Pilots and Memory: A Study of a Fallible Human System

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Abstract

This paper looks at human memory with an emphasis on pilot performance in the cockpit. The basic biological processes of memory are discussed, including how memory is formed, stored, and retrieved, and how organic and non-organic influences may degrade or impede memory performance. Key findings in current research indicate that prospective memory failures may pose a significant threat to flight safety. Information derived from NASA's Aviation Safety Reporting System (ASRS), as well as NASA research that investigated concurrent and deferred task demands for pilots, provides valuable insight into the fallibilities of human memory as it applies to flight operations.

Introduction

Human memory is a wonderful thing. It helps us remember where we parked our car, where we placed our keys, and what we were doing when we heard the news of the death of John Kennedy (if you were old enough to remember), or the attacks of 9/11. Strikingly, you may have snickered when the car parking and key examples were used because you may have had a bad experience with one of those. Haven't we all lost our keys and forgotten where we parked our car at one time or another? But memories of a larger magnitude, such as what you were doing when a major national tragedy occurred, are fairly well ingrained and reliable memories that last a lifetime (also known as a "flashbulb memories," [Brown & Kulik, 1977, cited in Searleman & Herrmann, 1994]). So, what is memory? How do we store memories? Why are some things so easily forgotten while others are permanently stored?

This paper will strive to answer those questions by discussing the basic system of human memory: its biological bases, outstanding capacity, lightening-fast speed, and most importantly, its inherent flaws and limitations. Case studies, personal observations, and literature reviews will then be used to illustrate how memory is used in cockpit operations, and how its limitations can become problematic.

Biological Bases of Memory

Memory of course, is a function of the brain. Over the years, researchers have postulated many theories of how memory actually works. Support and dissension are typical for many of these theories. Since memory is not truly an exact science (yet), the generally accepted theories of memory will be used as the anchor for this discussion.

The underlying mechanism that allows us to have memory is called a neuron. The brain has approximately 100 billion neurons, each of which connects with thousands of other neurons (Solso, 2001). The majority of these neurons reside in the cerebral cortex. It is believed that memories are stored at the junctions between neurons, called the synapses. The following
description of the neuron and the synaptic junction explains how this process works:

When a signal, an action potential, travels down the axon of a neuron, it may reach many synaptic junctions with other cells. At these junctions, chemical transmitters such as acetylcholine, adrenaline, noradrenalin, serotonin etc are released and travel the very short distance across the synaptic junction. Receptor sites on the dendritic spine of the next cell can each accept a molecule of transmitter. If enough receptor sites are activated, the dendrite will signal the cell body of the next neuron. Receptor sites may cause an excitatory (more likely to signal) or an inhibitory (less likely to signal) action. It is the sum of these effects that will eventually cause a response in the next neuron.

Memories are laid down when permanent changes are made to the effect of the release of chemical transmitters. Postsynaptic sites may become more sensitised to the effect of the chemicals or additional receptor sites may be grown. (AKRI, 2004)

Figure 1. The Synapse. Courtesy Applied Knowledge Research Institute website.
The exact location of where memories are stored in the brain may also be somewhat elusive, but a few things are fairly certain. Memories are distributed throughout various parts of the brain. The hippocampus, for example, seems to play an important role in converting memory from a short-term to a long-term, permanent form (TSFN, 2002, p.18). Damage to the hippocampus may result in a person not being able to remember new things yet able to remember clearly, events from before the damage (AKRI, 2004). Other areas of the brain where memory is stored include the medial temporal region and parts of the thalamus for declarative knowledge, the basal ganglia for procedural knowledge, the amygdala for emotional aspects of memory, and the cerebellum for motor learning where precise timing is involved (TSFN, 2001, p.18). Because of this compartmentalization of memory stores, traumatic brain injury can affect memory in varying ways, depending on the location of the injury. The next page illustrates the major components of the brain.
Types of Memory

Most of us are familiar with, or have at least heard of, the three types of memory storage classifications. They are sensory memory, short-term memory, and long-term memory. Each type serves a distinctively different function, varying in capacity (how much can we store), storage (where it is stored), and retrieval times (how fast we can access the information).

Sensory memory (also known as the sensory register) allows us to keep a highly accurate record of what each of our senses has just experienced for a brief period of time (Searleman & Herrmann, 1994). The duration of sensory memory is very short, with estimates of less than ½ second to a few seconds, depending on the sense involved and the physical conditions (p.51).

Short-term memory (STM) has a slightly longer retention time than sensory memory. Without rehearsal, 30 seconds is a good approximation. The use of rehearsal (i.e., repeating a phone number over and over) can significantly increase retention time.

Long-term memory (LTM) has the longest retention time (easily lasting a lifetime in some cases). How STM becomes LTM is dependent on a number of factors. Repetition, and over learning, for example, can facilitate this process. A major, sudden, life-altering event may be processed directly into LTM, bypassing STM. The beginning of this paper mentioned "flashbulb memory" as an example of this process.

