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Heuristics to Improve Human Factors Performance in Aviation

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Abstract

This paper reviews literature related to heuristic cognitive strategies as they are used by flight crews. A review of heuristic and naturalistic cognition is presented. An example set of heuristics and cognitive biases are presented and where possible exemplified by 19 airline accidents. The paper suggests two tentative research designs which could be pursued to quantitatively study heuristics and its impact on aviation decision making. The paper concludes that aviation pilot training would benefit by introducing pilots to the concepts and constructs of heuristic thinking.

This paper reviews the literature related to a variety of cognitive strategies under the broad umbrella of heuristics and biases. Where possible, the heuristics are demonstrated against 19 example airline accidents. Following the cognitive introduction, an inventory of heuristics is presented aimed at demonstrating that time limited decision making is defined by heuristic cognitive strategies. A research model is suggested to quantitatively study heuristics in aviation. The paper concludes that aviation pilot training would benefit by introducing pilots to the concepts and constructs of heuristic thinking.

Human Factors and Heuristics Background

In their book, *The Limits of Expertise,* Dismukes, Berman, and Loukopoulos analyze 19 airline accidents occurring over a near ten year period. While the authors draw out many themes and proximate causes of the accidents, Table 1 (see Appendix) summarizes the cognitive aspects of each accident. The cognitive aspects often point out faults in human decision making, such as plan continuation bias, the anchoring heuristic and availability heuristic (Dismukes, Berman, & Loukopoulos, 2007). Throughout this paper, reference will be made to Table 1 as examples of cognitive constructs.

Heuristic thought processes fall under the broader topic of naturalistic decision making and bounded rationality. The term *heuristic* is an often misunderstood term. In the popular mathematics book, *How to Solve It,* Pólya introduces heuristic as,

Heuristic reasoning is reasoning not regarded as final and strict but as provisional and plausible only, whose purpose is to discover the solution of the present problem...We shall attain complete certainty when we shall have obtained the complete solution, but before obtaining certainty we must often be satisfied with a more or less plausible guess. We may need the provisional before we attain the final. We need heuristic reasoning when we construct a strict proof as we need scaffolding when we erect a building. (Pólya, 1985, p. 113)

Pólya is pointing out that many aspects of problem solving may end up in a state of complete certainty, but problems often require thinking which is *sufficient* for the problem at hand. Heuristic reasoning may therefore either be a means or an end in problem solving: for probabilistic solutions, heuristics can be an end, while for problems requiring certainty, heuristics may be a means to an end. Pólya's heuristics view supports and complements the views of Nobel Prize economist Herbert A. Simon who posited a view of problem solving known as *satisficing*. Simon suggests real-world solutions by organisms and economics are often practically defined not by rationality or even probabilistic, recursive optimization, instead by a solution which is sufficient for the problem at hand,

Since the organism, like those of the real world, has neither the senses nor the wits to discover an 'optimal path'—even assuming the concept of optimal to be clearly defined—we are concerned only with finding a choice mechanism that will lead it to pursue a 'satisficing' path, a path that will

permit satisfaction at some specified level of all of its needs. (Simon, 1956, p. 136)

Simon advances Pólya's heuristic concepts into a framework where problem solving is defined holistically by considering both the person making the decision and the environment where the decision is made. Gigerenzer and Todd build upon Simon, and contrast the views of *unbounded rationality* and *ecological rationality* (1999). As shown in Figure 1, unbounded rationality, characterized by Gigerenzer and Todd as "Demons", assumes a complete, logical solution exists and resources are available to find such a solution, or as Pólya says, a solution of complete certainty. One common measure of an ideal, probabilistic

solution is to use Bayesian methods, which use statistical methods of probability to define an optimum solution named after the 18th century mathematician (International society for Bayesian analysis (ISBA), 2010). However, it is often the case resources do not exist to find a solution of complete certainty, furthermore, the environment in which one operates does not permit a solution of certainty. The environment may be sufficiently constrained to support a limited number of outcomes discoverable with heuristic thinking: A bounded solution—what Gigerenzer and Todd call ecological rationality and Simon calls satisficing.
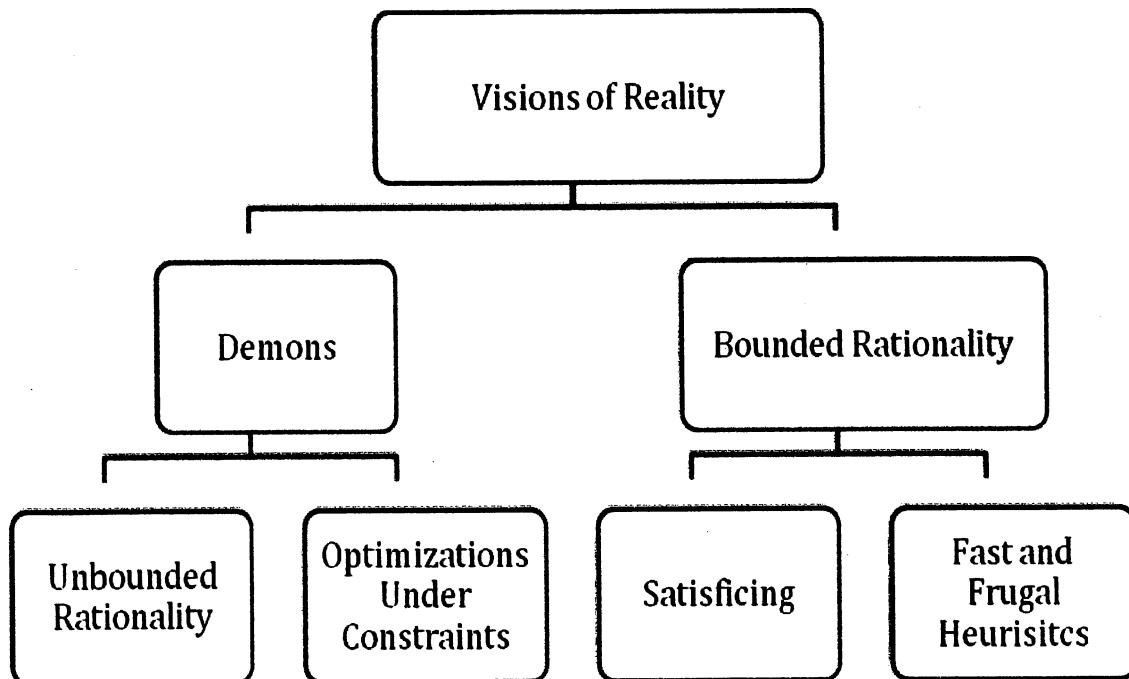
Figure 1. Visions of reality, adapted from "Fast and Frugal Heuristics: The Adaptive Toolbox," by G. Gigerenzer and P. M. Todd, 1999, *Simple Heuristics Which Make Us Smart,* p. 4. Copyright 1999 by Oxford University Press.

