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The Most Important Aviation System: The Human Team and Decision Making in the Modern Cockpit

John Cody Allee
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by John Cody Allee entitled "The Most Important Aviation System: The Human Team and Decision Making in the Modern Cockpit." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Ralph D. Kimberlin, George W. Garrison

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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THE MOST IMPORTANT AVIATION SYSTEM:

THE HUMAN TEAM
AND
DECISION MAKING IN THE MODERN COCKPIT

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John Cody Allee
August 2004

Dedication

This thesis is dedicated to Richard Kelly Greenbank, M.D. whose selflessness was remarkable and whose knowledge of psychiatry inspired my interest in the field. He will be missed.

Acknowledgements

I wish to thank all those who helped me complete my Master of Science degree in Aviation Systems. I would like to thank Professor Richards for his guidance during my time at the U.S. Naval Test Pilot School as well as for his help and patience in the preparation of this thesis. Gratitude is due to the U. S. Navy and Marine Corps for much of the training and experiences that influenced this effort. Colonel Joe Mortensen, USMC, deserves appreciation for his confidence in my abilities and for providing the opportunities to achieve lifelong goals, as does Captain Stephen Rorke, USN, for the same. My family deserves much credit for believing in me, always.

Especially I would like to thank Christina Stack, whose encouragement and support are certainly the reason this project was ever completed.

Nomenclature

ACT	Aircrew Coordination Training
ASN	Aviation Safety Network
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
EGT	Exhaust Gas Temperature
FAA	Federal Aviation Administration
FL	Flight Level
NASA	National Aeronautics and Space Administration
NSC	Naval Safety Center
NTSB	National Transportation Safety Board
ORM	Operational Risk Management
RAW	Risk Assessment Worksheet
SA	Situational Awareness
TDM	Team Decision Making
USMC	United States Marine Corps
USN	United States Navy

Abstract

The most critical aviation system is the human operator in the cockpit of modern aircraft. Regardless of the advancements in microelectronics and automated decision-making apparatus, the human will still remain ultimately responsible for the safety of those in the air and on the ground. Humans, however, are not entirely predictable or consistent when functioning in this capacity. The relationship between crewmembers becomes a critical aspect of this system, and this paper focuses on methods to improve both individual and especially crew decision-making in aviation. Concepts and structure from the Navy's Crew Resource Management program are used as the background for discussion. Initially, the individual is examined, followed by an assessment of the physical systems in the cockpit, and finally methods for improving human interaction are discussed.

To understand how decisions (whether good or bad) are made, an examination of the inputs to the human decision maker is required. The methods people use to evaluate their environment and choose a course of action will be discussed, as well as the effects of culture and experience on this process. The physical information and control systems of an aircraft will be briefly reviewed, and suggestions for improving the efficacy of the information provided and aircrew employment will be offered. Finally, the interrelationship between humans involved in the system will be studied, including suggested means to facilitate and improve these interactions. The intent is to provide insight to the human team and methods to improve decision making in the modern cockpit.

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1. BACKGROUND

The human being is the most important system in the modern cockpit. Computers have evolved fantastically, but nothing can match the ability of a human to process large volumes of disparate data, recognize trends and patterns, and adapt to rapidly changing environments and demands. Humans are fallible, however, and subject to make mistakes when surveying the environment and in making the subsequent necessary decisions. Because of this, the person in the cockpit is still the single most critical and complex system in an airplane. Automated decisions are more prevalent in modern systems, but none are robust enough to be solely responsible for the lives of hundreds of people riding inside the machine. So, humans are and will remain a decision-making component of any aircraft, especially one carrying passengers. The challenge is to improve the decisions made by aircrew. No system is perfect; improvements are always possible. This is the focus of this paper: to improve the decisions made by aircrew in the execution of their duties. Traditional methods of United States Naval Aviation will be used as the foundation for discussion, but the potential (and hoped for) application includes not only the entire Navy but commercial aviation and industry as well. The techniques will explore both the man-machine interfaces and human interactions that provide the source of information necessary to make intelligent choices in the cockpit. A sample of historical aviation accidents will show that there is much room for improvement in this area.

Aircraft are not designed to fail, nor are aircrew trained to crash airplanes. Thus, all aviation mishaps are attributable, at some level, to human error. But during the 100 years of powered flight, technology and oversight has progressively pushed human error toward the end-state user, those manipulating the controls and pressing the buttons. As the aviation community, including U. S. Naval Aviation, came to realize this, emphasis was placed on the mitigation of operator error. The initial Navy attempt to affect aircrew interaction was begun as Aircrew Coordination Training, and was started several years behind the commercial industry's version of the same. Later, in an effort to model the airline's increasingly effective programs, the Naval term was changed to Crew Resource Management. These curricula emphasized that errors were due primarily to a failure to "play nice with others": aircrew failed to "coordinate" with each other or to use all of the available "resources" to develop solutions to in-flight problems. These programs have proven beneficial, but each lacked a model of decision-making and missing were any rules for the application of the concepts proffered. This paper seeks to address those shortcomings, and to generalize the technique of mitigating operator error so that it may be applied in any situation involving complex mechanisms interacting with humans.

The critical skill sought among these operators is not just "coordination" or "resource management" – these are elements aircrew employ to harmoniously and effectively make team decisions. So, a better and more encompassing term is Team Decision Making. For simplicity of discussion, emphasis will remain on aviation and the aircrew's role in Team Decision Making. As the senior pilot's title on any flight deck implies, the aircrew are the "Captains" or the coaches in the aviation team. Just as a coach scouts for potential effective members of a team, so must aircrew function as coaches – ever vigilant for potential contributors to their awareness. So too, as a coach will cull ineffective or detrimental members of a team, the aircrew must reject information deemed to be invalid or misleading. Unlike sports, teams in aviation will be built and dissolved in moments, as every exchange may bring a new member in the form of a tower controller, a passing ground maintenance technician who sees a missing fastener, etc. Constants will be present, too, in the form of instruments and displays, but a failure to understand the capabilities and limitations of these items, as in chess and its pieces, can result in tragic failure. Aircrew are the coaches and captains of a very dynamic team, ultimately responsible for the lives of millions each year, and their decisions must be founded on a cast of players whose effectiveness is determined by the cohesion and consensus that is built on the strengths of their skills. Following are suggestions for improving those skills.

Why? Because in Naval Aviation, based on 1,000 hours of flying, the odds are:

1 of 25 fighter/attack aviators will crash

1 of 71 fighter/attack aviators will be killed

1 of 59 helicopter aviators will crash

1 of 177 helicopter aviators will be killed (NSC, 2001)

Reason enough to improve our decisions…

2. TEAM DECISION MAKING

2.1 Objective Statement

Team Decision Making, or TDM, requires the knowledge of how we, as human beings, make decisions. Then, TDM becomes the art of improving those decisions through the use of specific methods and techniques to relate to and recruit information from fellow humans and machines**.**

2.2 Risk Management

Team Decision Making, or TDM, is the logical evolution of Aircrew Coordination Training and Crew Resource Management. TDM addresses the occurrence of risk in real-time – the attempt to reduce operator error by involving all assets in the decision making process. It would be even better, though, to never face the specter of operator error. By planning evolutions to avoid exposure to risk, the need for TDM is reduced. This is risk management via planning. Traditionally, the United States Navy has employed planned risk management techniques not only in aviation but also in all operational areas. The broad-brush technique is termed "ORM" or "Operational Risk Management". This concept addresses only planned risk, and is an effort to consciously acknowledge activities that contain an inherently higher chance of a mishap occurring.

The U.S. Navy currently has a healthy and well-developed ORM program. The term ORM should actually include the current technique of risk planning as well as aspects of TDM, since risk management involves the mitigation techniques of forethought and the application of real-time containment methods. All members of the service are required to accomplish annual risk planning training and some areas, including Naval Aviation, use daily risk screening forms to force individuals and the command into awareness of the dangers present (see appendix for an example of a risk assessment worksheet). While this accomplishes the critical role of highlighting the potential for errors and accidents to occur, it fails to address what to do when, in the course of executing the mission, they actually happen. Too, no matter how creative the person is who devises the screening form or how long a crewmember spends brainstorming the possibilities, unforeseen circumstances will always arise. To deny this eventuality would be to assume a "zero defects" mentality of operations – which would be unwise and quite counterproductive. A healthy organization must accept that human error will occur, and cannot blindly punish inadvertent mistakes. This does not, however, mean that an organization should be resigned to expecting eventual catastrophes, as the goal of risk management is to avoid just that.

To effectively manage risk in modern Naval operations, training on the subject must include a "troika" theory - reducing the likelihood of error, trapping errors before they have an operational effect, and mitigating the consequences of errors when they do occur (Hayward, 1997). ORM is the appropriate title for this effort. Risk planning concerns the effort to reduce the likelihood of error though avoidance, while Team Decision Making is designed to aid in trapping errors and countering the effects once errors do occur. This triumvirate is required: consider risk management as a three-legged table - without each leg the table will not stand. An organization cannot expect that effective planning will eliminate all risk, nor can one afford not to survey and avoid the threats present in a given endeavor. After accepting that errors are inherent in all activities, methods of containing and limiting human mistakes among the operators are necessary, but if the upset comes from outside the organization's control, then plans must exist to smoothly handle the disturbance. This handling of errors in real-time could also be termed immediate risk management.

Although the entire U.S. Navy addresses planned risk management, currently only Naval Aviation consciously trains personnel in immediate risk management. As mentioned, this program is termed Crew Resource Management, or CRM, and has been in place for over ten years. Immediate risk management could also be termed "improved team decision-making" or "crew based minimization of error", as this concept seeks to reduce the impact of errors once committed and aid in guiding teams toward healthy decisions. The Navy's CRM program attempts to do so using seven skills: "Situational Awareness", "Adaptability/Flexibility", "Decision Making", "Communication", "Leadership", "Assertiveness" and "Mission Analysis". Combined into an acronym, they are best memorized as "SAD CLAM." CRM defines each of these "skills" as an aid to help the crew handle various negative situations. Current theory holds that each of these skills is a relatively independent element capable of being employed with or without the others. This is not the case: the skills are interrelated, and in some cases cannot exist except as part of a sequence of mental processes. Some require the presence of another human; some do not. Under the theory of Team Decision Making, the "SAD" portion of the seven skills defines a discrete process that nearly every human uses to make decisions in life. "CLAM" becomes a set of personal interaction skills that can be used to define and improve human interfaces. Both of these processes will be addressed in detail, but considering the complexities of human beings, it is appropriate to begin with the basic elements of this decision-making system.

2.3 The Elements of the System

Often a system is best analyzed by studying its components. This method is appropriate in the cockpit, as the informational and decision-making system consists of three basic components. There is the flight crew, seeking information and awareness of their environment, the instruments and electronic/mechanical systems supplying some of that information, and other humans, external to the cockpit but a part of the aviation team nonetheless. This is the basic functional division of cockpit, and although computers have begun to usurp the role of the human in making decisions, the aircrew still must verify the correct operation of any automation. From this outline, the study of how decisions are made in the modern cockpit should consider the role of each of these three elements separately before attempting a comprehensive review. Because it is possible for decisions to be made by an individual, without any input from instruments or other people, the psyche of the human is the logical starting point for this discussion.

Although the members of an aircrew should strive to function as a cohesive whole, any given flight deck team is certainly composed of individuals. Unlike mechanical systems, each person does not conform to a rigid set of specifications. This is both good and bad; to realize the reasons, a detailed examination of the mental processes of the crewmembers is necessary. Although human cognitive function is similar and often conforms to predictable norms, there is significant variety in the mental processes of each individual. Aviation typically tries to reduce the variables in this regime, by carefully screening potential candidates and then exhaustively training each to ensure at least a superficial conformance to established standards. Regular examinations and training events help to reinforce this attempt to model behavior. But, when unusual situations arise, or when excessive stress is present, the persons involved will likely revert to the norms learned while younger or those reinforced over the longest period of time (Baxter, 1998). Thus, it is important to analyze the cognition, especially the art of decision-making, based on not just aviation standards but on the more basic level of general human reasoning. As such, the individual and his or her method of decision-making is a critical element of the cockpit system.

3. THE INDIVIDUAL HUMAN

3.1 Levels of Human Performance

Decisions are made and actions taken on one of three basic levels of human performance. A person reacts to a scenario at either a skill-based, rule-based or knowledge-based level (Reason, 1997/Rasmussen, 1986). These descriptions refer to the amount of conscious effort required to elect a course of action. Through experience and training, given preconditions elicit predictable responses – skill-based actions. If, however, there is less empirical knowledge of an event, humans must increasingly rely on conscious analysis, progressing from rule to knowledge-based actions. The amount of subconscious, or automatic, functioning depends on the level of training or experience with a scenario. These divisions are important in determining how a team works together: since their level of training and experience will always vary, so will their level of performance in similar situations.

3.1.1 Skill Based Tasks

Skill-based tasks rely on training for the automatic execution of regular tasks under given stimuli. Repetitive work is an example of skill-based execution, where an assembly-line worker might become numb to the task, repeatedly doing the same actions over and over again. Little if any conscious effort is required in this instance, and in fact mental processes often wander outside the focus of the work at hand, simply because the attention is underutilized during such tasking. Under less persistent conditions, though, skill-based tasks may allow other conscious operations to occur. The act of driving to work is, after some experience, a skill based task – the existence of spare mental capacity can be seen in the many drivers on the road engaged in talking on cell phones, attempting to read, applying makeup, or any number of activities which require greater mental attention than the often practiced mission of driving. Skill based tasks require reinforcement and are subject to degradation with time – exactly the reason a gymnast practices daily. In aviation, checklists and scripted procedures also facilitate this type of action:

> This scripted approach to operating procedures has major advantages. Crews must often accomplish a very large number of procedural steps in a short time. Scripting allows pilots to perform procedural tasks consistently in line operations so that performance becomes largely automatic with practice; execution is fluid and rapid and requires little mental effort. (Loukopoulos, et al. 2003).