When speaking of LTM, there are a few associates that should also be mentioned. The first includes semantic memory. Semantic memory is knowledge about the world; knowing the meaning and definitions of things (AKRI, 2004). It is theorized that knowledge of the world is stored in the form of "frames," "scripts," and "templates" that allow a person to derive meaning for familiar, as well as unfamiliar, events and settings.

The second LTM associate is called episodic memory. Episodic memory is personal in nature and relates to personal experiences of a situation or episode. Two people perceiving the same event may have different episodic memories of that event. This depends on their own interpretation from their own individual experiences (AKRI, 2004).

The third LTM associate is called autobiographical memory. Related to episodic memory, autobiographical memory usually includes details about a particular time, place, and details about objects and events that were experienced (AKRI, 2004).

The fourth LTM associate is called procedural memory. Procedural memory is the memory used for skills, or doing procedures. Riding a bike, sewing, or knitting are common examples of this type of memory. Interestingly, people with severe memory loss, even for their own name, still have intact procedural memory. Patients suffering from learning problems are often still able to learn new skills, even though they may not know that they have learned them (AKRI, 2004).

The fifth and final LTM associate is called conditioning. Most people are familiar with this type of memory and the man that brought it to light (Pavlov). Conditioning results from pairing actions with reward or from pairing actions with parallel stimuli. Two types of conditioning exist: Classical conditioning, where a neutral event such as a bell ringing is regularly paired with a response-evoking event. Eventually the response can be evoked from
the neutral stimulus. Operant conditioning, where a reward is given for progressive improvement at a task that may start with random movement and due to the progressive reward, will end up in the completion of the task (AKRI, 2004).

Memory in Action

Why is it that some people have better memory than others? Why is it so hard to remember certain things while other things are "right there" for retrieval? What are the biological bases of faulty memory? What are the environmental bases of faulty memory? What about the emotional bases of faulty memory? This section will attempt to answer all these questions to help us understand why memory is so susceptible to errors.

Nobody has perfect memory. If they did, they would be able to retrieve every event or sensation that they were ever exposed to in their entire life, and be able to recall each and every one of those events with lightening fast speed and vivid clarity. Unfortunately, we do not have this "super" memory. Most people have what is classified as "normal" memory, which is reliable, but subject to numerous faults and limitations.

To begin with, a common fallacy of memory posits that the memory of a person in his or her 20s will have a better memory than a person in his or her 80s. Research indicate that although certain types of memory functions do noticeably decrease with age, other memory abilities either are unaffected or at most show only marginal decreases that have little practical importance (Searleman & Herrmann, 1994). There is also a wide amount of variation between older people; some do not experience a memory decrement at all. Undoubtedly, part of the reason is that the older persons have had so much more life experiences and recollections to draw upon, compared to their younger counterparts. Therefore, when the older person begins to experience biological decrements, the vast amount of stored knowledge of life events tends to provide an offset.

Countermeasures for retaining (or even improving) memory, as one ages, is as simple as staying active and challenging the mind. Older people tend to disassociate from mind-stimulating activities, likely because they are now retired, accepting of a world of relaxation, highly predictable daily activities, and less interaction with others. Countermeasures include increasing activities, socializing, hobbies, and reading. Just the act of doing a crossword puzzle every day can offer enough stimulation to slow down stagnation of one's memory. The adage "use it or lose it" may be the best advice here.

Information Gathering

You could think of memory in terms of a computer, as both systems are very similar in the way they process information (in its simplest form, a three-step process). The first step is information gathering. This is the step where sensory information is used to determine what the stimulus is, and what you would like to do with it. Five sensory channels are used to perceive the world; these are Olfactory (smell), Gustative (taste), Somatosensory (touch), Visual (sight), and Auditory (hearing) (AKRI, 2004). Sensory registers (that are really micro-memories) are used to store information for a very short time (a few milliseconds), but maybe longer if the stimuli are strong. Iconic store (visual information) and echoic store (auditory information) are examples of sensory registers. We are bombarded with stimuli every second of our lives, therefore some of this information will be disregarded because it is either meaningless or unimportant, while other parts of it will be encoded and sent to a storage
location (LTM).

**Writing the Information to LTM**

The second step, writing the information to LTM, enables vast amounts of information to be stored for indefinite periods of time. LTM can be compared to a hard drive on a computer. But, how does something become a LTM? As in most aspects of memory function, there have been a number of theories postulated to describe this process. For the sake of simplicity, the most widely accepted theory, called the consolidation theory, will be discussed here. The consolidation theory holds that the transformation from STM to LTM is usually a progressive one and while a particular memory is in transition, it is susceptible to disruption or even erasure (Searleman & Herrmann, 1994). According to the consolidation theory, most events and stimuli and not immediately placed into LTM, but only gradually, and only in certain circumstances, become fixed in our memory (p.155).

Problems that may be encountered in the transfer of STM to LTM are numerous. One example is retrograde amnesia (RA). RA can occur when someone loses consciousness for an extended period of time. Memories of events that occurred just before the loss of consciousness are erased (albeit temporarily), and events occurring at the actual time of the trauma are lost forever (p.156). However, all other memory functions remain normal.

