International Journal of Applied Aviation Studies, **2006, Vol 6(2), p315-333**

The evaluation of the decision making processes employed by cadet pilots following a short aeronautical decision-making training program

Running Head: Evaluation of decision making processes

Manuscript metrics

Words count for Abstract: 225

Words count for Narrative: 5,738

Number of References: 42

Number of Tables: 7

INSERT FOOTNOTE 1 HERE

The evaluation of the decision making processes employed by cadet pilots following a short aeronautical decision-making training program

ABSTRACT

Many aeronautical decision-making (ADM) mnemonic-based methods exist. However, there is no empirical research that suggests that they are actually effective in improving decision-making. Klein (1993), in his study of naturalistic decision making suggested that the decision-making process centers around two processes; situation assessment to generate a plausible course of action and mental simulation to evaluate that course of action for risk management. In this study a short, ADM training course was constructed around two mnemonic methods, SHOR (Stimuli, Hypotheses, Options, and Response) and DESIDE (Detect, Estimate, Set safety objectives, Identify, Do, Evaluate). Forty-one pilots from the Republic of China Tactical Training Wing participated: half received a short ADM training course and half did not. After training, the procedural knowledge underpinning their Situation Assessment and Risk Management ability, two skills essential for successful decision-making, were evaluated using pencil and paper-based knowledge tests based upon several demanding tactical flight situations. These scenarios were designed to encompass the six basic types of decision making described by Orasanu (1993); go/no go decisions; recognition-primed decisions; response selection decisions; resource management decisions; non-diagnostic procedural decisions, and decisions requiring creative problem-solving. The results show gains attributable to the decision making training course in both situation assessment and risk management skills. The results strongly suggest that ADM is trainable and such a training course is effective in improving the bases of in-flight decision-making.

INTRODUCTION

Aeronautical decision-making (ADM) is defined by the FAA (1991) as 'a systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances' (Hunter, 2003). Jensen (1995) defined pilot judgment as 'the mental process that pilots use in making decisions'. Both definitions implicitly include both process and outcome. For military pilots operating in a hostile environment, the normal hazards of aviation are compounded by the enemy's intent for the destruction of the aircraft. Fischer, Orasanu, & Wich (1995) suggested that risk and time pressure are situational variables that further constrain the decision process, as risk and time pressure may call for an immediate response whether or not the problem was fully understood. Minimal risk levels and fewer time constraints, in contrast, permit additional diagnostic actions or the deliberation of options.

Klein (1993), in his study of naturalistic decision making suggested that the decision-making process centers around two processes; situation assessment, which is used as a precursor to generate a plausible course of action and mental simulation to evaluate that course of action for risk management. If a pilot recognizes there is sufficient time for making wide-ranging considerations, s/he will evaluate the dominant response option by conducting a mental simulation to see if it is likely to work. If there is not adequate time, the pilot will tend to implement the course of action that experience (if any) dictates is the most likely to be successful.

Endsley (1997) defines situation awareness (SA) as 'the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future'. In the dynamic tactical environment, effective decision-making is highly dependent on situation awareness which has been identified as a critical decision component (Endsley & Bolstad, 1994). Situation assessment is the process by which the state of situation awareness is achieved and is a fundamental precursor to situation awareness, which is itself the precursor for all aspects of decision-making (Nobel, 1993; Prince & Salas, 1997).

Jensen, Guilke & Tigner (1997) suggested that risk management should be a key part of the decision-making process. Risk assessment feeds into decision making in two ways: during the assessment of the precipitating threats and in evaluating potential courses of action. Janis and Mann (1977) proposed that a good decision-making process is one in which the decision maker successfully accomplishes the collection of information about a wide range of alternatives, carefully assesses the risks and benefits of each course of action, and prepares contingency plans for dealing with known risks.

Tactical flight training has many aspects that challenge the quality and processes of pilots' in-flight decision-making. In addition to the tasks and situations faced by the pilot of a civil aircraft, military pilots must perform a wide range of other tasks in addition to flying their aircraft safely. Their primary task may be to intercept offensive aircraft or to deliver weapons, troops or equipment. Often the act of flying the aircraft *per se* in a hostile environment becomes a secondary task. As a result, military pilots must learn to make decisions related to mission performance in addition

to those related to flying the aircraft *per se* (Kaempf & Orasanu, 1997). Flying advanced fighter aircraft has made increasing demands on pilots' cognitive abilities as the complexity of cockpit systems and the tactical situation has grown. There is now a requirement for decision-making training to be incorporated into tactical training programs (Li, Harris & Yu, 2005a). Furthermore, many accidents are either wholly or partially attributable to poor decision-making (Li, Harris & Yu, 2005b). However, at the present time, there is little or no formal training available for military pilots in the ROC Air Force or elsewhere offering heuristics, procedures or advice about making effective decisions under high pressure and in a time-limited, tactical situation.

Many researchers have suggested that ADM is trainable (Endsley, 1993; Klein, 1993 & 1997; Orasanu, 1993; Prince & Salas, 1997; Li & Harris, 2005). Buch and Diehl (1984) found that judgment training produced significantly better decisions among civil aviation pilots. Connolly, Blackwell & Lester (1989) observed that decision-making skills could be improved by the use of judgment training materials coupled with simulator practice. However, Orasanu (1993) suggested that generic training techniques to improve all-purpose decision-making skills would not be successful. She suggested that different component skills were involved when making six different basic types of decisions (go/no go decisions; recognition-primed decisions; response selection decisions; resource management decisions; non-diagnostic procedural decisions; and creative problem-solving).