A skill-based reaction, however, can occur automatically (as it should) when one's Situational Awareness (SA) is incorrect. This can be a deadly response, so the tendency for crewmembers to allow trained reactions to occur should be tempered with the crew's confidence in their assessment of the environment. If there are unknown elements, skill-based reactions should be inhibited and treated as conscious acts by the crew to avoid inadvertently wrong reactions. It is critical that the necessary skills be trained correctly and positive actions reinforced. Even minor mistakes should be corrected, because these could potentially serve as the critical links in an eventual chain of mistakes leading to catastrophe. A jet fighter was once lost when a pilot attempted to shut an engine down using a switch designed to cut fuel in case of fire. The engine was stuck at high power, and normal methods of securing the throttle were not working. The wrong switch was activated, even though this action was practiced repeatedly in training and simulation – a skill based task. The error was not recognized, and the aircraft ran out of fuel before landing.

The saying "you fight like you train" is common in the military, and its meaning is simple: the habits built during less stressful training exercises determine the automatic responses and unconscious actions taken when a person is confronted with an overwhelming situation. In reality, training does even more. Training scenarios, if even somewhat realistic, build impressions of how events will unfold in reality. This actually creates models in the memory of the aircrew, which they will expect reality to follow. Even if an actual event differs from the presentation in a simulation, the aircrew will attempt to force the cues and indicators to conform to the model developed in their training. This can be dangerous, as it can easily lead to a misdiagnosis of a problem. Many simulator sessions, and some flights, end in disaster when someone declares "I've seen this before" and hastily concludes the wrong diagnosis. This tendency for humans to interpret scenarios in relation to their experience will be discussed shortly.

Skill-based tasks, though, are the ones most familiar to a person. For example, at the skill-based level, the pilot is subconsciously aware that pulling aft on the control stick of an airplane causes the nose to rise and the airplane to climb. This action-reaction pairing is reinforced from the first moment a pilot takes the controls of an aircraft, and is reinforced every time the controls are manipulated. When the pilot becomes aware of a need to climb, the motor skills required to accomplish this happen automatically and without conscious thought. This occurs due to years of training and conditioning accompanied by regular practice, since this skill is required anytime an aircraft is flown. Without regular reinforcement, skills can degrade, causing the operator to "think about" the task at hand. In this case, rule-based performance may occur.

3.1.2 Rule Based Tasks

Rule-based tasks involve cognitive as well as subconscious actions. Situations typically are not frequent enough for an aircrew to develop learned and automatic responses, yet some level of training has existed and there is familiarity with the scenario and the expected outcome. In this type of action, feedback is normally a required element in order to determine the efficacy of the decision. In rule-based decision making, sufficient data has been collected to build a model of the system and to establish causal relationships between events and outcomes. Essentially, "…rules provide a means for *multiple* people to explicitly represent their collective wisdom" (Kaliardos, 1999).

An abundance of rules exist in aviation. There are the imposed, confining rules that limit an aircrew's actions, but rules also exist to describe the regime of flight and establish standards of actions and reactions. One hundred years of practical research in powered flight has produced a plethora of rules that define the art of flying. Typically, aircraft and the atmosphere conform to these norms, allowing aircrew to study the rules and apply them to make rational decisions regarding flight. When practice is insufficient to elicit an automatic response, an aircrew must make mental reference to the training and collective experience of aviation – the "rules". For rules to exist, however, there must be either corporate knowledge of the situation or else research into the theoretical realm; in either case, the scenario must be foreseen. Too, the rules may be based on incomplete facts or faulty assumptions, rendering them invalid. This logically leads to the next level of decision making: knowledge-based tasks.

At the rule-based level, a pilot might desire to climb, but when the control stick is pulled aft the nose rises but the aircraft does not climb. This then invokes rule-based reasoning, and the pilot will examine the situation to determine the failure of the aircraft to climb. Rules specify that the aircraft will not climb in this situation if insufficient power is applied or if angle-of-attack is excessive, and so the pilot might begin a process of elimination to determine which rule is required to produce a climb. Limited cognition is necessary to discover that, perhaps, power is required to climb. Without the existence of a rule specifying this, then much greater mental effort, and probably a process of trial and error, would be needed.

3.1.3 Knowledge Based Tasks

Knowledge-based tasks require intimate cognition by the decision maker, and thus hopefully by the entire team. Knowledge-based reasoning occurs once rules have failed or when a situation transcends corporate experience.

An excellent example of a knowledge-based task is historical medicine, where typical doctors were expected to be very familiar with theory, but not necessarily have the experience to automatically generate a diagnosis and treatment. Feedback was critical to the doctor's task, as the results of initial treatment determined follow-on procedures. Trial-and-error was typical, and without any formal cause-effect relationships documented, incorrect assumptions and methods persisted for years. This is the nature of knowledge-based decision making: an unfamiliar environment requires a decision maker to employ aggressive cognitive attention to the task, since he or she must determine, based on speculation and feedback, the efficacy of the decision. In modern medicine, however, many doctors are specialized to a high degree. Past experience has been compiled to allow the community the benefit of prior experience, and treatment is progressing towards rule, even skill-based execution.

At the knowledge-based level of action, a pilot might desire to climb in an aircraft, and so pull aft on the control stick – but in this case the nose of the aircraft drops instead of rising, which is the expected response. Now the pilot is forced into active cognitive reasoning, since skills have produced an unexpected response and rules may not exist for a response opposite that expected. Although the rules discount this possibility, perhaps the controls were connected in reverse or an odd aerodynamic phenomenon caused the response. Success now depends on the creativity of the crew in deriving a solution using their ability to reason. Unfortunately, in aviation very strict time limits are typically imposed on this brainstorming process!

3.1.4 Human Performance

Significantly, aircrew in the same cockpit can be operating at distinctly different levels: a flight instructor is likely performing at a skill and rule-based level, while a neophyte student is struggling at the rule and knowledge-based level, if not completely overwhelmed! This is vitally important, and must be taken into consideration when relating to other crewmembers – the skills of interrelations will be addressed soon. So, from this point forward, let us consider only rule or knowledge based performance. Skill based actions do not require resource and information management. How the operator assesses the situation, which leads to the subconscious conclusion of which skill to apply, most certainly does rely on resource management. The improvement of rule and knowledge-based decisions, and the crew's awareness regarding their situation (and thus the skills applied), is the objective of Team Decision Making.

Humans make decisions throughout life, of course. Some decisions carry significantly more consequence than others, and are likely to be more carefully scrutinized. The data required to make intelligent choices is sought by most people, and the information gained becomes part of the consciousness – the awareness of that individual. As decisions are made and feedback is presented, a person's appraisal of the situation may change. Whether or not it does often depends on the flexibility and willingness of the individual to adapt to dynamic environments. This quick synopsis of events forms the structure of the human decision-making process: humans gain awareness of a situation, then, depending on one's ability to assimilate and react to changing information, a revised model may be developed, whereupon a decision is made and action taken based on that model. Feedback is supplied following action, and the cycle begins anew. This sequence of events essentially occurs for every decision a person makes throughout life.

In order to make any decision, humans require information. There are three primary modes by which information is supplied to aircrew: internal – instincts, experience and prejudices; the informational systems on an aircraft – the instruments; and other humans – air traffic control, copilots, etc. Each of these systems directly affects what the aircrew believes is happening around them: their "Situational Awareness", or "SA". This awareness affects the aircrew's actions, as all decisions made are based on the individual SA of each of the crewmembers. Regardless of what level an individual is performing at, there is a continuous quest for information about the state of the environment, thus allowing operators to make appropriate decisions.

3.2 Individual Decision Making

Before examining the sources of information, and how to improve each of them, one must first devise a model of how human decisions are made. U.S. Air Force Colonel John Boyd devised a prescient model he called the "OODA Loop" (USMC, 1992). The principle was that a person Observes a situation, then Orients himself, Decides on a course of action, and then Acts to carry it out. Per his theory, this cycle repeats continuously, according to the speed and dynamics of a changing environment. The OODA Loop concept was initially oriented towards warfare, but it has universal application in life. Every human, when faced with a dynamic situation, will follow those steps: Observe, Orient, Decide, and Act. This "OODA Loop" can also be considered a "Decision-Making Cycle" (Hammonds, 2002). To convert the terms into more aviation-related parlance, terms will be borrowed from the Navy's Crew Resource Management training syllabus. The "Decision-Making Cycle" can be described using three of the Navy's CRM skills: Situational Awareness, Adaptability / Flexibility, and Decision Making. The steps in the Decision-Making Cycle are shown in figure 1. In building a model for this cycle using these terms, a clear definition of each is required.

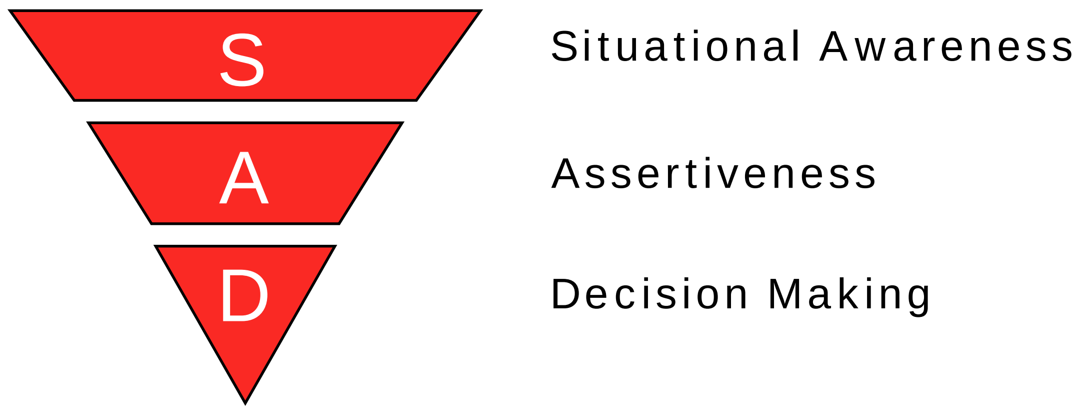

Figure 1
Elements of Human Decision Making
(Author)

3.2.1 Definition of Situational Awareness

Situational Awareness, or "SA", is most easily defined as one person's impression of "what is going on". It is comprised of all the recognized inputs around that individual: hearing, sight, smell, memory, etc. Humans automatically derive SA from any given situation, regardless of any effort not to – it is impossible to avoid developing an opinion of a scenario. A common saying in the military, when referring to someone who is lost or confused, is that "he has no SA". This is empirically impossible, since a total lack of sensory information would be required to leave a person with "no SA". What actually occurs is that the "clueless" individual has the wrong impression of "what is going on". This is the dangerous situation: when a responsible crewmember misinterprets the environment and proceeds to make decisions based on these incorrect perceptions. So, it is critical that a person's Situational Awareness be as accurate as possible, to ensure that courses of action chosen are based on the true environment.

But what defines a "true environment"? What in life serves as the standard of measure for SA? Unfortunately, there are no absolute references for life's occurrences. There are the strict numbers that serve to define an environment, such as the temperature, barometric pressure, etc., but once humans are involved, the definition of circumstances is heavily dependent upon the individual. The world functions because of agreed upon standards and measures. These are used to define the world and allow humans to relate under these common restrictions, for without them, each person would utilize individual definitions for their observations. Of course, if an event transcends experience or training, then that person is left to apply references that may or may not fit the situation. Just such an occurrence happened on the night of June 24, 1982 when a 747 operated by British Airways flew into the ash cloud emanating from the eruption of Mt. Galunggung on the island of Java (Job, 1996). Because it was nighttime, the crew had no idea they had entered the ash cloud, but the manifestations were alarming to say the least: the leading edges of all surfaces began to glow white; the engine exhaust became iridescent plumes of fire and the cabin began to fill with smoke. The crew had no idea what was causing these strange effects, and suspected a fire of some sort, when suddenly all four engines failed due to contamination from the ash! The 747 began an unpowered descent from 37,000 feet with the crew trying desperately to regain engine power, which they finally did at 12,000 feet, after flying out of the bottom of the ash cloud. Their actions were directed by their limited awareness (due to complete inexperience with such a scenario) – had the crew realized the odd effects were due to volcanic ash, they could have easily flown back out of the cloud, or avoided it altogether.

3.2.2 Adaptability / Flexibility

The ability of someone to accept and internalize information related to a changing situation can be referred to as one's Adaptability or Flexibility. This tendency could also be described as one's "internal inertia". Because humans tend to expect events to unfold based on past experience or expected outcomes, data that contradicts such expectations may be ignored or discounted. Emotions may play into this tendency, as desire or pride can induce inflexibility, when persons cling to plans (proven invalid) because of vanity or a misplaced sense of mission. The military refers to a form of this as "get-home-itis", where aircrew accept unsafe aircraft for flight or launch into questionable weather due to a desire to complete the mission – often to return home to loved ones after long deployments. The arrangements are not made in consideration of these degrading factors, simply because the conditions did not exist when planning. But when situations change and evidence contradicting the plans arises, aircrew are often loath to recognize or accept that the schedule must be revised. Outside observers can easily see the fallacy of continuing with the preset preparations, but those involved are blind to the obvious – they have become inflexible in the face of revised information. This inflexibility can be both recognized and unrecognized. In many cases, the data is acknowledged and dismissed, other times, the subconscious attempts to prevent conscious involvement and tends to mask cognitive assessment of contradicting observations.

Another aspect of adaptability is the presence of high levels of stress. Under dynamic conditions, and with the heavy consequences often present in aviation decisions, some people can become paralyzed when facing the fear of making an incorrect decision. The different levels of fear and stress are difficult to predict, as most humans avoid situations that bring them to such a level of duress. Because of the human predilection to avoid risk and conflict, few have knowledge of the level at which they will cease to effectively function. Thus, aircrew should be trained such that they recognize this point in themselves, and, more importantly, in others. A co-pilot who has "locked-up" and no longer contributes to the mission when under stress should be immediately recognizable to the other crewmembers, and procedures for circumventing or aiding this person should be reviewed. There is benefit in training aircrew by attempting to take them to this level, and simulator training for Navy and Marine Corps F/A-18 pilots typically does just that: during annual emergency procedure training, the simulator operator places the aircrew in increasingly dire circumstances, rapidly degrading the aircraft and weather until there is only one option left – ejection. The crew are trained to save the aircraft when possible, but when survival is contingent upon leaving the aircraft behind, the aircrew must recognize this and act without hesitation, as any delay may result in the loss of both the plane and the pilot. Early in training, the author found that his attempts to save the aircraft, due to pride and vanity, resulted in a late acceptance of the need to eject and a simulated loss of both the aircraft and himself.

