

Emergency Descent Plans, Procedures, and Context

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Abstract

When an emergency descent to land is required, planning this descent can be challenging; decisions must be made quickly but may dramatically alter the options available later. This study examines portraying emergency descent plans to pilots as procedures in which important elements of context are highlighted. Under time pressure, pilots evaluated plans which were presented with a variety of contextual elements, were accurate and inaccurate, and included situations where aircraft damage did and did not alter flight characteristics. Pilots were little better than chance in evaluating a plan's accuracy. However, procedure context information did improve their reasoning about the plan.

Introduction

When a situation suddenly demands an emergency descent to land, planning this descent can be challenging for several reasons. The most apparent stems from the multitude of competing demands on the pilot, including dealing with the source of the emergency itself and flying an aircraft whose failures or damage may alter its performance and flight characteristics.

An additional challenge arises from the inherent difficulty of generating a detailed plan addressing multiple (often conflicting) goals, such as minimizing time to land while also limiting maneuvering if the aircraft is damaged. Using the physics-based dynamic models common to engineering, a flight plan represents a continuously-evolving trajectory in which one maneuver can determine many aspects of subsequent maneuvers. For example, vertical descent rate can determine forward velocity, time to reach a safe altitude for approach, and, therefore, the corresponding lateral distance covered in the descent; this, in turn, then helps dictate the lateral path to follow. The more detail that a plan requires, and the more that a plan seeks to maximize a set of goals (such as the minimum time and limited maneuvering described before), the more all aspects of a plan become inter-dependent, thereby preventing its decomposition into a simpler representation.

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With the possible exception of sailplane flying, piloting does not normally conceptualize flight plans as these continuously-evolving trajectories. In this paper, we propose representing emergency descent plans as procedures, i.e., a set of trajectory-defining actions such as initiating turns, descents, and new target speeds, etc. Beyond a generally noted prevalence of procedures in aviation in general and in air transport in particular (Degani and Wiener 1997), the use of procedures in defining plans has been noted in situations such as specifying airport traffic patterns and creating efficient descent profiles through the waypoints and speed and altitude constraints noted on Standard Terminal Arrival Route (STAR) charts (Pritchett and Yankosky 1998).

Recent studies have suggested that pilots do not generate detailed flight plans of their own accord in emergency situations; even when explicitly given intervals to create an emergency descent plan, pilots either did not create a plan at all but asked to move straight to the 'flying stage', or created only very basic, sparse plans (Chen and Pritchett 2001; Pritchett, Nix and Ockerman 2001). Unfortunately, this lack of detailed planning was found to be problematic: in one of these studies, pilots either crashed or executed a time-expensive and risky missed approach in 6 of 72 simulator runs. These studies therefore suggested that automated planning aids may help pilots create more detailed and more accurate emergency descent plans.

Interaction between pilots and such automated planning aids may be mediated by representing plans as procedures. Historic methods of detailed trajectory planning created a continuously evolving path for the pilot to follow on blind faith either by following a flight director or by engaging an autoflight system (e.g., Corban, Calise and Flandro 1991). Portraying the plan as a procedure may enable greater comprehension by the pilot and corresponding interaction with a planning aid. However, improved comprehension does not negate the potential for both over-reliance on the aid and automation bias. Over-reliance may occur should the pilot choose to follow faulty output of the aid; automation bias may occur when the output of the aid acts as a heuristic replacement for the pilot's own reasoning, biasing his or her judgment of the situation. Both problems have been noted with automation

in general (e.g., Parasuraman and Riley 1997; Mosier and Skitka 1999) and with pre-flight planning in particular (Layton, Smith and McCoy 1994; Smith, McCoy and Layton 1997; Chen and Pritchett 2001).

In conceptualizing plans as procedures, therefore, it is also important to examine situating them in context; in this study, we examined the explicit presentation of *procedure context*. Procedure context is defined as information providing the interrelated conditions in which procedure steps exist or occur, i.e., information that clarifies the meaning, purpose, conditions, and relationships of the steps to the procedure, task, and environment. Specific elements of procedure context have been identified through a review of literature and procedures, and preliminary studies have demonstrated benefits of their presentation (Ockerman and Pritchett 2000; Ockerman and Pritchett submitted).