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A common theme of the accidents shown in Table 1 is that, while preventable, the accidents did not point to deficiency or negligence by an individual, rather to a failure of the aviation system. As the ICAO Safety Management Manual (SMM) points out, the safety adage that 70% of all accidents are caused by human error is a flawed perspective, "Simply put: humans design, manufacture, train, operate, manage and defend the system. Therefore, when the system breaks down, it is of necessity due to human error. From this perspective and depending upon the level of observation, one hundred per cent of accidents are arguably caused by human error" (International Civil Aviation Organization [ICAO], 2009, p. 7-14).

In the language of Safety Management Systems (SMS), the accidents of Table 1 had a certain chance of occurrence, given the probabilistic nature of the environment intersected with human decision making as opposed to a deterministic endeavor (Dismukes et al., 2007). Spoken in a different vernacular, in *Fate is the Hunter*, Gann says,

> And sometimes they [accident investigators] discover a truth which they can explain in the hard, clear terms of mechanical science. They must never, regardless of their discoveries, write off a crash as simply a case of bad luck. They must never, for fear of ridicule, admit other than to themselves, which they all do, that some totally unrecognizable genie has once again unbuttoned his pants and urinated on the pillar of science. (Gann, 1961, p. 9)

The end result is the operational environment of aviation is a resource constrained environment in variety of dimensions, including time and information. In this environment it is not always possible to attain a theoretically certain solution and only something less is possible: a plausible solution based on a bounded view of rationality. Where Gigerenzer and Todd have the Demons of unbounded rationality, Gann's genie is the resource constrained, bounded rationality. The aim of this paper is to transform the literary eloquence of Gann into a structured heuristic based categorization of cognitive processes which lead to human factor errors.

Heursitics, satisficing, ecological rationality and bounded rationality are concepts which can aptly be defined by Naturalistic Decision Making (NDM). NDM is "the study of how people use their experience to make decisions in field settings. We try to understand how people handle all of the typical confusions and pressures of their environments, such as missing information, time constraints, vague goals and changing conditions" (Klein, 1999, p. 1).

Klein points out NDM research funding started in the early 1980s by the U.S. Army and later by the U.S. Navy following the shoot down of an Iranian airliner by the USS Vincennes in 1988. Various researchers agree that the way people make time pressured decisions is not via a process of generating internal probabilities and comparing rational option sets, rather, decision makers use categorization of prior experience to solve new problems, often including rapid mental simulation of outcomes. These mental simulations are inferential based on past experiences and training (Klein, 2008).

Gigerenzer and Todd's view of unbounded rationality versus bounded rationality and Klein's perspective on NDM are part of the FAA's *Risk Management Handbook*. After pointing out the distinction between analytical decision making as a method useful when time is available, the handbook goes on to discuss automatic and naturalistic decision making as a useful tool in time critical situations. While the handbook mentions NDM, it makes no direct mention of heuristics and has only two references to the general topic of biases, which are often a byproduct of heuristic thinking (Federal Aviation Administration, 2009). If the cognitive processes of pilots are in fact modeled by heuristics, then it is plausible to suggest decision making education and training should include a discussion of heuristics.

While cognitive issues discussed thus far offer a possibility for increasing the performance of aviation personnel, heuristic classification of cognitive issues may offer another dimension to aviation safety reporting programs, such as the Aviation Safety Reporting Program (ASRS) or Aviation Safety Action Programs (ASAP). Hendrickson notes in his doctoral thesis revolving around ASRS data,

> The lack of a standard classification scheme available for sorting the numerous incident reports submitted to ASRS has led to difficulties in analyzing the incidents. There is great depth of information available within these reports, and yet it has remained largely untapped.... airlines are at a loss as how to fully evaluate and analyze the reports they are presented with. Although much emphasis on incidents and accidents is placed on what happened, a more important question is why it happened. (Hendrickson, 2009, pp. 13-14)

If heuristic categories, cognitive biases and NDM are in fact representative of human cognition in operational settings, then these rules may point to a new dimension in classification of error modes in accidents and incidents. The Threat and Error Management Model (TEM) developed by

the University of Texas was driven, in part, by a similar desire to categorize ASAP human factors data into a taxonomy based on an empirically derived model of flight crew behavior. TEM categorizes flight crew actions into threats, errors and undesired aircraft states. This ontology is not only applied to ASAP report categorization, but is also the basis of a training program to enhance flight crew performance. Much of the success of TEM has been attributed to it originating in a naturalistic setting, that of Line Operations Safety Audits (LOSA) (Merritt & Klinect, 2006).