Drugs, taken for psychological disorders, such as widely prescribed benzodiazepines (BZs), may also have an adverse affect on memory consolidation. BZs, with their more common names such as Librium and Valium, are prescribed for a variety of disorders including sleep disorders, anxiety, depression, epilepsy, panic, and muscular tension (Stephens, Duka, & Andrews, 1991, cited in Searleman & Herrmann, 1994, p.160). One of the side effects of BZs is a marked impairment in memory ability. However, the impairment seems to only affect the coding process, leaving STM and LTM largely unaffected (p.161).

Neurotransmitters, which are chemicals released by a neuron into a synapse, can increase or decrease the likelihood that other neurons will fire action potentials. Manipulation of neurotransmitters may alter the transfer process. For example, Squire (1987) found that drugs that affect the ability of neurons to secrete the neurotransmitter acetylcholine into their synapses can either improve or retard memory. Drugs that interfere with the normal use of acetylcholine prevent the formation of new memories. In fact, Alzheimer's disease occurs because of the tremendous loss of acetylcholine-secreting neurons.

Another neurotransmitter that can affect memory is called norepinephrine. In this case, norepinephrine, when administered at the proper time, can enhance memory performance. Research has shown that students who were administered norepinephrine immediately following learning, were able to retain more of the information than the control group (p.161).

The above examples illustrate how varying levels of arousal affect memory consolidation. Lower levels will inhibit memory, while higher levels enhance memory. Keep in mind that a high level of adrenaline, which the body produces naturally, increases the state of arousal and therefore increases memory consolidation.

Encoding of memories from STM to LTM involves much more than can be described in this paper. For simplification, the above examples were used as a basic introduction to the transfer
process and by no means are exhaustive.

Retrieval of Information from LTM

The third and final step involves retrieving the information from LTM. Now that the memories are stored in LTM, we have to be able to retrieve them. "LTM's most distinguishing feature is its diversity—of codes, abstraction of information, structure, capacity, and permanence" (Solso, 2001). With all these memories in storage, what makes us forget?

To start, it is undisputed that consumption of alcohol is one of the best ways to destroy nerve cells or change the balance of neurotransmitters in the brain leading to a loss of memory (p.105). You may have heard the expression "let's go kill a couple of brain cells" as an offer to go out for a few cocktails. Practically speaking, that's exactly what you are doing. This cell death is caused by an increased concentration of intracellular calcium which weakens the electrochemical gradient across the cell membranes (CampusProgram.com, 2004). Estimates of thousands of brain cells dying during a moderate drinking binge are not unfounded.

While the above example is organic in nature, along with head injuries and diseases, there are a number of other non-organic reasons we may forget. Among these is the Law of Disuse (Decay Theory). Simply put, "if you don't use it, you'll lose it." Unless there is an overwhelming reason to maintain an event in your memory, the information will slowly fade, and may eventually become irretrievable. From a pilot standpoint, this is the reason why recurrent flight and ground school training must be conducted every 12 months. During the 12 months between refresher training, very little, if any, reinforcement is encountered for systems knowledge or flight maneuvers. This is a good thing because the reliability and safety of modern-day aircraft makes abnormal or emergency situations a very unlikely event. However, the disuse of these very procedures can make recall that much tougher, particularly at a critical time. The classic "forgetting curve" explicitly demonstrates the effect of time vs. unreinforced recall. One of the first to research the subject, Ebbinghaus (1885), memorized lists of nonsense syllables and then tested his memory of the syllables at intervals ranging from 20 minutes to 31 days. As shown in this curve, he found that he remembered less than 40 percent of the items after nine hours, but that the rate of forgetting leveled off over time.
Another reason we may forget is due to Interference Theory. McGeoch (1932) suggests that there are always activities or events that occur between learning and retrieval, and that these intervening events cause interference that disrupts our memories. In fact, McGeoch dispelled the Disuse Theory of time being the reason we forget, strongly suggesting that forgetting occurs because of what happens during the time between learning and retrieval. Nonetheless, examples of interference abound in our everyday lives. Dialing someone's phone number is a classic example: Why did you call Aunt Bertha when you intended to call your friend Harry? Maybe it was because Aunt Bertha's name came up over breakfast that morning. Other types of interference may include retroactive interference (RI), which occurs when new information acts backward in time to inhibit recall of older information, and proactive interference (PI), which occurs when previously learned information acts forward in time to inhibit recall of more recently learned material (Searleman & Herrmann, 1994).

Another common problem in recall is Tip-of-the-Tongue phenomenon. This recall problem manifests itself on a fairly regular basis. You see somebody you know fairly well in the cafeteria, but you just can't remember his or her name. You saw a very funny stand-up comic just a few days ago, but for the life of you, you can't remember his name. Or, you are asked to name all of the Great Lakes and you easily get four, but the fifth has you miffed! You know the name; it just can't be dug out at that particular moment. In time, these names usually pop back into conscious retrieval, but not until after a long and agonizing bout with your memory. Sounds familiar, right? There you have the tip-of-the-tongue phenomenon.