There are a number of strategies embodied in mnemonics or acronyms describing the processes and procedures concerned with ADM. These have been developed

in recent years by researchers and used by pilots to support ADM 'best practice' (e.g. Wohl, 1981; Maher, 1989; Klein & Woods, 1993; Hormann, 1995; Oldaker, 1996; Jensen, 1997; David, 1997; Murray, 1997; Orasanu, 1997; Jensen & Hunter, 2002; O'Hare, 2003). The common aim of these techniques is to encourage a systematic approach to decision-making that should be less affected by the human nature and should also reduce the cognitive work for pilots (O'Hare, 2003). However, there is a lack of hard empirical research demonstrating the effectiveness of these ADM mnemonic methods.

Li & Harris (2005) undertook a study to identify the best ADM mnemonic-based methods for training military pilot's decision-making. From the results of this study it was found that SHOR (Wohl, 1981) was rated as being the best ADM mnemonic in time-limited and critical, urgent situations. DESIDE (Murray, 1997) was regarded as superior for knowledge-based decisions which required more comprehensive considerations but also had more time available to do so. The SHOR mnemonic (Wohl, 1981) consists of four steps: Stimuli, Hypotheses, Options, and Response. It was originally developed for use by U.S. Air Force tactical command and control, where decisions were required under high pressure and severe time constraint. In this situation, decisions require near-real-time reactions involving threat warning, rescheduling and other types of dynamic modification. The SHOR methodology is basically an extension of the stimulus-response paradigm of classical behavioral psychology developed to deal with two aspects of uncertainty in the decision-making process, information input uncertainty (which requires hypothesis generation and evaluation) followed by the evaluation of the consequences of actions, which creates the requirement for option generation and evaluation. DESIDE (Murray, 1997) was developed on a sample of South African pilots and comprises

six steps, Detect, Estimate, Set safety objectives, Identify, Do, Evaluate. The DESIDE method is a practical application to aid pilots in making in-flight decisions adapted from the conflict-theory model of Janis and Mann (1977).

O'Connor, Flin, Fletcher & Hemsley (2002) described several methods for the evaluation of CRM (Crew Resource Management) and ADM training, including the use of simulator/LOFT checks; self/peer/360 degree appraisals; the assessment of technical performance; the analysis of confidential reports and the use of knowledge assessment tests. The standard method for the assessment of the knowledge-based elements is normally a pencil and paper based test. This provides a reasonably quick and simple way of evaluating knowledge acquisition. The following study evaluates the effectiveness of a short ADM training course delivered to ROC Air Force cadet pilots based around the SHOR and DESIDE ADM mnemonic-based methods using a pencil-and –paper knowledge based approach. The ADM training course (described in more detail in the following section) also provided advice concerning which ADM approach was most suitable in any given situation. It is argued that the decision making training program delivered requires assessment in two aspects: the actual decision-making *performance* of students on completion of the training and an assessment of the *process* by which they arrive at their decision. In this paper emphasis is placed on the evaluation of the pilots' decision-making *process* and the quality of the decision based around the dimensions of situation assessment and risk management. The results of the *product*-based measures of the training program, evaluated using decision scenarios re-created in a full-flight simulator are reported elsewhere (Li, Harris & Yu, 2005b; Li & Harris, under review a; Li and Harris, under review b). While these simulator trials could assess the products of the ADM training program

in a time-pressured, real-time environment they had severe limitations in establishing if the processes taught within the training course were being applied appropriately, hence the requirement for the knowledge-based pencil and paper tests.

Furthermore, when evaluating decision-making efficacy, Baron and Hershey (1988) suggested that the study of 'outcomes' shows a tendency of people to assess the correctness of their decision-making with regard to the outcome of the decision. However, good decisions can lead to bad outcomes (and vice versa) especially when operating in a probabilistic environment, such as aviation. Decision makers cannot infallibly be graded by their results (Brown, Kahr, & Peterson, 1974). A good decision cannot guarantee a good outcome. All in-flight decisions are made under uncertainty. Evaluating a decision as good (or not) must depend as much on the stakes and the processes employed, not just simply on the outcome. Hence, in this study the evaluation of the effectiveness of decision-making training is based around the decision-making adjuncts of situation assessment and risk management measures rather than simply on assessing the outcomes of the decisions made.

Using Kirkpatrick's (1976, 1998) hierarchy for training evaluation, the current study assesses the product of the training interventions at the second level of evaluation (learning). The pencil-and-paper based evaluation of the ADM training program delivered is specifically concerned with establishing if the participants have acquired the decision-making procedural knowledge as a result of attending the training course. It was hypothesized that the provision of ADM training would produce superior situation assessment and risk management performance (two key factors underpinning effective decision

making) in a range of in-flight decision-making scenarios encompassing Orasanu's (1993) six decision-making categories.

METHOD

Participants

Forty-One male participants from ROC Air Force Tactical Training Wings participated in the study. The flying experience of participants was between 220 and 354 hours with an average of 292 hours. Participants were randomly divided into two groups, 21 pilots in the experimental (trained) group and 20 pilots in the control (untrained) group.

The Contents of ADM Training Programs

The results from a previous study by Li and Harris (2005) found that just two mnemonic-based methods provided a suitable basis for all aspects of ADM training. These methods encompassed all the requirements of the six basic decision making situations. SHOR (Wohl, 1981) was regarded as being the best for time-limited and urgent situations; DESIDE (Murray, 1997) was regarded as being superior for guiding knowledge-based decisions needing more comprehensive consideration. These two mnemonic methods formed the basis of the ADM training programs. The objective of the training course was to equip trainees with the procedural knowledge required to use these methods.

The training program commenced with an introduction to ADM theories, including the Recognition-Primed Decision Model of Rapid Decision Making (Klein, 1993); The ARTFUL Decision Maker: A Framework Model for Aeronautical Decision Making (O'Hare, 1992); Conflict-theory Decision Making Model (Janis & Mann, 1977); a Model of Situation Awareness in Dynamic Decision-making (Endsley, 1997); and the Decision Process Model (Orasanu, 1995). This was followed by a description of the content and method of application of the SHOR and DESIDE ADM mnemonic-based methods. To optimize decision making training effectiveness it was also necessary to instruct pilots with regard to which technique was the most appropriate to apply in any given circumstance.