The LOSA approach used to develop TEM is consistent with the *Critical Incident Technique* defined by Flanagan in 1954. Flanagan described the technique as, "The critical incident technique consists of a set of procedures for collecting direct observations of human behavior in such a way as to facilitate their potential usefulness in solving practical problems and developing broad psychological principles" (Flanagan, 1954, p. 1). Flanagan credits the evolution of the technique to the pilot selection process used by the Army Air Forces in the early 1940s during World War II. The critical incident technique involves a systematic interview process with individuals who performed a specific job function or engaged in a critical incident. The systematic method allows the qualitative data of interviews to be transformed into quantitatively useful conclusions. Flanagan described general application areas of the technique, including: "...(a) Measures of typical performance (criteria); (b) measures of proficiency (standard samples); (c) training; (d) selection and classification; (e) job design and purification; (f) operating procedures; (g) equipment design; (h) motivation and leadership (attitudes); [and] (i) counseling and psychotherapy" (Flanagan, 1954, Uses of the Critical Incident Technique section, para. 1). Flanagan cites numerous successes of the technique including the development of the Ethical Standards of Psychologists after the review of more than 1,000 critical incidents from this field.

A report in 1974 by NASA attempted to categorize human factors causes based on a detailed review of 74 accidents selected from a broader set of 200 accidents investigated by the NTSB from 1958 to 1970. This analysis used the computational abilities of 1974 in an attempt to cluster human factors causes after researchers manually identified factors in accidents and coded them against a taxonomy developed for the study. The codes were numerically assigned and grouped in an effort to detect patterns. One conclusion reached by the 1974 report was, "An over-all observation from the decision data leads us to

recommend further research into the decision-making role of the pilot. The present cockpit environment has been shown to be less than ideal for a pilot to be a reliable decision maker" (Kowalsky, Masters, Stone, Babcock, & Rypka, 1974, p. 49).

Since the 1974 NASA report, numerous attempts have been made at classification of human factors. In addition to TEM model, there is the ASRS anomaly codes, ICAO Accident/Incident Data Reporting System, Human Factors Analysis and Classification System (HFACS) and Aviation Causal Contributors for Event Reporting System (ACCERS) (Stolzer, Halford, & Goglia, 2008). Each of these models has strengths and weaknesses. Each is based on human behavior and as such, touches upon cognitive processes and biases. None of the models, however, are heuristic centric.

The review of heuristics, cognitive biases, NDM and classifications of human factors data leads to the following possible hypothesis for further research: The incorporation of vivid re-enactments of decision making scenarios in training, categorized by heuristic features and combined with training in heuristics, will improve the decision making performance of flight crews in time-limited scenarios compared to those crews not provided such training.

In order to address the plausibility of research supporting this hypothesis, a literature review of cognitive processes and NDM follows.

Cognitive Literature Review

This section presents an inventory of cognitive constructs drawn from heuristics and NDM. Where applicable, the summary of 19 accidents in Table 1 are used as a concrete example of the construct.

While many of the constructs are presented with negative examples, each has some positive value. In fact, it is the actual or perceived positive value which causes the construct to persist as a decision making technique, either overtly or unknowingly.

Checklists and Mnemonics

Checklists are the simplest form of a heuristic as they specify a procedure or rule (Bach & Bolton, 2007). A checklist requires a context for usage and a skilled practitioner for execution. Mnemonics are sometime used as a memory aid for checklists. Incident 19, American 1420 is an example of failed checklist usage.

Proverbs

Pólya recognizes the double edge nature of proverbs in problem solving, "It would be foolish to regard proverbs as an authoritative source of universally applicable wisdom but it would be a pity to disregard the graphic

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description of heuristic procedures provided by proverbs" (1985, p. 113). In aviation, there are numerous proverbs which follow the guidance of Pólya. "Hours of boredom with minutes of pure horror" imparts a warning about complacency. "God-Slob" or "ego shutdown" represent overbearing cockpit management styles leading to loss of crew resource management effectiveness in the cockpit (J.R. Cannon, personal communication June 20, 2010).

Analogy

Analogy is a common heuristic used to draw inferences between similar events. Understanding analogy is important as, "...people often use vague, ambiguous, incomplete, or incompletely clarified analogies" (Pólya, 1985, p. 41).

Analogy is a simple and often used heuristic. Like other cognitive models, overt awareness of usage avoids misuse and capitalizes on strengths, "It would be foolish to regard the plausibility of such conjectures [analogy] as certainty, but it would be just as foolish, or even more foolish, to disregard such plausible conjectures" (Pólya, 1985, p. 43). Incident 7, Ryan 590 provides an example of analogy of past experiences.

Auxiliary Elements

Pólya defines this heuristic as "An element that we introduce in the hope that it will further the solution is an *auxiliary element*" (1985, p. 46). Flight training examples of the addition of auxiliary elements include using a mental or physical geometric overlay of the directional gyro to visualize a holding pattern entry or traffic pattern entry. Auxiliary elements may also include placing objects in key places in the cockpit as a reminder aid, such as a laminated checklist between throttles as a reminder of a cross feed operation.

Decomposing and Recombining

Breaking a problem into smaller parts is a fundamental act of problem solving. Simply put, a problem is broken into parts and then recombined into a whole. The challenge is, "Too many or too minute particulars are a burden on the mind. They may prevent you from giving sufficient attention to the main point, or even seeing the main point at all" (Pólya, 1985, p. 76).

The 1972 Eastern Airlines flight 401 accident may offer a telling portrayal of this heuristic. In this accident the flight crew allowed the diagnosis of a landing gear indicator light to lead to controlled flight into the terrain of the Florida Everglades.