3.2.3 Decision Making

Decision making is quite simply that – the act of choosing a course of action and then following through. Even if one opts not to decide, a choice has been made – one not to act. A failure to act is not a lack of decision, it is a decision not to act. So, when confronted with even a minor dilemma, humans are required to elect a path of action. As previously stated, the decision will be based upon the individual's situational awareness, derived from the many sources available. The results of these actions typically provide feedback, and this feedback will result in a new appraisal of the situation, providing a new level of SA. So, the decision-making cycle repeats, continuously. This cycle is natural and unavoidable, as life is a dynamic enterprise.

In aviation decisiveness is usually seen as being beneficial. Excessive flexibility, "waffling" between decisions, belies a lack of confidence in one's assessment of the situation – a lack of SA. But decisions, when made, must be communicated. This allows the other personnel involved to update their awareness, and continue their own cycle with the knowledge of each person's elected course of action. The goal, discussed shortly, is that all crewmembers reach the same conclusion regarding the decision at hand!

3.2.4 The Decision-Making Cycle

With the three elements of the decision-making cycle defined, the process itself becomes a logical flow: an event causes a change in a person's SA, which may or may not be internalized based on the adaptability of that person. With the altered SA, the person is forced to make a decision, which may include the decision to do nothing. Again, this process occurs for every decision one makes, throughout life, and does not require any human interaction – the cycle occurs internally, mentally. An experience that befell the author illustrates this process and how it occurs internally:

While cruising at altitude in an experimental airplane, returning home, the author noted an unusual vibration. The propeller-driven aircraft had not previously exhibited this vibration mode, and this caused concern. Thus, the Situational Awareness of the author was now changed, in that the odd vibration elicited a serious concern for safety. However, the author was eager to return home, and a lack of flexibility caused him to seek only to define the vibration, so the decision to continue the flight was made. In the effort to define the vibration, the engine power and RPM were varied from minimum to maximum settings, with the author working now at the knowledge-based level. Shortly thereafter, and with the power at maximum, approximately 2/3 of one propeller blade fractured and departed the aircraft (see figure 2). This resulted in tremendous vibration, due to the out-of-balance condition of the propeller and the high RPM setting. Now, the author's SA was that the vibration had been the signal of the impending failure, and was able to rapidly adapt to the new situation, shifting between the skill-based task of maintaining control and the knowledge-based assessment of damage and possible courses of action. Fortunately, fear did not impede his actions, and although anxiety was rather high, the decision was then made to stop the rotation of the engine as quickly as possible. With this task accomplished, his SA immediately dictated that a forced landing would be required, and the decision was made to search for the nearest suitable airfield… this process continued until a dead-stick landing was safely completed on a nearby paved runway. No other human was involved in this process (the battery had been torn from its

Figure 2
Author's Aircraft Following Propeller Failure
(Author)

mounts and no radio calls were possible), illustrating the often dynamic, yet individual nature of the decision-making cycle.

This decision-making cycle occurs for all three categories of human performance: at the skill, rule and knowledge-based levels. During skill-based performance, the cycle is primarily subconscious, with sentient cognition being devoted to the monitoring of the subconscious performance. Behavior modification at this level must be accomplished through repetitive training, and again, is not the focus of this discussion. For the rule and knowledge-based efforts, however, information is consciously sought in the desire to develop one's Situational Awareness. Information comes from the three basic sources previously mentioned: internal sources, physical systems, and other humans. How each person interprets the data provided, though, may vary wildly.

3.3 How Humans Affect Sources of Information

No two humans perceive an event the same. Each will color the physical evidence presented with internal prejudices and expectations, regardless of attempts not to. Easy examples of this phenomenon are eyewitness accounts of anything unusual. People will have different, sometimes radically disparate recollections of exactly the same event. When examining interviews of witnesses to a recent aviation accident, the author noted surprising differences in the stories. An aircraft crashed over the top of a road, and several drivers saw the aircraft pass directly in front of their vehicles. Considering the proximity of the aircraft, it should have been relatively easy to determine the attitude of the plane, but half of the eyewitnesses saw the aircraft inverted and half saw it upright. Upon reviewing the backgrounds of the persons, it was noted that those who saw it upright had relatively little experience with aviation, while those who saw it inverted were either pilots or had spent considerable time working with aircraft. This discrepancy might be explained by the expectations and experience of each person: those with aviation experience knew that an aircraft was perfectly capable of flying inverted, while those unfamiliar likely never expected to see an aircraft upside-down and probably didn't think that such flight was possible. This simple observation implies far-reaching consequences: the people involved in any aviation activity, from the pilots to the ground controllers, rarely if ever completely agree on the events of any given moment.

Because of the inconsistency of human interpretation, any attempt to improve crew decision-making must recognize and address this phenomenon. The persons involved must "agree to disagree" and then work actively to resolve their differences of opinion. Although this disparity can be a severe hindrance to aircraft operations, it can also be a blessing and is the primary justification for having a multi-crewed cockpit. The ability of a second person to recognize judgmental or interpretive errors committed by another crewmember provides benefit and safety to operations. Certainly, humans are not perfect, and a second impression of the situation often serves to highlight a deficiency on the part of the person exercising control over the aircraft.

With this understanding, aircrew must seek to ascertain the factors that affect their fellow crew's interpretation of the world. Again, no two human beings are alike, and no two people will completely agree on circumstances. Three concepts are the most significant factors in the variance of human opinion. They are: past experience, overload conditions, and prejudices and biases. Each of these will be discussed in detail. Team Decision Making relies on the ability of each of the members to consider these concepts

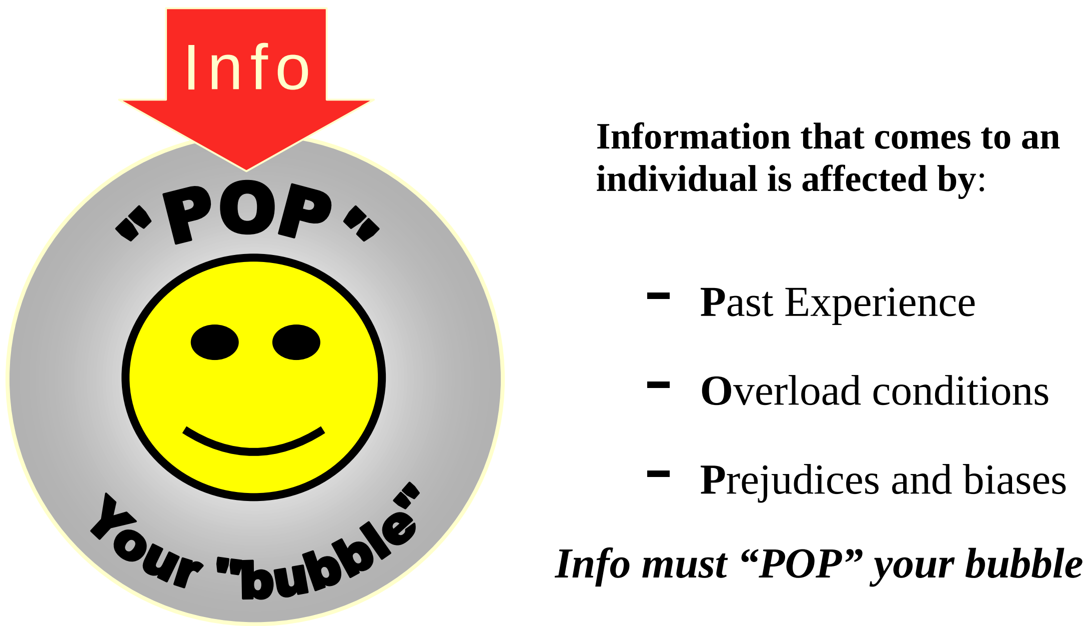

Figure 3
Human Corruption of Information
(Author)

when relating to each other. Figure 3 illustrates these three elements and how each affects information arriving at an individual: these elements form one's "bubble."

3.3.1 Past Experience

Past experience is the tendency for humans to model their world. Based on previous life experiences, humans tend to expect events to occur as they have observed in the past. This is unavoidable and is difficult to consciously recognize, but it occurs for every experience in life. Humans appreciate predictability, and seek to model their world so that they may anticipate the consequences of certain actions. The power of experience to shape and influence behavior is tremendous – consider the following anecdote:

Begin with a cage full of monkeys, place a ladder in the center and above the ladder, hang a stalk of bananas. As soon as the first monkey starts to climb the ladder seeking the bananas, spray all of the monkeys in the cage with cold water. Each time a monkey attempts to climb the ladder, again spray the entire group with freezing water. After a time, the group will begin to discourage or prevent any of its members from climbing the ladder, in an effort to avoid the punishment of the cold water. Once this behavior is consistent, replace one of the monkeys with an outsider, unfamiliar with the circumstances. Of course, the new monkey will begin to climb the ladder, seeking the bananas. Now, however, even before being sprayed with water the members of the original group will attack the new monkey to avoid the dousing. Continue replacing individual monkeys, until the entire original group is gone, but the behavior will persist. Although this scenario is fictitious, it is easy to see similarities in human behavior. This reflects the power of experience – once an event is expected to occur, people with prior experience will behave as though the outcome they expect is inevitable, regardless of its likelihood. There are, of course, varying degrees of commitment to expectations, but the severity of the consequences generally influences this commitment. If a general aviation pilot, when practicing stalls, enters an incipient spin upon adding full power to recover, then he or she will likely be hesitant to add full power during the next attempt at the maneuver. This reaction can be "trained out" through repeated demonstration of the maneuver and correct techniques, but what if that pilot was only given one chance to practice that maneuver before being asked to perform it at fifty feet?

Now, what if there was a co-pilot in this aircraft performing stalls at fifty feet? And what if, during this co-pilot's training, his or her one attempt at a stall recovery using full power resulted in a smooth and controlled recovery with minimal loss of altitude? It is reasonable to expect that the two aircrew would respond to the situation differently, based on their past experience and expected outcomes regarding traditional recovery techniques. While one pilot would be hesitant to add full power because of fear of a spin at fifty feet, the other would likely slam the throttle forward to avoid a hard landing, precipitating a conflict on the flight deck. This potential for disagreement is always present, as all humans and their attendant experiences are different. This must be acknowledged and addressed in risk management, especially in aviation. Aircrew must accept that the experience of their compatriots will not mirror their own, and so a primary goal of Team Decision Making is the reconciliation of each aircrew's expectations for a given situation.

An actual example of expectation occurred in March of 2002, when a cargo carrier's DC-8 landed at McGhee Tyson field in Tennessee and was instructed to taxi to but hold short of an active runway. The crew heard tower instruct landing traffic on the active runway to make a 180-degree turn and back-taxi on the runway. Upon observing the traffic land and begin its back-taxi, the crew of the DC-8 reached the hold-short and assumed tower had provided clearance to cross, as the traffic was obviously also at taxi speed and there could be no additional landing traffic with one already back-taxiing on the runway. Tower had, in fact, not issued the clearance to cross, and although no harm was done, the crew was reminded of the pitfalls of expectations (NASA, 2003). Another case where past experience caused a near-emergency was the flight of a Jetstream 4100 bound for Washington Dulles. When refueling, the crew was not given a receipt specifying fuel added to the aircraft. Because they had not received a receipt on an earlier trip that day to the same airport, and the aircraft had been refueled, they "were not too concerned". Due to time pressure to maintain schedule, the pre-takeoff checks were rushed, and it was not until reaching cruising altitude that the aircrew realized there was insufficient fuel onboard to reach Dulles – obviously the aircraft had not been serviced. In this instance, a safe divert was made, but the lack of receipt was an indicator which went unnoticed because of prior experience (NASA, 2003). Quoting Navy Lieutenant Lawrence Reay "Expectations can lead to disappointment, and in the air, they can be deadly." (NSC, 2001).

3.3.2 Overload

Overload can best be summarized as "too much information". There is a limit to the amount of information any given human can effectively process at a given time. Subconsciously, a person may be aware of most of the stimuli present, but cognitively, only so much will be internalized into the decision-making process. Under conditions of high stress, another negative aspect of overload is that only stimuli matching the expected outcome or supporting the current decision will be recognized. Information that conflicts with a person's desired outcome or past experience (see above) will be ignored or discounted as inaccurate.

In the presence of particular failures, especially those which create conflicting opinions on the flight deck, overload can lead to a focused, unyielding approach to a problem. In instances where the failure is correctly diagnosed, this can be a beneficial result. However, if the failure is difficult to discern or misdiagnosed, tragedy can be expected. An example of this is a COPA airlines 737-200, which, on June 6th, 1992 crashed near La Palma, Panama with the loss of all 47 onboard (ASN, 2004). The aircraft broke apart in-flight after exceeding its maximum allowable speed. The reason it plunged toward the earth at an attitude and speed known to be unsafe apparently lay in the cockpit instruments. At some point in the flight, the captain's attitude indicator insidiously failed. Thinking that the aircraft was diverging from the autopilot commanded attitude, the autopilot was disconnected and the aircraft hand-flown. Although the standby attitude indicator was apparently correct, the attention of the captain and first officer focused on the primary system in the effort to restore the aircraft to level flight. Unfortunately, the flight was at night, so there was no visible horizon available to easily diagnose the incorrect instrument. Following the failed primary instrument until the end, believing it to be correct, and unable to search for alternative solutions under the stress of a rapidly accelerating aircraft, the crew flew an otherwise healthy aircraft into a terminal dive.