Following this, participants underwent a period of supervised practice in the classroom in the application of SHOR and DESIDE in flight situations exemplifying the six basic types of decision making scenario described by Orasanu (1993). Finally, the application of ADM in military aviation was described and the participants who participated in the training course were de-briefed. The ADM training program lasted approximately four hours in total.

Scenarios for the Assessment of ADM Training Effectiveness

To develop scenarios for assessing the effectiveness of the ADM training intervention which corresponded to Orasanu's (1993) six decision making categories, six focus groups were conducted, one for each scenario. Each focus group comprised one human factors specialist and three senior instructor pilots. The purpose of these focus groups was to verify that the scenarios used in the pre-training and post-training evaluation of decision-making (which were developed from the ROCAF accidents and incidents database) corresponded to the appropriate categories of decision-making and were of

equivalent difficulty. Further details of the process validating the selection of the scenarios for each generic decision type can be found in Li & Harris (2005).

To negate practice effects, different (but equivalent) scenarios were used in the evaluations pre- and post ADM training. These focus groups also ensured enough detail was available for pilots to be able to make a decision and hence to evaluate their decision-making performance. These scenarios developed were as follows.

Go/no go decision-making scenario

Go/no go decisions are made under severe time pressure and involve considerable risk; the amount of thinking should be minimal. Orasanu (1993) suggests that training design should focus on developing perceptual patterns in memory that constitute the conditions for the required action. However, they should be trained under realistic time pressure and the training scenarios should include additional contingencies that require more complex risk assessment.

Pre-training scenario: F-5E No. 2 wingman has to make a decision as the No. 1 (Leader) abandons a tactical formation take-off at 145 knots.

Post-training scenario: F-5E No. 2 wingman practicing tactical formation training; during the take off run with the throttles increased to maximum, No.1 (leader) suddenly slants seriously towards the No.2.

In both the above scenarios the pilots had to make a decision under time pressure with high risk. The patterns of events needed to be recognized and pre-set responses needed to be executed swiftly. The cognitive activities required of the pilots were essentially perceptual and interpretive.

Recognition-primed decision-making scenario

Recognition-primed decisions are described by Orasanu (1993) as the recognition of the situational patterns that serve as inputs to condition-action rules, but which also require the decision maker to learn the response side of the rule and its link to that condition.

Pre-training scenario: F-5E right engine fails as a result of Foreign Object Damage just as the nose gear leaves the ground at a speed of 165 knots.

Post-training scenario: F-5E solo, after taking off at 500 feet, pilot hears two unusual sounds from the engines and feels the aircraft shake. Engine exhaust gas temperature is increased, and RPM decreased.

As noted earlier in the Introduction, Klein (1993) suggested that recognition-primed decisions focuses on the two processes of situation assessment and mental simulation. If there is no time to make a considered response (as in the case of both the above scenarios) the pilot will implement the rule that experience has determined will be the most likely to be successful. These situations require more conscious cognitive processing than go/no go decisions (cf Reason's rule-based errors; Reason 1990).

Response selection decision-making scenario

Response selection decisions involve a single option that must be selected from a set of possible options; pilots must identify the possible options and evaluate them in terms of how well they satisfy the goals and meet constraints. Often they must consider trade-offs among competing goals which are satisfied by different options.

Pre-training scenario: No. 4 wingman in a tactical formation of F-5Es is required to make a decision when *No. 1 (Leader) becomes* lost *in cloud during formation flight (3 feet distance between wing tips of the four fighters).*

Post-training scenario: F-5E leader was maintaining loose formation with No. 2 on the left, at 13,000 feet, the Ground Intercept Controller reports an unidentified aircraft at one o'clock and 5 miles away. At the same time No.2 makes visual contact with an airliner in front and head-on at 3 miles away with same altitude and approaching fast (leader had no orders).

In both scenarios the wingman has to make a decision to choose a response to deal with an impending hazard. Although these are not urgent situations, pilots may perceive the potential risk in front of them to be very high and choose an inappropriate course of action. However, once the nature of the potential threat is identified there are detailed procedures available from their training of how to deal with the situation.

Resource management decision-making scenario

Resource management decisions involve the *relative* priorities of various tasks, especially critical ones. Skills relevant to this type of decision include estimation of the time required to complete the various tasks, knowledge of the interdependencies among tasks, and scheduling strategies.

Pre-training scenario: F-5E leader of 4 aircraft needs to make a decision for the No.3 and No. 4 aircraft when a 'no joy' call (no visual contact with No. 1 and No. 2) is made and No. 2 calls 'one opposing target approaching on 12:30 o'clock with same altitude'. This occurs during practice of a 2 versus 2 Air Combat Maneuver engagement.

Post-training scenario: Leader and No.2 are practicing basic fighting maneuvers for a gunshot attack; the distance between No. 2 and the leader is only 500 feet, the angle off is over 90 degrees. The possibility of a mid-air collision is high; both aircraft are at 480 knots and same altitude.

Perhaps the most critical issues for resource management decisions are setting the priorities of the responses required to make and implement a decision. In the scenarios described above the resource allocation problem changes from one of practicing basic fighting maneuvers to one of avoiding a collision. There are certain actions that must be completed within a few seconds to avoid a mid-air crash and they must be prioritized and undertaken in a certain order, such as calling out to alert other traffic prior to climbing or descending or changing direction.