Availability Heuristic

The availability heuristic is an easily understood and often cited heuristic in cognitive biases. The heuristic is defined as, "People using this heuristic judge an event as likely or frequent if instances of it are easy to imagine or recall" (Slovic, Fischhoff, & Lichtenstein, 1982, p. 465). An everyday example of this heuristic is the fear people experience to go in the water after watching the movie *Jaws*. In Table 1, incident number 15 involving American 903 suggests the crew discussion of convective activity led them to improperly associate a stall with wind shear rather than a stall caused by insufficient airspeed. The result was an inappropriate selection of recovery technique based in part on the availability heuristic.

The availability heuristic in human thought is based upon how people use repetition as means to remember information. The availability heuristic inverts the repetition technique and uses the strength of association to judge frequency of occurrence. While the availability heuristic is a source of cognitive bias, it is also recognized as an "ecologically valid clue for the judgment of frequency because, in general, frequent events are easier to recall or imagine then infrequent ones" (Tversky & Kahneman, 1974, p. 164).

Representativeness Heuristic

This heuristic is widely known in statistical circles and is described as "people believe samples to be very similar to one another and to the population from which they are drawn. We also suggested that people believe sampling to be a self-correcting process" (Tversky & Kahneman, 1982, p. 25). An everyday example of this heuristic is the gambler's fallacy of believing a sequence of bad luck will be corrected or balanced by a sequence of good luck.

In flight operations, the representativeness heuristic may be used by pilots to judge the acceptability of continuing a flight operation in adverse conditions based on a sampling of other aircraft successfully executing the same operation. While this technique often works given the ecological reality of flight operations, misuse of representativeness in changing conditions may lead to negative outcomes. Incident 1, USAir 1016 demonstrates failure of the representative heuristic when a prior aircraft reported a smooth ride yet flight 1016 experienced windshear.

Adjustments from Anchor Heuristic

The adjustment from anchor heuristic is described as "anchor on a specific cue or value and then adjust that value to account for other elements of the circumstance. Usually the adjustment is insufficient. So, once the anchor is set, there is a bias toward that value" (Lehner, Seyed-Solorforough, O'Connor, Sak, & Mullin, 1997, p. 699). In aviation parlance, this is often known as *get-there-itis* and in cognitive circles as plan continuation bias.

There are numerous examples in aviation of the

anchoring heuristic. Table 1, incident 5, Southwest 1455 demonstrates a crew continuing an approach in the face of numerous other inputs indicating abandonment of the approach was the more suitable option.

Knowing with Certainty and Confirmation Bias

The consequence of the cognitive belief of certainty is overconfidence and lack of questioning the accuracy of the fact in question. Cognitive research has shown a cause of unwarranted certainty is "people's lack of awareness that their knowledge is based on assumptions that are often quite tenuous" (Slovic et al., 1982). While certainty has been the debate of philosophers far beyond the scope of this paper, in the context of flight operations, Gigerenzer and Todd frame the issue concisely as, "...Nature is deterministic and certain; but for humans, Nature is fickle and uncertain. Mortals cannot know the world, but must rely on uncertain inferences, on bets rather than on demonstrative proof" (Gigerenzer & Todd, 1999, p. 8). Knowing with certainty in time pressured decision environments inherently conflicts with the need to have certain foundations upon which to act.

Related to certainty is the heuristic of confirmation bias. Lehner describes this as "People tend to seek and focus on confirming evidence, with the result that once they've formed a judgment, they tend to ignore or devalue disconfirming evidence" (Lehner et al., 1997, p. 699). Table 1, incident 9, the gear up landing of Continental 1943 demonstrates an example of confirmation bias.

Frequency Bias and Quick Estimation

Lehner defines this heuristic as "People often judge the strength of predictive relations by focusing on the absolute frequency of events rather than their observed relative frequency... Information on the nonoccurrence of an event is often unavailable and frequently ignored when available" (1997, p. 699). Contrasting Lehner's view are those of Hertwig, Hoffrage and Martignon, who demonstrate an opposite view (citing Jonides and Jones), "'Ask about the relative numbers of many kinds of events, and you are likely to get answers that reflect the actual relative frequencies of events with great fidelity'" (1999, p. 212).

The conflict between the two interpretations of frequency bias points may be reconciled by an ecological context, "...what is the structure of the environments in which quantification occurs, and what heuristics can exploit that structure?" (Hertwig et al., 1999, p. 215). Hertwig et al. point out while many frequency distributions have a normal distribution or bell shaped curve, a large number of frequency occurrences have a skewed normal distribution or *j-shaped* curve, an example being the distribution of medals won in the Olympic games in a given year by various countries.

One inference to be noted from the disagreement is highly skewed populations are less likely to suffer from frequency bias. A negative aspect is an omitted frequency is likely to be ignored.

Concrete Information

The concrete information heuristic is framed as, "Information that is vivid or based on experience or incidents dominates abstract information, such as summaries or statistical base-rates...Concrete and vivid information contributes to the imaginability [sic] of the information and, in turn, enhances its impact on inference" (Lehner et al., 1997, p. 699). In everyday terms, the greater the impact of an experience, the more it is remembered.

The concrete information heuristic is used by Klein in *Sources of Power* in part to suggest how novices can be trained to think like experts. Klein writes how expert stories, "...contain many lessons and are useful as a form of vicarious experience for people who did not witness the incident...A good story is a package of different causal relationships—what factors resulted in what effects...a story records an event that happened within a natural context" (Klein, 1999, pp. 179-181). Stories, often expressed as retrospectives, have the potential to impart concrete information to those who did not directly experience an event. This is not to say stories should replace procedural knowledge, however, for the development of inferential skills vivid, vicarious stories may hold tremendous value.