A very similar occurrence caused the loss of at least five Piper Malibu aircraft in a two-year span from 1989 until 1991. Fairly inexperienced pilots flew these complex aircraft into instrument and icing conditions. In all cases, it was suspected that the pitot heat was not turned on in these circumstances. Predictably, the airspeed indicators soon failed, and as the pilots attempted to maintain control of their aircraft, they fixated on the airspeed indicator. Because the flights were in IFR conditions, there was no familiar truth data available in the form of a visible horizon, and so the SA of each of the pilots was that their airspeed was decaying and that a stall was imminent. Unfortunately, this focus, in a very intensely trying flight regime, caused each of the pilots to accelerate in an attempt to regain *indications* of flying airspeed with a resultant severe overspeed, structural failure and in-flight breakup of the Piper. Cognitive overload was certainly a factor, as the other instruments could have provided vital information, but were overlooked. This phenomenon, in addition to spatial disorientation, is described in the NTSB's report on these mishaps:

> Although the pilot's fixation on indicated airspeed was probably the initiating event in his loss of control of the airplane, spatial disorientation could easily have occurred because of the fixation. Fixation results in the omission of a cross check of other performance and control instruments. If the omission lasts for more than a few seconds in a dynamic situation, the pilot may tend to disbelieve the other instruments in preference to a single instrument when the cross check is resumed, particularly if the dynamics of the situation have confused the pilot's internal motion sensing and position sensing systems. When this occurs, the pilot is spatially disoriented, and he or she may tend to fixate more strongly on the single instrument. (NTSB, 1992)

3.3.3 Prejudices and Biases

Prejudices and biases are very similar to past experience, with the notable exception that personal experience is not a contributor. Prejudice arises as a result of cultural norms learned by an individual of the course of a lifetime. These cultural norms will develop when exposed to any related environment, and although flight related prejudices might not develop until interacting with that community, prejudices relating to human interaction will be present from soon after birth. Consider the anecdote of the monkeys above – the replacement monkeys in the experiment would be behaving based on prejudice, since there would be no actual experience of being sprayed with water. For example, while growing up in Texas, the author found that every soda was referred to as a "Coke". A typical exchange in a fast food restaurant would be: "I'd like a Coke." "OK, which kind?" "A Pepsi, please." This was the prejudice carried into the first fast-food restaurant visited in California, where, having no experience with the restaurant or the state, a "Coke" was ordered. Surprised at not being asked which version, the author was disappointed when an actual "Coke" was delivered when actually a "Sprite" had been desired!

Again, humans appreciate an ordered and predictable environment. A prejudice, unlike past experience, is a person's application of empirical knowledge to related circumstances. Despite having had no direct familiarity with a given event, humans will logically extrapolate recognizable characteristics into expectations of an outcome that falls within their mental model of the world. Certainly, this can be a dangerous predisposition, especially since the world does not always behave according to each person's predictive model.

Prejudice will also arise from communal exchanges, where one individual's experience can become the collective prejudice of a group. This can be both good and bad, depending on the information and outcome related by the person with the experience. In many cases, "chair flying", or storytelling by senior pilots is considered a beneficial event. In this way, a large group can learn from the experiences of a select few. By using this resource of collective experience and knowledge, aircrew may gain insight to situations and crises without directly suffering the consequences. Conversely, this empirical knowledge may be based on an unusual, single event or even derived from a misinterpretation of events by the experienced pilot. As previously discussed, perception of an environment is heavily dependent on the individual, and no two humans will agree on all of the features. In this way, second-hand knowledge gained through the filters of a primary instructor can be contaminated with the perceptive and judgment errors of that instructor. Because of this, standardized training examples that have been reviewed by a large pool of experienced aircrew are appropriate. By allowing a group norm to be applied to the event and decisions, assurance is gained that the lessons taught are appropriate for at least a majority of the community.

Biases are related to prejudice, but are defined as an internally developed preference to expect a given outcome. Simply, a bias is an extrapolation of a person's individual experience and the desired results of the current situation. A bias involves emotional attachment to a desired outcome. A bias may or may not include the influence of past experience or prejudice.

Biases include the expectation of a given outcome based on desire – a want or need for a particular solution. Because biases involve emotion, they are often somewhat irrational. In this respect, it is important that a crewmember be familiar with not only themselves, but with the other members of the crew, even on a personal level. There may be factors, not immediately apparent to others, which drive an individual to interpret events in a manner that supports their desired outcome. For example, a co-pilot might understand that a "chance of severe thunderstorms" indicates an area best avoided, while a pilot who desperately wants to reach that area might perceive the same information as "only a chance, so there should be no problems at all!"

The effects of bias might have been a factor in the runway overrun of an American Airlines MD-80, Flight 1420, on the 1st of June 1999, in Little Rock, Arkansas. In this mishap the aircrew were on the third leg of a long flying day, having also encountered delays. The weather forecast at Little Rock included a probability of thunderstorms, and there were in fact thunderstorms near the field when the aircraft entered the terminal area. Because of the storms, the winds at the airport were strong and gusting with significant variation in direction. The first officer and co-pilot engaged in a discussion of the crosswind limitations of the MD-80, anticipating problems due to the conditions. The first officer initially suggested that 30 knots was the crosswind limit, but the captain reminded him that a wet runway was likely and that 20 knots was the wet runway crosswind limit. The first officer revised his opinion to 25 knots, but neither aircrew took any further action to verify the limit (which was actually 20 knots). The crew then made several radio exchanges with the local controllers, discussing the severe weather present at Little Rock. After requesting and receiving a runway change to reduce the crosswind, the tower updated the winds. As reported, they were out of limits, but the first officer read the transmission back such that the crosswinds were within limits:

> At 2347:08, the controller again cleared flight 1420 to land and indicated that the wind was 350º at 30 knots gusting to 45 knots. The first officer then read back the wind information as 030º at 45 knots (NTSB, 2001).

There were many other meteorological effects during the aircrafts approach, including heavy rain, hail, reduced visibility and wind gusts ultimately recorded as high as 76 knots. Why the aircrew would even attempt the approach is questionable, but quite disconcerting is the fact that the first officer mentally altered the tower winds so that the crosswind would fall within limits. This could be attributed to a misunderstanding of the tower's transmission, but "030" is a significant transposition of "350". Considering this and the other contra-indicators that were discounted when attempting the approach, it is likely that both the captain and the first officer were subconsciously biased to hear only information supporting their attempt to land safely. Unfortunately, they did not, and the captain and nine others lost their lives as a result. The aftermath is shown in detail in figure 4.

3.3.4 Emotions

Emotions can also play a significant role in a person's approach to a given scenario. Although emotions are very difficult to quantify, they certainly affect how an individual gathers information, relates to others, and makes decisions. Varying states of distress or eustress (stress of a positive nature) can radically alter a person's behavior. Perhaps it would be beneficial if life was consistent and predictable, but it is certainly not and this unpredictability can lead to stress.

Stress is not always a detriment, as eustress can improve aircrew performance in times of crisis. When faced with an exceptionally challenging situation, many people "rise to the occasion" and better their normal performance. This is eustress – where demands or danger heighten a person's ability to process and interpret information and

Figure 4
American Airlines Flight 1420 Following Runway Overrun
(Unknown, http://www.airdisaster.com/photos/)

quicken the decision making process. Eustress occurs at different level for different people. A level of tasking that drives one person to excel may cause another to break down completely and cease functioning under the pressure. Thus, it is incumbent on each team member to be aware of how stress affects themselves as well as their teammates. At times, leaders may seek to employ this phenomenon by driving peers or subordinates to increase output. But this requires skill and the knowledge of the others in order to avoid breaking down the team by overtasking. Too, eustress is a time-limited occurrence, and one cannot be expected to function under severe conditions indefinitely as all people have a breaking point.

Fear can be another significant emotion, as fear can debilitate members of the team rapidly. Aircrew often consider themselves immune to fear, but it is not only the people airborne that must be considered. Air Traffic Controllers, Tower Controllers, and others play critical roles in aviation operations. The loss of effective contribution from these members during times of crisis can be disastrous if their contributions are required for the safe navigation and performance of the aircraft. When placed in imminent peril, some individuals will cease to function, and will be unable to perform even menial regular duties - this must be considered. Too, some individuals may react with panic or aggressiveness, which can become even more dangerous. Although the flight crew are probably not the immediate threat, what of the passenger who suddenly attacks others or begins screaming hysterically when discovering the aircraft is in danger?

Aviation can often be very time sensitive, considering the limited fuel and rapid speeds of modern aircraft. This adds considerably to the stress of all involved, and tends to expose emotions much more readily than more sedate vocations. Although the subject of controlling emotions is well beyond the scope of this paper, the substantial impact of emotions must be considered when relating to other members of the aviation team.

3.3.5 "Sixth Sense"

Although the existence of a "sixth sense" may not be universally accepted, there are certainly cases where humans have cited premonitions or "uneasy feelings" as guiding influences in decision making. Even in aviation, aircrew and other personnel respond to these influences. It is thus appropriate to address the existence of internal, subconscious factors best described as a "sixth sense". This attribute can often alter behavior patterns, such as the pilot who senses "something not quite right" and checks the engine instruments without prompting and independent of habit patterns, only to discover subtle and otherwise undetectable signs of impending failure. The author had just such an experience, re-checking the engine instruments of an F/A-18 Hornet after takeoff from Misawa, Japan. Although the indications were within limits and had been repeatedly checked during the takeoff roll, a subsequent scan revealed one engine to have slightly lower oil pressure than the other. While within limits, the value seemed odd, and the author returned to base, to find an aft bearing seal blown and half of the lubricating oil gone from the engine. Had the flight continued, the engine would have been lost over the middle of a cold and desolate sea.

Whether or not an individual accepts the idea of a "sixth sense", one should respect the power of premonition when dealing with others. These feelings can be overpowering in some cases, and can seriously affect a person's ability to function. Although one crewmember may discount the possibility, another may be virtually disabled by the effects of such a phenomenon. Because of this, all persons should accept the fact that others may be affected by premonitions or otherwise inexplicable feelings. Typically, a reasoning approach is the best method to combat this occurrence, and sympathy is advisable. An adversarial, dismissive attack on a person's emotions will likely meet with resistance and do little to resolve the situation.

3.4 Summary of Individual Decision Making

The elements of Situational Awareness, Adaptability/Flexibility, and Decision Making flow together to form a decision-making cycle, as illustrated in figure 5.

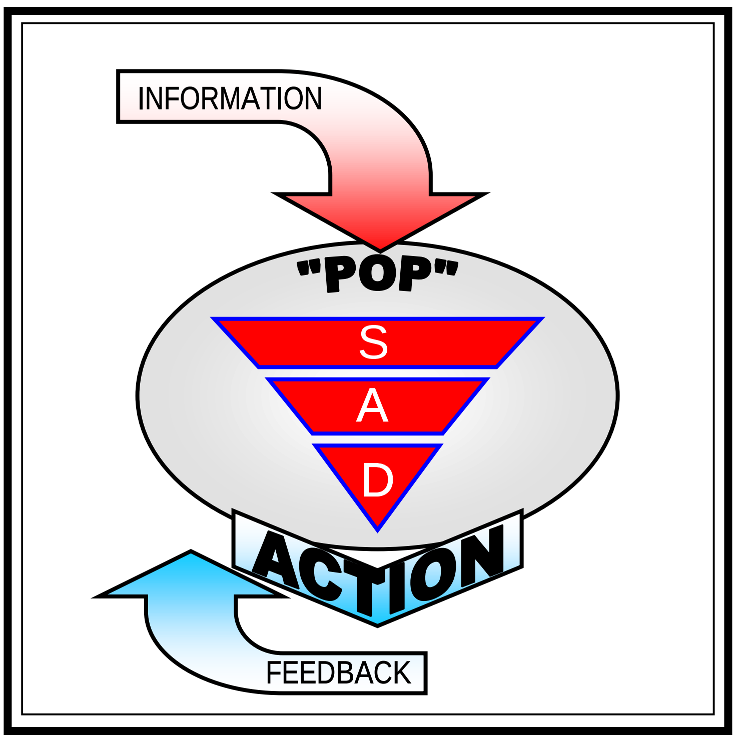

Figure 5
The Individual Decision-Making Cycle
(Author)

This cycle occurs for every decision we, as human beings, make throughout life. There need not be any other persons involved – the cycle can occur internally or with the interaction of many other people. A person assesses their environment, thus forming one's situational awareness. The flexibility of that individual determines if that assessment is internalized or ignored due to competing priorities, and then a decision is made. Once a decision is acted upon, the environment changes and a revised opinion is formed – one's situational awareness changes, beginning the cycle anew. Significantly, however, the cycle is not necessarily identical for people in "identical" situations.

Each member of a crew must acknowledge that others may not interpret a situation exactly the same, due to that person's past experience, overload, and prejudices (the "POP" phenomenon) and each must seek familiarity with how "POP" affects the others in a crew. Because the situational awareness of crewmembers will always exhibit minor (and sometimes major) differences, aircrew must understand that each will often reach different conclusions regarding the appropriate course of action. It is because of familiarity that longstanding crews become comfortable with one another – each has knowledge of how "POP" will color the other's reaction to certain situations. Still, there is always the possibility of truly unusual events, and complacency must be avoided. Knowledge truly is power, and the recognition of the aforementioned phenomenon is important for everyone involved in aviation decision-making.

4. AIRCRAFT SYSTEMS

The systems of modern aircraft have become increasingly capable and tend to supply far greater information and detail to the aircrew. Unfortunately, this trend has led to an overabundance of detail, or the masking of critical indicators that the aircraft is expected to monitor for the aircrew. Automation and computer aids can potentially relieve cockpit workload, but they can also greatly compound it. This section will deal with the methods of presenting vital information to the crew, examine some of the pitfalls, and proffer suggestions for improving the physical systems of the cockpit.

4.1 Instrumentation

The traditional source of information in the cockpit comes from the instrumentation. The daunting array of gauges and dials spread across the panel of almost any plane seems overwhelming to most people. The aircrew's need for an exceptionally detailed status of the critical systems onboard an aircraft drives this arrangement. The situational awareness of the aircrew is derived from the data presented, and decisions affecting, and sometimes risking, the lives of hundreds of people are made based on the interpretation of that data. But, instrumentation does not always present information. Too often, the multiple gauges and dials report only relatively meaningless numbers, when the goal is to present information – where "…*information* [is] the reduction of uncertainty"(Sanders & McCormick, 1993). A modern cockpit must be assembled so that the advanced displays improve the crew's situational awareness by eliminating uncertainty regarding the aircraft's operational state. This places a tremendous responsibility on the designer of the modern cockpit: to ensure that the means of conveying information are both accurate and easily interpreted. This does not always occur, and the aircrew are left to compensate for deficiencies in the design of the human-machine interface in many aircraft.

How, then, to best ensure that data is conveyed efficiently and without error? There are decisions regarding the medium, the format, and the content of each element of displayed information or active message. Is it best to rely on directed-attention discrete messaging, or passive, continuous presentation of critical parameters? This is but one of many questions the cockpit designer and end-state user must ask, and the answer depends on what is being conveyed. In order to simplify the morass of possible questions, it is best to break the designer's task into three basic areas: what is the best method of classifying the data to be presented, then; what is the best means of presenting that data, and finally; what decisions can be automated to relieve the aircrew of the need to interpret data? These functional questions will be addressed in succession, with the intent of explaining the efforts of a human factors engineer and providing some structure for modern crews to evaluate and employ a modern, efficient, and safe cockpit.