Non-diagnostic procedural decision-making scenario

Non-diagnostic procedural decisions involve a number of cues falling into a category with no prescribed response. The nature of the problem is unclear and many different types of ambiguous cues may also signal potentially dangerous conditions. Orasanu (1993) suggests that training for this type of decision should involve mainly situation assessment and risk assessment. Cues that signal possible emergencies need to be distinguished from those that are troublesome but not severe enough to precipitate an emergency landing.

Pre-training scenario: Both the leader and wingman in a formation of F-5Es are unable to land at home-base in a 'bingo' (low fuel) situation during instrument flight in bad weather.

Post-training scenario: When an F-5E is finishing Basic Fighting Maneuver training, the Ground Intercept Controller reports that home base weather is worsening. Surplus fuel is down to only 1,400 lb. The pilot asks for weather conditions at alternative airports.

In both the pre-test and post-test scenarios pilots had to evaluate the strengths and weakness of using alternative airfields in deteriorating weather in a 'bingo fuel' situation. There was no clearly defined 'correct' answer. Although the nature of the immediate problem is clear (deteriorating weather at home base) the problems imposed by diverting to an alternate airfield are unclear and deviations from the optimal solution may be required due to the low fuel state.

Creative problem-solving decision-making scenario

Creative problem-solving decisions are the most complex, as they involve both diagnoses to determine the nature of the situation and response generation. Pilots must determine what their goals are, develop a plan and candidate strategies, and evaluate these strategies and actions based on projections of likely outcomes (Orasanu, 1993).

Pre-training scenario: When flying an F-5F both left and right generators warning lights become active during a tactical maneuver.

Post-training scenario: When lowering the landing gear while on the down-wind leg the landing gear shaft warning light illuminates, indicating the nose landing gear is abnormal.

In both the decision-making scenarios presented, once the true nature of the problem has been determined (from the indications in the cockpit the pilot was only initially aware of the symptoms of the problem in both cases, not their ultimate cause) they would determine that there were no recommendations in the SOPs/manuals for its resolution, hence a novel solution had to be developed to address the situation.

Procedure

Both experimental (trained) and control (untrained) groups undertook an initial set of pencil and paper based evaluations where they were required to describe how they would deal with each of the problems described in above pre-training decision making scenarios. These evaluations were simply in the form of narrative-based reports describing the steps that they would take when assessing their options and coming to a decision. After these initial tests the experimental group attended a four-hour 'ADM training Program for military pilots'. The Control group had no such training. Both groups then participated in a further set of pencil and paper evaluations.

To eliminate order effects, the six decision making scenarios were presented in a randomized order in both the pre- and post-training trials. The narrative responses describing the process by which the participants would arrive at their decision were evaluated by a flight instructor with regard to their situation assessment and risk management performance. These dimensions were derived from the earlier study (Li and Harris, 2005) used to select the most appropriate ADM training mnemonic methods. Each aspect of performance was rated using a nine-point Likert-type scale (with a high score of 9 and a low score of 1).

To enhance the reliability of the measures, the same instructor evaluated trainee performance on all occasions. The instructor was trained by an aviation human factors specialist to evaluate performance in the required manner. The narratives describing the decision making process were anonymized before being passed to the flight instructor, thus he was blind to the

experimental condition. Furthermore, the instructor took no part in delivering any aspect of the aeronautical decision making training course.

For the evaluation of both Situation Assessment and Risk Management performance in the narrative answers produced, a list of key performance factors (taken from the training manuals) was derived for each scenario. The steps that should be undertaken and sources of information that should be interrogated in each circumstance were listed, these being factors underlying Situation Assessment performance in particular. Emphasis on the risk management dimension was placed upon the generation and analysis of options and the quality of reasoning underlying the pilot's final decision based specifically on the control of risk.

Ethical Approval

This research program was approved by the Ethics committee of Cranfield University. This committee operates to the principles prescribed by the British Psychological Society (the UK professional body for psychologists). Participants were volunteers and informed of the purpose of the study prior to participating. All data were collected anonymously.

RESULTS

Data

The ADM decision making process that each participant employed was evaluated in all six scenarios in both pre- and post ADM training. In total 492 narrative responses were collected, 246 prior to ADM training taking place and the same number after the training course had been delivered. Two hundred and fifty-two trials were undertaken by the experimental group and 240 by the control group. To re-iterate, the ADM processes described in the narratives produced by the cadet pilots were rated on the dimensions of situation assessment and risk management.

Go/no go Decisions

Irrespective of experimental group, there was no overall difference in situation assessment performance between the pre- and post-test ($F_{1,39}$=1.214; p=0.277). There was an effect approaching significance between the trained and untrained group ($F_{1,39}$=3.277; p=0.078). The group that had received ADM training tended to outperform the group that had not received training (table 1). The interaction term between the trained/untrained group and pre-post-training was significant ($F_{1,39}$=4.355; p=0.043). The group that had received ADM training showed significantly greater gains in the second trial compared to the untrained group. Overall, there was no difference on risk management performance between the pre- and post-test ($F1_{,39}$=0.448; p=0.507). There was also no significant difference between the trained and untrained group ($F_{1,39}$=2.207; p=0.145). However, there was an effect verging on

significance with regard to the interaction term between the trained/untrained group and pre- post-training trial ($F_{1,39}$=3.266; p=0.078). The group that had received ADM training showed somewhat greater gains in risk management performance during the second trial compared to the untrained group.