Other theories of forgetting abound. What is presented here is just an example of a few common causes. Other theories, such as Availability vs. Accessibility, Motivated Forgetting, Cue-Dependant Forgetting, Context-Dependent Memory, and of course Freud's theories, could fill a book.

**State Dependent Memory**
Studies have shown that state dependence may have a significant effect on memory recall. In other words, recall appears to be better if someone is put into the state for which that initial memory was encoded. According to Howard (2000), "the synapses formed to create a specific memory are connected to neural networks that form the basis of the conditions associated with the time and place of learning." State dependence can have a wide variety of venues. If we learn something while we are driving on a freeway, we will likely recall it while driving on that freeway. If something is learned while studying in a classroom, that very classroom will elicit recall of the subject. Even odors may contribute to state dependent recall. If you learn something while the room is filled with the smell of peppermint, your recall for that event will be enhanced if you once again smell the peppermint aroma.

**Retrospective Memory**

Retrospective memory is simply memory of things that have happened in the past, and up to this point has been the focus of discussion. What you ate for breakfast this morning, which team won the superbowl two years ago, what your mother's maiden name is, and what high-school you attended, are all examples of retrospective memory. By the way, who did win the superbowl two years ago? It should not come as a surprise that the recall may take a few moments! Think about why…

**Prospective Memory**

Can we forget to remember? Can we remember tomorrow? These are interesting questions, but with potentially dangerous implications. Something that has not been discussed so far, and contrasting to retrospective memory, is prospective memory, or our ability to remember future tasks.

Remembering to perform a task in the future is by nature, not a simple thing. People forget "to do" things all the time. Forgetting about a dentist appointment, not remembering to take a prescription medication, or picking the kids up from school, are all examples of failures in prospective memory. As an example from cockpit operations, the act of forgetting to put the landing gear down is a prospective memory error (you already know from training [retrospective memory] how to physically put the gear handle down), it is the act of remembering to put it down at the right time that may become challenging. This is where the use of salient cues becomes a vital part of prospective memory.

Like other parts of memory, some people are better with prospective memory than others. You own personality characteristics may in fact contribute to how well you remember to do future tasks. Searleman and Gaydusek (1989) found evidence that people with Type A personalities are more likely to remember to perform prospective memory tasks and perform them quickly than those who are not considered to have a Type A personality. Characteristics of a Type A personality include a strong sense of time urgency, highly competitive, and having a perfectionist attitude. Type A's are also known to walk, talk, and eat rapidly, and do two things at once.

"Prospective memory tasks are more vulnerable than retrospective ones to changing conditions. To be successful, prospective plans often must change in response to changing conditions” (Searleman & Herrmann, 1994).

Cues and reminders form the backbone of how we remember to do something in the future.
Cues give us something to help "jog our memory" for a task we are supposed to perform. If you have to set your alarm clock to wake up at 5:00 am, the cue to set the alarm clock may be the act of looking at the clock itself, or getting ready to turn in for the evening, or maybe a call from your friend that tells you "not to forget to set your alarm clock."

Reminders, similar to cues, can take on an infinite amount forms. The tying of a ribbon around one's finger is symbolic of reminding someone that they have to do "something." The problem that may arise though is trying to figure out what that "something" was that we were supposed to do! Other reminders, with more salient meanings, may include notes, calendar entries, and of course, the use of checklists and placards in flight operations.

**Learning to Remember (and Sensory, STM, LTM Revisited)**

No discussion of memory would be complete without an explanation of how we can enhance our memory performance. Chunking is the key to memory formation. Data is collected in chunks, which consists of capturing the chunk (immediate memory), developing it (short-term memory), and fixing it (long-term memory) (Howard, 2000).

Immediate memory, also referred to as sensory memory, is a storage area that can hold large amounts of information for a very short period of time. A telephone number is a good example of the volatility of this type of memory. If you look up a number and then dial it, the memory of that number will disappear quite rapidly. However, if rehearsal is used (i.e., repeating the number over and over again), the number will have a longer recall time.

Short-term memory (STM) works by selecting chunks of data to remember. A chunk is defined as an unfamiliar array of seven (plus or minus two) pieces, or bits, of information. Humans tend to process information most effectively when it involves approximately seven (plus or minus two) bits of information (Miller, 1956). Therefore it may not be coincidental that telephone numbers have seven digits and we have all heard of the Seven Wonders of the World, the Seven Mortal Sins, and the Seven Virtues (Howard, 2000).

According to decision theorist Herbert Simon, it takes about eight seconds of attention to add one new chunk to short-term memory. Once a chunk is mastered, it becomes a bit and can then be combined with other bits to become a new chunk (cited in Howard, 2000, p.530).

Long term-memory (LTM) also uses the chunking process to store LTM from STM. In a study by Henry Holcomb, a researcher at John's Hopkins University, it was determined that the memory for a new motor skill takes five to six hours to move from temporary storage in the front of the brain to permanent storage in the rear of the brain (p.530). A device that measures blood flow to various parts of the brain was the method used for determinations. During this five to six hour period, attempting to learn another new skill will cause problems for the prior learning. It is not currently known whether non-motor skills are affected this same way.