One of the most critical human factors in the design of a cockpit is the presentation of information and the execution of decisions associated with that information. The physical accommodation and support of an aircrew is vital, but the time critical and precise nature of aircraft positioning, attitude and condition demands special consideration. The complexity of a typical cockpit is daunting. All of the gauges, dials, and switches form an overwhelming interface, one that typically requires a great deal of practice in order to achieve efficiency in the interpretation of data. Because mistakes in aviation can hold dire consequences, this task is unusually important. The task of the cockpit designer is thus simplifying and streamlining this interface as much as possible while aiding the aircrew in making, and executing, decisions. Until very recently, there were many technological factors that limited the interface options available in aviation. With the advent of the microcomputer, however, there is now a myriad of possibilities regarding the gathering of data, display of information, and ultimately the control of an aircraft. This section will take an abbreviated look at each of these functional areas and make generic recommendations regarding each. Although not a comprehensive treatise, the intent is to explore the rapidly expanding technology regarding the man-machine interface present in the modern cockpit and the configurations a modern crew must become proficient with.

4.2 Classification of Data and Organization

The most obvious need within the cockpit is the means of communicating information to the aircrew. This requires addressing the medium of communication, but even before this decision is made, it is important to determine how data will be classified and organized. Data is usually what is being presented to the aircrew, but the goal is for it to immediately become information. Information is an abstract concept, but is best represented through the following description:

> Data are numerical representations… If the data can be associated with a specific sensor or source, the meaning of that data becomes clear, and this transforms the numerical data into information that can be viewed and interpreted by human beings or automated systems. (Marsh, et al., 2001)

As a rule, data should be: classifiable, identifiable, and readily interpreted. This leads to rapid assimilation as information. Classification of data could best be described as tying it to a general system on the aircraft. Identification would then be obviating the specific item within that system. Making data readily interpreted is a distinct challenge, and requires consideration of both human factors and psychological impacts. Classification can be accomplished through grouping, commonality of shape or actuation, method of presentation, or many other methods. Grouping would be keeping certain items in one location in the cockpit, like all of the engine instruments in one area of the panel. Using identical shapes and sizes for those engine instruments, or perhaps only levers to control landing systems, would address commonality of shape or function. The presentation methods might include visual displays, auditory cues, tactile shapes, and others. For example, in Navy aircraft, emergency system controls are all painted yellow and black – thus classifying them. In a P-3 Orion, the gear handle has a round shape while the flap handle is shaped like an airfoil, identifying each of these landing system controls. The interpretation of data, however, involves a more complex cognitive process.

To make data readily interpreted, additional considerations must be addressed. The most important is: what is the required level of precision for interpretation? The more precision necessary, typically the more space required. An obvious example is the dashboard of a car – the speedometer is dominant, indicating its importance and the precision with which the operator must judge speed. Next smaller in size would often be the temperature gauge, which is important performance information but does not need to be interpreted to the degree. Smallest might be the "oil low" light, which does not indicate performance or require significant interpretation, but is critical nonetheless. The concept of "performance information" is simply how that information relates to decision making within the cockpit. If the information will lead to adjustments to reach desired states of operation, then it should be considered performance information. If the information indicates failure states, it may be vitally important but it is not performance information. There is limited space in a cockpit, and so determination of the criticality of each piece of information is required. A cockpit must present information, and do so with the necessary resolution. There are three basic mediums by which this can be accomplished: auditory, visual or tactile means, and each deserves consideration.

4.3 Presentation and the Interpretation of Information (Data)

With the technology of today, there are countless options regarding the presentation of data, far more than even ten years ago. Instead of round dials, the instrument panel can consist of color displays, LED bar graphs, animated checklists, and more. But just because something is new does not mean it will positively contribute to safety and awareness in the cockpit. "Technology for technology's sake" is a very real danger in modern design. Replicating traditional instruments on a video screen does not make a "glass cockpit". Rather, modern cockpit design should contribute to reduced workloads and improved awareness through innovative methods – not innovation applied to traditional methods.

> With regard to the flight deck work, …there is mounting evidence that modern flight deck avionics systems can reduce pilot situational awareness instead of

> improving it. A recent report by British Airways concluded that "glass cockpits have not been as successful as had been hoped in improving situational awareness," and that "degradation of situational awareness ... is a serious problem." Future developments in civil operations that could increase pilot workload and might even overload the flight crew with information are also a concern, ... (Birch, 2000)

When presenting information, there are three basic mediums available to the designer: visual, tactile and auditory. The most prominent is the visual medium, since we, as humans, use our eyes as our predominant sensor. Auditory and tactile cues are much less employed, but still very valid means of communicating both data and information. In practice, auditory cues appear to be more reliable than tactile, depending on the data presented. This is due to a lack of resolution in tactile input. A human's ability to accurately and consistently spatially locate items (without visual input or a great deal of practice) is limited, and tactile identification of similar items is difficult. However, certain discrete items of information can easily be transmitted via tactile methods, such as a stick shaker, which is typically used to indicate the onset of a stall. There is research being conducted by the Navy into the use of a tactile vest that transmits aircraft attitude information to a helicopter pilot. The intent is to allow a helicopter pilot to hover in instrument conditions, while looking outside of the aircraft. The vest uses small vibrators placed about the torso to indicate drift and attitude changes via pulsations in discrete locations. This is certainly an esoteric example of tactile information, but it effectively illustrates the variety of methods available to convey information.

4.3.1 Visual Information

Often the simplest and most reliable method is visual presentation. The visual sense is the primary source of information for the human being, and is heavily relied upon. As a result, it is also the most developed, and is highly accurate and sensitive. This allows the cockpit designer a great deal of flexibility but coincidentally places much responsibility upon him or her. Any flaws or shortcomings in the visual equipment will be readily noticed and, if critical information is lost, result in mistakes. Visual systems are also the most highly developed, and can include such advanced items as "Heads-Up Displays (HUDs)". This innovative display places information in the pilot's field-of-view, focused at infinity, and thus alleviates the need to scan traditional instruments. The human eye requires approximately ¾ of a second to re-focus (Mansueti, 2002), and this timesaving can result in benefit in truly time critical situations. Other displays that can be located in or near the aircrew's field-of-view include basic indicators that rely upon simple shapes or colors, and can thus be interpreted using peripheral vision. For these to be successful they must dominate that portion of the scene – the shape or color must stand out from the background in order to be recognized and interpreted via peripheral vision. On the instrument panel itself, the advent of Cathode Ray Tubes (CRTs) and Liquid Crystal Displays (LCDs) have allowed the display engineer the ability to create a re-configurable panel – one that can adapt to the flight phase and the information requirements attendant with it. This is an area requiring much research – what is the best format for presenting each bit of information so that the flight crew readily interprets it. All of the human factors involved are beyond the scope of this paper, but some basic principles are worth noting.

An unfortunate trend in modern design is toward the presentation of strictly data. In many cases, new cockpit displays supply only raw numbers to the aircrew. Despite the obvious utility of a large, easily read number placed prominently on a screen, there is actually less "information" supplied than on a dial gauge with markings. A number is just that – a number – and it has no meaning (and thus is not information) until it is correlated to some respective database contained in the aircrew's memory. A dial gauge, though, shows not only the current, say, airspeed, but also the significance and magnitude of that airspeed in relation to the marked never exceed and stalling speeds of the airplane. Rate information is also present, seen in the speed of movement of an analog pointer. This provides information to the pilot without the cognitive correlation that numerical data demands. Tape gauges that show no endpoints or relative scale lack information – they are data only. The goal of the modern cockpit must be to present readily assimilated information – information that is intuitive. This is accomplished through displays that employ motion relative to the data being presented, that show data in linear relation to the appropriate limits, and use consistent symbology and graphics within the same classification of data. Graphical depictions also make interpretation much easier, such as a moving map to show aircraft positioning and ground track, or an end view of the airplane with each weapon station and loading depicted on a display. When using graphical presentations, attempts should be made to use consistent presentations and to adopt any industry standards that might exist (whether formal or by general acceptance).

4.3.2 Auditory Information

Auditory information has great potential to relieve some of the visual burden of overtasked aircrew. Unfortunately, the auditory sense is generally unused except for communication with external agencies. Modern fighter aircraft, though, rely greatly on sounds for the purpose of conveying critical information to the pilot. A notable disadvantage of this format, however, is that "auditory rather than visual presentation often leads to more rapid but more error-prone processing, a fact that in part leads aircraft designers to use auditory displays only for the most critical alerts, where speed response is vital." (Wickens, 1992). The response time for auditory stimulation is 120-185 msec, while visual stimulation requires 150-225 msec to be processed (Casler, 2000). The F/A-18 Hornet, for example, uses tones to inform the pilot of enemy radars tracking his aircraft, of any exceedance of aerodynamic limitations, and of the status of weapons about to be fired. The Hornet also uses pre-recorded voices to announce failure states of the aircraft (NAVAIR, 2000). Current research includes the use of three-dimensional audio systems to provide spatial information to the listener. Although the stall warning horn is a long-lasting example of auditory information, the potential will soon exist to supplement an aircrew's spatial, temporal and general situational awareness using auditory input. The challenge will be applying technology smartly – as conflicts with communication messages may arise and create priority issues. Deconfliction of audio messaging can be accomplished using variances in the format of the communication (tones vs. the spoken word) or by relative volumes, including eclipsing.

4.3.3 Tactile Information

Tactile information is the least common form of presentation. The primary reason is the limited interface available – the pilot's hands are the highest resolution interface present (Mansueti, 2002) and are generally in contact with the aircraft – but are usually actively involved in the control of the aircraft. The other areas in constant contact – the feet, back and buttocks – possess much lower concentration of nerve endings and are of much lower resolution. As such, only limited precision can be tactilely communicated. Switch and control levers typically use some form of tactile coding, however, to permit ready identification without visual confirmation. General aviation has adopted a standard for engine controls that includes a smooth knob for the throttle, a grooved knob for the propeller control, and a sharp-ribbed knob for the mixture control. This permits tactile-only identification. But very few examples of tactile information systems currently exist: one would be the stick shaker employed on several business jets and airliners to indicate a near stalling angle-of-attack. Future uses of this medium could include a vibrating brake pedal to indicate functioning ABS, a vibration in the seat to warn of an impending exceedance of the acceleration limit of the airplane, or even the attitude vest mentioned above. Fortunately, tactile information must be very simple, and thus should be easily interpreted. Too much complexity, though, can make this medium almost impossible to resolve. A bank of multiple switches can prove difficult to sort through without direct cognitive attention, just as too many vibrations or pressures would readily overwhelm an aircrew not solely focused on interpreting that information.

4.4 Automation of Decisions

The rapid development of the computer has made true revolutions possible in the control of mechanical systems. Previously, all monitoring and decision making in mechanical systems was relegated to either a human or a simple hydro-mechanical device with limited inputs. But with the tremendous processing power of the computer, decisions can now be made automatically and with due consideration to an ever-increasing number of variables. The modern cockpit designer must carefully apply this technological revolution, though, in order to avoid serious safety concerns. A computer is only as good as the folks who program it, and is still very fallible as a consequence. This means that humans must retain oversight of the automation, and have the ability to immediately override any decisions deemed unsafe. A computer is very accurate, but a human is able to maintain awareness of the "big picture" and is also capable of predictive modeling and rapid pattern recognition that a computer simply cannot. When employing automation, the designer and aircrew must look at the characteristics of the decision to be made and weigh the advantages of both humans and computers. In Table 1, a model for doing so is provided.

Another potential pitfall of automation is the removal of the pilot from "the loop". If the aircrew are not actively involved in the operation of the aircraft, then complacency and disinterest could beget different failures: the development of automation has resulted in a shift from errors resulting from commission errors (an operator's action evolves into a problem) to those resulting from omission errors (the operator fails to recognize a problem) (Sarter & Woods, 1995). Checking for untoward events that rarely occur is a vigilance task, at which humans are notoriously poor. (Loukopoulos, et al. 2003).

Table 1
Decision Characterization Matrix

	HUMAN	COMPUTER
Set, predictable, constant conditions	LESS	MORE
Amount of Repetition		
How time critical		
Precision AND Complexity required (i.e. fuel metering)		
Mathematical/Algebraic content		
Amount of Prediction required	MORE	LESS
Pattern recognition required		
Safety Impact/Consequences		
Future Impact/Additional decisions required as a result		

So the problem then becomes how to keep the aircrew aware of the decision making occurring, but not require exceptional mental processing.

Of course, another consideration is the requirement for the human to be able to interrupt and override the automated decisions. There are cases where it is simply impossible for a human to perform a computer's task, such as the flight control computers of an unstable airplane like the X-31 (Friehmelt, 2002). But when possible, the aircrew must be kept subtly informed and capable of reversing any inappropriate decisions. Correctly applied, computers and the capability they bring to relieve aircrew workload are a boon to aviation.

The modern cockpit is certainly a daunting environment, but through intelligent application of the aforementioned principles it can become more intuitive, safer and more productive than was ever possible before the microcomputer. The challenge lies in that intelligent application. The organization of the displays and controls should be carefully analyzed, as poor organization can substantially increase cognitive workload and reaction times for a given procedure. Although aircrew cannot immediately rectify problems, this analysis can direct training efforts to areas of expected difficulty. The presentation of data must be avoided. Although this sounds contradictory, it is information that should be provided to the aircrew. The less mental correlation or imaging required of a pilot, the better. Information, if presented in a manner that is easily interpreted, supports rapid and accurate decision making without the need for the aircrew to mentally assemble discrete bits of data into an overall picture. In an effort to support easy interpretation, the format of the information must be selected based upon its content. Visual, auditory and tactile mediums are possible, with the visual medium predominating. However, because certain items of information readily adapt to auditory presentation, aircrew can expect future designs to relieve some of the visual workload of the modern cockpit. All of this, and a great deal more, must be considered when assembling a team in this very compact information and control center, the cockpit. When thoughtfully applied, these principles will lead to a safer and more productive flight deck, enhancing the crew's ability to reach the same state of situational awareness.

