UNIVERSITY OF CALIFORNIA, SAN DIEGO

Cognition in Flight:

Understanding Cockpits as Cognitive Systems

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in Cognitive Science

by

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for John

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PAPERS AND PUBLICATIONS

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Studies in Cognitive Neuroscience
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ABSTRACT OF THE DISSERTATION

Cognition in Flight:

Understanding Cockpits as Cognitive Systems

by

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I apply distributed cognition theory to study the cockpit of a SH-60B Seahawk as a cognitive system. Video recordings were made of pilots flying in a full motion flight simulator. I recorded cases when pilots crashed the simulator and compared them to cases when they recovered without incident. The empirical data included three cases of engine failure and four cases of tail rotor failure. Field notes from participant observations, interviews, and direct observations were analyzed with video transcripts to describe the cockpit as a cognitive system and to identify interaction patterns.

A trajectory of representation analysis was conducted to track the flow of representations through the system in the context of activity. A cross-case analysis of representation trajectories revealed system anatomy and critical computational pathways. When a disruption such as a mechanical failure was introduced into the system, successful systems adapted the flow of representations to meet the immediate processing demands of the system. Systems that did not adapt missed critical representations and formed processing bottlenecks that impeded representation flow.

An interaction analysis was developed to identify three system-level properties. These properties are emergent interaction patterns I named coaching, dominance, and intersubjectivity. These patterns emerged from individual interactions in the system and were not produced by a single pilot. The data suggest these patterns influence system performance and flight safety.

Interactive processes do not occur in isolation, they occur simultaneously across social, physical, and conceptual dimensions and shape system interactions. These findings have implications for display design, training, meaning construction, and crew coordination.

CHAPTER 1

Introduction

> Upon returning from a night training flight, an SH60-B helicopter was approaching its ship at 1600 feet in preparation for landing when a report of a sinking boat in the area prompted the crew to join a search and rescue effort. While the pilot flew the aircraft, the copilot tried to locate the sinking boat using the aircraft's multi-purpose display. The aircraft began descending at 1400 feet per minute. The pilot had intended to level off at 200 feet of altitude but became preoccupied with locating the position of the distressed boat on the multi-purpose display. The helicopter entered the water. The crew escaped with minor injuries, but the aircraft broke up and sank.

When an SH60-B aircraft goes down an accident investigation board is convened to determine the cause of the crash. A report is issued citing the factors that are believed to have contributing factors. In the accident described above, the board concluded that crew coordination problems played a prominent role in this mishap. Specifically, "The pilot failed to monitor his instruments while the copilot failed to monitor instruments and assist the pilot at the controls and crew coordination was not established during the descent. The entire crew developed cockpit fixation trying to locate the missing boat and prepare for the rescue."

These statements point to crew accountability and responsibility for safe control of the aircraft through a process of crew coordination. Unfortunately these accident reports are the only source of data about SH-60B crashes and they are helpful but do not help us understand how breakdowns in crew coordination processes occur.

This study is concerned with describing the SH-60B Seahawk cockpit as a cognitive system. The Seahawk is a naval tactical helicopter. I utilized high fidelity flight simulators to observe and record cockpit operations while navy pilots flew during training sessions. Flight simulation made it possible to compare system configurations of cockpits that crashed to ones that maintained safe flight under emergency conditions. Utilizing principles of Hutchins (1995) distributed cognition theoretical framework I set about the task of describing how the cockpit functioned as a cognitive system in both cases.

Thinking of a cockpit as a cognitive system requires an expanded unit of analysis that includes not just the pilots, but also the displays, procedures and interactions that contribute to aircraft operation. Thus, the cockpit may be seen as an information processing system that is distributed across its social, physical, and conceptual environments. Pilots are participants in a cognitive system and aircraft behavior is not merely a function of pilot knowledge it also depends on how pilots coordinate cockpit resources to organize actions, decisions, and judgements.

In subsequent chapters, I present an illustration of how the cockpit system breaks down under the stress of an emergency condition. The data point to the emergence of different interaction patterns in flights that result in a safe outcome than the interaction patterns that present is flights with unsafe outcomes. These patterns of interaction constrain and facilitate the representations that are processed within the system. When representations that are critical to the safe outcome are inhibited, the system begins to breakdown. A single pilot acting alone cannot accomplish the propagation of representations in emerging situations. It requires the coordinated activity of crewmembers. The safety of the outcome can, thus be shown to depend on system level properties rather than on the properties of the individual pilots alone. Interaction patterns also have a role in establishing the division of cognitive labor between crewmembers and that division is dependent on the kinds of interactions that are initiated and sustained during the flight.

The data were collected over the course of a year and a half at a naval helicopter-training center in San Diego, California. The study group included pilots participating in training during that time, but flight instructors were also observed and interviewed. I relied on several ethnographic methods (participant observation, interviews, and observations) to collect qualitative data that included field notes, video recordings of simulator sessions, and interview notes. I acquired domain knowledge for this research through participant observation and that enabled me to connect cultural aspects of the naval pilot community to behaviors in the cockpit. I also made video records of pilots flying in flight simulators.

Aviation is a technical domain and conducting research in aviation settings requires technical expertise in the domain to know what is meaningful to domain participants. I hold a pilot's license for single engine fixed-wing airplanes, but I do not hold a helicopter rating. Therefore, I had to familiarize myself with helicopters and their operation. My expertise with airplanes, in conjunction with reading about helicopters, provided me with sufficient background to fly the flight simulator and successfully complete ground training with a group of student pilots.

Setting

When driving onto Naval Air Station North Island (NASNI) things are notably different from the affluent surrounding community of Coronado Island. Everything from runways to front lawns is tidy, but somewhat drab. Drivers obey speed limits and stop for street-crossing pedestrians. Everyone wears their hat outdoors and removes them indoors and civilians like me, stand out amongst uniformed officers and enlisted personnel.

Helicopter Squadron Light Forty-one (HSL-41) is situated in the middle of the base between two runways, next to five other Seahawk squadrons. To get there you have to drive across a taxiway and cars must yield to taxiing aircraft of all sizes and types that pass by. All vehicles must have decals to enter and park on base. Being a civilian, I received a temporary decal that gave me base access, without a salute, and parking privileges in the training center parking lot.

HSL-41 is a helicopter training squadron and training center. All pilots going through training are attached to the HSL-41 squadron and call themselves Seahawks, which also happens to be the name of the aircraft. The Sikorsky SH-60B Seahawk (SH-60B) is a lightweight helicopter with a single main rotor and dual jet engines. The Seahawk is considered lightweight by military standards, but it is actually a large aircraft weighing in at 21,700 pounds.

Most military flight training is specifically designed to prepare the crew for the rigors of combat. The SH-60B naval tactical helicopter community is responsible for a variety of missions that range in difficulty and objectives. The Seahawk may be deployed from a destroyer, frigate, or missile-cruiser ship as an airborne extension. Primary missions for the SH-60B are subsurface and surface warfare, specifically submarine hunting. Other missions include medical evacuation, search and rescue, and communication relay. Routine flight operations for naval helicopter pilots include formation flying, low-level flight, and landing on a rolling, pitching airfield on a ship at night.

Upon entering the training center, there is a reception area with a guard shack. One must identify himself to the guard to pick up a badge or visitor’s pass. The building is secure meaning personnel can carry, read, and talk about classified material openly. People with security clearances get blue badges and visitors and people without clearances get green badges. That way people with blue badges know whom they can and cannot talk to about sensitive topics. Green badges usually require an escort. Initially I had a green badge and was escorted throughout the building until mutual trust was established and I was permitted to move about the building on my own. Once my clearance came in, I was given a blue badge and was granted autonomous access to all areas of the training center and the administration building.

The training center is a large two-story building. The lower deck is the main floor of the building. Briefing rooms and offices line the walls surrounding a large open area with couches. The open area is used for formal occasions like graduation ceremonies and receptions and informally for hanging out, studying, and meeting before simulator briefs and during breaks. Down the hall there is a large hanger that houses one aircraft for static training. Two full-motion flight simulators are located at opposite ends of the briefing rooms. The training center also has a secure room where the computer-based trainers (CBT) are located and a library where books and other documents are kept. The library looks like a high school equipment cage, the door is locked and documents are checked out through a chain link window. Pilots complete lessons on the CBTs for all phases of training. A specified number of lessons must be completed prior to flight events and exams.

Up the ladder on the second deck are eight classrooms, a conference room, the security office, and a large cubicle-filled room called the maze. The maze is the primary workspace for training officers and enlisted personnel. Although officers and enlisted are segregated they are proximal enough to overhear each other's meetings, questions, conversations, and so on. Because it is difficult to find people in the maze, people often enter the room, call out someone's name, and several people call out in response "he's flyin" or "he's in the sim". Sometimes there's no reply, sometimes heads pop up and replies are made over cubicle walls. It is common for personnel to carry on full discussions or conversations over cubicle walls.

I was given my own cubicle in the training officers' area. My status as a researcher was considered commensurate with being staff so I was given a workspace with the training officers. Being close to the officers gave me ample opportunity to conduct impromptu interviews or ask for clarification on a number of subjects. I was also asked to participate in meetings and to review drafts of proposed training material. These activities gave me insight into the processes and procedures members of that community use to review and implement new training material. Because I participated as a member of an incoming class of trainees, I was often asked to give the student pilot's perspective of training. Training officers would also ask me what I thought of a lecture, lesson, and sometimes an instructor. I learned to be cautious, but honest in my response. I also studied lessons and manuals with my classmates in the open area downstairs and in the CBT room. I spent most of my time in the field observing or video taping training sessions in flight simulators and briefing rooms.

A new group of pilot trainees arrive at the training center every six weeks. Nuggets who arrive with shiny gold wings from advanced-primary flight training are called category one (CAT1) pilots and have never flown the Seahawk before. Returning fleet pilots are seasoned aviators and are placed in category two (CAT2) training. They arrive at the training center from a non-flying tour but have previously flown the Seahawk in the fleet. CAT1 pilots usually rank Ensign or LT Junior Grade while CAT2 pilots rank Lieutenants or LT Commanders. It is common for pilots from both categories to be in the same class of arriving trainees.

Both navy flight instructors and civilian flight instructors teach at the training center. Navy instructors give lectures, exams, flight instruction in the simulator and aircraft, and conduct flight evaluations. Civilian instructors only instruct pilots in the flight simulator, but they do train incoming navy pilots who are serving a tour as flight instructors. Before each simulator flight there is an hour-long briefing session where one student draws a schematic of an aircraft system (e.g. fuel) and the other student explains the system to the instructor. The instructor quizzes each pilot about details of the system, although each instructor has his own style and particular focus. Students are graded on their knowledge of maneuvers, procedures, and systems as well as their ability to perform flight maneuvers and error recovery. In the simulator each student is graded on individual achievement and the grades are recorded in the student’s grade book. Students are also graded on how well they coordinate with each other (crew coordination) and maintain an accurate understanding of the situation (situation awareness). However there is no standard for what constitutes good coordination and awareness, although instructors argue that they can sense when a crew is working in coordination and when they've "lost the bubble" and are unclear of the problem or situation. One main objectives of this dissertation is to define the kinds of crew interactions that lead to safe or unsafe outcomes under emergency conditions.

Acquiring Site Access

Acquiring initial entry into HSL-41 was a long, but worthwhile venture. I asked an acquaintance who was working at NASNI if he thought a squadron would be open to having a researcher come in and observe for awhile. He gave me the name and phone number of several people in the administrative offices of Command Naval Air Pacific that oversee naval aviation in the pacific theatre. After placing several phone calls, I finally talked to two people about the possibility of conducting research with a squadron. One of them put me in touch with a civilian administrator who could make it happen. After explaining my motives over the phone I was invited to give a brief[1] to the administrator, a captain, a commander, and a lieutenant commander on what I could offer the navy in exchange for access to their facilities. I bartered free research and a set of recommendations to use at their discretion, expressing my desire to make a contribution toward improving flight safety and training and expand our understanding of human cognition in technological setting. I was open to conducting research in whatever

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[1] The naval term brief refers to a meeting or presentation.

squadron they felt would yield the most benefits from my efforts but I would select the research topics. They agreed and sent me to HSL-41.

Developing and Maintaining Field Relations

My early days in the field were awkward and exhausting. I was under immediate suspicion especially from the training officers who saw my position as a direct conflict with theirs. They were relieved to learn that I am a pilot but were disappointed that I did not have a helicopter rating. They also were quick to emphasize that military aviation has entirely different dimensions to flying and is not comparable with civil aviation. I responded with smiles and tried to be agreeable. No one was familiar with cognitive science and rumors about my work and purpose quickly flew around the squadron with tremendous variation in explanations. I went from being the new staff education specialist the first woman flight instructor to a fuzzy researcher who is trying to figure out what everyone is doing wrong. Although I set the record straight countless times I began to accept the rumor mill and its variety of themes for my purpose as part of community life.

As I got to know the instructors, staff, and students everyone started to become more relaxed in my presence. This was facilitated by the support I had from the administrative offices, the commanding officer of the squadron, and the civilian education specialist. The commanding officer would always greet me when our paths crossed and all the pilots took notice of those encounters. I gave several briefs (presentations) to the commanding officer and the pilots who knew about the meetings would ask "what are you gonna talk to the skipper about?" Eventually my relationship with the pilots grew secure enough that I could joke “I’m gonna talk to the skipper about your last simulator event”. Sometimes the pilots would ask me to “put in a good word for them” or to “tell the skipper to give me a raise”. The skipper regularly asked me how my research was proceeding and if there was anything he could do to help. That kind of support made my research experience positive and productive. Over the course of a year, my husband and I attended a squadron Christmas party, a change of command ceremony, and sadly a memorial for five sailors who were killed in a Seahawk accident.

My status in the community really changed when I began participating in training with a class of incoming student pilots. I went from being the creepy researcher to one of the guys, and gained a whole lot of respect from the student pilots as well as the instructors. It seemed as if over night my research was cool and many pilots started offering their views about naval life, training, and their ambitions.