**Memory Fact:** We acquire one or two bits of information per second during concentrated study; by midlife we have acquired roughly 109 bits. Our average brain capacity is 2.8 x 1020, or approximately ten million volumes (books) of a thousand pages each. (Howard, 2000)
Tips on Improving Memory

If you are like most people, you have probably wished your memory were better. Much literature and scientific evidence abound to support memory enhancement. There are also some unscientific claims that “magic pills” can improve memory through herbs, flowers, and extracts of various biological objects. Since research cannot verify these claims, and the Food and Drug Administration (FDA) does not approve them, you are probably better off staying away from memory enhancers that come "in a bottle." However, there are some very good and easy to use memory enhancement techniques that you may want to consider. These include:

- **Positive thinking** – if you're feeling good, your brain is more likely to learn and remember. If you're feeling down, it is easy to be distracted by what troubles you.

- **Deal with stress** – while some stress in learning is good stress, because it can raise levels of brain activity, continuous stress produces chemical by-products, which inhibit memory.

- **Get enough sleep**, particularly if you have large amounts of material to learn, (e.g., when preparing for an exam or interview.). Dream (or REM) sleep is important for giving your brain the opportunity to process new information and consolidate learning.

- **Certain foods are thought to improve memory performance.** They include:
  - Oily fish
  - Eggs
  - Beef
  - Whole-wheat
  - Chicken
  - Bananas
  - Dairy products
  - Avocados

- **Exercise** can improve general fitness, and therefore help your whole body work more efficiently. A short exercise break every 30-50 minutes when learning (even if it's just a quick stroll round the room, or going to make a drink) can help push oxygen around your body and to your brain.

- **Watch your sugar levels** – low blood sugar inhibits learning and makes you tired. Ensure you eat regular small meals, with snacks (especially from the memory enhancing food types) to keep your blood sugar levels up.

- **Drink lots of water**, or non-caffeinated drinks. Even a small degree of dehydration can reduce your alertness and ability to give your attention, and if you do not pay attention in the first place, you will not remember the material later.

- **Engage in the practice of observing details all the time**, even when you're not trying to memorize something. Observation and attention giving is a learnt skill that you can develop
through practice.

☐ Practice remembering things. Give yourself a list of things to remember and test yourself each day (this is a good activity for those blank spaces in the day such as the commute to work, or in the lift.)

☐ Practice using the mnemonic tools until you find what works for you. (Mnemonics, as you recall, are devices such as a formulas or rhymes, that are used as an aid to remembering. If you are a pilot, you are probably familiar with the expression "ARROWE." This is the mnemonic you probably used to remember what documentation must be onboard the aircraft before you can legally fly. But, do you remember what they are?) (Added for emphasis by author).

(Management Resources.org, 2004)

**Memory in Cockpit Operations**

Now that you have been briefed about the fundamentals of memory processes, a direct application to cockpit operations follows. The cockpit can be a very busy place during the course of a flight, and at times (i.e., takeoff and landing) can become extremely busy. The cognitive demand placed on crewmembers is significant, and there are bound to be memory-related errors. Indeed, upcoming case examples exemplify how insidious memory errors can create benign mistakes…or…become a life-threatening event.

This discussion will be divided into two distinct areas; pilot/controller communications processes and their inherent memory limitations, and, memory limitations for pilots operating in the cockpit environment.

**Pilot/Controller Communications**

The exchange of communications between pilots and air traffic controllers (ATC) can at times become challenging, to say the least. This typically begins on the ground when the pilot first picks up a clearance for the route of flight. The clearance will contain a certain number of elements, most of which the pilot can anticipate. However, when the clearance is issued in a very rushed manner, it makes copying the clearance very difficult. Take the following hypothetical clearance for example:

*TriJet 123Alpha Bravo is cleared to Acme Airport via after departure, fly runway heading, expect vectors to intercept Victor 123 Grimes intersection, Victor 456 Hollis, direct. Maintain two thousand, expect one six thousand one zero minutes after departure, departure frequency is 123.0, squawk code 0673.*

When a pilot files a flight plan, there is a good chance that what was filed will actually be the clearance that will be received. However, there are numerous times when a clearance is not delivered as filed and the pilot must be able to write down the new clearance as it is given. The problem is compounded by the fact that many air traffic controllers read these clearances to pilots at a speed which is apparently efficient for them, but beyond the comprehensible writing ability of the pilot. It is obvious that most people do not have the ability to retain this much information in working memory for any amount of time, so writing it down is going to
be the only way it is remembered. When ATC reads a clearance, and the pilot reads it back, many errors are noticeable, based on the delivery speed of the clearance. It is this author's estimate that clearances that are delivered at the highest speeds have as much as a 80% readback error rate, whereas clearances that are delivered at conversational speeds may only have a 10%-20% readback error rate. Repetition of readbacks will only cause the controller and the frequency to become busier since the time the controller thinks he or she is saving by "firing out" the clearance will be countered by the extra workload of having to repeat or clarify the clearance multiple times.