5. CREW INTERACTION SKILLS

With knowledge of how an individual gains awareness in the pursuit of effective and safe decisions, and how the mechanical systems in the cockpit support this effort, the next objective is to improve the efficacy of the process of exchanging information between members of the team when making joint decisions – Team Decision Making. Every human interprets the world differently, as previously discussed, and the once an individual has reached awareness of a situation, the next effort is to reconcile that view of events with the other team members. There are many methods for accomplishing this, but for simplicity, the four remaining Navy CRM skills will be examined: Communication, Leadership, Assertiveness and Mission Analysis. A synopsis of the meaning of each term follows:

Communication	-----	*Being understood*
Leadership	-----	*Breaking down barriers*
Assertiveness	-----	*Being heard*
Mission Analysis	-----	*Team goal setting*

Each of these terms reflects a different method of relating to other team members. All are important. Through the use of these skills, the flight crew can promote a commonality of awareness among the team.

In figure 6, a visual model of the team decision making process is shown. The illustration assumes that two individuals are exposed to the same environment, but

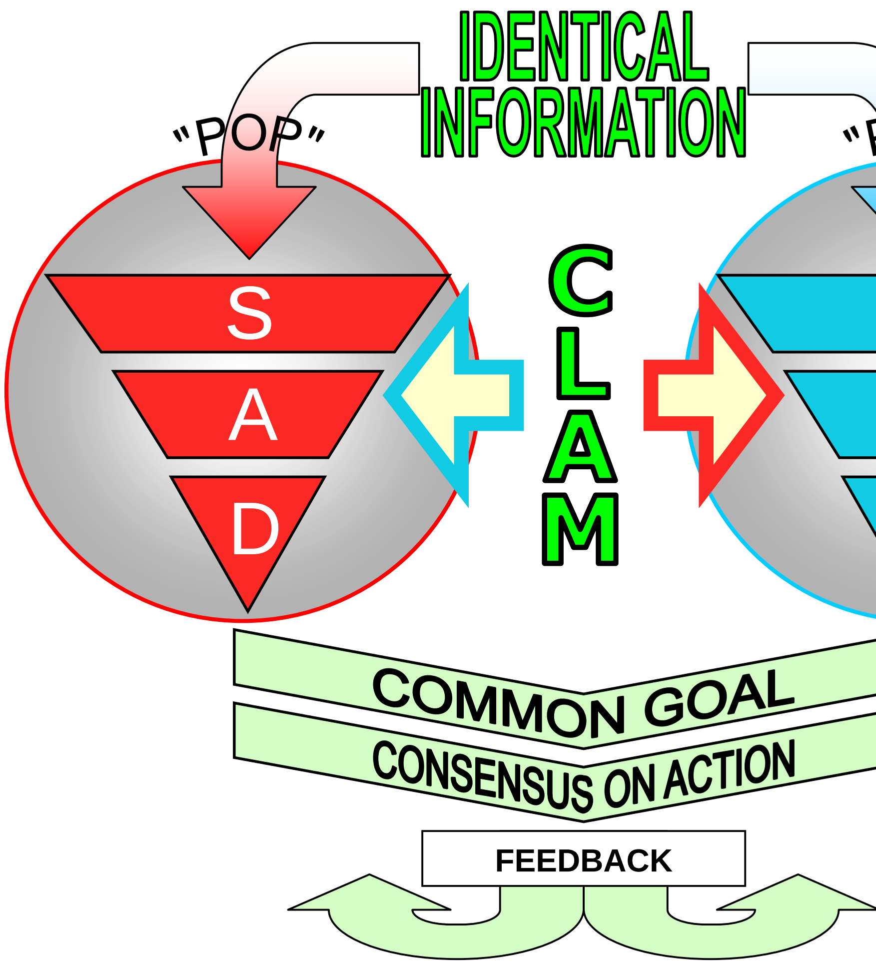

Figure 6
Graphical Model of Crew Interaction
(Author)

through factors such as the "POP" phenomenon, their respective opinion, or "SA", of the situation is disparate (shown through the use of differing colors for each decision-making cycle). The skills of communication, leadership, assertiveness and mission analysis, however, allow the two crewmembers to reach agreement on the situation and reach a consensus on action to be taken. With the execution of their decision, the environment changes, feedback occurs, the two individuals interpret this according to their own idiosyncrasies, and the process begins again.

5.1 Communication

The most important feature of a functioning crew is communication. It is the bedrock of all of the processes that follow. It is primarily verbal, although it may occur in any form including physical, visual, and even through prior common experience (such as the statement "same as last time"). Although communication seems a simple concept, there is significant complexity to it. For anyone who has tried to use hand signals to convey complex information, or even just played a game of charades, the challenge of communication becomes immediately apparent. Verbal, physical, or other exchanges cannot always be treated as communication. For communication to occur, there must be receipt of the sender's information. Herein lies the difficulty in achieving effective communication – determining if the receiver understood the intended message. If this is not the case, there are several possible levels of mis-communication, listed and described below:

Effective Communication – both sender and receiver are adept and message is effectively received.

Ineffective Communication – either sender or receiver is not adept at conveying or interpreting the message and this is recognized.

> "I don't understand", despite the efforts of both parties, cultural or conditional differences prevent reaching a mutual and correct level of situational awareness.

False Communication – sender thinks it effective when it is not, receiver is aware of deficiency but does not inform sender.

> Such as a timid subordinate under an oppressive boss, unwilling to seem incompetent by requiring amplification of the message.

Deceptive Communication – both sender and receiver feel that effective communication has occurred, but receiver misinterprets message and is acting on incorrect assumptions.

Of these four possibilities, deceptive communication is potentially the most harmful. Because both parties are content, there are no warning flags regarding the misunderstanding. An example of deceptive communication occurred in March of 2002 when a Gulfstream II was inbound to San Francisco International (NASA, 2003). The controller cleared the crew for a "Tiptoe Visual Approach" which the first officer read back to the controller. The captain, however, understood and began to execute a visual approach – ignoring the restrictions of the "Tiptoe Visual" approach. This caused a traffic conflict and resulted in the Gulfstream being waved off during the approach. The approach controller was probably surprised to see the Gulfstream deviate from assigned track, since the first officer had correctly read back the "Tiptoe Visual" instructions. The captain obviously understood the clearance to mean "own navigation", despite an admonition from the first officer, who recognized the disparity in awareness.

The question, then, is: who is responsible for effective communication? The sender is ultimately required to ensure effective communication. Only the sender can determine if the intended message was conveyed, and even that is difficult. The communication method of using negative statements often leads to deceptive communication. Aviation is rife with examples where statements such as “do not descend” are heard as “descend!” This is the purpose of a readback, as this permits the sender an opportunity to verify the instruction was received correctly, but often a readback is skipped or becomes “roger.” In August of 2002, a Cessna 177 pilot was instructed to “hold at the hold line, [do not] taxi into position and hold” in Oakland, California (NASA, 2003). The pilot, hearing the words “position and hold”, “rogered the transmission” and continued onto the runway. The tower controller asked the Cessna to immediately exit the runway, and fortunately no conflict occurred. This example serves to accentuate the purpose of a readback of an instruction: to automatically provide a sender the opportunity to check the receiver’s interpretation of the message.

Often, communication is hampered by the sender. When seeking information, many people tend to state their desired answer in the form of a question. This is sometimes referred to as a “leading question”. Leading questions can deny the responder an opportunity to objectively analyze a situation, especially in confusing or pressured environments. A subordinate who subconsciously is attempting to placate a superior is given the desired outcome, often enticing the subordinate to agree with the superior’s position in an effort to avoid confrontation. To avoid this, questions should be stated as objectively as possible, and should not include any elements of the questioner’s assessment of the environment. Instead of “I’m pretty sure it’s that right engine that’s giving us trouble, don't you think?" or even "Is the right engine the malfunctioning one?" a better question would be "What is your assessment of the engine trouble?" Of course, even this implies that the engine is at fault, and so perhaps a question such as "What is causing that vibration?" is most appropriate, for this question includes only a fact that should be recognizable by the receiver – that the aircraft is vibrating. When communicating through questions, the construction of the question is of critical importance in order to avoid coloring the receiver's opinion of the situation.

5.2 Leadership

Leadership is the ability of an individual to break down the barriers that prevent effective communication, to allow and encourage individuals to function as a part of the team and to share their level of awareness. In aviation, leadership is typically dictated. Historically, the judgment of the captain was considered sacrosanct, and he was the final authority on all matters. Several historical aviation accidents proved that the aircraft captain was not always perfect (although traditionally the captain was infallible). The responsibility of perfection should never have been placed on a single person, as the resulting power (authority) gradient in the cockpit often made the opinions of lesser crewmembers insignificant. Over time, the power gradient in the cockpit has been reduced somewhat, and this is a good thing. In some cultures, however, there still exists a strong respect for authority and significant hesitation to question one of higher position. The problem of a leader is how to maintain authority without dominating the environment and quelling the opinions and suggestions of those "lesser" persons who also are part of the crew.

The amount of leadership required is dependent on the environment. Under most modern operating conditions, leadership is not a critical feature of an aircrew. This is because modern flight operations have been sufficiently designed so that each member knows their role, discharges it effectively, and communicates necessary information effectively. In unusual circumstances, though, the need for leadership is significantly great. Too, when the job is such that individuals are so undertasked that simply remaining awake is a challenge, leadership is also of great benefit. Figure 7 illustrates the times when leadership is most critical: when things are not going as planned. Here, communication tends to break down, and individuals are less sure of their roles and responsibilities since these situations are not encountered as often. In this instance, a leadership role is necessary to facilitate and encourage communication and to keep

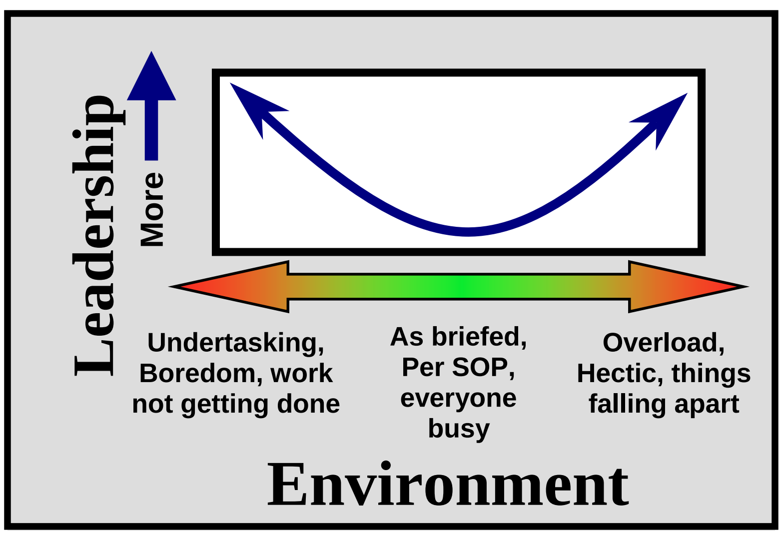

Figure 7
Environmental Conditions and Leadership Requirements
(Author)

crewmembers focused on the task at hand. In some cases, unwilling or unsuspecting people will possess necessary information, and a leader must recognize their ability to contribute to awareness and then encourage their participation. Perhaps a passenger witnessed the failure of an engine – although not a traditional member of the flightcrew, the passenger has critical information that could aid the SA of the crew, and the leader of the crew must recognize this and solicit input.

During one of the author's air combat training flights, substantial confusion existed after an engagement between a flight of F/A-18 Hornets and F-16 Falcons. The author, in a two-seat F/A-18, turned to leave the area of the engagement when another flight suddenly appeared nearby on the radar screen. Unsure whether this contact was friendly F/A-18s or "enemy" F-16s, the author asked a ground-based controller to identify the contact, but the controller was unable to do so. Now, the author and his wingman were unsure of what to do, and were pressured to decide quickly on a course of action due to the close proximity of the unknown contact. At this point, the flight was towards the right side of the graph in figure 7. With a single codeword, though, the author's backseater was able to take a leadership role in the situation and immediately resolve the entire flight's situational awareness. He simply said "VID", which stands for Visual Identification, and the roles of everyone in this scenario were well known by all four aircrew in the flight. With a single codeword, the author's backseater had defined the scenario – which was that the flight would visually identify the contact by passing close by – and assigned roles to all members – which were defined by doctrine and training. The flight successfully completed the VID and was able to effectively engage what turned out to be a pair of "enemy" F-16s.

5.3 Assertiveness

It is important that individuals be willing to contribute to the collective awareness of the crew. Too, the team must be willing to accept the information offered. In instances where the leader may be preoccupied or even unwilling to consider a colleague's opinion, then it is necessary for that individual to be assertive. Assertiveness is not always aggressiveness. It may involve an alternate approach such as a diplomatic request for information, forcing the team to consider the state of their knowledge and awareness at the time. At times, aggressiveness may be required, but the method of presentation is very dependent on the personality of the other team members.

Under high levels of stress, when the impact of a decision is particularly consequential, there may be a tendency for crewmembers to transfer responsibility for the decision to either the senior individual or the person making the decision. Incidents such as the holocaust can be attributed to the transference of responsibility for the consequences to the accepted authority figure. Although crewmembers may disagree with a proposed course of action, if there is interpersonal conflict or even if despair exists, then that individual may relinquish liability for the actions of the crew, cease participating in decision making, and emotionally absolve themself of culpability for the outcome. The potential danger of this phenomenon is obvious – a critical crewmember may cease to be an effective member of the team during times of high crisis.

The Federal Aviation Administration offers guidance on assertiveness, but includes inquiry and advocacy as related concepts. The following is from Advisory Circular 120-51E, "Crew Resource Management Training":

Inquiry/Advocacy/Assertion. These behaviors relate to crewmembers promoting the course of action that they feel is best, even when it involves conflict with others. Behavioral Markers:

(1) Crewmembers speak up and state their information with appropriate persistence until there is some clear resolution.

(2) "Challenge and response" environment is developed.

(3) Questions are encouraged and are answered openly and nondefensively.

(4) Crewmembers are encouraged to question the actions and decisions of others.

(5) Crewmembers seek help from others when necessary.