I did everything my classmates did except fly in the actual aircraft, attend safety review boards, or read accident reports. I completed all the reading, lessons, and studying required to pass exams. Sometimes I received the highest score on the exams and I was never the worst performer--something that shocked the instructors. I attended all the static aircraft events and observed all my classmates’ simulator events and briefs before and after each flight. The simulators run from six in the morning to midnight everyday. My classmates were surprised to see me observing the late night simulator events and word spread quickly to everyone in the squadron that I really was serious.

Overview of the Thesis

In Chapter 2, I introduce the distributed cognition theory, offer some relevant background on information processing theory and how it has influenced the research investigating pilot performance. I provide an overview of distributed cognition theory and how I applied it to formulate a description of the Seahawk cockpit as a cognitive system. I discuss the ethnographic methods I used to collect data and the rationale for selecting those techniques. I also describe some of the methodological issues involved in conducting ethnographic fieldwork. Finally I describe my methodology in which distributed cognition motivates data collection and analysis.

Chapters 3 and 4 make up the empirical portion of the thesis. In chapter 3 I present data from three case studies involving an engine failures and in chapter 4 I present four case studies of tail rotor failures. The analysis presented in the two data chapters suggest that multi-crew performance is not just a function of pilot knowledge and skill, it also depends on the social interactions between pilots and the material interactions between pilots and cockpit structure. Interactions combined with pilot knowledge determine how proficiently the crew manages cockpit resources and organizes their actions and ultimately determines the outcome of the flight.

In Chapter 5 I offer the summary of findings and recommendations I presented to the navy. I also discuss the influences of culture in training and in the cockpit.

In chapter 6 I revisit distributed cognition theory and address the theoretical implications of the findings.

CHAPTER 2

The Simulator Cockpit as a Cognitive System

The flight simulator cockpit is a tight system with a manageable locus of cognitive activity. My objective was to observe cockpit cognition as it naturally occurred during flight simulator training sessions and to do so with a situated, embodied perspective. I approached the cockpit using Hutchins' (1995) theoretical framework of distributed cognition. I emphasized the interactions that occurred within the system and their emergent effects on system behavior. A fundamental principle of distributed cognition is that cognition occurs as an emergent property of interaction within a system, such that it is distributed among the participating units. The system may range in size from a neuron to a city. The system boundary depends on the cognitive phenomena under investigation and the questions one poses. Boundaries may be conceptual, physical, or social or any combination of these.

For this study, I selected the Seahawk cockpit as my system and drew the boundary around the two officer pilots and the cockpit, which includes flight controls, several instrument panels, and other media. I could not include the enlisted aircrewman because he is only present in the simulator, when I could not be present, during classified operations. I included the flight instructor's evaluation of the crew in the analysis but did not count him as a crew participant. The instructor is present to evaluate and train the crew and does not participate as a crewmember and for me that placed him outside the system boundary.

In this chapter I briefly discuss information theory and describe how it has been applied to understand pilot performance in the aviation domain. Then I introduce the distributed cognition alternative, its theoretical principles, and why it is a superior approach. Then I describe the methods I used for data collection, how they fit into the theoretical framework and what cognitive phenomena they capture. Finally I describe how I analyzed the data to understand how the cockpit functions as a cognitive system.

Information Theory and Aviation Research

Information theory has motivated much of the research in human performance in aviation. Information processing models present a computational model of cognition that treats cognition as a series of mental operations occur between stimulus and response within a goal-oriented framework (Card, Moran, & Newell, 1983; Simon, 1981) (Wickens & Flach, 1988). Thus we perceive cues in our environment and code them in a sensory storage system where they are mapped to symbolic representations stored in memory. Once the cue is recognized it is moved to the next stage for decision and response processing. The cue may be stored in memory or it may be acted upon via the motor system to effect change in the outside world (Figure 1). Much of the experimental research in aviation has focused on the capacity, duration, and representation of these processing stages in pilots but are not representative of real world conditions and complexity.

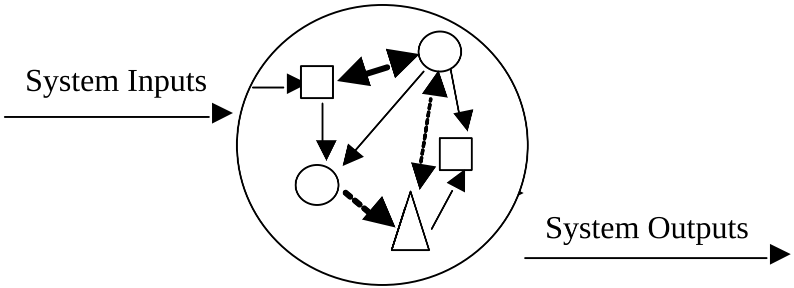


Figure 1. Generic information processing system. Arrows represent pathways along which representations may move through the system. Bi-directional arrows represent interactions that transform representations. This model is applied to individual human cognition the inputs are environmental stimuli and the outputs are motor movements. Under an individual view, representations and the processes that transform them, reside inside the heads of individuals.

There are many aspects of pilot performance that are explained by information processing models. However there are other issues that it does not explain as well and an important one is context. For example, situation assessment is a mapping process between cockpit displays and aircraft behavior and pilot knowledge about the aircraft and the flight environment. The mapping process empowers pilot to infer aircraft state and predict its behavior (Endsley, 1995). It is important to investigate the role of cockpit displays in the flight environment because the meaning of displayed representations must be considered with respect to the task, the situation, and pilot's interpretation (Flach, 1995). In the information-processing paradigm cockpit displays are merely inputs processed by the pilot. Whereas distributed cognition treats displays as representations within the cognitive system of the cockpit. Flach (1995) calls for a shift in the aviation research agenda to one that emphasizes meaning with respect to task constraints and mental interpretation.

In a series of experiments, Zhang addressed the role of display properties in situation assessment (Zhang, 1997). He compared representational properties of navigation instruments and found the representational characteristics had consequences for subjects' correct assessment of the aircraft's position in relation to navigational aids and course. He argued that the physical representation of a display has cognitive consequences in terms of the computational demand, and thus cognitive demand, it imposes on the pilot. Faulty situation assessment may also arise when an operator's knowledge is not activated or applied in a problem-solving context. Even though a pilot has acquired knowledge about aircraft systems in training, he may not know when it is relevant to the particular situation or how to apply it to a unique problem. Situation factors and knowledge have an important role in directing the distribution of attention.

Attention overloading has been linked to poor display design in aircraft cockpits as well as the amount and kinds of tasks that constitute cockpit workload (Andre & Wickens, 1991). Chou, Madhavan, and Funk (1996) found visual, manual, and mental resources in the cockpit influenced task initiation and prioritization and that the number of tasks in conjunction with complexity of flight path had a significant effect on task prioritization performance. They predicted when many concurrent tasks compete for attention there is a danger that some of the critical tasks will not be initiated and attention will be withdrawn from other critical tasks, such as monitoring altitude.

Recent research in cockpit workload management suggests that preoccupation with one task may result in the shedding of other important tasks. Under some circumstances the tasks shed may include the navigation and control of the aircraft. Raby and Wickens (1994) found that as workload increased, subjects adjusted their task performance strategies, but those strategies were not elaborate. Tasks of higher priority were given more attention over time and lower priority tasks were further degraded in priority or shed. They concluded pilots who performed well appeared to perform their tasks earlier and were more flexible in switching between tasks. Attention saturation, or tunnel vision, may be induced by cognitive demand (Williams, 1995). Information-gathering activities that contribute to situation awareness add to workload and the maintenance of situation awareness requires resources that may compete with ongoing task performance(Adams, Tenney, & Pew, 1995). In situations where the state of the aircraft is changing not every change is important nor meaningful. Pilots who shift attention from one item to another may not be able to formulate a coherent picture, but unless pilots shift attention critical cues needed to update a situation assessment may be missed (Woods, Johannesen, Cook, & Sarter, 1994).

At the training center helicopter pilots learn about the mechanics of flight and aircraft control and about aircraft systems such as engines, hydraulics, and fuel. They are presented with descriptions of the system in writing complemented by printed schemata of the system depicting different parts of the system from different perspectives, and the behavioral aspects of the system's functioning are presented in the simulator or in the aircraft. Pilots need a good command of the aircraft's performance limitations and its systems in order to respond to an emergency condition. Cockpit switches, dials, displays, and lights make up a representational layer to the aircraft's systems. Pilots learn to map these representations into meaning about the aircraft's state. They have to know what indicators in the cockpit connect to what sensors in the systems and what a particular set of indications mean in terms of appropriate actions under various conditions.

Beyond the Laboratory

One way to move beyond the current aviation research paradigm is to study cognition in the environment where it naturally occurs. Controlled experiments to date have not retained the richness of natural settings. Instead of conducting basic cognitive research in the laboratory, it is possible to move to its natural laboratory and attempt to link experimental research with field research to develop a comprehensive understanding of cognition. Of course this move adds complexity but it preserves the richness of natural setting and expands the scope of aviation research beyond simplistic tasks and characterizations of pilots and displays.

Distributed Cognition

In this study I applied distributed cognition to understand the Seahawk cockpit as a cognitive system. Under this framework cognition is taken to be computational in terms of re-presenting until the solution becomes apparent (Hutchins, 1995). Computation is taken to be the processes that coordinate representations inside the head with representations in the world. Hutchins argues that “the firm inside/outside boundary creates the impression that individual minds operate in isolation and encourages us to mistake properties of complex socio-cultural systems for properties of individual minds” (1995, p. 355).

A representation is taken to be a piece of structure that may be interpreted as representing something other than itself. A representation is only such when it is involved in the interactions with other components of the distributed system. This definition of representation is different from the symbolically encoded notion of representation in information theory. Information theory takes representations to be static structures that are operated upon; whereas distributed cognition takes representations to be a dynamic participant of a larger cognitive process. Thus representations can hold state and that state may be transformed as the representation is moved in the context of an activity. For example an engine out warning light on an instrument panel is a representation of the engine's functioning. When a pilot perceives that light and transforms it into a statement like "the number one engine is out" he is re-presenting the state of the engine. In addition, the distributed cognition view locates representations inside and outside of an individual's head.

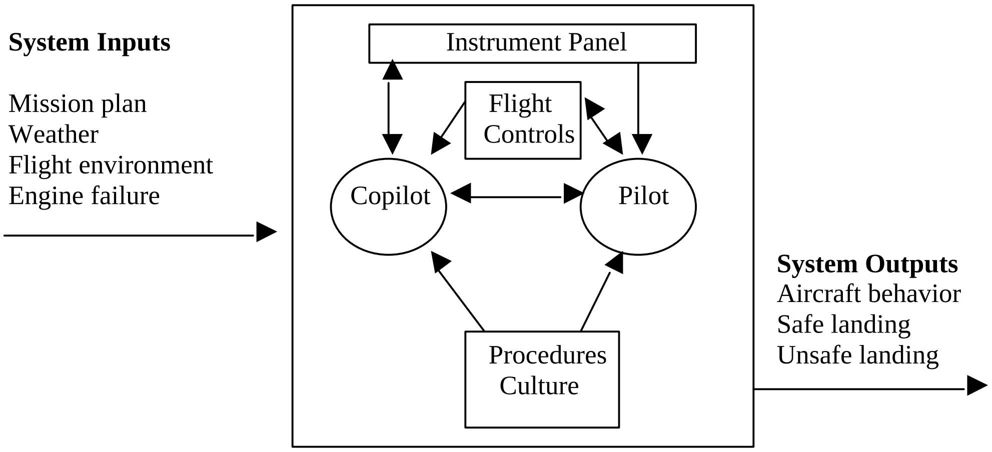


Figure 2. Information processing model applied to a distributed cognition system. Here the system is a helicopter cockpit. The density of representation flow within the system may change over the course of a flight.

The representations present in the cockpit include speech, displays, written notes, checklists, movements, gestures, actions and absence of action, rank, authority, and knowledge. I took the Seahawk cockpit to be my unit of analysis (Figure 2). Notice the similarities between Figure 1 and Figure 2. In Figure 1 the information-processing model was applied to an individual mind whereas here, the information-processing model is applied to a socio-cultural system. In this cockpit system, pilots interact with each other to coordinate their actions. Pilots also interact with flight controls and instrument panels. The physical structure of the cockpit is organized in a consistent manner so pilots experience the same typical pattern of representations for a given mechanical failure. Cockpits present a complex environment of static and dynamic representations of aircraft status. Pilots have substantial knowledge about the aircraft and flying that they utilize to interact with displays and flight controls to produce meaning about a situation. Flying an aircraft requires an integration of many different streams of dynamic representations from different sources and in different representational forms into an accurate understanding of the flight situation.

From Theory to Methods

The main objectives of this research are to understand how the Seahawk cockpit functions as a cognitive system, how pilots construct meaning from the immediate context, and why some crews crash the simulator while others do not.

The questions I posed and the theoretical commitments motivating them constrained the data collection methods I selected. Cognition is taken to be inseparable from its context and is embedded within other cultural systems (Cole, 1996; Hutchins, 1995; Shore, 1996; Woods, Johannesen, Cook, & Sarter, 1994). To honor this principle requires a method that does not separate the cognitive phenomena from the setting where it occurs. I used video to record cockpit activities during flight simulator training sessions. To understand the social and cultural context of the activity I spent 15 months in the field conducting ethnographic fieldwork and participating as a member of the community. These methods also accounts for the principle that cognition is distributed across individuals, technology, and processes (Hutchins, 1995). I take cognition to be a continuous, evolving process so that requires spending time with study participants.

There were some restrictions imposed on my data collection methods by the organization. There was only one video recorder so not all flight events could be taped. I was restricted to collecting data during the pilot phase of training because it is the only unclassified phase of training in the syllabus. The quality of the video data is fair because the recording equipment is old and technologically limited to black and white images.