In the area of flight training, the methods available to impart concrete information to students include flight training, simulator training, reenactments, observation flights and lecture—each with its own monetary cost, time commitment and value. In speaking with David Zwegers, Director of Flight Safety of Embry Riddle, the author inquired about the frequency of the use of emotive reenactments in the pilot training program. Mr. Zwegers indicated reenactments were used occasionally, but not to a great degree, and observation rides in simulators with other students would be more common. He also noted Embry-Riddle would soon be using Flight Operations Quality Assurance (FOQA) data from training flights to replay flight information (personal communication, June 14, 2010). The author agrees with Klein when he says, "The method we have found most powerful for eliciting knowledge is to use stories" (Klein, 1999, p. 189). A demonstration comparing an emotive and non-emotive way of imparting knowledge is available at http://www.tuccio.com/dav712a. Additionally, the AOPA Air Safety Foundation has a number of instructional and emotive, interactive courses at http://www.aopa.org/asf.

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Regression Towards the Mean

This heuristic of this behavior suggests people misattribute cause and effect rather than recognizing statistical normal distributions. That is,

> ...maximum performance is usually followed by less than maximum performance (i.e., towards the mean) and minimum performance is followed by greater than minimum performance...In a discussion of flight training, experienced instructors noted that praise for an exceptional smooth landing is typically followed by a poorer landing...while harsh criticism after a rough landing is usually followed by an improvement on the next try. The instructors concluded that verbal rewards are detrimental towards learning, while verbal punishments are beneficial, contrary to accepted psychological doctrine. (Tversky & Kahneman, 1974, p. 1127).

Awareness of regression towards the mean is similar to the learning curve known as the *learning plateau*, where student progress slows after a period of growth (Federal Aviation Administration, 2008). However, there may be advantages of expressing the human behavior from both perspectives, as each allows insight into cognitive processes.

Recognition Heuristic

In its simplest form, the recognition heuristic is the ability to recall something from memory as unknown, familiar or well known. Recognition is then used to make inferences about objects related to the recognized object. In other words, an inaccessible thing to be measured is measured by an accessible mediator (Goldstein & Gigerenzer, 1999). Absent human cognition, numerous measurement instruments use mediators, in aviation altitude and airspeed are measured by calibrations of pressure and predictions of turbulence are based on rainfall intensity.

In certain domains of knowledge, when the object to be measured has directional correlation to the mediator which can be recognized, the recognition heuristic may offer reliable benefits to the user, absent a more deterministic method. An academic example is to ask subjects unfamiliar with population sizes of cities to judge which cities are larger based solely upon their recognition of the city name. When this experiment has been attempted, not only did it yield significant results, it actually showed subjects more ignorant of the true population numbers scored better than the informed group. This leads to Gigerenzer and Goldstein to state a *less-is-more* heuristic "occurs when the recognition validity is greater than the knowledge validity" (1999, p. 46). Misused, the less-is-more heuristic could yield disastrous consequences in aviation; however, as a building

block in a cognitive process, understanding the use of accessible mediators to infer inaccessible things is a valuable skill.

One broad example of the accessible pointing to the inaccessible is go/no-go decision. This fundamental safety decision in inaccessible and it is arrived at by looking at directionally accessible indicators for the determination.

Minimalist, Take the Last, Take the Best Heuristics

Benjamin Franklin proposed what he called *Moral or Prudential Algebra*, or *Franklin's Rule* as a method to make decisions. In its simplest sense, the method involves making a list of pros and cons, applying weights to each factor, adding up the result and taking the higher result to make a decision. An attempt to execute Franklin's Rule considering all factors and using regression techniques may result in problems challenging even to computers. Building on the representative heuristic, Gigerenzer and Todd suggest what is needed for time and resource limited decision making is a *stopping rule* (Gigerenzer & Goldstein, 1999).

A simple heuristic, the "Minimalist" prescribes if one feature is recognized and another is not, stop the search for cues and use the recognized feature as the basis of inference to make an inferential choice. If both features are recognized, choose another cue and continue the process until something is not recognized. A modified version of the Minimalist approach is, "Take the Last" which tries to positively use the *Einstellung Effect*. The Einstellung Effect suggests people have a predisposition to solve a new problem based on a prior success, even though the new problem may not be best suited by the prior solution method. In the Take the Last approach, the order of cue selection is based on a prior success of cue selection. A modification of Take the Last is "Take the Best", whereby one orders the cues selected based on their highest inference validity to solving the problem. The order of selection is based either on intuition or institutional learning (Gigerenzer & Goldstein, 1999).

While these heuristics may seem trivial in their presentation, in the opinion of the author, this type of heuristic is used in practice for the deviation around thunderstorms based on weather radar interpretation. The weather radar interpreter looks for recognized features, takes the best match of prior familiarity, and uses that as the basis of inference for best path selection. Thunderstorm deviation is often a satisficing solution process.

Classical Decision Making (Non-Heuristic Alternative)

In a classical decision making model, the *rational choice* method includes: Consider a wide range of options; consider various objectives; weigh costs, risks, benefits of each option; search for new information in evaluating

options; assimilate all new information; consider the positive and negative consequences and risks; and plan for alternatives if the risks occur. Klein points out in time-pressured situations, some flaws with this plan include, "...you do not have all the data you need, or are not sure how to do the ratings, or disagree with the weights, or run out of time before you have finished" (Klein, 2008, pp. 28-29).

Klein continues to point out in many scenarios the rational choice method is appropriate. However, in a time or resource constrained domain, the rational choice method only serves as a model, not how people really think in time-pressured, resource constrained scenarios.

