from the major carrier to mitigate the safety risk associated with their decision. This pattern of findings may reflect differences between the two carriers in corporate climate, nature of their typical operations, pilot selection procedures, or training.

CONCLUSIONS

To prepare their pilots for flight risks, air carriers have emphasized training activities that were directed at specific threats, such as windshear and unusual-attitude recovery. Recently carriers have developed courses to assist their pilots in coping with the kinds of ambiguous and uncertain situations that have been associated with plan continuation errors (cf., Barcheski, 2001; Gunther, 2001). These programs are grounded in documentation of actual threat encounters, including crew errors, and corrective pilot behavior. However, one aspect that has not received sufficient attention is the impact of ambiguous flight conditions on pilots' risk perception and assessment, and ultimately on their risk management strategies.

Our research indicates considerable variability in pilots' assessments of risks, which in turn determined the extent to which pilots were willing to take or avoid a risk. Differences in risk assessment, moreover, were associated with the presence of ambiguous cues, dynamically changing conditions, and uncertain threat and action outcomes. While these environmental characteristics invite multiple interpretations, pilots, like operators in other high-risk environments, may not realize that the same cues could lead to very different decisions and courses of actions. Consequently, as one safeguard against plan continuation errors, risk management training should encourage pilots to verify their initial risk assessment and look for alternative interpretations, especially if their first inclination was to continue as originally planned.

A second safeguard against plan continuation errors involves a change in pilots' goal frame from a "Go-mode" to a "No-Go-mode." Our research suggests that pilots examine cues in the environment with their minds set on continuing with their current plan unless a perceived threat surpassed their subjective threshold of safety. This strategy provides some protection against plan continuation errors as pilots seek to disconfirm rather than simply to confirm their original plan. Nonetheless it may be too weak a barrier, especially in ambiguous and dynamically changing conditions since disconfirming cues may lack the strength or salience to induce a change in plan. In general, people tend to hold on to their opinions and plans, and are likely to resist changes even if there is evidence to do so (cf., Davies, 1997; Jelalian & Miller, 1984). To guard against plan continuation errors in these situations, pilots may need to change their mindset. That is, instead of asking themselves, "Why shouldn't I continue?" which presupposes an inclination to "go," it may be safer if they asked: "Why should I continue?" which presupposes a willingness "not to go." By changing their mindset to a no-go mode, pilots will raise their criterion for a "go" decision: it will be more difficult to conclude that it is safe to go, if they looked at ambiguous cues with their mind set on "not-going," than if they were inclined to "go" (see also Vaughn's 1996 analysis of the Challenger accident as an illustration of this argument).

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