INSERT TABLE 1 HERE

Recognition-Primed Decisions

There was no difference in situation assessment performance between the pre- and post-test ($F_{1,39}$=0.927; p=0.342). There was also no significant difference between the trained and untrained group ($F_{1,39}$=1.337; p=0.225). However, there was a significant interaction effect between the trained/untrained group and pre- and post- ADM training trial ($F_{1,39}$=9.555; p=0.004). The group that had received ADM training showed significantly greater gains in performance in the second trial compared to the untrained group (table 2). There was no significant difference in risk management performance between the pre- and post-test ($F_{1,39}$=0.141; p=0.710). There was, however, an effect approaching statistical significance with regard to pilots' performance between the trained and untrained group ($F_{1,39}$=2.900; p=0.097). The group that had received ADM training tended to perform better than the group that had not received training. There was also an interaction term verging on significance ($F_{1,39}$=3.266; p=0.078). The group that received ADM training showed greater gains in performance in the second trial compared to the untrained group.

INSERT TABLE 2 HERE

Response Selection Decisions

There was an effect approaching statistical significance with regard to pilot performance between the pre- and post-test on the dimension of situation assessment ($F_{1,39}$=3.520; p=0.068). This suggested that pilots' situation assessment was rated as having improved on the second trial regardless of whether they received training or not (see table 3). There was also an effect verging on statistical significance between the trained and untrained group ($F_{1,39}$=3.277; p=0.078). The group that had received ADM training tended to outperform the group that had not received training. There was no significant interaction effect ($F_{1,39}$=1.461; p=0.234). There was no significant difference on risk management performance between the pre- and post-test ($F_{1,39}$=2.0641; p=0.112). There was a result approaching statistical significance on risk management performance between the trained and untrained group ($F_{1,39}$=4.022; p=0.052). The group that had received ADM training tended to exhibit better performance than the group that had not received training. There was also a significant interaction term between the trained/untrained group and pre-test post-test trial ($F_{1,39}$=5.591; p=0.023). The group that had received ADM training showed greater gains in risk management performance in the second trial compared to the untrained group.

INSERT TABLE 3 HERE

Resource Management Decisions

There was a significant difference in pilots' situation assessment performance between the pre- and post-test ($F_{1,39}$=4.914; p=0.033). Pilots' performance was superior on the second trial (table 4). There was, however, no significance between the trained and untrained group ($F_{1,39}$=1.767; p=0.191) and there was also no significant interaction ($F_{1,39}$=1.238; p=0.273). Overall, there was an effect verging on significance in risk management performance between the pre- and post-test measures ($F_{1,39}$=3.035; p=0.089). Pilots' risk management performance was superior on the second trial. There was no significant difference between the trained and untrained group ($F_{1,39}$=0.052; p=0.820) and there was no significant interaction term ($F_{1,39}$=2.247; p=0.142).

INSERT TABLE 4 HERE

Non-diagnostic Procedural Decisions

Overall, there was no difference in situation assessment performance between the pre- and post-test ($F_{1,39}$=1.007; p=0.322). There was an effect verging on significance in performance between the trained and untrained group ($F_{1,39}$=3.593; p=0.065). The group that had received ADM training tended to

outperform the group that had not received training (table 5). There was also a significant interaction term between the trained/untrained group and pre-test/post-test trial ($F_{1,39}$=19.540; p=0.000). The group that had received ADM training showed significantly greater gains in situation assessment performance in the second trial. There was no significant difference in risk management performance between the pre- and post-test ($F_{1,39}$=0.067; p=0.797). There was also no significant difference between the trained and untrained group ($F_{1,39}$=1.887; p=0.177). There was a result verging on significance in the interaction term between the trained/untrained group and pre-test/post-test trial ($F_{1,39}$=3.266; p=0.078). The group that had received ADM training showed greater gains in performance in the second trial compared to the untrained group.

INSERT TABLE 5 HERE

Creative problem-solving

There was a significant difference in situation assessment performance between the pre- and post-test measures ($F_{1,39}$=10.320; p=0.003). It showed that pilots' performance was better on the second trial than the first trial (table 6). There was no significance between the trained and untrained group ($F_{1,39}$=0.187; p=0.668) and there was also no significant interaction term ($F_{1,39}$=2.393; p=0.130). There was a significant difference on the dimension of risk management ($F_{1,39}$=5.885; p=0.020). It indicated the pilots' performance on risk management was superior on the second trial. There was no significant

difference between the trained and untrained group ($F_{1,39}$=0.162; p=0.690). There was also no significant interaction term between the trained/untrained group and trial ($F_{1,39}$=2.509; p=0.121).

INSERT TABLE 6 HERE

DISCUSSION

Overall, the results show gains being made in terms of both the participants' situation assessment and risk management skills that are attributable to the short decision making training course. Perhaps the most direct indication of the efficacy of the ADM training course lies in the significant interaction effects obtained. These interaction terms indicate disproportionate gains in performance on the second trials (post ADM training) in the participant group that received ADM instruction. To summarize, significant results (or results approaching significance) were obtained showing improvements in participant's performance in the scenarios concerned with go/no go decisions; recognition-primed decisions, and non-diagnostic procedural decisions. With regard to risk management, significant results (or results verging on significance) were observed in the go/no go decision making scenario; recognition-primed decision making scenario; response selection, and non-diagnostic procedural decision making scenario. These results are summarized in table 7.

Even though every effort was made to ensure that the pre- and post-training decision making scenarios were of equivalent difficulty, inspection of the results from the untrained group would suggest that in several cases the post-test scenarios were actually slightly more difficult (see tables 1, 2 and 5). Nevertheless, in spite of this evidence that would suggest that these post- training scenarios were more difficult, the trained group still generally showed improvements in situation assessment and risk management performance (see the associated interaction terms). In all cases the performance of the group that received the ADM training course improved.

INSERT TABLE 7 HERE

For the evaluation of both Situation Assessment and Risk Management performance in the narrative answers produced, a. The steps that should be undertaken and sources of information that should be interrogated in each circumstance were listed, these being factors underlying Situation Assessment performance in particular. Emphasis on the risk management dimension was placed upon the generation and analysis of options and the quality of reasoning underlying the pilot's final decision based specifically on the control of risk.