Recognition-Primed Decision Model

In response to a request in 1984 by the Army to study how people make decisions under time pressure, Gary Klein defined the Recognition-Primed Decision Model

(RPD). After living with firefighters and extensive interviews, Klein came up with the RPD model shown in Figure 2. Klein's RPD identifies three models of time pressured decision making all starting with recognition of a typical situation. In Variation 1 of the RPD, the typicality is obvious to the decision maker based on expert experience and intuition allowing a set of *expectations, goals, cues* and *typical actions* to be recalled and set in motion. Variation 2 of the RPD recognizes the need to diagnose the situation to determine a typical situation, and then compare expectancies of the prototype to the actual occurrence and adapt accordingly. Variation 3 introduces deviations from typicality and how actions must be modified to suit the novel situation using *mental simulation*, again based on experience (Klein, 1999).
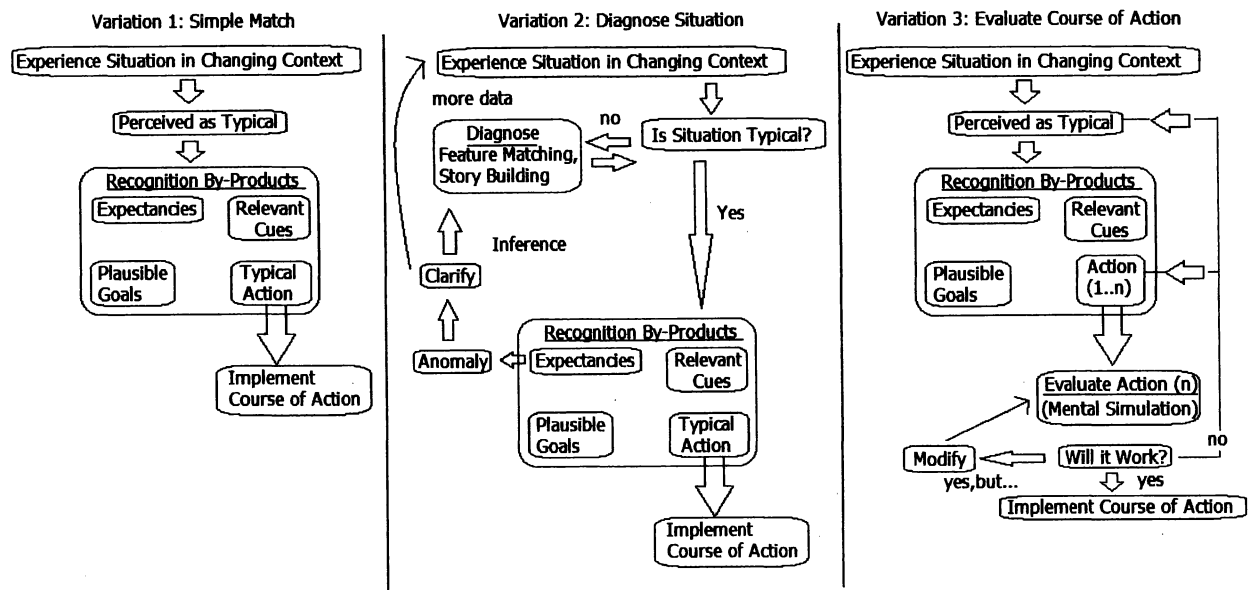

Figure 2. Recognition Primed Decision Model (RPD). Adapted from *Sources of Power: How People Make Decisions*, by G. Klein, 1999, p.25.

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The RPD model is an outgrowth of the satisficing concepts of economist Herbert Simon, previously discussed, whereby the solution found is the first workable solution rather than the optimum solution. The RPD model is one expression of NDM and Klein reports it models 80-90% of time pressured decision making (Klein, 2008). Figure 3 shows a comparison made by the FAA between a non-time constrained approach to decision making and the NDM/RPD model advocated by Klein.
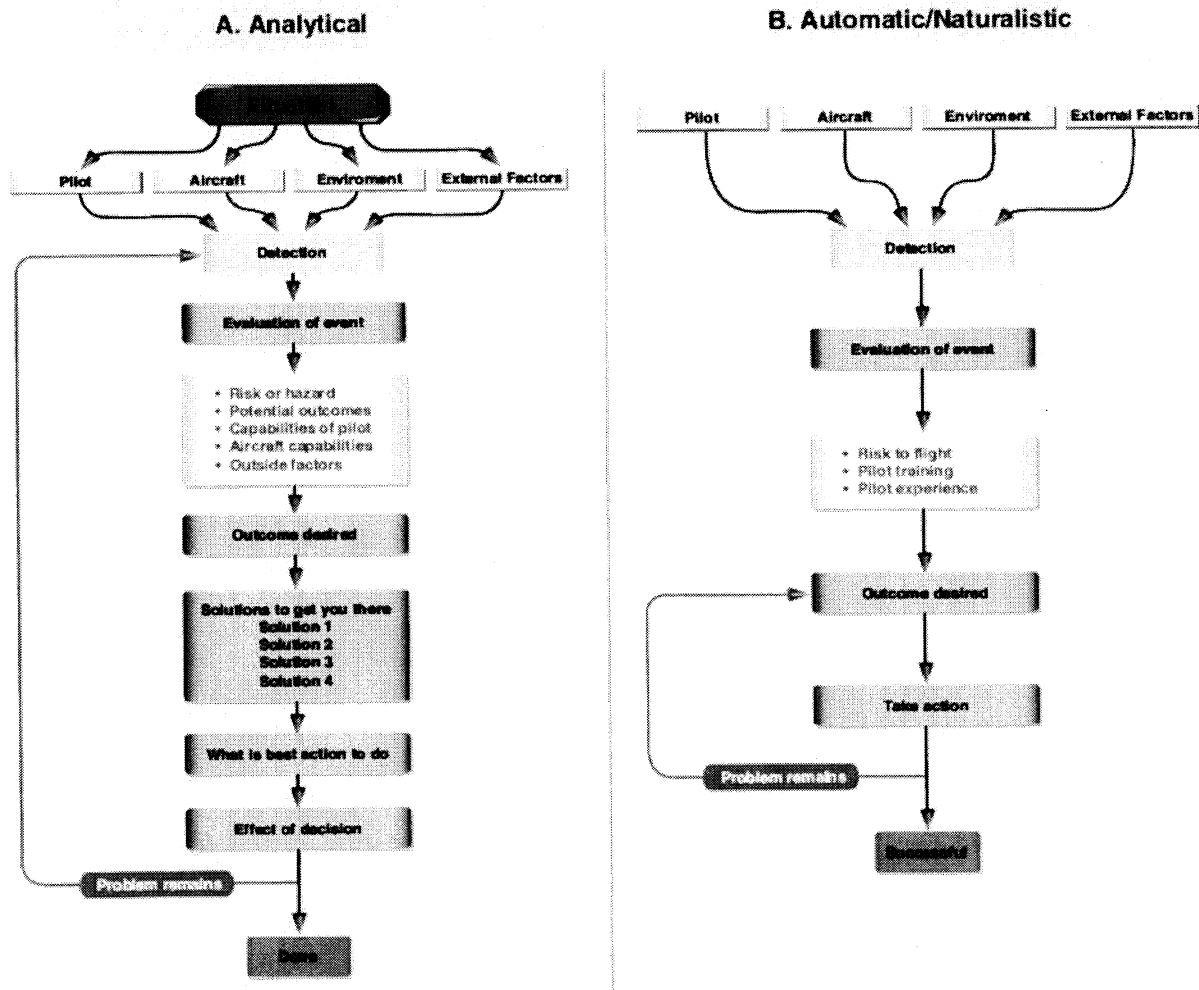