Looking back at the clearance example, you will notice that there are nine bits (or pieces) of information in the body of the clearance. ATC can help make clearance deliveries more efficient by keeping the speed at a conversational level, placing emphasis on each bit of information, and speaking in a clear and concise tone.

Air Traffic Controllers do have a manual that provides tips on communication with pilots (FAA, 1999). Under chapter two in the manual entitled "Human Factors for Air Traffic Control Specialists: A User's Manual for Your Brain," the limitations of human memory are elucidated to remind controllers that human memory is fallible, and practical techniques should be used to offset these limitations. Highlights of the chapter include:

**Recommendations**-

> Speaking slowly and distinctly gives any listener a better chance of correctly hearing what was said. However, it is especially important to speak S-L-O-W-L-Y and DISTINCTLY to foreign pilots. As we speed up our speech rate, we lose many of the cues that help us tell the difference between certain speech sounds. Those cues can mean the difference between understanding the clearance that was issued and needing to ask for a repeat, especially for pilots whose native language is not English.

> Give pilots no more than three pieces of information in a single transmission. Studies have shown that cramming too much information in a single transmission can cause problems.

> Avoid issuing strings of instructions to different aircraft. A pilot's memory for an instruction is hindered by extraneous information presented before and after it.

> When issuing a clearance that is different from what the pilot was told to expect, EMPHASIZE the difference. A study of Aviation Safety Reporting System (ASRS) reports found that 33% of the communication errors between the cockpit and ATC that resulted in runway transgressions identified pilot expectations as contributing to the error.

**Statistically speaking**-

> In a study of incident reports submitted by pilots and controllers, "multiple instructions given in the same ATC transmission" were associated with 49% of altitude deviations and 48% of the potential altitude deviations.

> Studies of voice tapes from actual operations reveal that readback errors occur in less than one percent of all controller transmissions. On average, 66% of these readback errors are corrected by the controller, but the proportion of readback errors corrected by the controller varies widely with the ATC environment. While en route controllers corrected 89% of the
readback errors, only 50% of the readback errors on the ground frequency were corrected. On the TRACON and local control frequencies, controllers corrected 60% and 63%, respectively.

> A study of reports submitted to the Aviation Safety Reporting System (ASRS) on pilot-controller communication errors showed that: 1. Over half (54%) of the reports describing incidents of pilots accepting a clearance intended for another aircraft involved similar call signs. 2. Similar call signs were also identified as a contributing factor in 43% of the reports of communication errors resulting in near mid-air collisions and 21% of the errors resulting in loss of standard separation.

> A study of en route (ARTCC) voice tapes showed a 1-3% miscommunication rate (i.e., readback errors and requests for repeats) for clearances containing one to four pieces of information and an 8% rate for transmissions containing five or more elements. Clearances containing five or more pieces of information made up only 4% of the messages examined, but accounted for 26% of the readback errors found in the study.

> Almost two-thirds of the pilots who said they had difficulties in remembering ATC ground instructions said that ATC issues too much information too rapidly.

(FAA, 1999)

One other area that is worthy of attention is something the author calls "spotlight effect." This typically occurs during the enroute portion of the flight when the pilot not flying (PNF), who is typically responsible for radio communications, experiences difficulty in reading back an ATC clearance. A hypothetical clearance is presented:

*TriJet 123 Alpha Bravo, descend pilot's discretion flight level two three zero, expect to cross three zero miles east of Grimes at one zero thousand, Big City altimeter three zero one zero. Big City is landing Runway two two left.*

Combine a noisy cockpit with an air traffic controller reading you this clearance at lightening speed, and you can see where readback problems can manifest themselves. The spotlight effect is created by the PNF trying to hear and readback the clearance exactly as it was delivered to verify to ATC that the clearance was received and will be complied with. In effect, the PNF is "in the spotlight" because not only does he or she typically not have the time to write down the clearance, but the lack of rehearsal makes retention time extremely limited (i.e., rapid decay time). Look again at the hypothetical clearance and notice how many combinations of numbers are used. Mileage, altitudes and altimeter settings are very similar sounding. The Laws of Primacy and Recency also become a factor: Many pilots will read back the first bit of information correctly (i.e., descend pilot's discretion flight level two three zero) and the last bit of information correctly (i.e., landing Runway two two left), but all of the information in the middle tends to get lost. Can you see why enroute readback problems are so common?

One final note about the spotlight effect: The author has observed on numerous occasions that although the PNF experiences difficulty on a clearance readback, the pilot flying (PF) is often able to accurately repeat the clearance back in its entirety, either to the PNF or, in some cases, to ATC. It is interesting to note that the PF is "not in the spotlight" in these situations. Can you figure out why this disparity in memory retention becomes apparent?
Prospective Problems

As mentioned earlier, prospective memory is our ability to remember future tasks. In the cockpit, prospective memory problems outweigh retrospective memory by a large margin, as reported by pilots in the Aviation Safety Reporting System (ASRS), a confidential self-disclosure reporting system sponsored by NASA. An example of the consequences where there was a failure in prospective memory is highlighted by the crash of Northwest Airlines Flight 255 in August of 1987:

Northwest flight 255 was preparing for takeoff on the evening of August 16, 1987. Bound for Phoenix and continuing on to Orange County, the DC-9 was carrying 148 passengers and six crew members. The aircraft was cleared for takeoff on Detroit Metro's runway 03C and began its takeoff roll. After a longer than normal roll, the aircraft lifted off and immediately began rocking laterally. It only gained 50ft in altitude before clipping a light pole with its left wing. It hit a number of other light poles and then clipped the roof of a building, rolling past 90 degrees and then slamming into the ground and bursting in flames. Everyone aboard the aircraft was killed with the exception of a four-year-old girl. Two motorists who were driving along a highway where wreckage was strewn were killed also.