The results obtained add support to the findings of earlier research (e.g. Buch and Diehl, 1984; Connolly, Blackwell & Lester, 1989; Endsley, 1993; Klein, 1993 &1997; Orasanu, 1993; Prince & Salas, 1997) that suggested that ADM was trainable. Orasanu (1993) advocated there was no evidence that generic

training techniques to improve decision making skills would be effective as different component skills were involved when making different basic types of decisions. As a result of this Li & Harris (2005) elicited the opinions of a large sample of instructor pilots concerning the best ADM mnemonic-based methods for use in a variety of different types of flight situations. SHOR (Wohl, 1981) was identified as potentially the best ADM mnemonic in a time-limited situation; DESIDE (Murray, 1997) was rated as being superior for more complex, knowledge-based decisions where more time was available. The results obtained in this study support the conclusions of the earlier opinion survey. These decision making mnemonic-based methods promote better ADM. There is now empirical evidence demonstrating that pilots trained in the use of these techniques actually produce superior performance on two of the essential components underlying ADM for at least some varieties of decision making problems.

The data in the narrative reports produced by the participants in each decision making scenario suggested that the majority of pilots who had received ADM training applied the most appropriate ADM mnemonic method for a given situation. The SHOR mnemonic tended to be applied in the go/no-go decision making scenario, recognition-primed decision-making scenario and in the response selection decision-making situation. DESIDE was most commonly used in the remaining scenarios (resource management decisions, non-diagnostic procedural decisions and creative problem-solving).

CONCLUSIONS

This research investigated the efficacy of a short ADM training course using two mnemonic-based methods (SHOR and DESIDE) to improve ROC Air Force pilot decision-making in six different basic types of decision-making scenarios. The results from simple paper-and-pencil based evaluations assessing the knowledge acquired show that such a short training course is generally effective in improving pilots' situation assessment and risk management skill (two underpinning requirements for effective decision-making) in a range of decision-making situations. Complementary research undertaken in a flight simulator has also shown behavioral gains in decision making by those who underwent the training course (Li & Harris, 2006; Li & Harris, under review a; Li and Harris, under review b). These complimentary behavioral gains further establish the validity of the use of pencil and paper based tests to evaluate the ADM training course. They provide convergent evidence to support the efficacy of the decision making training program. However, the longer-term effectiveness of such courses needs evaluation to see if it translates into improved decision-making behavior during day-to-day operations which, ultimately also results in a reduction in the accident rate attributable to poor decision-making. By necessity, the initial evaluations of the training program focused upon 'problem' situations where pilots were required to make a satisfactory decision to avoid a potential accident. Further research is required to establish if the ADM principles conveyed in the training course are equally as successful in lower workload, less pressured decision making situations. Nevertheless, this simple, short, cost-effective training program in the appropriate use of ADM mnemonic methods can potentially produce significant gains in flight safety. Such a course may easily be

integrated into the existing CRM and/or simulator-based training programs currently undertaken by cadet pilots in the ROC Air Force. Furthermore, there is no reason why a modified version of the ADM training course devised should not be equally as successful in a civil aviation training organization.

REFERENCES

Baron, J. and Hershey, J.C. (1988), 'Outcome bias in decision evaluation', Journal *of Personality and Society Psychology*, Vol. 54, pp. 569-579.

Brown, R.V., Kahr, A.S., & Peterson, C (1974). *Decision analysis for the manager*. New York: Holt, Rinehart & Winston.

Buch, G. and Diehl, A. (1984), 'An Investigation of the Effectiveness of Pilot Judgment Training', *Human Factors,* Vol. 26, No. 5, pp. 557-564.

Connolly, T.J., Blackwell, B.B. and Lester, L.F. (1989), 'A Simulator-based Approach to Training in Aeronautical Decision Making', *Aviation, Space, and Environmental Medicine,* Vol. 60, No. 1, pp. 50-52.

David, G. (1997), 'Decision Making Training for Aircrew', in Flin, R., Salas, E., Strub, M., and Martin, L. (Editor), *Decision Making Under Stress: Emerging Themes and Applications*, Ashgate, Aldershot, England, pp. 243-251.

Endsley, M.R. (1997), 'The Role of Situation Awareness in Naturalistic Decision Making', in Zsambok, C.E. and Klein, G. (Editor), *Naturalistic Decision Making*, Lawrence Erlbaum, Mahwah, pp. 269-284.

Endsley, M.R. (1993), 'A survey of Situation Awareness Requirements in Air-to-Air Combat Fighters', The *International Journal of Aviation Psychology,* Vol. 3, No. 2, pp. 157-168.

Endsley, M.R. and Bolstad, C.A. (1994), 'Individual Differences in Pilot Situation Awareness', The *International Journal of Aviation Psychology,* Vol. 4, No. 3, pp. 241-264.

Federal Aviation Administration (1991), *Aeronautical Decision-making*, Report no. Advisory Circular 60-22, US Department of Transport, Washington.

Fischer, U., Orasanu, J., and Wich, M. (1995), 'Expert Pilots' Perceptions of Problem Situations', in Jensen, R.S. and Rakovan, L.A. (Editor), *Eighth International Symposium on Aviation Psychology,* Vol. 2, Columbus, Ohio, U.S.A., The Ohio State University, pp. 777-782.

Hormann, H.J. (1995), 'FOR-DEC: a perspective model for aeronautical decision making ', in Fuller, R., Johnston, R., and McDonald, N. (Editor), *Human Factors in Aviation Operations*, Ashgate Publishing, Aldershot, England, pp. 17-23.

Hunter, D.R. (2003), 'Measuring General Aviation Pilot Judgment Using a Situational Judgment Technique', *The International Journal of Aviation Psychology,* Vol. 13, No. 4, pp. 373-386.