Figure 3. Comparison of convential, non-time constrained, analytical decision making and time-constrained, naturalistic decision making. From *FAA Risk Management Handbook,* by the Federal Aviation Administration, 2009, p. 5-5.

The RPD model is not purported to be fool proof, only a realistic model of cognition in time pressured decision making. In Table 1, incident 2, the response of TWA 843 can be modeled in part after the RPD model leading to an erroneous and negative outcome.

Research Design

The literature review presented leads to the following for a research design: The incorporation of vivid re-enactments of decision making scenarios in training, categorized by heuristic features and combined with training in heuristics, will improve the decision making performance of flight crews in time-limited scenarios compared to those crews not provided such training.

The elements necessary to investigate the hypothesis includes: (a) An inventory of heuristics and decision making features; (b) a collection of vivid, re-enactments of decision making scenarios set in a natural, pilot environment organized by heuristic; (c) a training syllabus using the heuristic taxonomy and re-enactments; (d) a sufficiently large group of pilots of varied experiences to participate in the training; and (e) generic, yet realistic, pilot performance exercises to test the trained and control groups to measure differences. Each of these elements is discussed in turn.

Heuristic Inventory

An inventory, building upon the ones presented in this paper, will be the basis of a training syllabus and as an organizational method for the vivid re-enactments. Each heuristic will consist of a cognitive explanation, practical examples, negative and positive aspects and quiz questions to verify student understanding.

Vivid Re-Enactments

As discussed in the section, *Concrete Information*, and central to the hypothesis, vivid re-enactments are believed to be a key part of inferential decision making. A collection of vivid re-enactments, likely taken from simulator sessions, or other means, will be created and targeted at each heuristic. The re-enactment will incorporate sound, realism of flight scenarios and parameters both from a cockpit and external perspective, along with human emotion designed to elicit emotive responses from the student.

Training Syllabus

A training syllabus will be developed to effectively administer the heuristic and re-enactment information. The training syllabus will incorporate standard elements of training, including diagnostic quizzes.

Subject Pilots

A statistically representative group of pilots of varied experiences will be selected to participate in training. Two groups will exist, one which will receive the outlined training, another which will not.

Pilot Performance Exercises

The pilots who receive the training will be subjected to in-flight decision making, typical of aviation scenarios where there is limited time and incomplete information. Both the control group and the pilots who received the training will be subjected to the same exercises.

Data Analysis

After the training and exercises, the collected information will be statistically analyzed. The information analyzed will be the pilot performance exercises as well as surveys of the trained pilots and their impressions of the value of the training.

Alternative Research Design

The outlined research design is likely a resource intensive undertaking. An alternative design to discover support of interest in heuristics and NDM could be done using a survey. Questions designed to gauge present population understanding of heuristics would not only support the hypothesis but also help refine the full research design.

Conclusions

Heuristics persist as a cognitive strategy because they often work. The recognition heuristic describes the use of an accessible mediator to measure an inaccessible item. The recognition heuristic can be easily understood through a building block description first of how an altimeter measures altitude by way of pressure, then one can explain how the go/no-go decision uses similar accessible measurements to make the inaccessible decision. However, it is language and concepts that permit the encapsulation of examples into abstract constructs. Heuristics and its associated constructs are the language necessary to fully describe a key aspect of human cognition in the operational environment of aviation—an environment often fraught with incomplete information and time critical decisions.