Video

I collected data from participant observations, interviews, and from video of pilots I recorded during Operational Flight Trainer (OFT) sessions. The OFT is a full motion, high-fidelity flight simulator with fully operational pilot and co-pilot stations, dusk and night time visuals, and 6 degree of freedom motion base. The Operational Flight Trainer is used to train pilots in normal and emergency flight procedures including takeoffs and landing for field or ship, navigation, communication, and system malfunctions. HSL-41 simulators only offer dusk-night visuals because most SH-60B flights in the fleet are conducted at night, and because it is considerably less expensive to simulate night visuals than day visuals.

The OFT is equipped with a video camera that is located to the right of the pilot station so the video preserves a side view of the cockpit and pilots (Figure 3). The video system records all verbal communication made over the intercom system in the cockpit.

There is an observation jump seat in the OFT trainer directly behind the copilot seat where direct observations can be made. There is also an instructor console outside of the simulator, where I could observe the crew (without being inside the simulator) via the video system.

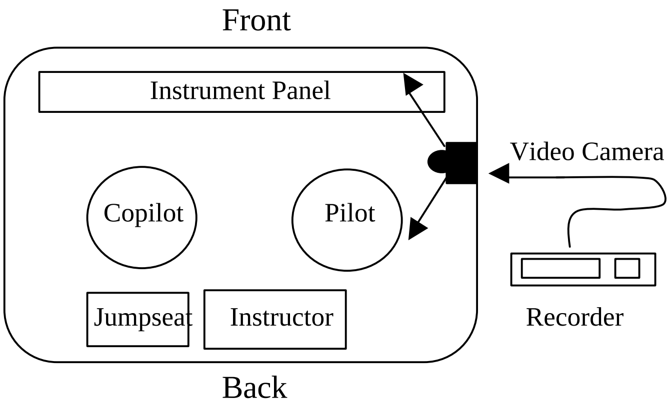


Figure 3. Video camera placement in the flight simulator. The video camera is located to the right of the pilot flying the aircraft. The video recorded is located outside the simulator cabin in another room. The arrows represent the angle of view captured on tape.

The video camera was installed in the trainer specifically for aircrew coordination training (ACT). The video system was intended for use as a de-briefing tool. Flight instructors were to tape the simulator session then play back key situations to the pilots for feedback and additional instruction. The system was never used for that purpose because the recording equipment is located outside the simulator making it difficult to use. The system provides no means for marking key situations on the video that can be reviewed in the debriefing session. In addition, the only recording and playback device is located at an instructor console that is often in use. Furthermore pilots who did not want to be monitored move the camera so that it points at the floor. Maintenance workers are the only ones who are allowed to reset the camera. Many staff members I interviewed about the system’s history of use could not recall anyone using it to record training sessions before I did. Flight instructors do use the video monitor to observe pilots and enlisted aircrew during classified mission-oriented training sessions, but pilots still move the camera for those sessions.

The position of the camera is based on a philosophy that ACT is primarily concerned with pilot/copilot interactions so the camera points at the pilots and not at the cockpit instrumentation. Here the camera angle and position reflect a theory about what is relevant for ACT, as does any camera angle (Goodwin, 1994). Some of the instruments on the pilot side are recorded on the video and both pilots' gestures and faces are visible, but the displays are difficult to read. The camera position was further constrained by the physical layout of the trainer. It was placed to the right of the pilot where it could be easily mounted and still capture the pilots faces and some of the displays. I had direct access to the simulator so I could locate information displays in the cockpit and document how they are physically represented.

Ethnographic Field Notes

I directly observed sessions to supplement the video data with observations that were recorded as field notes. In writing field notes I followed the method outlined by Emerson, Fretz, and Shaw (1995), particularly their suggestion to give specific attention to the meanings and concerns of the people being studied. They also note that Field Notes reflect the observational process and that the data they contain are inseparable from it. In Field Notes I kept record of my daily experiences. I tried to detail the interactions that were part of the pilot’s everyday activities. I also took notes during training sessions in the flight simulator, while working through lessons, and during interviews. These notes were later complied into a larger field note for that day.

The field notes that I wrote contained different kinds of data. My field notes ranged in content from recording social events, training events, to a pilot's reported experiences during survival school, to my own interactions and frustrations in the field. I used the data from field notes to understand how pilots made sense of the training, how they learned and the cultural pulls navy culture imposes.

The following field notes are examples of the content and format of my field notes. The first note documents a brief before a simulator event and the second note describes my impressions at a change of command ceremony.

> OFT Brief
> I was late for the 0630 brief this morning. Traffic crossing the bridge was horrendous. When I arrived, CW was briefing the oil system. MP had already briefed the fire detection system. MP will be doing OFT 4 tomorrow with a sandbag because CW already completed the event. After CW described the system, the instructor (CSI1) began his usual discussion about the intricacies of the system.
>
> The big danger in an engine seizure is the possibility of slinging compressor blades. 80KIAS is the safe single engine airspeed, 60 knots is the bucket airspeed but that is the minimum safe airspeed so you want to stay above that at around 80.
>
> On page 23 of the PCL CSI1 pointed out a huge category of malfunctions: engine Chip caution light, engine oil pressure high, engine oil press caution light on, engine oil pressure low. The procedures say to look for secondary indications, but if you lose oil pressure there won't be any like the ones listed in the procedure (caution light, VIDS, temp). CSI1 said he requested a change to NATOPS on this point.
>
> CSI1 said whoever is CP to call Nr. He said torque probably would catch your eye first when there is an engine power problem because it is a large display and it will split. It tells you something is wrong but you won't be able to identify the malfunction from it. The first step is to watch Nr. If it's high what does that tell you? MP nor CW knew the answer. If Nr goes up there is a power gain, if Nr goes down there is a power loss. You must determine if you have just lost

> power or lost the engine. If you are in a climb or a fast descent the power problem may be masked so get to straight and level to diagnose.

This field note relates how a civilian flight instructor runs a brief. This instructor explained where in the checklist they could find the procedure and some problems with the checklist. Then he explained what to expect during an engine failure and what instruments to use in the diagnosis.

> Change of Command
>
> The change of command is a big day for the squadron. The day before the ceremony the training center is scrubbed till it sparkles. Then the decorative banners are hung, and the center is quite festive. Rumors are flying about the new CO and his style, which is supposed to be very hands on and there has been some grumbling about it.
>
> I walked over to the ceremony with JF. Female guests are greeted at the hangar entrance by an officer in full dress, medals and all, and are escorted to one of the guest seats. JF and I sat together. The ceremony was held on the flight line—very cool. There were two Seahawks and a group of flags set up behind a podium. A band played while guests arrived. It was really windy and although it was sunny it was chilly. The guests sat in chairs and the squadron stood in back. Everyone was in winter dress (black) and had medals and ribbons and stuff. They only wear medals for ceremonial occasions. I asked BD about his medals earlier and he told me what they represented. Some of his were service medals e.g. tour in the middle east while it was “active” and the others were achievement medals. The ribbons represent the same but are worn on the opposite side. The officers call their formal dress “monkey suits” and complained about not being able to wear sunglasses during the ceremony.
>
> I was told this kind of ceremony is specific to the naval community. It was quite beautiful. The ceremony begins when the COs arrives. There is a parade of “the colors” or flags, followed by the national anthem. Then there is a prayer and the outgoing CO gave a speech and the incoming CO gave a speech. Both speeches were touching, the COs expressed gratitude to their wives for putting up with their naval career and moving so often. The speeches were also full of Navy/HSL-41 rah rah. The new CO seemed nervous and fidgety. Hopefully he will support my research! The ceremony ends with another prayer and the colors are “retired”.
>
> After the ceremony there was a cake cutting ceremony (they cut the cake with their swords) and reception in our building. The place was packed with spouses and children, officers, enlisted, and staff. I did some mingling and tried to talk to some people I didn’t know. After they cut the cake I went home.

Social events are an important part of naval life. In the note I tried to express the structure of the ceremony, what happened, how the participants behaved, their impressions and my impressions of the impact the change of command would have on their daily lives.

Participant Observations and Interviews

Other data came from participant observation and interviews, which were also recorded as field notes. Participant-observation includes systematically recording observations while participating in the activities of the study group. I participated as a member of a group of student pilots progressing through the pilot phase of training. I did everything they did which included attending lectures and briefs, taking exams, participating in simulator sessions, and other training-related events. Participant observation is a critical method because it enables the researcher to participate in the culture. Thus the ethnographer can characterize a phenomenon because he has participated in the culture. This participation imbues him with insight to make claims about cognitive phenomena in the cockpit.

The pilot phase of training is organized into 15 topic units. The early units introduce the operating environment, starting and shutting down the aircraft, checklists and basic flight operations including the course rules. The course rules are a set of instructions for air traffic operating at and around North Island with emphasis on facilities (such as helicopter pads) used primarily by helicopters. The next six units cover systems such as fuel, transmission and rotors, hydraulics and so on. There is no system overview unit, so the burden of system integration falls on the students. This is not too difficult for most pilots because all of them have flown some kind of helicopter prior to their SH-60 training. The final units of the pilot phase cover shipboard operations, search and rescue, and hostile environment training. When a pilot successfully completes this phase of training he transitions to the tactical phase of training.

Informal interviews supplemented my observations and reflected the participant's perspective. I took what an informant said as data and not as an analysis of the topic we discussed. Sometimes I interviewed the crew in the de-briefing session about errors or problems that arose during the trainer event. For example if the pilot lost control of the aircraft and we crashed, I asked what happened. Most of the time the instructor asked the pilot anyway so I took note of what he said. I also interviewed subject matter experts for specific information about the tasks given in the flight trainers. Subject matter experts are designated as such and are always navy flight instructors with fleet experience. None of the interviews were audio recorded. I jotted notes during the interviews and then reconstructed the main ideas and arguments from my jottings later that same day. Everyday that I was at the training center I wrote notes about my observations, experiences, interactions, and impressions. I wrote field notes from jottings I made during the day and sometimes I wrote field notes from my desk in the maze.

Ecological Validity

An advantage to studying performance in high-fidelity flight simulators is that pilots perform tasks and encounter flight situations that closely resemble those in the aircraft. I was not permitted to manipulate any training materials so I used existing scenarios and tasks used in the training curriculum.

I identified a set of focus tasks by analyzing pilot grade books for below average scores on tasks given in the trainer and totaled the number of low scores that were given for all 50 pilots trained in 1996 (Table 1). Student performance on all flight events in the simulators and the aircraft are graded on the following criteria:

AA = Above Average	4.0 points
A = Average	3.0 points
BA = Below Average	2.0 points
U = Unsatisfactory	1.0 points

Grades are given by the instructor and are recorded on a grade sheet for the event. Grade sheets make up a student's grade book where his progress through all phases of training is documented. All fleet replacement pilots are grouped into categories on the basis of rank and experience:

CAT 1--straight from flight school	140 training days
CAT 2--prior H2 or SH-60B pilot	80 training days
CAT 3--special officer (commanding officer)	70 training days
CAT 4--NATOPS check (no mission systems)	55 training days
CAT 5--TBD (foreign pilot, H-2 transition)	140 training days

All participants in this study were CAT1, CAT2, and CAT4 pilots.

The video record of the event provides data about the interactions within the system over time. The video captured action as it actually happened, but pilots knew they were being taped. Whenever I taped the crew, I observed them from outside of the simulator at an instructor console so that the setting would remain as natural to them as possible. Pilots reported they often forgot I was taping them until I arrived at the de-briefing session after the simulated flight.

An interesting aspect of flight simulation is that it gives pilots a realistic feel for aircraft, but even the best full-mission simulation will not precisely match operational flight of the real aircraft. The simulator has limited visibility and a very slight delay (about a half second) in response to flight control inputs. Pilots reported flying the aircraft is easier than the simulator because of its excellent visibility. Flight instructors introduce mechanical disruptions while the crew is flying to test their knowledge, skill, and crew coordination but no crew handles the disruptions in exactly the same manner.

Table 1. List of focus tasks. Tasks were selected from an analysis of 50 pilot grade books. Each number represents one below average given to a pilot for each task. Notice that 16 out of 50 pilots received a below average score for performance on an engine low side failure and 15 out of 50 pilots received a below average score for performance on a malfunctioning tail rotor condition.

Task	BA Totals
Single engine failure	9
Headwork	6
Crew coordination	6
Engine High-side failure	12
Engine Low-side failure	16
Planned ditch	8
Tail rotor malfunction	15

When a pilot performs poorly in the aircraft, the flight instructor may intervene by taking control of the aircraft away from the pilot flying. In the culture of the navy it is a severe reprimand to the student when his partner or instructor takes over the flight controls. The act makes a big impression on the student and is a cultural dimension of training that is not replicated in the simulator. Another dimension of humiliation is added when the flight instructor proceeds to tell everyone how student so and so “tried to kill me today”. After these incidents students are subjected to both humiliation and peer pressure to improve their performance. These interventions in the aircraft are far more serious than putting the simulator into freeze, which is still an embarrassment for the student. The freeze option is a culturally acceptable means of saving a senior officer from embarrassment in the simulator. It is a rare incident when an instructor, especially a navy instructor, allows a senior officer to crash the simulator but they commonly allow crashes for junior officers. Regardless of the reason, in the simulator everyone knows it's a simulator.

Sample

I observed, interviewed, and video taped crews of pilots over a period of 15 months. During that time I made 18 video records of crews flying in full-motion flight simulators. I did not tape the same crew more than once except for crews comprised of individuals in the group of pilots I followed through training. The center welcomes a new group of pilots every five weeks and class size varies from one to twelve pilots. I sampled pilots from 6 different classes progressing through the training program and only taped pilots who were members of the Seahawk squadron. Two of the tapes were confiscated and destroyed by the security officer because they were recorded during classified simulated operations. From the remaining 16 tapes, I selected emergency cases to transcribe. Five of those tapes have pilots from the same class, but are not the same crew. I selected one case from each crew so that the crew was not repeatedly sampled. I also selected crews with varying individual ranks. So one crew might have paired two ensigns and another a LT. Junior Grade with a LT. Commander.