Examination of the wreckage showed no signs of any system malfunctions. The only significant find in the wreckage was that both the slats and flaps were retracted. Both would normally be extended during takeoff. Examination of the cockpit also showed that the flap handle was in the retracted position. This was further confirmed by recovery of the FDR (Flight Data Recorder). Readout of the CVR (Cockpit Voice Recorder) showed that the crew had neither called for nor completed the taxi checklist, on which the extension of the slats and flaps are the first item. Just as the aircraft was pushed back from the gate, the first officer, who would have normally started the taxi check at that time, was instead copying the latest ATIS (Automatic Terminal Information Service), which had just been updated. By the time he was done copying, the aircraft was already taxiing to the runway and it's possible that he believed the extension had already been done. The captain is responsible for calling for the checklists, though the captain of 255 did not call for the after-start, taxi, or pre-takeoff checklists. The crew also had difficulty taxiing to the proper runway even though they had
flown out of Detroit several times before. The DC-9 is equipped with CAWS (Central Aural Warning System), which should have alerted the crew to the improper configuration, but no such warning was heard on the CVR. This was accounted to a power loss prior to taxi, though it could not be determined whether it was intentional or accidental. This improper configuration severely degraded the aircraft’s climbing performance. The stick-shaker activated less than one second after liftoff and continued throughout the short flight. At the time of the incident, the weather was good though there were storms in the immediate vicinity of the airport and windshear advisories were issued. It's possible that the crew believed themselves to be caught in windshear, which was evidenced by the captain's increased pitch-up, which is standard windshear avoidance procedure. Had the crew lowered the nose and extended the flaps and slats, the accident probably could have been avoided. It was speculated that the crew might have been hurried in an effort to depart before the weather got any worse. Also, they may have been rushed in an effort not to miss the noise curfew at Orange County, their final destination. (Aviation Disasters, 2004)

In the Northwest 255 example, the following factors contributed to the accident:

1. Flaps and slats were not extended for takeoff.

2. Critical checklists were omitted.

3. There were a number of distracters, including the First Officer's heavy workload (effectively removing him from monitoring the captain), confusion about which taxiways to use, and trying to depart before the weather worsened, which could have meant a delay.

4. The CAWS (Central Aural Warning System) was inoperative (which would have brought the misconfiguration to the pilots' attention with an aural warning).

5. The crew was in a hurry to depart.

Why then, did this crew depart without extending the flaps and slats for takeoff like they had done hundreds of times before? The answer is relatively simple. The salient cues that were required for setting the flaps and slats were, for all intents and purposes, non-existent. The checklists (After Start, Taxi, and Pre-Takeoff) were not called for and subsequently not performed by the First Officer. The first item on the Taxi checklist calls for the extension of flaps and slats. The second cue, an aural alert that notifies the crew of this misconfiguration, was inoperative. The third and final cue was the final verification by the pilots upon arrival at the hold short line. All three of these cues were missed. The pilots forgot to perform an intended task and 156 people (including two on the ground) lost their lives that day. This shows us, in its purest form, how fallible human memory can be, particularly when salient cues are removed or are not available.

One of the current studies being conducted by NASA's Ames Research Center is centered on task interruptions and prospective memory. In an informal analysis of 37 NTSB reports involving crew error, Dismukes, Loukopoulos, & Jobe (n.d.) found that nearly half showed evidence of interruptions, distractions, or preoccupation with one task to the detriment of another task. Some recommendations by Dismukes, et al. include creating salient reminder cues, breaking concurrent tasks into subtasks and pausing between subtasks to monitor, and identifying specific things to monitor. As of yet, there is no empirical research to verify the validity of these recommendations.
There is, however, research being conducted jointly by San Jose State University and NASA in the area of "task interruptions becoming prospective tasks". The purpose of the study was to develop a paradigm that is flexible enough to investigate cognitive characteristics of interruptions (Dodhia & Dismukes, 2003). The report posits two hypotheses:

1. Reminders of the prospective memory task increase successful prospective memory performance, and,

2. Similarity of the interrupting task to the interrupted task affects PM (prospective memory) performance negatively.

The result of their brief report is included on the next page for convenience.
A Task Interrupted Becomes A Prospective Task

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Introduction

Definition of Prospective Memory (PM). We prefer to define PM in terms of task demands rather than as a type of memory separate from retrospective memory. PM tasks require retrieval and execution of an intention at an appropriate time or combination of circumstances, usually while a separate, ongoing task is being performed.