Mathematics Magazine from 1987 described Pólya's 1944 heuristic based approach to problem solving, *How To Solve It!* in this way, "For mathematics education and the world of problem solving it marked a line of demarcation between two eras, problem solving before and after Pólya" (Pólya, 1985, p. xix). If in fact heuristics plays such an important part in problem solving and human bias, then the author believes it a failing of pilot training that a significant part of the pilot community is not overtly educated in this form of cognition.➤

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Appendix

Table 1

Summary of Aircraft Accidents and Cognitive Analysis

ID	Flight/Year	Encounter	Cognitive Observations
1	USAir 1016, 1994	Windshear	"Characteristic human cognitive tendencies under high workload, time pressure and stress…and retrieval of declarative knowledge…is impaired." (p. 22)
2	TWA 843, 1992	Erroneous Stick Shaker	"Rapid decisions by experts are often driven by automatic retrieval from memory of scenarios from past experiences…to match the current situation (described as 'recognition-primed decision making')." (p. 32)
3	AA 1572, 1995	Descent Below MDA	"[the flying pilot] may have been unwittingly depending on the first officer's [non-flying pilot] callouts his cue to take action…Wiener and Curry describe examples of this phenomenon in aviation operations, referring to it as "primary-backup inversion", in which a backup cue such as an altitude alert becomes the primary signal to which the pilot responds." (p. 44)
4	American International 808, 1993	Missing Visual Cue	"…pilots, like all individuals, are vulnerable to plan continuation bias, which makes them slow to recognize that an original or habitual plan of action is no longer appropriate to the situation and must be revised." (p. 59)
5	Southwest 1455, 2000	Unstabilized Approach	"…cognitive factors probably make all individuals vulnerable to some degree of plan continuation errors. Among those factors are overconfidence bias, a tendency to overestimate one's own knowledge; confirmation bias, a tendency to seek and notice only those cues that confirm a currently held belief or plan…; and the anchoring heuristic, which weighs cues supporting the current plan more heavily than conflicting cues when plans are revised." (p. 78)
6	FedEx 14, 1997	Pilot Induced Oscillations ("PIO") During Landing	"…quickly retrieving and executing declarative knowledge in the midst of a PIO is at best difficult. In contrast to highly practiced procedural knowledge, retrieval of infrequently used declarative knowledge from memory is often slow and effortful." (p. 90)
7	Ryan 590, 1991	Wing Contamination on Takeoff	"Individual experiences may not cover the full range of possibilities and thus may lead to incomplete and sometimes misleading mental models of prototypical situations." (p. 97)
8	Tower 41, 1995	Loss of Control on Takeoff Roll	"This accident illustrates the unanticipated ways in which habits that seem harmless or even advantageous in routine situations pose a latent threat that may cause harm when circumstances combine in just the wrong way." (p. 107) (described as "practical-drift" (p. 104))
9	Continental 1943, 1996	Gear Up Landing	"In general, when confronted with a problem, individuals are prone to settle on an explanation that seems consistent with their previous experience (described as 'recognition primed decision-making by Klein, 1997)…The phenomenon, called confirmation bias, has been observed in diverse settings…" (p.122)
10	AA 102, 1993	Runway Excursion After Landing	"…under time pressure, surprise, workload, or stress individuals are often unable to retrieve quickly from memory all information relative to the situation, especially if that information is not elaborated or is not used frequently. Among the distinctions cognitive psychologists make about the ways in which information is organized and stored in memory is a distinction between *declarative* and *procedural* knowledge." (p. 138)

ID	Flight/Year	Encounter	Cognitive Observations
11	Continental 795, 1994	Aborted Take-Off	"…limitations in human memory can lead individuals to confuse memory of performing a task many times previously or memory of having recently thought about performing the task with actually having performed the task currently." (p. 154)
12	USAir 405, 1992	Stall on Take-Off	"This accident and others discussed in this book illustrate the difficulty expert decision-makers sometimes have in recognizing whether past experience and knowledge are adequate to evaluate the current situation." (p. 163)
13	Valujet 558, 1996	Landing Short of Runway	"Experts operate largely by recognizing familiar situations and automatically retrieving directly relevant information from memory." (p. 180)
14	Air Transport International 805, 1992	Disorientation, Loss of Control in IMC	"Individuals suddenly confronted with a totally unexpected anomaly with which they have no experience typically require at least a few seconds to recognize and evaluate the situation and decide on an appropriate response, and even longer if the anomaly is subtle." (p. 191)
15	American 903, 1997	Loss of Control at Altitude	"This discussion [about thunderstorms in the vicinity of the flight path] would have primed them [flight crew] to think about possible consequences of the weather, such as windshear, and would have facilitated retrieval from memory of windshear recovery techniques (described as 'availability heuristic). Research on human memory has shown that the way individuals conceptually frame their current situation substantially biases what information is retrieved from memory and how that information is interpreted." (pp. 205-206)
16	Simmons 3641, 1994	Application of Propeller Beta in Flight	"Automatization can make us vulnerable to errors in which we automatically execute a response to a situation that resembles – but only superficially – other situations in which the response *is* appropriate." (p. 220)
17	AA 1340, 1998	Cat II ILS Autopilot Deviation	"Considering the inherent limitations of human reaction time to unexpected events that require recognition, analysis, and response selection, the rapidity of the large pitch-down at the moment the captain was transitioning to outside visual references…" (p. 228)
18	Delta 554, 1996	Landing Short of Runway	"Plan continuation bias and the difficulty of quickly and correctly assessing whether attempts to salvage an approach will work should be emphasized…" (p. 243)
19	American 1420, 1999	Destabilized Approach and Runway Excursion	"Under high workload and stress, individuals attempt to simplify their tasks and reduce mental demands. We suspect that one way pilots unwittingly simplify task demands in these challenging situations is to shift from a proactive stance to a more reactive stance, responding to each event as it occurs, rather than managing the overall situation strategically." (p. 252)

Note: This table is not meant to imply one factor caused each accident. The intent of this table is to draw out only the cognitive aspects of each accident for the purpose discussing cognitive issues in a broader context. Page numbers of citations refer to the original source. Adapted from Dismukes, R. K., Berman, B. A., Loukopoulos, L. D., 2007, *The Limits of Expertise: Rethinking Pilot Error and the Cause of Airline Accidents*, Ashgate Publishing, Burlington, VT.