While I was video taping I recorded all the emergency conditions given during the flight and the outcome. I transcribed cases in which the crew performed well, there was a crash, or the crew had difficulty with some aspect of the emergency. I performed all the video recording, observations, and transcriptions myself.

Methods Summary

In the process of data collection I used several different methods to converge on an understanding of the cockpit as a cognitive system. My participation as a student pilot with a group of other student pilots gave me insight into how pilots learn to fly the aircraft, how they are reprimanded and supported. Obviously my overall experience was different from those of the pilots, after all I am not a naval aviator. However we progressed through the syllabus in the same manner taking all the same exams and answering all the same questions.

As a participant I received the same instructional materials and lessons. I used those materials to understand what the pilots did in the cockpit and why, and I could follow along. I learned the procedures, what the displays meant, and how to respond. I recorded the experience as Field Notes and then I used the notes to compare my observations of what pilots did in the flight simulator. Not all of the flights could be recorded because there were two simulators and only one camera. So I observed many more events than I recorded. In the analysis I was able to compare what pilots did across cases and develop an understanding of what was good performance and poor performance according to the navy.

I also conducted many informal interviews. All interviews were conducted at the training center and in the operations building. None of the interviews were recorded, but I did take notes and later converted them into Field Notes. Interviews served many purposes. For example, I used them to clarify events that occurred during a simulator flight, to inquire about some aspect of naval life, and to verify my own understanding of a system. I also used interviews with flight instructors to check my interpretation of the flight events I had recorded and transcribed. My participant observations and interviews were used to inform my analysis of the video transcripts. It was through these methods that I acquired the expertise I needed to understand why pilots did what they did in the cockpit.

The video records most of the activity in the cockpit. The video quality and camera angle degrades the resolution of cockpit activity, but I tried to compensate by supplementing the recordings with direct observations. The video captures pilot speech, actions and gestures, most of the instrument panels and the instructor's assessment. I used the video to record what happened in the cockpit when disruption was introduced and crew response. My intense participation as a student pilot enforced the conclusions I draw from the data.

Video Analysis

The first generation characterization of the cockpit is the video transcript. Speech and action were recorded at one-second intervals. I transcribed everything that was visible in the video whether or not it appeared to be processed by the pilots. Then I coded the speech for its representational content for each statement (Appendix A). In this transcript the codes appear in parentheses.

Time			**Displays and Actions**
18:17	Pilot:	And looks like we (detect)	BDHI begins to spin slowly left
18:18		got a loss of (diagnosis)	Pilot moves cyclic left, forward, aft
18:19		tail rotor control	Master caution light illuminates
18:20			
18:21	Copilot:	Got two hundred feet (status)	
18:22			
18:23	Pilot:	Kay get your hands (direct)	BDHI spins faster
18:24		on the PCLs	
18:25	Copilot:	Okay (reply)	Copilot reaches for PCLs
18:26	Pilot:	and I'll just try to keep it (narrate)	Copilot places hand on both PCLs
18:27		level and bring it back down	Copilot's hand remains on PCL until
18:28	Copilot:	Roger that, (reply)	impact
18:29		two hundred feet (status)	
18:30		Still quite-- (coach)	
18:31		even it off there (coach)	
18:32			
18:33		two hundred feet, (status)	
18:34		I'm ready to go (ready)	
18:35		when you are	
18:36	Pilot:	Okay (reply)	
18:37	Copilot:	Hundred feet (status)	
18:38			
18:39	Pilot:	There's thirty (status)	
18:40		aircraft crashes into the ground	

For each case I recorded I also attended the brief before the flight and the brief after the flight. In the brief before the flight, the pilots establish limits for the procedures they will perform. For example they decide before the flight at what altitude they will attempt a particular maneuver. That kind of information is not explicitly represented in the transcript because it is shared knowledge between the pilots. One pilot may access that knowledge with a single statement and since I was present I know what it means.

Trajectory of Representation Analysis

Using the video transcript I also performed a trajectory of representation analysis. Trajectories of representations identify pathways where there is heavy flow of representations or transformations of representations. Trajectories are the direction representations are propagated through the system. I made the theoretical commitment that in tracking the flow of representations along their trajectories I could identify the distribution of cognitive workload in the cockpit and how representations are transformed in the context of action. Such an analysis reveals the cognitive response demands that are imposed on the system and how the system organizes to respond to a disruption.

Anselm Strauss (1993) also uses the term *trajectory* to describe the actions and interactions that contribute to the evolution of a process and the path the process take over time. In my analysis I use trajectory at a micro level to indicate the direction that representations flow and at a macro level to characterize flow patterns in the system that affect outcome.

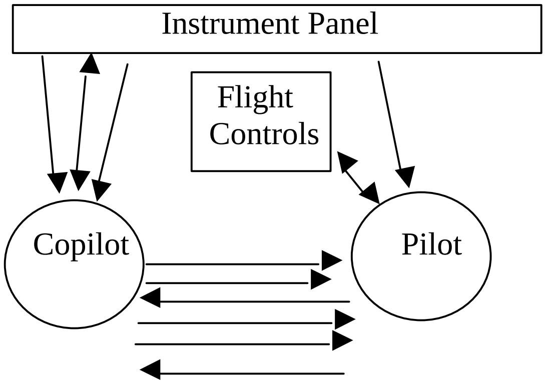


Figure 4. Trajectories of representation analysis for the cockpit. Arrows represent flow pathways. Bi-directional arrows represent interactions.

At the micro level I traced the trajectory of each representation as it moved through the system using a schematic (Figure 4). For each representation I drew an arrow from it to its destination. So if a caution light illuminated and the copilot acknowledged it, a single arrow was drawn from the instrument panel to the copilot. If the copilot pressed the button on the instrument panel, I used a bi-directional arrow to represent the interaction and bi-directional flow of representations. When the tracking for a case was complete I counted the number of representations and noted the main pathways of representational flow. Then I modeled the flow for the case at a macro level (Figure 5). The thickness of arrows represents the density of representation traffic relative to the other pathways. So if a copilot made twice as many statements than the pilot made the copilot to pilot arrow is represented as twice as thick as the arrows from pilot to copilot.

The flow diagram characterizes the trajectories and density of representation flow in the system during an emergency response. The instrument panel (IP) presents pilots with complex and dynamic representations of aircraft system functioning and aircraft behavior. The pilots filter the representations from the instrument panel and interpret them according to the immediate task demands. The pilot (P) and copilot (CP) coordinate their knowledge with the instrument panel representations to negotiate decisions and judgments about how to manipulate the flight controls (FC) and the power control levers (PCL). The power control levels are used to manually control the engine power supply to the main rotor. Under normal flight operations power is supplied to the main rotor via the handle of the collective lever. The collective and cyclic control the

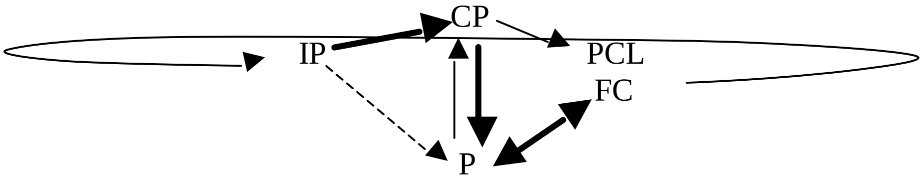


Figure 5. System model of representation flow in a Seahawk cockpit. Arrows represent the direction of representation flow. Bi-directional arrows represent an interaction that changes the state of media in the cockpit. The width of the arrows represents the density of flow. Density of flow is calculated by the relative frequency of the representation. Dashed arrows represent a degraded flow of representations. Degradation is measured by the absence of representations in the flow that are critical to a safe outcome but for some reason were not processed.

pitch of the blades of the main rotor and the two pedals control the pitch of the tail rotor. Together these flight controls govern the all the aircraft's movements.

The flow analysis provides a visual representation of the distribution and flow of representations across cockpit media and between pilots. I used the models to compare flow patterns across cases and to identify the kinds of flow disturbances that arise in the system that had an impact on performance.

The trajectory of representation analysis is powerful descriptive tool. It has limited capability for addressing the content of representations and how meaning is constructed from representations. To get at the meanings of interactions I devised an interaction analysis. Because cognitive phenomena emerge from the interactions within an activity system those interactions are of theoretical interest (Hutchins, 1995).

Interaction Analysis

In Figure 6, I present a representation of the interactions within the cockpit system as it becomes configured during an ideal response to a single engine failure. The analysis is based on the theoretical assumption that system output (in terms of performance) is influenced by system level properties that emerge from interactions occurring within the system and not from the properties of individual pilots alone.

The interaction diagram is a composite representation drawing upon multiple data sources (Figure 6). The vertical columns represent interactions between the crew and the representational media: instrument panels, speech, flight controls, and checklist. In this characterization of the system social interactions and the material interactions between are identified in a visual representation that and may be compared with other cases.

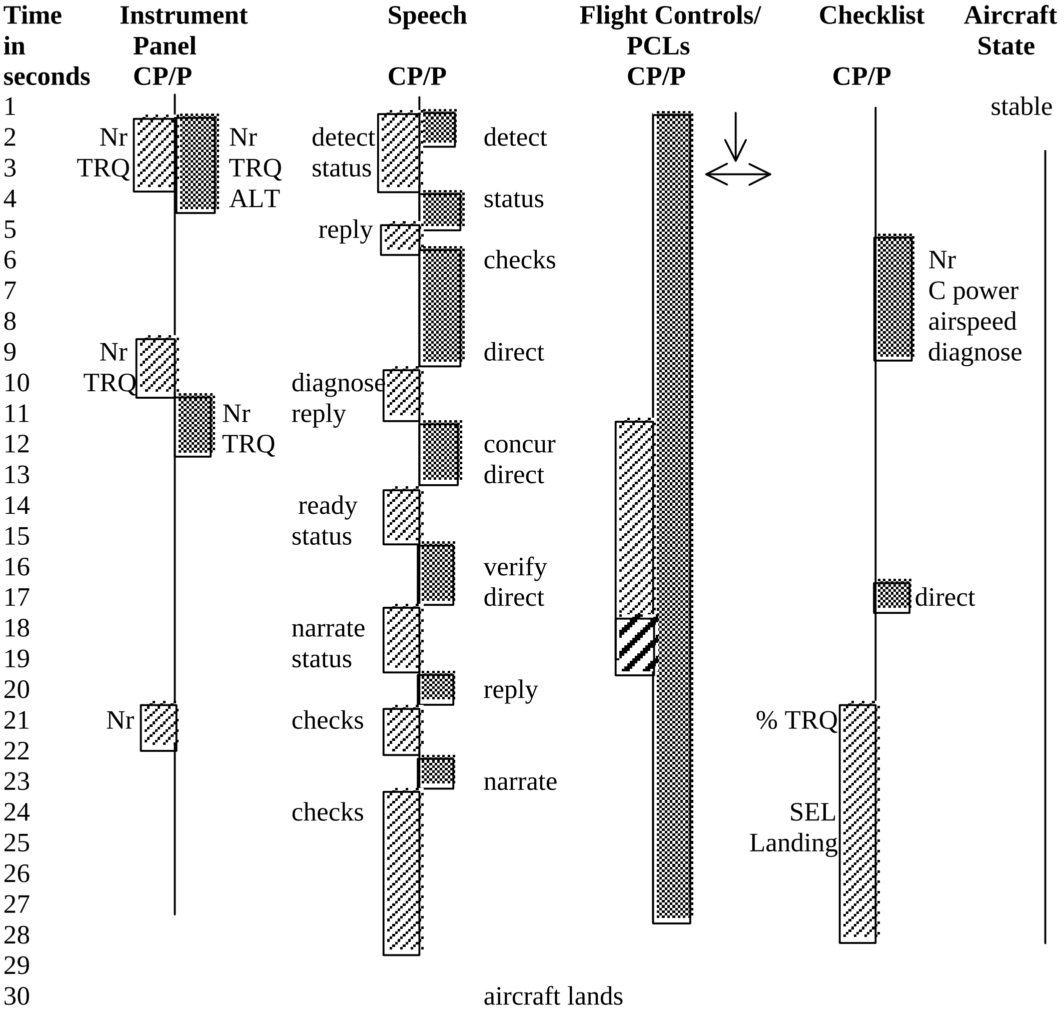


Figure 6. Interaction pattern schematic.

The interactions are organized, vertically through time in seconds. The flight stability of the aircraft is presented in the right column and represents the outcome of the system's interaction patterns. Representations from the instrument panel that were processed by the system appear in the instrument panel column. Only those representations that were stated or acted upon are presented because only these were observable. This is a different characterization from the video transcript where I identified everything that was visible in the system whether or not it was processed.

The speech is coded with content codes from the transcript analysis, to indicate the content of the speech (Appendix A). The instrument panel is coded with the display representation involved in the interaction (Appendix B). The pilot's hands must always remain on the flight controls and subtle control movements are not visible on the videotape, but large amplitude control inputs are visible. These movements are represented with arrows indicating the direction the pilot moved the cyclic in the flight controls column. A copilot's interaction with the power control levers may be sustained or intermittent. Finally the checklist interactions indicate

The interactions I just described are individual interactions. These interactions include verbal statements between pilots, the processing of display representations, moving flight controls flight controls, and reading the checklist matched against aircraft stability.

I identified interaction patterns by the sequence of representation flow into organized chunks of activity with a distinct beginning and end. In the analysis of the seven case studies three distinct interaction patterns were identified and have an influence on the outcome of the flight. I call the patterns coaching, dominance, and intersubjectivity.