The procedure context elements used in this study are considered explanatory, which means they supply meaning, purpose, relationships, or conditions. Explanatory procedure context elements are needed in designing a procedure, but are often not communicated in the presentation of a procedure. For example, it has been noted that sometimes a significant amount of time transpires before a worker might realize why the procedure is designed as it is (Hutchins 1995) and even then there is no guarantee that he or she has figured it out correctly. Conversely, the explicit presentation of explanatory procedure context has been shown to increase the rate at which each step is read, aids in recalling the steps of the procedure at a later time, and improves performance when performing the task without the procedure (Smith and Goodman 1984). The elements used in this study are:

Rationale The rationale element provides the reason why a step is included in the procedure. In one study, inspection of a commercial pilot's own copy of procedures found that 38% of the annotations made by the pilot could be classified as notes on "why a procedure is the way it is" (Wright, Pocock and Fields 1998). Knowledge of a step's rationale can aid the user in understanding when this particular step is appropriate for the current situation and improve his or her knowledge about the procedure.

Triggering Conditions The triggering conditions element identifies the external events that signal the starting or stopping of a procedural action. For example, crossing a fix may trigger a change in speed and descent rate. Making procedure followers aware of triggering conditions can help them to determine not only when a step should be done but also provide insight into the relationship between the environment and the task.

Ordinality The ordinality element defines any order requirements; i.e., whether an action must be done before or after other actions. For example, an aircraft must first slow below a certain speed before deploying the flaps; otherwise the aircraft structure could be damaged. Ordinality differs from triggering conditions in that it only concerns the order of the procedure steps, not their relation to external events.

Method

Participants and Apparatus

The participants of this investigation are current airline pilots. A total of 32 pilots participated in this study, with 28 of them choosing to provide demographic data. Those pilots have an average of 11,500 flight hours with just over 4000 hours in glass cockpits. Twenty-two of the participants are captains, and five are first officers.

The eight emergency descent scenarios they evaluated were presented on paper and consisted of 6 items: (1) a description of the emergency that has occurred along with a display of the current primary flight display and navigation display, (2) an enroute map for the new airport, (3) an approach plate for the new airport, (4) a STAR chart for the new airport, (5) horizontal and vertical map displays of the suggested descent path, and (6) a text procedure for the suggested descent.

Procedure

The pilots were told that they were captains of a glass cockpit air transport jet and that an emergency required landing at a different airport than originally planned. The scenarios' emergencies may or may not affect the performance of the plane; none involved terrain or traffic conflicts. Each scenario consisted of a written description of the emergency and the current situation.

To emulate a time-critical situation in which the pilot is presented with a plan generated by an automatic aid (or, conceivably, another crew member), the pilots were given 3 minutes to evaluate each emergency descent procedure and record their assessment. The pilots categorized each flight procedure as one they would be comfortable flying or one they would not be comfortable flying, and explained why or why not. They also provided their confidence in their response as a percentage.

Design

This experiment used a 2⁴ factorial design. The first factor was the condition of the aircraft (performance altered [PA] or not [NPA]), the second was the accuracy of the procedure, the third was the structure used in the presentation of the procedure, and the fourth was the presence of rationale (i.e., explanations).

Performance of the aircraft in each scenario was either altered in some way (PA) (e.g., lost engine or loose aileron) or was not (NPA) (e.g., sick passenger). Determining the future flight trajectory of a performance-altered aircraft is more difficult due to its unpredictable nature and pilot inexperience with this aircraft behavior.

Half of the procedures given to the pilots were inaccurate. Either the graphic map display accompanying the procedure showed a much tighter turn radius than feasible for the aircraft's speed and configuration at that point, or the graphic vertical profile was erroneous, i.e., it did not reflect that, at the given descent rate the aircraft would arrive at glide slope intercept at least 1000 feet too

high. In both cases the text accurately listed the erroneous actions creating the infeasible procedure.

The two structure variants and two presence of rationale variants resulted in four distinct display formats. The structure was either sequential or concurrent. The sequential structure listed all the actions that were required to complete the descent in a single column and noted when to do each action by attaching a 'fix' to the action that was also presented on the graphical display (see Figure 1). The concurrent structure listed the actions in a matrix where the columns related to horizontal motion, vertical motion, speed, or configuration, with all concurrent actions listed in the same row (see Figure 2). Again each row was notated with a fix and/or event to indicate when they should be done. The rationales, when provided, explained why an action should be done in general and/or done at a particular time (see Figure 1). Thus, the four formats are sequential, sequential with rationales, concurrent, and concurrent with rationales. These display formats correlate with the three procedure context elements discussed earlier. The presence of rationale maps directly to the

rationale procedure context element. The trigger condition and ordinality elements are mapped to the plan structure. The trigger conditions for the sequential structure are listed as fixes while the trigger conditions for the concurrent structure are fixes and speed events. For example, at the point where the aircraft will have slowed to a safe extension of flaps 1, the trigger condition is fix FLP1 and the speed event 238knt (V_{FI}). The ordinality element in the sequential structure is a simple linear order that arbitrarily orders actions at the same fix that could be done in any order. For the concurrent structure the ordinality element is more clearly shown, with the matrix format illustrating that actions attached to the same fix should be done at roughly the same time but that the exact order is not important.