Interruptions: When an ongoing task is interrupted, a PM task is created to resume the interrupted task. The individual may or may not encode it explicitly. The PM target that cues the PM task is the end of the interrupting task.

Interruptions are common in everyday and professional life. A previous study found that interruptions of a pilot’s preparations for flight can have disastrous consequences.

The purpose of this study was to develop a paradigm that is flexible enough to investigate cognitive characteristics of interruptions. To illustrate its flexibility, we included two manipulations: the effect of reminders on resuming the interrupted task and the effect of the similarity between the interrupting task and the interrupted task.

Hypotheses

Reminders of the prospective memory task increase successful prospective memory performance

A reminder will cause a person to encode the interruption explicitly. This should create a stronger association between the end of the interruption (PM Target) and the intention to resume the interrupted task (PM Task).

Similarity of the interrupting task to the interrupted task affects PM performance negatively

If the interruption is a similar task, subjects may be less likely to recall at the end of the interruption that it was in fact an interruption.

Experiment Design

Participants completed 20 blocks of 11 questions. Each block had one category of questions - vocabulary, general knowledge, math or analogies.

Interruptions occurred during blocks 3, 7, 12 and 18. After the interruption was over, they were taken on to the next block of questions. At this point they were supposed to press the back-arrow (→) key, otherwise a PM failure was recorded.

Between-Subject Factors:

Similarity of Interruption: Similar (S1) - interruptions were blocks of questions, but of a different category. Dissimilar (D1) - interruptions were various tasks containing different stimuli and response formats, such as aagram solving.

Reminder: Reminder condition - right before the interrupting task started, participants were given a 4 second text message that reminded them to return to the interrupted task. Control condition - participants were not given a reminder and the interrupting task began immediately.

Participants pressing the back-arow key resume the interrupted task (PM success). Other participants carry on with the next block of questions (PM failure).
In another NASA study (Lang-Nowinski, Holbrook, & Dismukes, n.d.), and again using the ASRS database, a random sample of 20% of all reports involving Part 121 (airline) operations was extracted for occurrences in the year 2001. There were 1299 reports and each was analyzed to determine whether the incident involved a memory failure. The results showed that:

- One hundred and five (8%) were identified as examples of memory errors (possibly an undercount because many reports did not include enough information to evaluate the presence of memory errors).
Thirty of the reports indicated maintenance or controller errors.

75 indicated memory errors by pilots.

Only one of the 75 memory reports described an instance of a retrospective memory failure (the crew recalled another crew’s clearance instead of their own). The remainder involved some form of prospective memory failure.

It appears that the low incidence of retrospective memory failures is such because most cockpit tasks are so overlearned that experienced pilots may rarely experience retrieval failures—a seasoned aviator is not likely to forget how to program the flight management computer or how to lower the landing gear (Lang-Nowinski, et al.).

There is much more information available from NASA in this area of study. For now, the previous few pages have provided you with a basic understanding of the limitations of prospective memory in cockpit operations. NASA’s countermeasures include the following three suggestions:

1. Recognize non-routine situations, namely interruptions, deviations from habitual actions, and deferred tasks, as potentially dangerous. If possible identify exactly when a deferred or interrupted task will be performed and what cues will be available. Create salient cues as reminders. If possible enlist the help of other crewmembers. At the very least, acknowledge the fact that a task is being deferred.

2. Stick to established operating procedures as much as possible—they provide both obvious and subtle safeguards against forgetting (i.e., the use of checklists).

3. Recognize monitoring as a critical task. Several airlines have formalized monitoring procedures for both pilots and have changed the designation of pilot not flying to pilot monitoring (Sumwalt, Thomas, & Dismukes, 2002).

(Extracted from Lang-Nowinski, et al., n.d.)

Smart Drugs?

In relatively new research, there is some indication that normal memory can be enhanced by already existing medications. A study by Stanford University, as reported by BBC News (2002) indicated that the current drug used for Alzheimer's patients could increase the mental power of people without the illness. Tests involving 18 airline pilots with an average age of 52, found that those taking the drug Aricept were better able to retain complex training than those given a placebo. Aricept works because it blocks the action of a body chemical in the brain. This chemical breaks down another called acetylcholine (discussed earlier) which helps pass messages between brain cells in parts of the brain key to memory and conscious thought.

The limitations to the study included a small sample base (validity problems for a larger population), side effects— which included diarrhea and vomiting (not a good thing for a pilot), and costs- Aricept is very expensive. Remember, there is no magic pill, but current research is at least investigating the possibilities of memory enhancement for now and in the future.
Conclusion

This paper has presented the basic concepts of memory function as well as its application to pilots in the performance of their flight duties. The limitations of memory were discussed, and, specifically, the vulnerabilities of prospective memory were annunciated.

Memory is a wonderful gift. It preserves the pictures of what we have encountered in our lives and the things that we eventually will encounter. It lets us ride a bike, remember who our relatives are, and how to get a good grade on a test. Take good care of your memory. Remember- human memory is fallible and as a pilot you must incorporate your own countermeasures to ensure a safe and memorable flight.

References


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