Coaching occurs when one pilot transforms representations into statements that are supportive of a specific task of the other pilot, such as controlling the aircraft. During a coaching interaction there tends to be heavy flow of representations from the instrument panel to the copilot and then to the pilot. Coaching statements may be given as directives (“get that nose over”) or as status (“that’s a good rate”) or as reassurance (“you've got it”). The pilot being coached may verbally acknowledge the statements or acknowledge them through his actions. The coaching pilot monitors the other pilot’s actions and continues to coach as required. Coaching interactions tend to vary in duration because pilots transition in and out of coaching to perform other tasks such as verifying a mechanical failure.

The notion of coaching is represented in the pilot community in the phrase *back each other up*. The wisdom of this notion is passed within the community by word of mouth from instructors to students. In the following field note excerpt the spirit of coaching is evident in the words of this flight instructor to his students during a debriefing session:

> Near the end of the brief the instructor told us about a recent mishap in the gulf where the pilot swapped ends of the helo because he didn’t know his aircraft’s limits. “It is one thing to have book knowledge and another to have operational knowledge,” he said. “We live in a dangerous 3-D world, be an aviator not an operator you have to apply your knowledge. Flying is half art and half science. Back each other up, don’t rush, check each other, always back up a diagnosis, fly the aircraft and maintain control. Have a game plan and think a couple of steps ahead just like chess. In advanced training they taught you to fly within very tight parameters so you don’t kill yourself, but now it is time to expand your capabilities.”

This particular instructor was more conscientious than most and this kind of explicit instruction was rare. Here he explains that a pilot got into a dangerous spinning situation because he didn’t know the limits of the aircraft’s capability. He uses the phrase *back each other up* as a way to emphasize the importance of coordination, planning, and error checking in the operational component of flight. Unfortunately there is little documentation in the training program about what it means to *backup* someone, how to do it effectively and why it works.

A *dominance* interaction occurs when one pilot does everything—processes instrument representations, speaks, acts, decides, without assistance or concurrence from his partner. The other pilot tends to remain a passive partner even if he was not passive before. This pattern is often characterized by a unidirectional flow of representations centering on one pilot. Pilots construct an understanding of the situation independent of each other and the understanding of the dominant pilot may sway the understanding of the other pilot. Communication between pilots tends to be one-sided flowing from the dominating pilot to the other pilot with little or no opportunity for negotiation and discussion.

These kinds of interactions are known to be dangerous and are addressed in the navy’s aircrew coordination training under assertiveness. Assertiveness is defined in the programs as: *the willingness one has to take action and to actively participate*. All members of the crew, pilots and aircrewmen, receive some kind of assertiveness training. Under aircrew coordination training, barriers to assertiveness are presented as authority and rank of crewmembers, the skills and knowledge of crewmembers, and individual personality traits. But assertiveness training is directed at the more passive partner so even if someone asserts himself it may not be sufficient to break a dominance interaction.

The last interaction pattern is *intersubjectivity* as the emergence of a shared understanding between pilots. Hutchins and Klausen (1996), documented the emergence of intersubjectivity between crewmembers flying a commercial airplane. These interactions occur when both pilots make relevant contributions in terms of speech and action to a joint activity. We see abbreviated sentences, overlapping speech, and actions in response to an understanding not a command. The interaction may vary in length and intensity and may incorporate coaching. The exchange transitions into parallel coordination when the pilots begin another separate, but contextually appropriate, activity following an interaction. Parallel coordination occurs when both pilots perform separate, complimentary activities in parallel such as one pilot performing checks while the other calls air traffic control.

Intersubjective interactions usually occur during intense activity, like during a diagnosis, detection of a malfunction, or when the crew is regaining aircraft control. These are periods where crew coordination is essential. The closest term to intersubjectivity in the training program is *synergy*, but it is not clearly defined nor is it used to describe behavior outside of the books. It is not surprising that this is a more difficult phenomenon to conceptualize in training terms. Both coaching and dominance are asymmetric interactions, but intersubjectivity is a symmetric interaction that is a balance between both pilots’ contributions to action and understanding.

Aircrew Coordination

The interaction analysis is of theoretic interest but it is also of pragmatic interest to the Navy because interaction patterns have a role in establishing aircrew coordination in the cockpit. Aircrew Coordination Training (ACT) was derived from Cockpit Resource Management (CRM) training originally developed by commercial airlines, and has since been renamed Crew Resource Management (ACT, 1995). CRM research has been instrumental in successfully identifying crew behaviors that contribute to pilot-induced accidents (Wiener, Kanki, & Helmreich, 1993). Teamwork has been shown to be essential for managing demanding situations (Fonne & Myhre, 1996) and other studies link social interaction in the cockpit to mission performance (Prince & Salas, 1993). The seven coordination behaviors of the naval ACT program are adaptability/flexibility, situation awareness, leadership, communication, decision making, mission analysis, and assertiveness.

Adaptability and flexibility are concerned with one’s ability to be flexible to a changing environment. Leadership is concerned with one’s ability to direct and coordinate the activities of the crew. Decision making focuses on the application of logical, sound judgment based on the information available. Intuitive decision making is considered acceptable behavior as long as one’s intuition is correct. Situation awareness is about understanding what is happening to the aircraft compared with what is supposed to be happening. Situation awareness also refers to knowing your spatial location and the status of the mission. Mission analysis is the ability to coordinate, allocate, and monitor crew and aircraft resources. It primarily involves short and long term planning and plan evaluation. Communication is considered the foundation of ACT. The main focus of communication is to train the pilots to communicate relevant information to other crewmembers in a clear, concise manner.

Aircrew coordination training is the navy’s primary vehicle for training pilots to coordinate in the cockpit. I used the interaction analysis to assess how pilots fall into and out of coordination during emergency situations. The analysis was then used to inform recommendations for improving the aircrew coordination training program.

Conclusion

A pilot’s understanding of a flight situation is shaped by many variables, among them are the social and material factors in the cockpit (such as communication patterns and rank), trajectories of representations in the cockpit, procedures, and the quality of representation form. For example, the checklist is a physical artifact pilots use to organize their actions. The checklist is a book of institutional procedures ranging from normal to non-normal operations. The procedure is a representation often transformed by the copilot into a set of instructions to the pilot. How it is transformed depends on the situation and on the social relationship between the pilots. A senior copilot who believes his pilot is having difficulty may transform the checklist or the displays into a set of flight commands: “slow to 80 knots” or the copilot may transform the checklist into an information statement about a completed action: “generators are on”. These kinds of representation transformations are linked to the underlying social and cultural fabric of the cockpit and have consequences for system performance.

Institutional regulations and procedures, military culture, and crew compatibility each have different pulls and influences on how pilots think in the cockpit. One objective of describing the cockpit at a system level is to understand what the representations mean to SH60-B pilots and why those representations are transformed in a particular way. Once the representations are identified and their transformations traced, it is possible to evaluate the representations, their properties, and the processes that transform them.

Studying the cockpit as a cognitive system is a fundamental shift in aviation research because it emphasizes context and its role in cognitive performance. Distributed cognition, like situated cognition theory claim that “cognitive activities should be understood primarily as interactions between agents and physical systems and with other people” (Greeno & Moore, 1993, p. 49). They do not take situated cognition to be a special kind of cognition, similarly distributed cognition is not a kind of cognition. It is a characteristic of all cognitive phenomena (Hutchins, 1995) and the boundary between what is inside and what is outside the head is permeable thus the individual and his environment are inseparable.

CHAPTER 3

Engine Case Studies

Pilots are trained to respond to a range of mechanical failures and emergency conditions and are expected to expertly manage them under any flight configuration. Modern aircraft are extremely reliable flying machines and the likelihood of a mechanical failure is low, but military aircraft are unique in that they may sustain damage during combat. Pilots must be prepared to decide if they can continue to fight their airplane. That decision requires extensive knowledge of aircraft capabilities and systems and the relationships between them, plus the criticality of that system to operations and the consequences of losing it. The navy expects her pilots to know their aircraft so well that response feels “instinctive”.

The entire pilot phase of SH-60B training is devoted to learning the aircraft, its systems and capabilities. During the flight portion of this training students learn to fly the helicopter, land it on the back of a ship, and to identify and respond to a series of mechanical failure and emergency conditions. There are emergency procedures for each condition, some of which must be memorized so that the response is immediate without reference to the pilot pocket checklist. The checklist is a small book of procedures that pilots keep handy as a reference to a range of normal and non-normal operations.

When there is an engine failure, it must be detected and identified by the pilots. Pilots must detect a problem using cockpit cues and aircraft behavior. Then pilots must determine what those cues mean in terms of aircraft functioning and mission capability. Meaning is constructed through a distributed process of matching cues in the immediate environment with knowledge about systems and aircraft performance. The cockpit instrument panel is the pilots' window into aircraft and system functioning. Indications of an engine failure are represented by changes in engine instrument readings and illumination of caution and warning lights.

Once the pilots determine and verify an engine failure they configure the aircraft for single engine flight following a set of prescribed procedures for each type of emergency. Even though there are institutionalized procedures for responding to an engine failure, there is considerable variability in acceptable responses because flight environments are dynamic. The NATOPS flight manual acknowledges the role of pilot judgment in determining the proper response (Navy, 1997):

> "Action to be taken after failure of one engine will depend upon altitude, airspeed, gross weight, phase of flight, single-engine capability, and environmental conditions. In addition these factors should be taken into consideration should the functioning engine fail and a dual engine failure result. The pilot's first consideration must be aircrew survival and second minimizing damage to the aircraft. If airspeed is low and altitude permits, an attempt to achieve single engine airspeed may be made by lowering the nose. The helicopter should not be placed in a nose low attitude because of reaction time and high rate of descent." (NFM, p.12-9).

The roles and responsibilities of each crewmember during an emergency are also described in the flight manual (Table 2). The pilot's role and responsibilities read: "Pilot in command must evaluate all the factors involved in an emergency situation to determine the landing site and duration of flight. The pilot shall complete the immediate action items that do not require releasing the flight controls" (ibid., p. 12-9) Similarly, the copilot's role and responsibilities are defined: "The copilot shall assist in assuring the continued safe flight of the aircraft. He will perform the immediate action items the pilot has not completed. He will then complete the appropriate procedure using the checklist as a guide and troubleshoot as required". An institutional division of labor in makes it possible for pilots to build reliable expectations about what each pilot will do and say under these emergency conditions, and serve as an important basis for coordinating activity in the cockpit.

Table 2. Division of labor for engine failure.

Pilot	Copilot
Maintain aircraft control	Assist in assuming continued safe flight of aircraft
Determine precise nature of the problem	Determine precise nature of the problem
Evaluate all factors in an emergency procedure to determine landing site and duration of flight	On takeoff, approach to landing, and landing the pilot not flying shall monitor all systems to alert the pilot at controls of malfunctions
Determine landing criteria and land as required	Complete appropriate procedure using the checklist as a guide and troubleshoot as required, take action appropriate for the problem

The physical layout of the instrument panel and the cockpit provides both pilots with equal access to flight relevant displays. Both pilots have redundant pilot display units but the pilot also has tactile feedback from the flight controls while the copilot only has visual access to the movements of the flight controls. The pilot also has access to some of the configuration switches on the flight controls, such as cargo release and contingency power and can activate them without removing his hands. The copilot is responsible for moving the power control lever to the appropriate position because the pilot cannot move it without releasing the controls.

The SH-60 B instrument panel has redundant pilot display units, one in front of each pilot, that present primary flight displays such as rotor speed, engine speed and power, and aircraft altitude. A central display unit offers secondary engine gauges such as fuel, oil, and temperature and are used to cross check engine readings on the pilot display unit. The instrument panels supply engine performance indications that are represented by ascending and descending columns of multicolored lights (red, yellow, and green) measured against vertical scales. An engine control system matches engine power output to maintain a constant power supply to the main rotor. Engine control system malfunctions or engine alternator failures can cause an engine to go to a high or low torque condition resulting in Nr (main rotor speed) increasing or decreasing from its normally governed range.

High and Low Side Engine Failures

A high side failure results when the torque of one engine significantly increases above the torque of the other engine creating an uneven distribution of power to the main rotor system. During an engine high side failure, the primary indications are an increase in Nr (main rotor speed), Np (power turbine speed), and a significant split in engine torque readings (Figure 7). Secondary indications may also include an increase in Ng (gas generator turbine speed gauge) and TGT (turbine gas temperature gauge), and aircraft vibrations. The engine out warning light may illuminate even though the engine has not failed. A low-side failure results when the torque of one

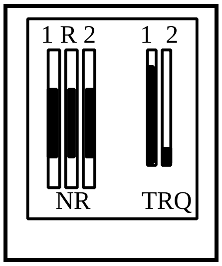


Figure 7. Number one engine high side failure. Nr indicates an increase in power and TRQ indicates a significant split.

engine significantly decreases below the torque of the other engine. The severity of a low-side failure can vary. An engine low side failure is indicated by a decrease in Nr, Np, and a large split in torque readings without indications of an engine compressor stall or engine flame out (Figure 8).

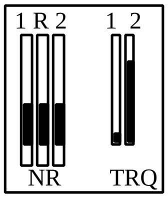


Figure 8. Number one engine low side failure. Nr indicates a decrease in power and TRQ indicates a significant split.

Standard Procedure

I used the standard procedure as a baseline for comparing across cases. Even though there are deviations from the procedure in each case, the overall response structure is similar. Flight instructors also use deviation from the procedure as a measure of pilot performance.

The procedures state the appropriate response to an engine high side failure is to control Nr with increased collective and apply contingency power (an additional source of power) to prepare the aircraft for safe single engine flight. The engine with high Ng should be disconnected from the ECU using the power control lever (PCL) to reduce power. The aircraft is capable of flying on a single engine but single engine flight must be established and maintained by the pilot. The pilot's first concern should be aircraft control and the completion of critical memory items (procedures pilots are required to memorize). It is navy policy that memory items be initiated and performed without reference to the checklist, but in practice the copilot often reads them from the checklist while the pilot performs them. The checklist procedures for a high-side emergency are presented in Figure 9; critical memory items are indicated with an asterisk.