We used 8 different scenario orders; four pilots did each order of scenarios (see Table 1). We blocked on the factor rationale to mitigate learning effects, so the pilots either saw a combination of scenarios 1-4 and then scenarios 5-8 or they saw scenarios 5-8 and then scenarios 1-4.

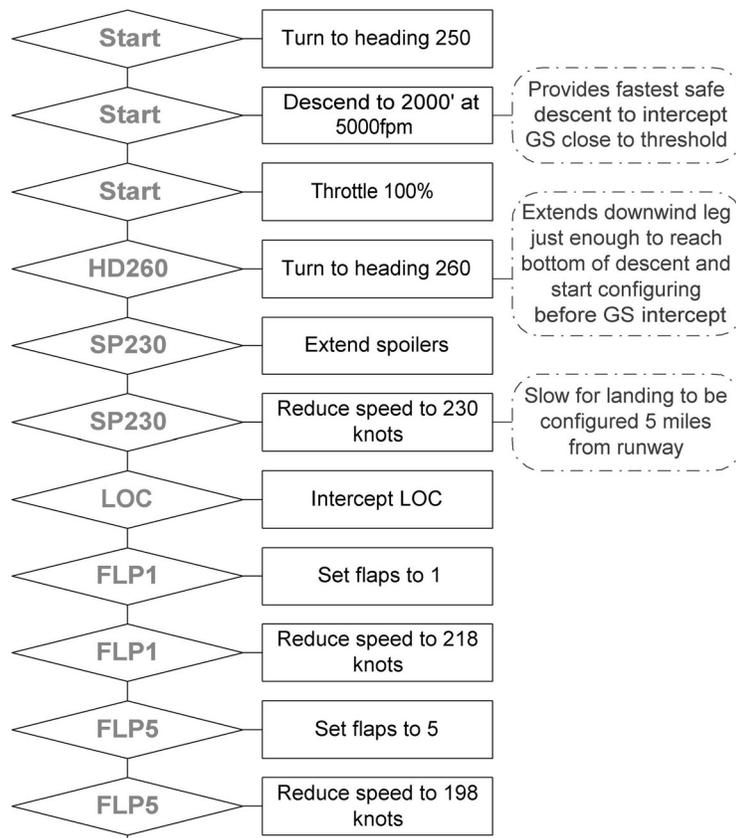


Figure 1: Portion of Sequential Structure with Rationale

Measurements

Measurements consisted of the pilots' responses to the procedures and a follow-up questionnaire. The pilots' responses included their assessments (i.e., would or would not follow the procedure), the confidence they assigned to their assessment, the correctness of their assessment (i.e., whether their assessment matched the flight procedures' accuracy), and the correctness of the pilots' reasoning about the procedure as recorded in written comments. A final questionnaire solicited pilots' opinions about the different presentations of the plans.

Table 1: Scenario Descriptions

	Condition	Accuracy	Structure	Rationale
1	PA	Accurate	Sequential	None
2	PA	Inaccurate	Concurrent	None
3	NPA	Inaccurate	Sequential	None
4	NPA	Accurate	Concurrent	None
5	NPA	Inaccurate	Concurrent	Present
6	NPA	Accurate	Sequential	Present
7	PA	Accurate	Concurrent	Present
8	PA	Inaccurate	Sequential	Present