(6) Crewmembers question status and programming of automated systems to confirm situation awareness. (FAA, 2004)

An excellent method of being assertive without confrontation is to ask questions of another crewmember. If an intellectually subordinate position is taken, such as stating "I don't understand the problem" or "I'm not as proficient as you, could you please explain your gameplan?" then the obstinate individual will be forced to mentally evaluate his or her awareness of the situation in order to answer the question. The colloquial saying "you never realize how little you know until you attempt to teach the subject" is the goal of this approach – to place the isolationist individual in an intellectually superior position, that of an instructor, and to force that individual to make a thorough assessment of their awareness as they attempt to convey it. An excellent example of this principle is related by Air Force Major Bernard Mater, where his persistent questions, from an intellectually inferior position, avert a flight deck-fire during C-130 operations in Alaska (Mater, 2002). The crew were all experienced on the C-130, and reasoned slightly low engine power to the age of the aircraft, but Major Mater's questions led to an in-flight analysis that uncovered a severe bleed-air leak underneath the cockpit! Another option is to demand "what are you doing?" but this places the same individual in an intellectually and authoritatively inferior position, one of being asked to account for actions that the other crewmember apparently deems inappropriate. This will often alienate someone who is already uninterested in serving as a contributor to team awareness and decisions.

Perhaps the best known example of a lack of assertiveness is the tragedy at the Los Rodeos airport on Tenerife Island, on March 27, 1977 (ASN, 2003). The airport at Tenerife was clogged with aircraft diverted due to a bomb explosion in the terminal of Los Palmas Airport, and many were waiting to be allowed to continue to the destination. One aircraft, a KLM 747, was anxious to leave as the crew were approaching the limit of their authorized duty day. The captain onboard the KLM aircraft was the most senior pilot in the company. As soon as emergency in Los Palmas was resolved, most of the diverted aircraft began to depart, while the KLM crew called for additional fuel. While they refueled, a Pan Am 747 was trapped on the ramp by the KLM aircraft. Once refueling was completed, the KLM began to taxi, with the Pan Am close behind. Because of the congestion on the ramp, departing aircraft were required to back-taxi several thousand feet down the active runway, and then turn onto a parallel taxiway to clear the runway for aircraft ahead in the sequence. On this day, the KLM reached the end of the runway first, and was preparing to takeoff. Simultaneously, the Pan Am 747 was still back-taxiing, not yet clear of the runway. Fog had developed, and although patchy, it obscured the aircraft on the runway, preventing the tower from seeing the aircraft or the aircraft from seeing each other. The captain of the KLM 747, tired of waiting, instructed his first officer to call for takeoff. As he was doing so, the captain began the takeoff roll. The tower instructed the KLM flight that he "would call them for takeoff." A discussion ensued on the KLM flight deck, with both the first officer and the flight engineer expressing concern that they were, in fact, not cleared for takeoff. No one expressly disagreed, however, and the takeoff continued.

Meanwhile, the Pan Am 747 had reached the midpoint of the runway, and was having difficulty finding the assigned taxiway to turn off on. The crew had been listening to the KLM's conversation with the tower, and as the KLM 747 accelerated, the first officer onboard announced over tower frequency "we are at takeoff." The Pan Am crew immediately realized the conflict, and transmitted that they were still on the runway. Unfortunately, tower made a similar transmission at the exact same time as the Pan Am aircraft, producing a loud squeal in the cockpit of the KLM aircraft (although the transmissions were still audible on the CVR). The crew of the Pan Am 747 added power and began a desperate attempt to turn and get clear of the runway. Seconds later, before the Pan Am could leave the runway, the KLM 747 appeared out of the mist, trying in vain to get airborne as the KLM crew suddenly saw the gravity of the mistake. The KLM 747 became airborne, but then slammed into the midsection of the Pan Am 747, killing 574 persons in the impact and ensuing fire (see figure 8).

Onboard the KLM 747, the first officer and the flight engineer attempted to be assertive, using the both inquiry and advocacy, but both stopped short of direct and

Figure 8
Remains of 747 at Tenerife
(Unknown, http://www.airdisaster.com/photos/)

aggressive confrontation with the captain. The first officer asked questions such as "Is he not clear then?" in regards to the Pan Am aircraft. When the KLM 747 captain began to takeoff, however, neither continued the challenge. Instead, the first officer began to attempt other techniques to mitigate the danger, but these were unsuccessful and the greatest aviation disaster prior to September 11, 2001 resulted.

5.4 Mission Analysis and Team Goal Setting

Mission analysis occurs on two levels – first, each individual determines what their impression of the mission is, and in doing so provides a model that begets situational awareness. Secondly, the team shares among its members these goals, with the elected leader determining which is the correct course of action. The first level must occur, while the second, group sharing only occurs with healthy teams. As such, all teams should strive to share the member's visions of goals, while recognizing that there must be the ability for a recognized leader to focus the team on a common, understood objective. Mission analysis should also occur at different times. For common operations, there should a definition of goals prior to the execution of a task. This is simply planning, but objectives must be included in the plan. As the task progresses and develops, re-assessment is required to ensure the continued relevance of the mission statements and to account for any substantial changes that might redirect the entire effort. If an F/A-18 is on a mission to destroy an enemy weapons plant, but is then hit by anti-aircraft fire, the mission will likely radically change to safely recovering the damaged airplane.

Within the task of setting realistic goals for the team is the need to identify the expected contributions of each person involved. In many cases, the distribution of duties is defined by standard operating procedures or acknowledged standards, but in unusual situations, the team leader may need to be directive to avoid confusion. In cases where roles and responsibilities are institutionalized, deceptive communication is a threat where a crewmember, instructed to perform a given procedure, may agree to participate without fully understanding the contribution expected of him or her. In all cases, the benefit of a common goal should not be discounted:

> Common Goals are also important for safety, since it is assumed that humans have a survival instinct that drives them to access whatever resources possible – beyond any predefined rules – in order to stay alive. (Kaliardos, 1999)

The leader must also be responsible when defining the mission for the crew. There are certainly many examples of irresponsible mission analysis. Flathatting, unauthorized aerobatics, sightseeing, buzzing and many more pitfalls have resulted in the loss of thousands of lives. Unfortunately, the trend will continue. Essentially, these mishaps are the result of poor mission analysis on the part of the crew and typically are a single person's agenda vice the objective of the crew. A well documented case of this rogue mentality is the loss of a B-52H at Fairchild Air Force Base on the 24th of June, 1994. In this instance, a senior, experienced pilot in the aircraft flew the plane well beyond established limits under the direct supervision of other senior, knowledgeable aircrew. The mission of the flight was to demonstrate capabilities of the B-52 during an upcoming air show, but LtCol Holland apparently had an independent agenda with the intent to perform impressive, yet unauthorized, maneuvers. His propensity for pursuing individual goals, despite actual opposition from his crew, had existed and been verbally addressed for several years, but no significant action was taken against him. Many junior aircrew refused to fly with him, due to past air show performances and a flight performed for a journalist crew where, under protest from all onboard, he flew a B-52 across a ridgeline a approximately 30 feet. A few minutes later, he repeated the performance, but in this case was so low that the camera crew abandoned their equipment as the airplane passed by – at an estimated three feet above terrain. This was done strictly for personal reasons, as no legitimate mission, training or otherwise, would include flying a B-52 at three feet. This attitude was likely the one that drove LtCol Holland, while practicing for an upcoming air show, to place the B-52 in an impressive attitude – but one that proved unrecoverable and ultimately fatal to the four senior aviators onboard (figure 9). Here, a

Figure 9
Crash of B-52 at Fairchild AFB
(Unknown, http://www.airdisaster.com/photos/)

misguided mission analysis – the desire by LtCol Holland to perform maneuvers thought impossible (which, in fact, were) – resulted in the loss of the aircraft and four valuable personnel.

6. SUMMARY

The entire process of risk management can be summed up as:

Anticipate the hazards

then…

Participate in their mitigation

always...

"Share" your "Aware"-ness

This seems a bit of an understatement, but it effectively captures all of the principles presented in this paper. Operational Risk Management is the detailed combination of these simple principles. Risk planning is effective anticipation of the potential hazards, while Team Decision Making requires the participation of persons involved to help make safe decisions and to avoid critical errors. All crewmembers must share their opinion of the situation to truly build a team level of situational awareness. "Information is power, but it is pointless power if hoarded. Power must be shared…" (DePree, 1989).

The physical systems present on most modern aircraft promise a revolution in decision making, however, the careless application of technology can impede situational awareness. The tendency to apply technology to traditional information techniques and the trend towards the presentation of data, vice much more useful information, can cause disparate states of awareness between members of a crew. Each individual member of an aviation team will progress through the decision-making cycle independently, unless efforts are made to reconcile the situational awareness of all participants. In doing so, the fact that no two humans will interpret a situation identically must be considered. Each individual will form a different opinion of the situation due to the "POP" phenomenon. Once a team has accepted this fact, then the application of the principles of communication, leadership, assertiveness, and mission analysis will allow the exchange of awareness among crewmembers. Ultimately, the goal is to reach a common situational awareness for all team members. If this is accomplished, due to regulations and training a consensus on action can typically be reached. Once a course of action is elected and carried out, then the cycle repeats, continuously.

7. ANALYSIS OF INCIDENTS USING THE "SADCLAM" METHOD

Fortunately, the SADCLAM model of cockpit decision making also serves as a tool for constructive analysis of events ex post facto. Because this model determines all of the information fed into the cockpit, the decision can be reversed and analyzed in respect to the information that led to its execution. To do so is very simple. The decision in question becomes the starting point, and the individual who ultimately made the decision final. There may be no apparent mistake – if a missile shot down the aircraft, then the missile was obviously responsible for the aircraft's demise. However, a series of decisions led to the aircraft being placed in harm's way, and those decisions can be analyzed using this model. This technique can, in fact, be applied to any decision in any respect, as all decisions in life are based on some level of situational awareness. The critical question is: "What was the situational awareness of the person or persons at the time the decision was made?" From this point, all of the events leading up to the critical point must be included in the analysis. A poor decision rarely happens spontaneously – many events must normally conspire to cause accidents in aviation.

To analyze a mishap using the SADCLAM method, begin by determining who made the decision under scrutiny. Analyze what the situational awareness of that person was at the time of the decision. Compile a list of the information that would be necessary for an average person to make a safe, effective decision in the same circumstances. Compare that list with the information available to the person or crew in question. Most importantly, attempt to evaluate each person's actual interpretation of every element of required information. This will be challenging, as the particular prejudices of each individual will be difficult to determine, but research the history of them and conduct interviews with friends and family, if possible. This will help to determine the mindset and likely dispositions of the individual.

7.1 Example of Incident Analysis using TDM Principles

An example is the best method of illustrating this process. One of the most distressing instances of a failure in Team Decision Making is the loss of a British Midland Airways Boeing 737-400 on January 8, 1989 at the East Midlands Airport in England. The mishap was tragic in the fact that although the 737 had suffered an engine failure in-flight, the remaining engine, although functional, was shut down due to a misdiagnosis of the problem. While on final approach to an emergency landing, the previously damaged engine failed completely, without sufficient time or altitude to effect a restart of the good motor. This begs the question: how could such a massive error occur unchecked?

As with most mishaps, the end result was the product of a chain of events leading to the final, fatal outcome. The decisions made throughout the flight were, as all decisions are, made according to the situational awareness of the persons involved. What remains distressing is the fact that sufficient information was available to the aircrew to establish "correct" situational awareness. Unfortunately, they did not, and thus provided an excellent example of multiple failures of effective Team Decision Making. A narrative of the mishap is appropriate, to illustrate the predicament and actions of those involved before attempting an analysis:

On the evening of Sunday the 8th of January, 1989, British Midlands flight 092 took off from London's Heathrow airport bound for Belfast. During the climbout, while passing Flight Level 283 (28,300 feet), the aircraft experienced a series of engine stalls on the port motor, with flight attendants and passengers seeing "sparks", "flames" and "torching" produced by the left-hand, No. 1 engine. The aircrew on the flight deck could not see the visual indications of the engine problems, but were aware of airframe vibrations and could then smell, along with the other occupants of the aircraft, a scent of something burning. A light smoke began to invade the cabin through the air-conditioning ducting also. Immediately the pilots began an attempt to identify the problem.

When the aircrew scanned the engine instruments, they appeared to be normal. The captain, based on his training and own understanding of the aircraft's air conditioning system, assumed that the right engine was the culprit. He then queried the first officer regarding the instrument indications of trouble, to which the first officer hesitantly responded that the right engine appeared to be the abnormal one. With his suspicions thus confirmed, the captain directed the right engine to be throttled back. The crew were now actively involved in the navigation of the aircraft to a suitable divert airfield, and while doing so, the first officer began the shutdown procedures for the right motor. The captain, focused on the decisions and communication to reroute the airliner, did not questions these actions – which is unremarkable, as his SA was that the degraded engine was being shutdown.

Since the selected divert airfield of East Midlands was nearby, a rapid descent was necessary. To facilitate this, the left engine was reduced to idle power. Although this was, in fact, the malfunctioning engine, at idle power settings the discrepancies were nearly undetectable. A slight rise in Exhaust Gas Temperature (EGT) had occurred on this engine, of approximately 50 degrees, but since this would have been well below maximum EGT (at idle power) this would be easy to overlook. The only other substantial indicator was the engine vibration value, which was radically higher than normal. Unfortunately, this instrument reading was overlooked by both crewmembers. After the right engine was secured, the captain made a Public Address announcement to the passengers that there was a "problem with the right engine" and that it had been shutdown. Apparently, this statement did not register concern among the flight attendants or the passengers who had seen the fireballs emanating from the left engine, or perhaps these individuals felt that the crew was obviously better informed than they were and that the aircrew's decisions were correct regardless of what had been seen from the cabin.

With the good engine now secured and the failing one operating at flight idle, the crew descended and prepared the 737 for a straight-in approach to East Midlands Airport. During the descent, the captain began to review the decision to secure the right-hand motor. As he began to verbalize the indications he and the first officer had responded to, the discourse was interrupted by air traffic control providing vectors, a further descent, and a frequency change to approach control. After switching frequencies, the first officer began reading the One Engine Inoperative Descent and Approach checklists. These, in turn, were interrupted by additional transmissions from approach control. The approach checklists were not completed until the 737 was 15 nautical miles (nm) from the runway and passing 6,500 feet. Approaching 3,000 feet it was, of course, necessary to reduce the rate of descent by increasing engine power on the one remaining motor. As the power was increased on the No. 1 engine, the vibration reading again spiked to the maximum value.