ENGINE HIGH SIDE FAILURE

On deck:
***1. Both ENG POWER CONT levers……IDLE**

In flight:
***1. Control Nr.**
***2. CONTGCY PWR……………………….ON**
***3. Establish single-engine airspeed.**
***4. Identify Malfunction**
***5. ENG POWER CONT lever of the**
malfunctioning engine………………………RETARD
TO SET:
  a. Torque 10% below good engine, or:
  b. Matched Ng or:
  c. Matched TGT.
6. Land as soon as practicable.

Figure 9. Checklist for Engine High Side Failure. Control Nr means to control the main rotor RPM. Contingency power on, resets the engine electrical control unit to operate at a higher temperature. This additional power is made available by a switch on the collective. Engine power control lever of the malfunctioning engine: Retard to set, means manually control malfunctioning engine by adjusting the power control level to a reduced power setting. Land as soon as practicable, means extended flight under these emergency conditions is not recommended.

The correct response to an engine low side failure is to control Nr with decreased collective and apply contingency power. The malfunctioning engine should be operated in the lockout position to control fuel flow directly through the power control lever and collective position. When a copilot moves the power control lever (PCL) to the lockout position he disconnects that engine from the engine control system so that he may manually control the power of the failing engine while the pilot controls the power to the functioning engine via the collective. This is like putting a manual transmission automobile into neutral. The checklist procedures for a low-side emergency are listed in Figure 10.

The procedures for both kinds of failures are nearly identical and the response patterns are similar enough for comparison. If pilots follow the standard procedure, then the interaction patterns presented in Figure 11 should emerge. Interactions are coded with the engine failure codes developed in the transcript analysis (Appendix B).

ENGINE LOW SIDE FAILURE

***1. Control Nr.**
***2. CONTGCY PWR……………………ON**
***3. Establish single-engine airspeed.**
***4. Identify Malfunction**
***5. ENG POWER CONT lever of the**
malfunctioning engine……………………MOMENTARILY ADVANCE TO LOCKOUT THEN RETARD TO SET:
  a. Torque 10% below good engine, or:
  b. Matched Ng or:
  c. Matched TGT.
6. Land as soon as practicable.

Figure 10. Checklist for an Engine Low Side Failure. The checklist for a low side failure is almost identical to the high side checklist with two exceptions. First, the procedure is the same for an in-flight failure or a ship side failure. Second, the engine power control lever of low torque engine should be momentarily advance to the “Lockout” position and then retard to set and manually control the malfunctioning engine to increase power.

During the response an equitable division of labor should emerge with the pilot focusing on the controls and the copilot monitoring the instruments and performing the checks. We should see coordinated problem solving during the diagnosis and coordinated action on the PCLs (Power Control Levers) and some checklist actions.

Moving down the Figure 11 through time, there is immediate detection of a problem. The crew communicates status and prepares for single engine flight. Then the crew identifies which engine is malfunctioning and the nature of the malfunction. The failing engine is taken off-line and the crew configures the aircraft for single engine flight and prepares for landing.

The flow of representations through the system should follow flow patterns similar to the one shown in Figure 12. We'd expect heavier flow from instrument panel to copilot during detection and diagnosis and then heavier flow from instrument panel to pilot when the copilot performs checklist activity. Communication flow between pilots will vary with the specific task being performed, but in general, the overall pattern should be equitable.

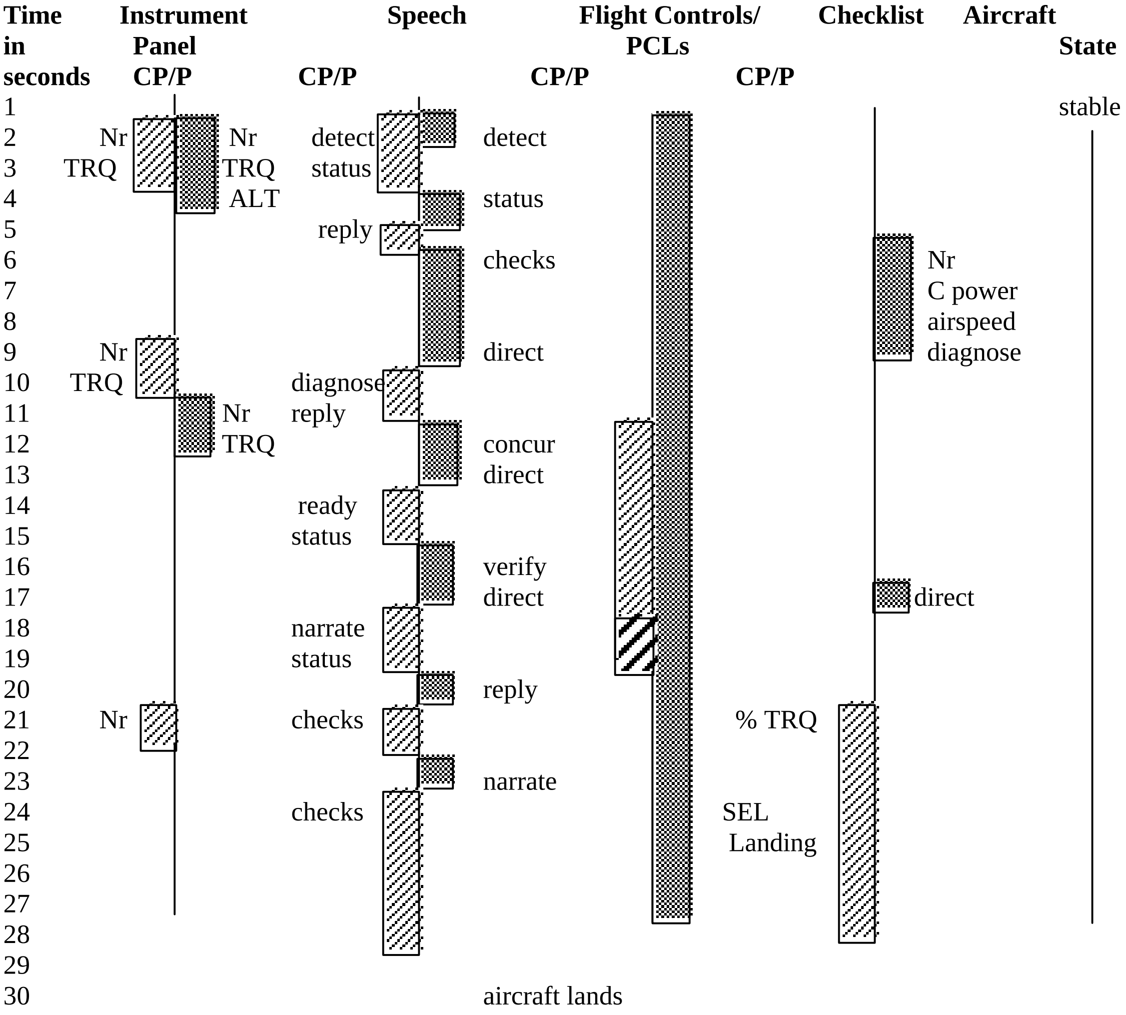


Figure 11. System interactions for responding to an engine failure.

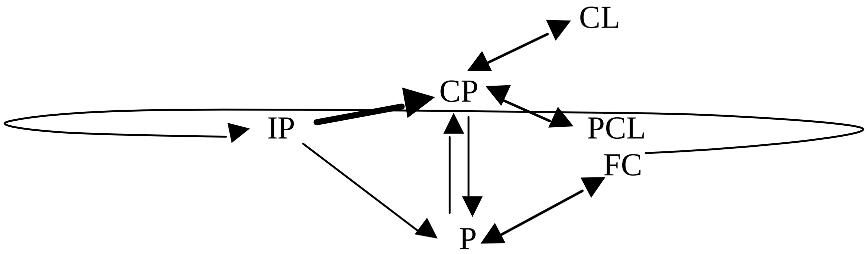


Figure 12. Standard procedure flow model representing a safe system configuration. The arrows represent the direction of representation flow. Bi-directional arrows represent an interaction that changes the state of the media in the cockpit.

Consequences of an Incorrect Diagnosis

The Nr display is the primary diagnostic instrument for an engine problem. It is located adjacent to the larger TRQ display. When an engine fails the TRQ display splits and tends to grab the pilot's attention over the Nr. Both high and low side conditions will cause a dramatic split in the torque gauge representation and the Nr will increase or decrease respectively. The Seahawk's engine load-sharing mechanism will match engine output to keep Nr at 100 percent. That means if one engine drops in power, the other engine will increase in power to maintain 100 percent Nr. If an engine gains power the other engine will lose power to compensate. The good thing about the Nr and the TRQ displays is they display real-time engine functioning, literally giving pilots a dynamic representation of engine functioning. As a diagnostic tool, however, these displays are difficult to interpret because they are dynamic and at times ambiguous making an accurate diagnosis difficult.

The standard response is to move the malfunctioning engine to a different power setting. If the crew mistakes a high side failure for a low side failure, they may disconnect the engine displaying a low power setting and cause the failing engine to increase its output to maintain 100 percent Nr. The high engine will quickly reach its limit and automatically shutdown. If the crew recognizes their error soon enough and returns the lower engine to full power while retarding the high engine (if it hasn't already shut down) they might recover. The high engine may still function even though it is degraded, the problem with pulling the low engine is that it may cause the high engine to over-speed and shut down and if the low engine is also set back and a dual engine failure may result. If a pilot attempts to get the low engine back too late, a compressor stall may result because the power available will not meet the power demand. If a dual engine failure results, it is possible to restart the good engine however, considerable altitude is required to do so.

If the crew mistakes a low side for a high side and the high engine is disconnected, the low engine will not increase because it is the failing engine so little or no power will be available to drive the rotor system. Again, the crew may recover if they realize their error and have sufficient altitude to take the appropriate response.

Engine Failure Case Studies

In this section I present three cases of engine failure. The first case is an engine high side failure and the other cases are engine low side failures. Even though these are different kinds of failures, pilots often diagnose one kind of failure for the other. A narrative analysis of each case is presented and followed by a discussion of case-specific issues.

Case 1: High Side Engine Failure

The example begins with a cargo lift maneuver. Immediately after departing a hover with cargo hanging from the aircraft, the number two engine failed high and the pilot incorrectly diagnosed it as a low side failure. In this case the pilot (P) ranks LT. Commander and his copilot (CP) ranks LT. Junior Grade, which makes him junior in rank to the pilot. The Instructor (I) is a navy flight instructor and ranks Lieutenant which is also junior in rank to the pilot but senior to the copilot. In operational environments cargo handling operations are performed by an enlisted air crewman but in the flight simulator they are performed by the instructor. The aircraft was in a stable flight configuration before the engine failure occurred.

Time in Seconds		**Speech**	**Gestures and Displays**
11	P:	Comin up, comin up,	
12		slowly slowly	
13	I:	Load is comin on the	
14		aircraft	
15		load's off the deck	
16		cleared forward flight	
17	P:	Away we go	
18			
19		How's the load	
20		ridin?	
21	I:	Eh, she's ridin	
22		fine	
23	P:	Okay	

The cargo load on the aircraft made flight operations slow and cautious. The pilot and the instructor in his role as aircrewman communicated cargo hookup status while the copilot monitored the flight instruments. A few seconds later the Radar Altimeter Warning System (RAWS) beeped to alert the pilots of a decrease in altitude. The copilot acknowledged the altitude and began calling out display readings that indicated anomalies: altitude, engine warning light, and Nr high.

<table>
<tr><th>Time
in Seconds</th><th></th><th>Speech</th><th>Gestures and Displays</th></tr>
<tr><td>29</td><td></td><td></td><td></td></tr>
<tr><td>30</td><td></td><td></td><td>RAWs tone</td></tr>
<tr><td>31</td><td>CP:</td><td>Kay altitude</td><td>RAWs tone, TRQ splits, Nr, Np, TGT rise
CP touches Radar altimeter</td></tr>
<tr><td>32</td><td></td><td></td><td>RAWs tone</td></tr>
<tr><td>33</td><td>P:</td><td>What the heck?</td><td></td></tr>
<tr><td>34</td><td></td><td>What da</td><td>Engine out light on,</td></tr>
<tr><td>35</td><td></td><td>hell?</td><td>#2 fluctuates, Np rises on both</td></tr>
<tr><td>36</td><td>CP:</td><td>(unintelligible) number one engine</td><td></td></tr>
<tr><td>37</td><td></td><td></td><td></td></tr>
<tr><td>38</td><td>P:</td><td>Okay</td><td></td></tr>
<tr><td>39</td><td>CP:</td><td>Nr is |high</td><td></td></tr>
<tr><td></td><td>P:</td><td>|pickle</td><td></td></tr>
<tr><td>40</td><td></td><td>the load</td><td></td></tr>
<tr><td>41</td><td></td><td></td><td></td></tr>
<tr><td>42</td><td>P:</td><td>pickle the load</td><td></td></tr>
<tr><td>43</td><td></td><td>simulated</td><td></td></tr>
<tr><td>44</td><td></td><td></td><td></td></tr>
</table>

The first step in the procedures is to control Nr, but the pilot decided to deviate from the procedure and jettisoned the cargo first, a step that is procedurally out of sequence but was probably required to maintain aircraft control. The copilot did not reach for the checklist nor initiate the checks and the pilot did not direct him to begin the checks. So far the only interaction between the pilots was to communicate status. The pilot interacted with the flight controls and used his memory of the checklist to organize his actions. The copilot coordinated with the instruments and stated Nr high as the pilot spoke over his status statement.

The cockpit indications needed for a specific diagnosis were ambiguous at this point. The engine out warning light was illuminated and the power readings (Np and Nr) were fluctuating, TRQ already split with some indications of power loss on the number two engine. After jettisoning the cargo the pilot completed the first three checklist items from memory.