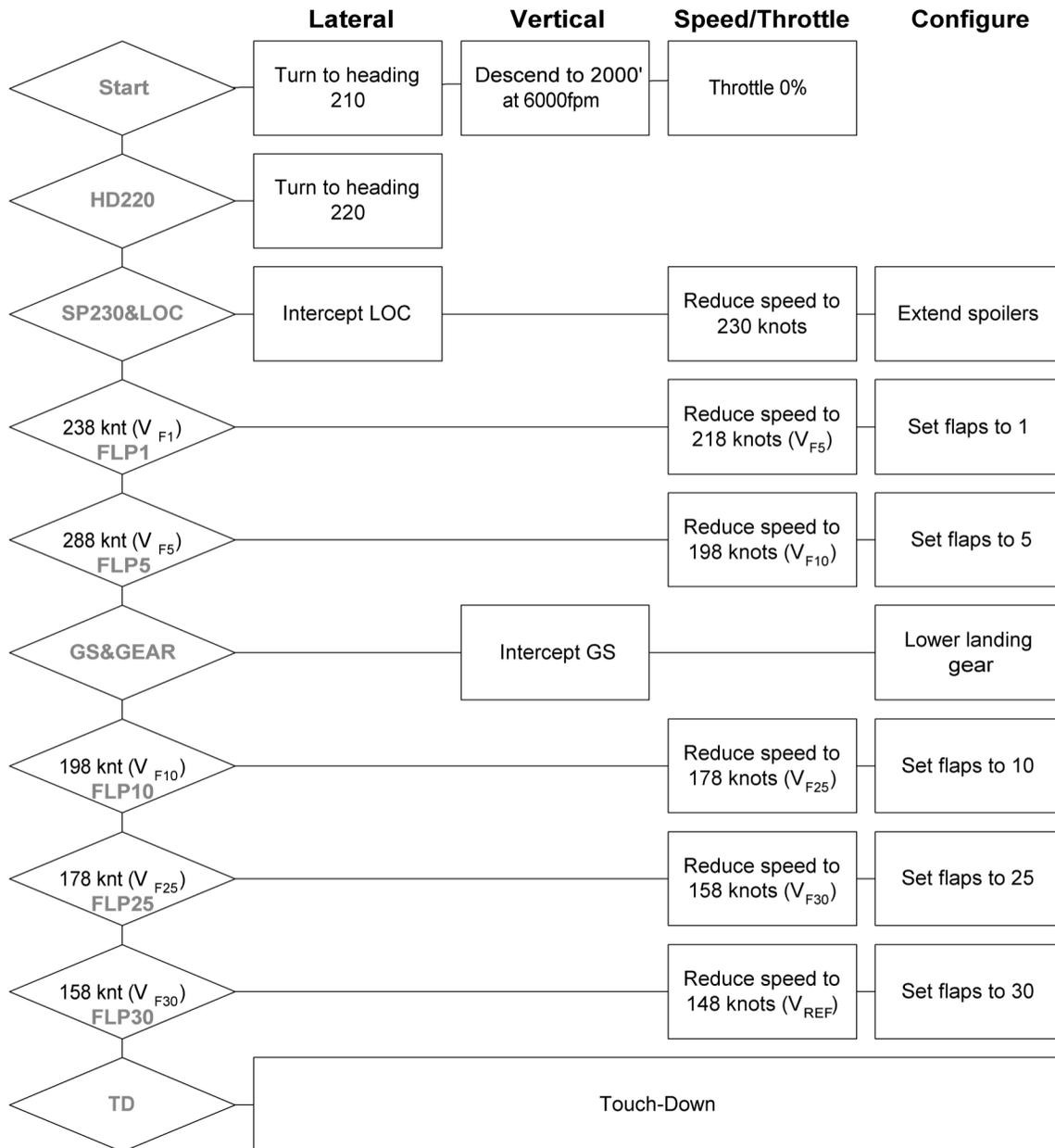


Figure 2: Concurrent Structure without Rationale

Results

There were 256 data points for each of the response variables: pilot assessment, pilot confidence, correctness of pilot assessments, and correctness of pilot reasoning. In addition to the four experimental factors, the pilot group, which represents the order in which the pilots saw the different scenarios, was also examined for main effects, but was found to not have an effect.

An initial multivariate analysis of variance (MANOVA) indicated that the experimental factors aircraft condition and rationale were significant main effects with $F=4.66$, $p<0.01$ and $F=3.01$, $p=0.02$ respectively.

Pilot Assessments

For the correctness of the pilots' assessments when compared to the accuracy of the presented procedures, none of the four experimental factors had a statistically significant effect. In fact, on the whole the pilots did little better than chance (52%) on correctly judging the accuracy of the presented procedures.