Continuing the descent and decelerating in preparation for landing, the crew began to realize that the left motor was not completely healthy. As the power was advanced on the remaining engine, the vibrations began again and the engine began to stall. The first officer initialized the restart procedures for the operable right motor, but before the engine could be brought to starting speed, the left motor catastrophically failed. Now below the minimum airspeed required for an airstart, the 737 was doomed to landing immediately – in this case, just short of the runway at East Midlands. In the ensuing impact with trees and a motorway, the aircraft broke apart as it plunged into an embankment, killing 39 persons at impact (figure 10). Eight more later perished due to injuries sustained in the crash. The cause of the left engine's failure was traced to a vibration-fatigue failure of the fan blades of the SNECMA motors of the Boeing 737-400. Under the specific conditions of climb power and pressure altitudes of 25,000 – 30,000 feet, the vibration became severe enough to result in fan blade failures. The right engine had suffered no damage.

The question, in hindsight, is simple: "How could a trained cockpit crew shut down the incorrect motor?" To answer this using the SADCLAM method of analysis, it is necessary to begin at the tragic end and work backwards to the critical decision that ultimately cost 47 people their lives. Obviously, the engine-less landing occurred because the operable motor was shut down and not restarted while reliance was placed on the failing motor. The fact that the good engine was not restarted earlier can be attributed

Figure 10
Aftermath of British Midlands Flight 092
(Unknown, http://www.airdisaster.com/photos/)

to the SA of the aircrew. They were convinced that the situation was reversed and unfortunately, had no additional reason or information to make them doubt their decision – until the engine they were relying on failed. Sadly, there was a different level of awareness among the cabin crew and the passengers on the aircraft. So what led the aircrew to shut down the wrong engine?

Of course, the captain would not have intentionally ordered the good engine secured, so his SA must have been incorrect. There were several contributors to the captain's SA:

a. Based on his statements, his training led him to conclude that cabin air was primarily supplied by the right engine. When smoke began entering the cabin, this led him to suspect the right engine as the culprit. Actually, engine bleed air from both motors supplies cabin air conditioning, but the captain's misconception due to past experience and biases caused his SA to be otherwise. When power was reduced on the right motor, the smoke abated, but shortly thereafter power was actually reduced on both engines. Thus, the captain's SA was not contradicted.

b. There were no apparent indications of failure on the engine instruments. Actually, the EGT of the left motor rose significantly, but this was missed by both aircrew. The engine vibration value for the left engine, however, was well above that of the right – at the maximum value at the time of the initial and final failures. The captain had learned to distrust the engine vibration indications though, as his previous experience with these instruments led him to deem them unreliable and misleading. These indicators were considerably advanced in comparison to the systems the captain had experience with, though, and were the primary instruments used to diagnose an identical fan blade failure on another 737-400 just five months after this incident.

c. When the captain consulted the first officer regarding his opinion, the CVR recorded a momentary hesitation on the part of the first officer, who then agreed with the captain that the right motor was malfunctioning. Once the first officer reversed his decision and concurred with the captain's analysis, no other contradicting information was recognized or accepted by the flight deck crew.

d. It seems that the captain might have been uneasy about the choice of which motor to shut down, as he began a review of the indications and assumptions made by the aircrew at the onset of the emergency. Unfortunately, this analysis was interrupted by communications and it was never logically completed. Perhaps there was a bit of "sixth sense" concern by the captain.

e. The captain did a poor job of managing his team, in that he limited his SA when communicating with the cabin crew. Instead of asking what the SA of the senior flight attendant was, he simply queried "Did you get smoke in the cabin?" to which the flight attendant replied "We did, yes." Had the captain asked "Any idea what's going on?" he most likely would have received a comment regarding not only the smoke in the cabin but also the flames and sparks out of the left engine.

But what of the awareness of the team?

a. Based on the first officer's hesitation when answering the captain's question of which engine had failed, it is possible that he was not entirely confident of his assessment. He did not, however, question the analysis after this, and he actually began the shutdown procedures without direction from the captain. So, if doubt did exist for the first officer, it was apparently removed when the captain concurred with his interpretation of the failure, and his SA matched that of the captain's throughout the remainder of the flight.

b. The cabin crew were most likely aware of the health of the left motor.

c. The passengers, especially those seated at windows near the left engine, certainly had significant awareness of the predicament.

In this case, though, the awareness of the whole team was not reconciled with that of the cockpit crew. Leading questions prevented critical information from reaching the captain, and had the first officer been more assertive when he initially seemed unsure of the diagnosis, perhaps the captain would have been less confident of his assessment. The training of the captain was a factor, since his SA was heavily dependent on it, but this analysis did not seem to be sufficiently conveyed to the team, and his past experience colored his perceptions of the problem.

In any aviation mishap, a multitude of factors is responsible. There are typically several critical links that could prevent the occurrence. The danger lies when those links go unnoticed, and the purpose of Team Decision Making is to aid the team in recognizing those links. This is done by sharing the awareness of all the possible contributing members, and then deciding on the most correct assessment of the situation. Hopefully, through education of effective methods of doing so, such as TDM, future aviation mishaps can be averted.

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Appendix

MARINE ALL WEATHER FIGHTER/ATTACK SQUADRON 121 RISK ASSESSMENT WORKSHEET

DATE: 16 MAR 04 EVENT: 04 AIRCREW:

48HRS			
UNIT TRANSITION CONDITION		YELLOW	NORMAL
TRANSITION OPS IN LAST 14 DAYS			
	JOINT/COMBINED	M	
	OUTSIDE AGENCY	M	
MISSION PLANNING TIME		8-12 HRS	< 8 HRS
	MAGTF	M	H
	JOINT/COMBINED	M	H
	OUTSIDE AGENCY	M	H
MISSION TYPE		TAC TRNG	CNTNGNT
	IN HOUSE	L	M
	MAGTF	L	M
	JOINT COMBINED	M	M
	OUTSIDE AGENCY	M	H
PILOT T&R PROFICIENT		NO	
	CURRENT	M	
	PREREQ MET	M	
CURRENCY			
	INSTRUMENT	M	
	NATOPS	M	
	NVG	M	
FLIGHT CURRENCY		> 30 DAYS	
IN ACCORDANCE W/SOP		M	
48 HOUR RISK ASSESSMENT		L M H	

OPS REP SIGNATURE ____________________

24 HOURS		
BRIEF BETWEEN 2400-0500L	M	

A/C STATUS	YES	NO
DO UP GRIPES AFFECT MISSION	M	L
ASSYMETRIC LOAD	M	L
LOAD IN ACCORDANCE WITH VOL IV	L	H
LAUNCH/RECOVERY	YES	NO
T/O PLAN APPROP. FOR WX	L	E
RNDZ PLAN APPROPRIATE FOR WX	L	E
LOST SIGHT/NO RADAR PLAN	L	H
PERF. NUMBERS BRF	L	H
RALT PLAN BRF	L	H
SUITABLE APPRCH AVAIL.	L	H
VASI/PAPI/OLS AVAIL.	L	M
ARRESTING GEAR AVAIL.	L	M
BIRD CONDITION OTHER THAN LT.	M	L
TRANSIT	YES	NO
FORM APPROP. WX	L	M
ANTI-EXPOSURE SUIT REQ.	M	L
CONTROLLER LANGUAGE BARRIER	M	L
SOP FUEL REQ. MET	L	H
MISSION INCLUDES DEMO/FLYBY	H	L
AIRSPACE		
IFR	L	
VFR W/RADAR ADVISORY	L	
SCHEDULED MTR	M	
VFR MUTUAL USE	M	
UNCONTROLLED A/S	H	
AERIAL REFUELING	YES	NO
A/C DECONFLICTION BRF	L	H
AR TRACK, COMM, RNDZ BRF	L	H

LGB DELIVERY	YES	NO
MIDAIR/CFIT BRF	L	M
DELIVERY APPROP. FOR WX/WPN	L	H
DESIGNATOR BRF	L	E
RANGE APPROPRIATE	L	E
A/C CURRENT FOR WPN	L	M
NIGHT SYSTEMS	YES	NO
NVG TRNG RULES BRF	L	H
NVG ILLUSION/SPATIAL D BRF	L	H
A/C LIGHTS BRF	L	H
WX APPROPRIATE	L	H
SENSOR USAGE BRF	L	H
RALT PLAN IAW SOP	L	H
LIGHT LEVEL IAW SOP	L	M
A/C NSQ OR SYLLABUS	L	H
LOW ALT AREAS CHUM	L	H
LOW ALT AREA FAMILIAR	L	H
LOW ALT. TACTICS	YES	NO
WX & RALT PLAN IAW SOP	L	H
TRNG RULES BRF	L	H
MANEUVER BRFD & UNDERSTOOD	L	H
LOW ALT AREA CHUM	L	H
LOW ALT AREA FAMILIAR	L	H
LAT APPROVED AIRSPACE	L	H
BASH IAW SOP	M	H
CREW FLOWN IN < 30 DAYS	M	H

FLIGHT BRF				
		YES	NO	CHANGED
FLT SCHEDULED		L	M	M
DELAYED> 4 HRS		M	L	
WEATHER		VMC	>MINS	<MINS
	LAUNCH	L	L	H
	ENROUTE	L	L	M
	OP AREA	L	M	M
	RECOVER	L	L	H
CONDITIONS		LIGHT	MOD	SEVERE
	ICING	M	H	E
	TURB.	L	L	M
	T-STORM	L	L	H
WATER/AIR TEMP/SEA STATE			<NATOPS	>NATOPS
			L	M
AIRCRAFT STATUS		NO FCF	FCF	
		L	M	
REVIEW 24HR ASSESSMENT				
	CMND RELATIONS		M	H
OVERALL MISSION PLAN			M	H
AIRCREW FACTORS			M	H
	CORE COMPETENT		M	H
	T&R PROFICIENT		M	H
	NAOPS/INST		M	H
	FLT CURRENT		M	H
	FLT DURATION		M	H
	CREW REST		M	H
	PERSONAL FACTOR		M	H
	BRF TIME		M	H

PLANNED FLIGHT DURATION		3.0-5.0	> 5.0
	IMC	L	M
	FORM	L	M
	NVG	M	M
PERSONAL FACTORS		MARGINAL	SUSPECT
HEALTH		M	H
PERSONAL		L	M
COLLATERAL DUTY		L	M
CREW REST		8 TO 9	< 8
		M	H
SPECIAL MISSION PLANNING			
AIRCRAFT STATUS		M H E	
LAUNCH RECOVER		M H E	
TRANSIT		M H E	
AERIAL REFUEL		M H E	
AIR SURFACE		M H E	
AIR TO AIR		M H E	
LGB DELIVERY		M H E	
NIGHT SYSTEM		M H E	
24 HOUR ASSESSMENT		L M H E	

VMC	L	M
PLANNED FUEL > NON-EMERG DIV.	L	H
DAY	L	M
PILOTS CURRENT ON PLATFORM	L	M
AR TRACK ABOVE 5000AGL	L	M
AIR TO SURFACE	YES	NO
TRAINING RULES BRF	L	H
NVG TRAINING RULES BRF	L	H
FUZE/ORD RESTRICTIONS BRF	L	H
Z DIAGRAMS APPROPRIATE	L	H
RALT PLAN BRF	L	H
SENSOR USAGE BRF	L	H
FAMILIAR RANGE	L	M
SOP CURRENCY	L	H
WX BETTER THAN MISSION MIN.	L	H
FRIENDLY POS. CLEAR	L	H
AIR TO AIR	YES	NO
SOP CURRENCY	L	H
WX APPROPRIATE FOR MISSION	L	H
TRAINING RULES BRF	L	H
SPINS REDUCE MID-AIR POTENTIAL	L	E
A/C LIGHTING/NVG RULES BRF	L	H
ACTI REQ. MET	L	H
SYLLABUS FLIGHT	L	M

24 HOUR REVIEW SIGNATURES				
MSN RISK	L	M	H	E

OPS REP SIGNATURE

DOSS REP SIGNATURE

CO SIGNATURE

MISSION COMMANDER/FLT LEAD SIGNATURE

X

Vita

John Cody Allee was born in Houston, TX on September 1, 1970. He was raised in Midland, TX and graduated from Robert E. Lee High School in 1988. From there, he attended the United States Naval Academy in Annapolis, Maryland and received a B.S. in Aeronautical Engineering in 1992. He was commissioned a Second Lieutenant in the United States Marine Corps, and proceeded to Naval Aviator Training in Pensacola, Florida. Eventually selected to fly the F/A-18 Hornet, Cody reported to VMFAT-101 at MCAS El Toro, California for training on the Hornet. After graduating in 1996, he moved to MCAS Miramar and was assigned to the VMFA(AW)-121 Green Knights, making two Western Pacific deployments to Japan and other nations flying the F/A-18D Hornet. While with the Green Knights, he served as Schedules Officer, Airframes Officer and the Pilot Training Officer. His flight qualifications earned during this tour included Air Combat Tactics Instructor, Forward Air Controller (Airborne) Instructor, Night Systems Instructor and Tactical Air Controller (Airborne), among others.

In 1999 he was selected to attend the U.S. Naval Test Pilot School, and after completion of the one year course in December, 2000, he joined VX-23 as an experimental test pilot in Patuxent River, Maryland. During his time at Patuxent River, Cody was a project officer for several new technologies, including advanced mission computers and terrain awareness warning systems. Promoted to Major in May 2002, he then assumed responsibilities as the U.S. test pilot on the X-31 VECTOR international experimental flight research project. Successfully completing the VECTOR program in April 2003, having achieved several aviation "firsts", Cody then resumed his duties as an F/A-18 test pilot and project officer. During his time at VX-23, Cody attended the Navy's CRM Facilitator's Course, and then served as the squadron Crew Resource Management Instructor for two years. This project was inspired by that effort, and deficiencies perceived while teaching the subject. In February of 2004 Major Allee assumed his present duties as Executive Officer of the 1st Air Naval Gunfire Liaison Company.

Major Cody Allee is a graduate of the Naval Fighter Weapons School, the Marine Weapons and Tactics Instructor's Course, and the U.S. Naval Test Pilot's School.