As the pilot completed memory items he recited them and made their status available to the copilot. The pilot has not yet controlled Nr nor acquired safe single engine airspeed, but was attempting to and his recitation indicates he knew the procedure. The pilot did turn on contingency power by pressing a switch on the flight controls.

Time in Seconds		**Speech**	**Gestures and Displays**
45	P:	Control Nr,	Power cubes displayed on #2 TRQ, #1 display reads high
46		Contingency power on	
47		Safe single engine	
48			

The next item on the checklist is identify the malfunction. Usually the pilot will instruct the copilot to identify the malfunction for him. This request does three important things: it divides the cognitive labor, establishes coordination between the pilot and copilot; and it informs the copilot that the pilot is prepared to proceed with the response. This pilot diagnosed the failure on his own without requesting assistance or concurrence from the copilot and in doing so distributed the workload in a way that increased his own tasks.

The pilot proceeded and incorrectly diagnosed the number one engine high side failure as a number two engine low side failure. The copilot reached for the number two PCL and kept his hand on it until the instructor put the simulator in freeze. His action was available to the pilot for interpretation as tacit concurrence on the diagnosis that may have strengthened the pilot's interpretation of the failure. The copilot did not initiate troubleshooting nor did he explicitly challenge the pilot’s diagnosis. Even though the copilot was correct, he cautiously expressed his interpretation in the statement “Nr’s high”. After the diagnosis the pilot completed the remaining checklist items from memory “stores already gone, anti-ice is off” and announced their status as completed.

Throughout this dialogue the pilot and copilot did not coordinate their actions or decisions with each other, each proceeded with the emergency on his own, and consequently constructed opposing meanings about the nature of the failure.

Time in Seconds		**Speech**	**Gestures and Displays**
48			
49	P:	and	CP looks up to PCLs
50		we have an	CP reaches up to number two PCL
51		engine failure	no power on # 2 displayed
52		it appears	# 1 rises high
53		stores already	P looks left to CP
54		gone	
55		anti-ice is off,	P looks up to upper panel then looks forward
56		malfunction is	Some power cubes on #2 displayed
57		we got the number	
58		two engine	
59		shit out	CP looks right #2 power drops off
1:00			
1:01	CP:	Nr’s high	
1:02			
1:03	P:	Okay	
1:04		uh	
1:05		we’re gonna	
1:06			
1:07			

At time 50-52 the pilot offered a generic engine failure diagnosis because he was unsure of the problem. A little later the pilot made a specific diagnosis (time 57-59) that the number-two engine had failed. He arrived at these diagnoses from his interactions with the displays. Because he was busy controlling the aircraft he could not continuously monitor Nr so he missed some of the critical indications that Nr was indeed high. The copilot waited then replied with the statement: “Nr's high”, which is incompatible with the pilot’s diagnosis and the copilot's hand placement on the number two PCL. However the copilot's statement stalled the pilot and this is when we see a transition out of the dominance interaction.

The instructor interrupted the task by putting the simulator in freeze. Freeze suspends the simulator in its last position and maintains instrument readings and aircraft attitude. Freeze is used when the pilot is doing something wrong or when the instructor wants to explain something. The freeze provided the pilot with enough slack time to reflect on the instruments and situation. It only took a second for the pilot to realize his faulty diagnosis.

Time in Seconds		**Speech**	**Gestures and Displays**
1:08	I:	okay wait a minute---	Some power cubes on #2 displayed
1:09		time out	P looks down at RPM
			CP looks back to I
1:10			CP releases PCL
			#1 power displays high
1:11	P:	I got a number	
1:12		one engine high side	

As I mentioned earlier, the SH60-B aircraft is equipped with automatic engine load sharing that keeps both engines operating at a matched power setting. The matching system makes it difficult to determine which engine has failed because one engine may drop low to match a high power failure, making it seem as though the good engine is winding down, and therefore failing.

Line		**Speech**
A	I:	Yeah the big thing to remember is the Nr was high and he (the copilot) tried to
B		cue you (pilot) into that Nr is high, and in an engine failure you’re not gonna,
C		you’re gonna have Nr low, and that’s the big thing, it’s a high side failure. The only
D		reason it looked like it was engine number two was out, was because number one was
E		over-it was peaking and load sharing and said, well I don’t need number two so I drop it
F		off line, I’ll drop it down low. Remember your Nr’s high. That’s uh the reason you
G		saw Nr low--or I’m sorry Nr high but you saw number two low it’s because number one
H		was doing so well.

I P: Yep (CP nods) Doing so well, exactly.

It is common practice for the instructor to briefly critique the pilots' performance at the end of a scenario. Here the instructor told the pilot that his copilot had tried to inform him that Nr was high but the pilot did not listen (Lines A-B). Such a light critique of the pilot's performance is unusual because most pilots, especially one who ranks LT. Commander would receive a below average score for incorrectly diagnosing the high side failure. It's also interesting that the instructor did not critique the copilot his lack of initiative in making an explicit diagnosis. Then the instructor offered an explanation of how it might be possible for the pilot to see that the number two engine was low (Lines C-F). In his explanation, he attributed the error to the properties of the display and how it was possible to misinterpret a number two engine failure because the number one engine displayed high torque. Here the instructor offered the pilot an out, a socially acceptable explanation for making an incorrect diagnosis, and the pilot accepted the explanation and so did the copilot when he concurred with a nod (Lines F-H).

Ultimately the responsibility for the aircraft is in the hands of the pilot in command, in this case the LT. Commander, but I take the instructor's comments as recognition for the role of displays in pilot perception and decision making. That the instructor emphasized the contribution display behavior made to the pilot's incorrect diagnosis is indicative of an implicit understanding of the relationship between displays and diagnoses.

In this case a dominance interaction pattern emerged (Figure 13). Beginning at time 10 till time 33 all of the processing is conducted by the pilot with the copilot remaining passive. Note the numerous speech acts made by the pilot. Also note the

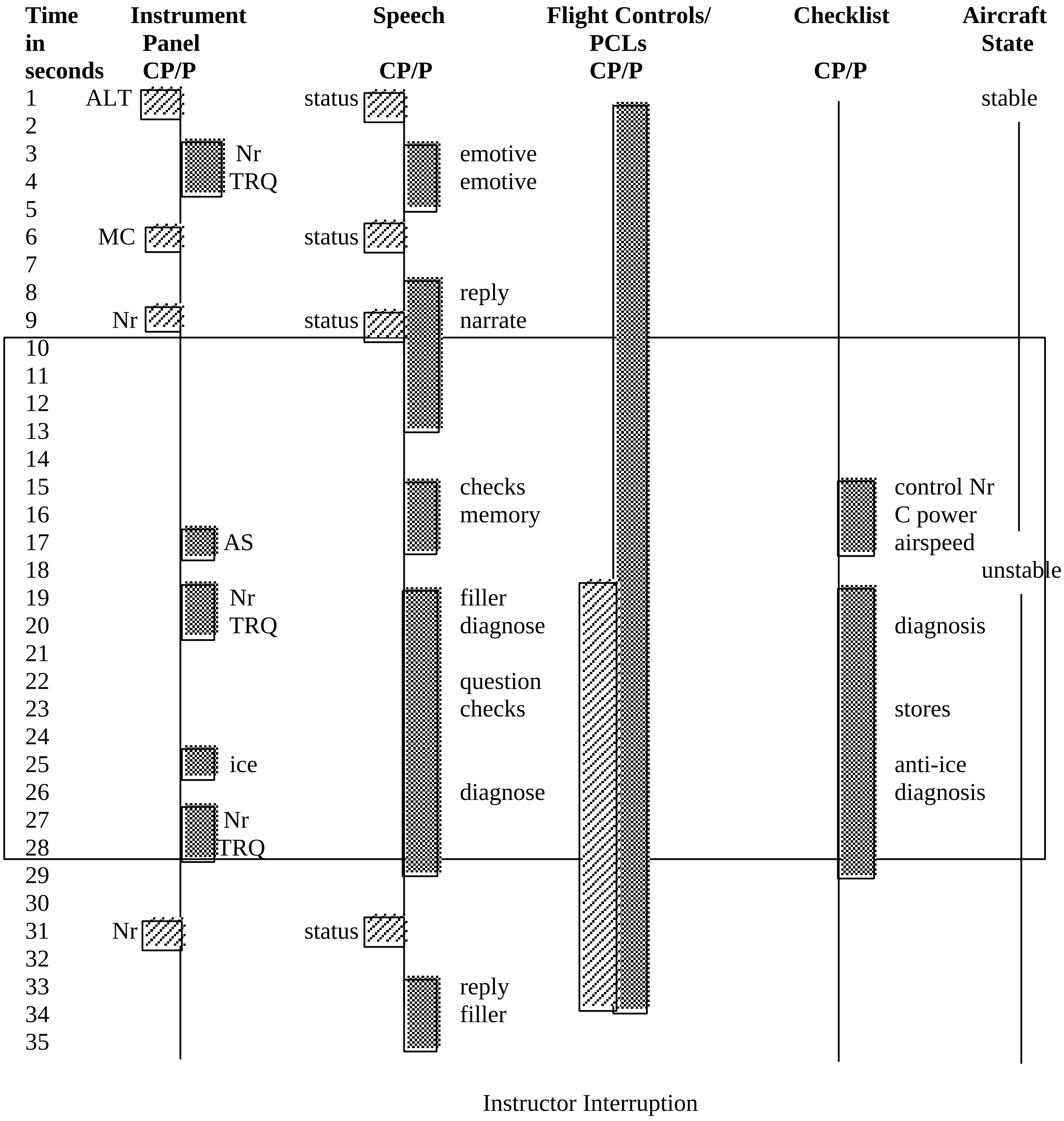


Figure 13. Interaction patterns for case 1. The interaction analysis begins 30 seconds into the flight when the copilot detects a drop in altitude. Notice the copilot only communicates status to the pilot. The dominance interaction pattern emerged as indicated by the box enclosing time10-28. The pilot experienced heavy mental workload processing the checklist memory items from the single engine failure checklist. Consequently he become too busy to monitor Nr and misdiagnoses the failure. Before they crash the instructor puts the simulator into freeze.

Number of memory checklist items processed by the pilot. The pilot diagnosed the failure independently of the copilot and they did not concur on an exact diagnosis. The crew deviated from the standard procedure by not explicitly determining the precise problem and the copilot did not use the checklist or monitor the systems to keep the pilot informed. The checklist memory interaction is a complex coordination of the pilot's knowledge, the displays, an interpretation of the displays, and action. Pilots are required to know the memory items for each emergency procedure and these items are marked with an asterisk in the pilot's pocket checklist so that the copilot can verify their completion as the pilot recites each item. The pilot recited and performed the correct memory items for the failure however the copilot never opened the checklist to verify them so the system lost redundancy in error checking.

The pilot diagnosed the malfunction, made all the decisions himself and diagnosed the problem without assistance from his partner. The copilot offered Nr status statements only twice during the scenario and never made a diagnostic statement like "High side". Nr is a key representation during an engine failure and it must be correctly interpreted and propagated in order for the system to succeed. In this case the pilot interpreted Nr as low while the copilot interpreted it as high but the system was not organized in a way to facilitate negotiation of competing interpretations.

The diagnosis interaction pattern primarily involves the displays and the pilots' interpretation of them. In this example the pilot made an incorrect diagnosis based on a faulty interpretation of the display representation. From a procedural perspective the pilot should have enlisted the copilot for assistance. The copilot monitored the displays and implicitly challenged the pilot's erroneous diagnosis in stating "Nr's High" after the pilot made a diagnosis of a low side failure, but the challenge did not effect a change in the diagnosis.

The flow patterns in Figure 14, illustrate a degraded flow of representations. There is heavy flow from the pilot to the copilot but there is no flow from the checklist to copilot. There is degraded flow from the instrument panel to the pilot. The pilot performed all the checklist items from memory without error checking and verification support from his copilot.

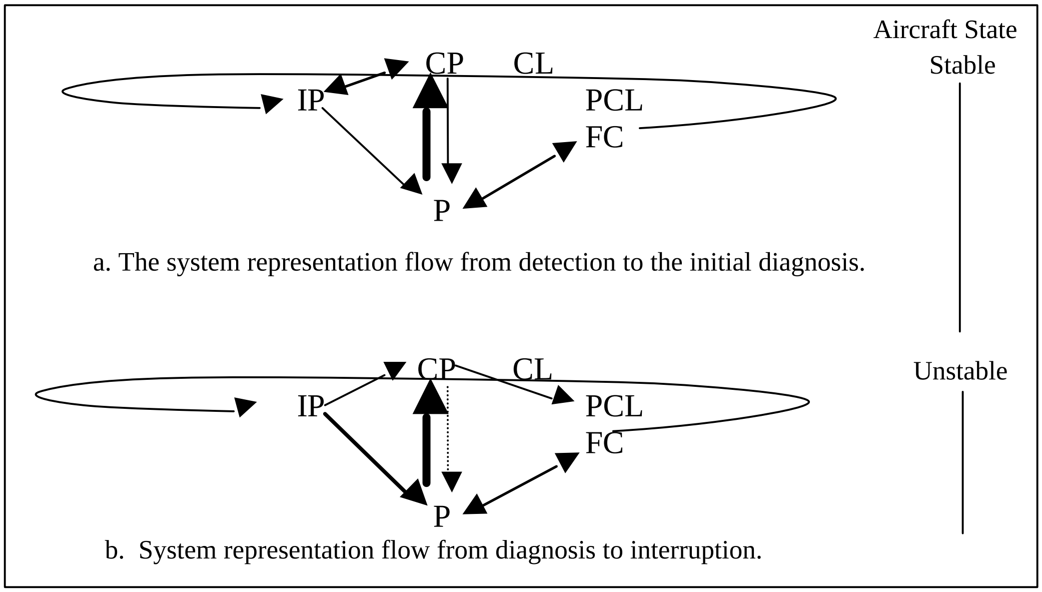


Figure 14. Flow patterns for engine case 1. The system starts out in a Stable configuration but then organizes to task the pilot with managing the flow of representations. As the system became unstable, the copilot became passive and the flow patterns are dominated by the pilot.