Janis, I.L. and Mann, L. (1977), *Decision making: A Psychological Analysis of Conflict, Choice, and Commitment*, Free Press, New York.

Jensen, R. and Hunter, D. (2002), *General Aviation Aeronautical Decision-making*, FAA, Washington, D.C.

Jensen, R.S. (1997), ' The Boundaries of Aviation Psychology, Human Factors, Aeronautical Decision Making, Situation Awareness, and Crew Resource Management', The *International Journal of Aviation Psychology,* Vol. 7, No. 4, pp. 259-268.

Jensen, R.S. (1995), *Pilot Judgment and Crew Resource Management*, Ashgate, Aldershot, England.

Jensen, R.S., Guilke, J. and Tigner, R. (1997), 'Understanding Expert Aviator Judgment', in Flin, R., Salas, E., Strub, M., and Martin, L. (Editor), *Decision Making Under Stress: Emerging Themes and Applications*, Ashgate, Aldershot, England, pp. 233-242.

Kaempf, G.L. and Orasanu, J. (1997), 'Current and Future Applications of Naturalistic Decision Making', in Zsambok, C.E. and Klein, G. (Editor), *Naturalistic Decision Making*, Lawrence Erlbaum, Mahwah, pp. 81-90.

Kirkpatrick, D.L. (1998), *Evaluating Training Programs*, Berrett-Koehler, San Francisco.

Kirkpatrick, D.L. (1976), 'Evaluation of Training', in Craig, R.L. and Bittel, L.R. (Editor), *Training and Development Handbook*, McGraw Hill, New York, pp. 18.1-18.27.

Klein, G. (1997), 'The Current Status of the Naturalistic Decision Making Framework', in Flin, R., Salas, E., Strub, M., and Martin, L. (Editor), *Decision Making Under Stress: Emerging Themes and Applications*, Ashgate, Aldershot, England, pp. 11-28.

Klein, G.A. (1993), 'A Recognition-Primed Decision (RPD) Model of Rapid Decision Making', in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), *Decision Making in Action: Models and Methods*, Ablex, Norwood, New Jersey, pp. 138-147.

Klein, G.A. (1993), 'Twenty Questions: Suggestions for Research in Naturalistic Decision Making', in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), *Decision Making in Action: Models and Methods*, Ablex, Norwood, New Jersey, pp. 389-403.

Klein, G.A. and Woods, D.D. (1993), 'Conclusions: Decision Making in Action', in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), *Decision Making in Action: Models and Methods*, Ablex, Norwood, New Jersey, pp. 404-411.

Li, W.C. and Harris, D. (2005), 'Aeronautical Decision-Making: Instructor-Pilot Evaluation of Five Mnemonic Methods', *Aviation Space Environmental Medicine,* Vol. 76, pp. 1156-1161.

Li, W-C. and Harris, D. (under review a). The Evaluation of the Efficiency of a short Aeronautical Decision-making Training Program for Military Pilots. Submitted to *International Journal of Aviation Psychology*.

Li, W-C. and Harris, D. (under review b). A Systems Approach to Training Aeronautical Decision-Making: From Identifying Training Needs to Verifying Training Solutions. Submitted to *The Aeronautical Journal*.

Li, W.C., Harris, D., and Yu, C.S. (2005a), 'The Identification of Training Needs for Developing Aeronautical Decision-making Training Programs for Military Pilots', in Jensen, R.S. (Editor), *Thirteenth International Symposium on Aviation Psychology,* Oklahoma City, U.S.A., The Ohio State University, pp. 351-356.

Li, W.C., Harris, D., and Yu, C.S. (2005b), 'The Investigation of Suitability of Aeronautical Decision-making Mnemonics in Tactical Environments', *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting,* Orlando, FL., Human Factors and Ergonomics Society, pp. 2187-2191.

Li, W-C., and Harris, D. (2006). SHOR and DESIDE: Evaluating the Effectiveness of ADM Training Using a Flight Simulator. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting,* (October 16-20), San Francisco, CA.

Maher, J. (1989), 'Beyond CRM to Decisional Heuristics: An Airline Generated Model to Examine Accidents and Incidents Caused by Crew Errors in Deciding', in Jensen, R.S. (Editor), *Fifth International Symposium on*

Aviation Psychology, Vol. 2, Columbus, Ohio, The Ohio State University, pp. 439-444.

Murray, S.R. (1997), ' Deliberate Decision Making by Aircraft Pilots: A simple Reminder to Avoid Decision Making Under Panic', The *International Journal of Aviation Psychology,* Vol. 7, No. 1, pp. 83-100.

Noble, D. (1993), 'A Model to Support Development of Situation Assessment Aids', in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), *Decision Making in Action: Models and Methods*, Ablex, Norwood, New Jersey, pp. 287-305.

O'Connor, P., Flin, R., Fletcher, G. and Hemsley, P. (2002), 'Methods used to evaluate the effectiveness of Flightcrew CRM Training in the UK Aviation Industry', *Human Factors and Aerospace Safety,* Vol. 2, No. 3, pp. 235-255.

O'Hare, D. (2003), 'Aeronautical Decision Making: Metaphors, Models, and Methods', in Tsang, P.S. and Vidulich, M.A. (Editor), *Principles and Practice of Aviation Psychology: Human Factors in Transportation*, Lawrence Erlbaum, New Jersey, pp. 201-237.

O'Hare, D. (1992), 'The Artful Decision Maker: A Framework Model for Aeronautical Decision Making', *The International Journey of Aviation Psychology,* Vol. 2, No. 3, pp. 175-192.

Oldaker, I. (1996), 'Pilot Decision Making - An Alternative to Judgement Training', *Technical Soaring,* Vol. 20, No. 2, pp. 36-41.