An analysis of variance (ANOVA) general linear model (GLM) (type III adjusted sum of squares) was used as the analysis method. The GLM for pilot assessments versus the experimental factors: performance of the aircraft (PA or NPA), procedure accuracy (accurate or inaccurate), procedure structure (sequential or concurrent), and the presence of rationale showed that only the aircraft condition, PA or NPA, is a statistically significant factor ($F=17.00$, $p<0.01$). Examination of the data shows that pilots were more likely to respond 'No' (not comfortable following) in performance-altered conditions and 'Yes' (comfortable) in non-performance-altered conditions.

Pilot Confidence Level in Assessment

The GLM for pilot confidence level versus the experimental design factors also had a significant factor – performance of the aircraft once again ($F=4.15$, $p<0.05$). Examination of the data showed that the pilots had a higher level of confidence with non-performance altering conditions. This is not surprising but does show that the pilots did account for the aircraft performance when making their assessment.

Correctness of Pilot Reasoning

Finally, the correctness of the pilots' reasoning for accepting or not accepting a procedure was analyzed by categorizing pilots' reasoning and then comparing these categorizations with those provided independently by a subject matter expert (an instrument-rated pilot with over 10 years experience in flight deck research and design). Looking at the four experimental factors versus correctness in pilot reasoning showed that two of the factors were statistically significant: accuracy of the presented procedure ($F=3.87$, $p=0.05$) and rationale

($F=10.10$, $p<0.01$). Examination of the data showed that the pilots had more accurate reasoning for accurate scenarios. This is not surprising since they basically only had to agree that it was done correctly. In addition, further analysis showed that procedures displaying rationale resulted in more correct reasoning by the pilots.

Questionnaire Results

The questionnaire measures came from the opinions of the pilots on the four different formats. Of the four different formats, 45% of the pilots volunteering an opinion preferred the concurrent with rationale format. Overall, 67% of the pilots volunteering an opinion preferred the concurrent format over the sequential format, and 91% of the pilots volunteering an opinion preferred having rationales over not having rationales.

Discussion

There were large individual differences between the pilots in their acceptance of the flight procedures and their reasoning for that acceptance. In addition, overall the pilots were not any better than chance at distinguishing feasible procedures from infeasible procedures. This is not surprising since this is a task that they have rarely, if ever, performed and does not have any standardized training. Pilots do practice emergency situations in simulator training but these often focus on the initial procedural response to the emergency as opposed to generating a new emergency descent plan on the fly.

However, there are several interesting aspects of the results of this study. Not only were the pilots more likely to accept a procedure in the NPA condition, they also had more confidence in that acceptance. This may be due to a higher level of comfort with a "normal" aircraft that should perform as expected. However, this comfort may be misapplied, as they often indicated high confidence in decisions to follow inaccurate NPA flight procedures.

When the four experimental factors were examined in relation to correctness of pilot reasoning, procedure accuracy and the presence of rationale were significant. Having the correct reasoning for an accurate procedure was not overly difficult since basically the pilot had to just accept the procedure as correct without listing caveats. More interestingly, the procedures with rationales lead to a more correct reasoning by the pilot for acceptance or non-acceptance of a procedure. The pilots also reported that they liked being provided with the rationale of a procedure.

There is no support for the structure impacting the pilots' responses or correctness in the objective results, but a majority of the pilots did believe the concurrent structure was more effective than the sequential structure.

Conclusions

This study suggests several results – and highlights several questions worthy of further research. The fact that pilots were found to be little better than chance in judging the accuracy of an emergency descent plan is consonant with the previous studies noted earlier, and suggests further study is warranted of several aspects of flight planning, including both how pilots currently conceptualize this task, and how their performance may be improved through training and automatic planning aids. Simulator studies would be useful in refining further investigations.

Although the presentations of procedure context tested here were not found to improve pilots' performance in assessing the accuracy of emergency descent plans, it was found to improve their reasoning about the plans in terms of important attributes and potential flaws. This study examined only three elements of procedure context (rationale, ordinality and triggering criteria). Other elements of procedure context – and other methods of portraying it relative to a procedure – may be even more successful in aiding pilot assessments of, and reasoning about, procedures representing emergency flight plans.

In this study, plans were presented to pilots in a form emulating the output of an automated aid. Pilots' poor performance in assessing the accuracy of the plans also suggests a potential for over-reliance and automation bias should the automated aid be 'wrong'. One major weakness of automated aids is their 'brittleness' to contexts outside their design boundary conditions. Representing the relationship of a plan to the aid's boundary conditions may be another fruitful application of procedure context beyond that studied here.

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