Orasanu, J. (1993), 'Decision Making in the Cockpit', in Wiener, E.L., Kanki, B.G., and Helmreich, R.L. (Editor), *Cockpit Resource Management*, Academic Press, San Diego, pp. 137-172.

Orasanu, J. (1997), 'Stress and Naturalistic Decision Making: Strengthening the weak Links', in Flin, R., Salas, E., Strub, M., and Martin, L.

(Editor), *Decision Making Under Stress: Emerging Themes and Applications.* Ashgate: Aldershot, England, pp. 43-66.

Prince, C. and Salas, E. (1997), 'Situation Assessment for Routine Flight and Decision Making', *International Journal of Cognitive Ergonomics,* Vol. 1, No. 4, pp. 315-324.

Reason, J. (1990), *Human Error*. Cambridge: Cambridge University press.

Wohl, J.G. (1981), ‘Force management decision requirements for air force tactical command and control', *IEEE Transactions on Systems, Man and Cybernetics,* Vol. SMC-11, pp. 618-639.

Table 1

Go/no go decisions		Group	N	Mean	Standard deviation
Situation assessment	Pre-test	Trained	21	5.38	1.20
		Untrained	20	5.25	1.74
	Post-test	Trained	21	6.19	0.98
		Untrained	20	5.00	1.65
Risk management	Pre-test	Trained	21	5.57	1.08
		Untrained	20	5.30	1.53
	Post-test	Trained	21	5.95	1.07
		Untrained	20	5.05	1.23

Table 1 Means and Standard Deviations in performance scores in the Go/no go decision-making scenario, broken down by both main effects (pre-test/post-test: trained/untrained) on the measures of situation awareness and risk management

Table 2

Recognition-primed decisions		Group	N	Mean	Standard deviation
Situation assessment	Pre-test	Trained	21	5.43	1.12
		Untrained	20	5.55	1.23
	Post-test	Trained	21	6.10	0.94
		Untrained	20	5.20	1.44
Risk management	Pre-test	Trained	21	5.29	1.19
		Untrained	20	5.30	1.13
	Post-test	Trained	21	5.86	0.73
		Untrained	20	4.95	1.19

Table 2 Means and Standard Deviations in performance scores in the Recognition-primed decisions scenario, broken down by both main effects (pre-test/post-test: trained/untrained) on the measures of situation awareness and risk management

Table 3

Response selection decisions		Group	N	Mean	Standard deviation
Situation assessment	Pre-test	Trained	21	5.14	1.46
		Untrained	20	4.75	1.55
	Post-test	Trained	21	5.90	0.99
		Untrained	20	4.90	1.78
Risk management	Pre-test	Trained	21	4.86	1.01
		Untrained	20	4.85	0.99
	Post-test	Trained	21	5.67	0.86
		Untrained	20	4.70	1.17

Table 3 Means and Standard Deviations in performance scores in the response selection decisions scenario, broken down by both main effects (pre-test/post-test: trained/untrained) on the measures of situation awareness and risk management.

Table 4

Resource management decisions		Group	N	Mean	Standard deviation
Situation assessment	Pre-test	Trained	21	4.95	1.56
		Untrained	20	4.80	1.32
	Post-test	Trained	21	5.86	1.15
		Untrained	20	5.10	1.51
Risk management	Pre-test	Trained	21	4.71	1.19
		Untrained	20	4.95	1.00
	Post-test	Trained	21	5.38	1.07
		Untrained	20	5.00	1.52

Table 4 Means and Standard Deviations in performance scores in the resource management decision scenario, broken down by both main effects (pre-test/post-test: trained/untrained) on the measures of situation awareness and risk management.

Table 5

Non-diagnostic procedural decisions		Group	N	Mean	Standard deviation
Situation assessment	Pre-test	Trained	21	5.00	1.30
		Untrained	20	5.30	1.22
	Post-test	Trained	21	6.19	1.12
		Untrained	20	4.55	1.64
Risk management	Pre-test	Trained	21	4.95	1.16
		Untrained	20	5.25	1.07
	Post-test	Trained	21	5.71	0.96
		Untrained	20	4.60	1.47

Table 5 Means and Standard Deviations in performance scores in the non-diagnostic procedural decision-making scenario, broken down by both main effects (pre-test/post-test: trained/untrained) on the measures of situation awareness and risk management.

Table 6

Creative problem-solving		Group	N	Mean	Standard deviation
Situation assessment	Pre-test	Trained	21	4.71	1.35
		Untrained	20	4.90	1.48
	Post-test	Trained	21	5.71	1.01
		Untrained	20	5.25	1.02
Risk management	Pre-test	Trained	21	4.71	1.35
		Untrained	20	4.95	1.76
	Post-test	Trained	21	5.67	0.97
		Untrained	20	5.15	1.23

Table 6 Means and Standard Deviations in performance scores in the Creative problem-solving scenario, broken down by both main effects (pre-test/post-test: trained/untrained) on the measures of situation awareness and risk management

Table 7

Six basic types of decision-making	Dimensions of evaluation	Main effect of before/after training	Main effect of trained/untrained	Interaction effects
Go/no go decisions	SA		👌	✓
	RM			👌
Recognition-primed decisions	SA			✓
	RM		👌	👌
Response selection decisions	SA	👌	👌	
	RM		👌	✓
Resource management decisions	SA	✓		
	RM	👌		
Non-diagnostic procedural decisions	SA		👌	✓
	RM			👌
Creative problem-solving	SA	✓		
	RM	✓		

Table 7 The summary of main effects and interaction effects of paper-pencil trials on both dimensions of situation assessment and risk management across six basic types of decision-making scenarios

Note: 👌 indicates a result approaching significance ($p<0.10$);
✓ Indicates a significant result ($p<0.05$);
SA = Situation Assessment; RM= Risk Management.