The flow patterns of this system are indicative of an uneven distribution of labor that burdens the pilot. The system started in a stable configuration but organized itself in a way that tasked the pilot with managing the flow of representations, an activity that could have been shared with the copilot. As system stability declined, the copilot became passive and communicated less with the pilot as the pilot dominated the interactions.

Case 1 Summary

This case is an example of a dominance interaction. The copilot attempted to sway the pilot's interpretation of Nr without being overtly assertive. However the copilot's initial statements were not enough to break the dominance interaction. The transition out of dominance finally occurs when the pilot hesitates after the copilot stated Nr is high. Rank probably had a role in the copilot's reserve. Recall the copilot ranked LT Junior Grade, which is junior in rank to his LT Commander pilot. Rank also played a role in the instructor's assessment of the pilot's performance. The instructor ranked LT, which is still junior to the pilot. Even though the instructor is more experienced in the aircraft and would be justified in giving the pilot a below average score on this task, he didn't. This case suggests that whenever a junior aviator is in a position of authority over a senior aviator, the power of rank is still present.

Finally this case illustrates that it is possible for pilots in the same setting to develop competing interpretations of the situation. Both pilots had access to the same representations but their interpretations differed. It is also possible for an experienced aviator to incorrectly diagnose a high side engine failure.

Case 2: Engine Low Side Failure

The aircraft was in a climb after take off and passed through 500 feet when the number-two engine failed. The pilot ranks Lieutenant (LT.), the copilot ranks Lieutenant Junior Grade (LT.J.G.) and the instructor is a civilian. The crew's performance is an excellent example of a model response.

Time in Seconds		Speech	Gestures and Displays
01	CP:	There's five hundred	
02		there's vibrations	TRQ splits, number two engine drops
03	P:	---There's a split here	RPM on number two drops to zero
04	CP:	Roger, looks like number	
05		two torque's droppin off	CP reaches up then puts his hand down
06		low-side	CP looks at P
07	P:	Just lost number two	#2 engine out light
08	CP:	Roger	CP presses master caution and both
09		Number-two engine out	warning lights extinguish. P moves thumb
10			up on cyclic in vicinity of trim control
11	P:	(unintelligible)...keep up airspeed	
12		Go ahead	
13		right there	
14		identify malfunction	P moves thumb to previous position
15	CP:	Number two engine failure	CP looks at P, CP opens checklist
16			looks at pilot then closes checklist
17	P:	Concur.	

The pilot and copilot coordinated their behavior with the behavior of the displays and attention was focused to the cockpit displays and aircraft behavior. The first indications of a problem were aircraft vibrations and a drop in the number-two engine RPM and torque. Each pilot made alternating observational contributions to the detection task and established an intersubjective understanding of an engine failure.

The copilot offered "low-side" as the initial diagnosis. To correctly diagnose the low side the copilot must know that a severe drop in torque indicates a low-side failure. The "#2 engine out" light illuminated on both pilots' master warning panels adding another representational input to the diagnostic process. This light is a secondary indication that strengthens the copilot's initial diagnosis. The pilot transformed the display representation into a verbal one with, "Just lost number two". The copilot acknowledged his statement with another verbal representation, "Roger, number two engine out" that is conceptually the same as the two previous representational forms, but in form the copilot's words blend both representations into one verbal representation.

During this exchange, the pilot maintained control of the aircraft. The aircraft is capable of flying on a single engine but it requires a specific configuration to do so. This crew followed the standard procedures for configuration almost to the letter. Eleven seconds into the emergency the pilot performed the first three steps and simultaneously verbalized them. The pilot completed the critical memory items then directed the copilot to identify the malfunction even though he had already diagnosed and stated the problem. It is possible that the pilot did not hear the copilot say “low side”. However, it is also possible that the pilot did not acknowledge the copilot because identification was done out of procedural sequence. The pilot did not concur with the diagnosis until the preceding checklist items were completed.

The copilot identified the malfunction as a number-two engine failure and the pilot concurred and together they complete the diagnosis. The information processing focus of the system shifts from diagnosis to configuration. During the diagnosis, both pilots were coordinating with the display representations and verbalizing their interpretations making them available to each other.

Next the pilots performed configuration tasks and coordinated their activities. The copilot read the checks, configured the aircraft, and directed the pilot. The pilot controlled the aircraft, concurred with the copilot, and planned the remaining flight activities. The copilot's attention was focused to the checklist and the states of the switches.

Time in Seconds		Speech	Gestures and Displays
18	CP:	And anti-ice is on	Fuel light on caution advisory panel starts
	P:	-------anti-ice is on	flashing with the master caution light CP
19	CP:	We have no stores to jettison	reaches to the upper panel where anti-ice is
20			located, CP reaches to lower panel
21			A caution light flashes
22		We still have ten,	
23		uh hundred pounds of fuel	CP opens checklist
24			
25	P:	We have a number two	CP looks at light flashing on the master
26		fuel pressure	caution panel
27	CP:	I'll mash that as soon as	
28		it steadies out	CP looks at flashing light, looks at P and 29 then returns to the checklist
30			

At this point the copilot has opened the checklist and consulted the appropriate page. Meanwhile the pilot declared an emergency then directed the copilot to go through the checklist. The copilot's speech is a verbal representation of the checklist. By reading the checklist out loud the copilot made printed procedures available to the pilot. This copilot did more than just read the item verbatim, he includes content about state. For example, the first item on the checklist is "Control Nr". The copilot refers to it as an acquired state by saying "we got" rather than as a directive to the pilot to control Nr.

Time in Seconds		Speech	Gestures and Displays
31	P:	Uh Beach tower	
32		Island Ruler zero one,	
33		I'd like to declare	CP presses master caution panel and fuel
34	P:	an emergency,	light goes out
35		uh single engine failu--	
36			
37	T:	Roger,	
38		you'll be cleared to land	
39		runway zero nine,	
40		winds zero nine zero	
41		at ten, and uh	
42		crash crew is standing by	
43	P:	Zero one roger ,	
44		I'll go ahead and extend	
45		our downwind	
46		Go ahead and go	
47		through the checks there	
	CP:	--Roger	

The copilot has visual access to the Nr display and can see if it is being controlled. Similarly, the two checklist items, 1) Engine anti-ice as required, and 2) External cargo, stores, fuel jettison, as required, are verbalized as state "Ice off" and "Fuel, stores required". The copilot does not have control over the state of contingency power and airspeed so he reads them as instructions to the pilot.

Time in Seconds		**Speech**	**Gestures and Displays**
48	CP:	Okay we got	CP looks at pilot,
49		control Nr	then reads from single-engine failure
50		Cont power on	checklist
51		Establish sing-eng-airsp-	
52		Ice off	
53		Fuel stores (pause) required	
54		Engine shutdown complete	CP looks up and grabs
55		I have the number two	
56		PCL	
57	P:	Concur	
58			
59		its coming off	CP pulls PCL back then
1:00			looks down at checklist
1:01			
1:02	CP:	And shut down	
1:03		number two--	

The copilot selects checklist steps that are specific to the task at hand and in doing so restricts the flow of representations from the checklist. The pilot has no trouble understanding these changes and never questions them. The last item on the single-engine failure checklist is to land as soon as practicable. Depending on where the aircraft is located the crew has two options to try to restart the failed engine, or perform a single engine landing.

Time in Seconds		Speech	Gestures and Displays
1:04	P:	--Alright,	
1:05		let's get max	CP looks at Pilot, torque display on number
1:06		power check	one engine increases
1:07		--out here	
1:08		while we're out	
1:09	CP:	Roger that	CP continues with the checklist
1:10		-kay and land as	
1:11		soon as practicable	
1:12		Engine air restart	
1:13		or single engine	
1:14		landing checklist	
1:15			CP looks at P
1:16		What do you wanna	
1:17		do? here uh,	
1:18		let's go ahead---	
1:19	P:	Looks about 126 (% torque)	torque limit is 135%
1:20	CP:	Okay	CP continues flipping through checklist
1:21	P:	We'll just go ahead	
1:22		and do a single engine--	CP flips to single engine landing checklist

While the copilot completed the checks, the pilot planned the remaining flight. The pilot performed the maximum power check early to off-load future tasks into his spare time. The last item on the list is to land or attempt an engine air restart. Instead of directing the pilot to land, the copilot asked him what he wanted to do. Ultimately the decision to land is up to the pilot since he is the one controlling the aircraft. For some engine malfunctions, a restart will damage the engine, but for a low side this danger is negligible. However an air restart takes time and in the aviation domain, time often translates into altitude. If the crew was over water and the only landing option was their ship, an air restart would be a viable option. However, with a land-based runway in front of him, the pilot decided to land. The copilot could have easily directed the pilot to perform a landing and not even give him the option, remember the pilot does not have direct physical access to the checklist, but he has memory access. The copilot distributed the decision process by asking the pilot what he wanted to do and in doing so acknowledged the pilot’s authority.

The pilot narrated his actions while acknowledging aircraft state (Time 1:24). This verbal representation offers information to the copilot about when the landing will happen, the kind of landing (running) and that they are high for the approach. The copilot acknowledged him with a simple "Okay" and completed the before landing checks.

Time in Seconds		**Speech**	**Gestures and Displays**
1:23	CP:	Okay	
1:24		before landing checks	
1:25		here	
1:26		everyone check your	
1:27		harness	
1:28	I:	Locked aft	Aircraft climbs from 500 feet to 600 feet
1:29	P:	Locked right	P leans forward to check harness
1:30		I'll put down	
1:31		to the right here,	
1:32		a little high,	
1:33		but I'll just	
1:34		go ahead	
1:35		and run it on	CP flips through checklist
1:36	CP:	Okay	
1:37		and	
1:38		Cpower,	
1:39		brakes set	CP's head is down and looking at checklist
1:40		Crewman's checklist	Altitude drops to 400 feet
1:41		in the back	
1:42	I:	Complete	
1:43	P:	You all set	
1:44		and ready to land	
1:45		in case this goes?	

The final task that remained was the single-engine land checklist. Here the copilot read directly from the list without adding state information.

Time in Seconds		Speech	Gestures and Displays
1:46	CP:	Before landing checklist	CP reads from the checklist
1:47		-kay max power checklist	
1:48		Approach airspeed eighty knots	
1:49		Establish a rate of descent	Low altitude warning beeps sound
1:50		not over a thousand feet	
1:51		per minute and five hundred	
1:52		knot straight away	
1:53		We're comin to runway	
1:54		uh hundred and fifty eight	
1:55		Reduce airspeed,	
1:56		rate of descent	CP looks up from checklist
1:57	P:	I'm slowin it down	
1:58		right now	
1:59	CP:	Roger....and	
2:00		you're goin there	
2:01		real fast, really fast	CP puts hands on front panel
2:02		There's eight hundred	
2:03		five hundred	
2:04		you're at fifty feet	
2:05		thirty	
2:06		twenty	
2:07		still at	
2:08		you're uh, lil-bit	
2:09		and...	
2:10		go to flare...	
2:11		There we go	
		aircraft lands	

The copilot guided the pilot down to the runway by calling out altitude and rate of descent something the copilot initiated himself. By reading the displays, the copilot transformed the visual display representations into an auditory verbal representation and changed the distribution of cognitive labor. Reading the displays to the pilot reduced the pilot's visual attention workload such that more attention may be allocated outside because the copilot is attending inside. The system's attention resources are distributed in such a way it reduces the cognitive workload of the pilot.

This was a by the book response, the crew made no errors and coordinated their actions, communicated and supported each other throughout the scenario. We see coaching and verbal scan emerge as well as narration. The pilot kept the copilot in step with the procedure by deferring the diagnosis until aircraft control was established and did so in a way that was cooperative.

Line		**Speech**
A	I:	Okay, uh, okay uh pretty good reactions there. You said you were gonna extend a little
B		bit but then we kinda, you know, came on in there. Recognize, you know, recognize in
C		real life you probably don't wanna do that but uh, ninety-eight percent of the time you'll
D		be comin to two seven, So if you extend off uh two seven that's not a big deal. Uh okay,
E		uh okay, other than that uh (pause) other than minor junk things like that--good job.

The instructor’s comments indicated the crew did a fine job (Line E). The instructor’s only complaint was that the pilot said he was going to fly an extended downwind leg on approach to the runway, but he didn’t (Line A-B). Furthermore the instructor said in the approach to some runways an extended downwind leg is not suitable and suggested the pilot know for which runways the extension is suitable (Lines C-D).

Notice that the instructor’s critique is directed at the pilot rather than to both pilots as a crew. The civilian flight instructors also focus their assessments on the pilot, suggesting the technique is not specific to the navy, but is an institutional practice at the training center.

An appropriate division of labor was established and the aircraft was not in an unstable state for a sustained period of time. The aircraft was unstable and the crew devoted itself to determining the nature of the problem then returned the aircraft to a stable state. The crew had a brief intersubjective interaction during the detection beginning at time 2 and ending at time 9. At the end of the scenario we see a coaching interaction emerge. The pilot was approaching the runway a little fast. The copilot initiated coaching on the approach and the pilot responded through his actions. The interaction began at 1:59 and ended at 2:10.

The flow patterns illustrate the dynamic organization of the system during the failure situation. The aircraft remained stable throughout the response, unlike case 1 where system stability deteriorated. In this system the representation flow changed to meet the needs of the immediate flight context. From the beginning the representation processing workload is equitable. Later the copilot's task load shifted to performing checklist steps and shutting down the failed engine. While the copilot is busy performing the checks, the pilot processed representations from the instrument panel and filtered them to the copilot. In this particular kind of emergency, the copilot's workload increased as they approached the landing phase, because there is a lot to configure. Once the checks are completed the copilot has the resources to assist the pilot in landing the aircraft.

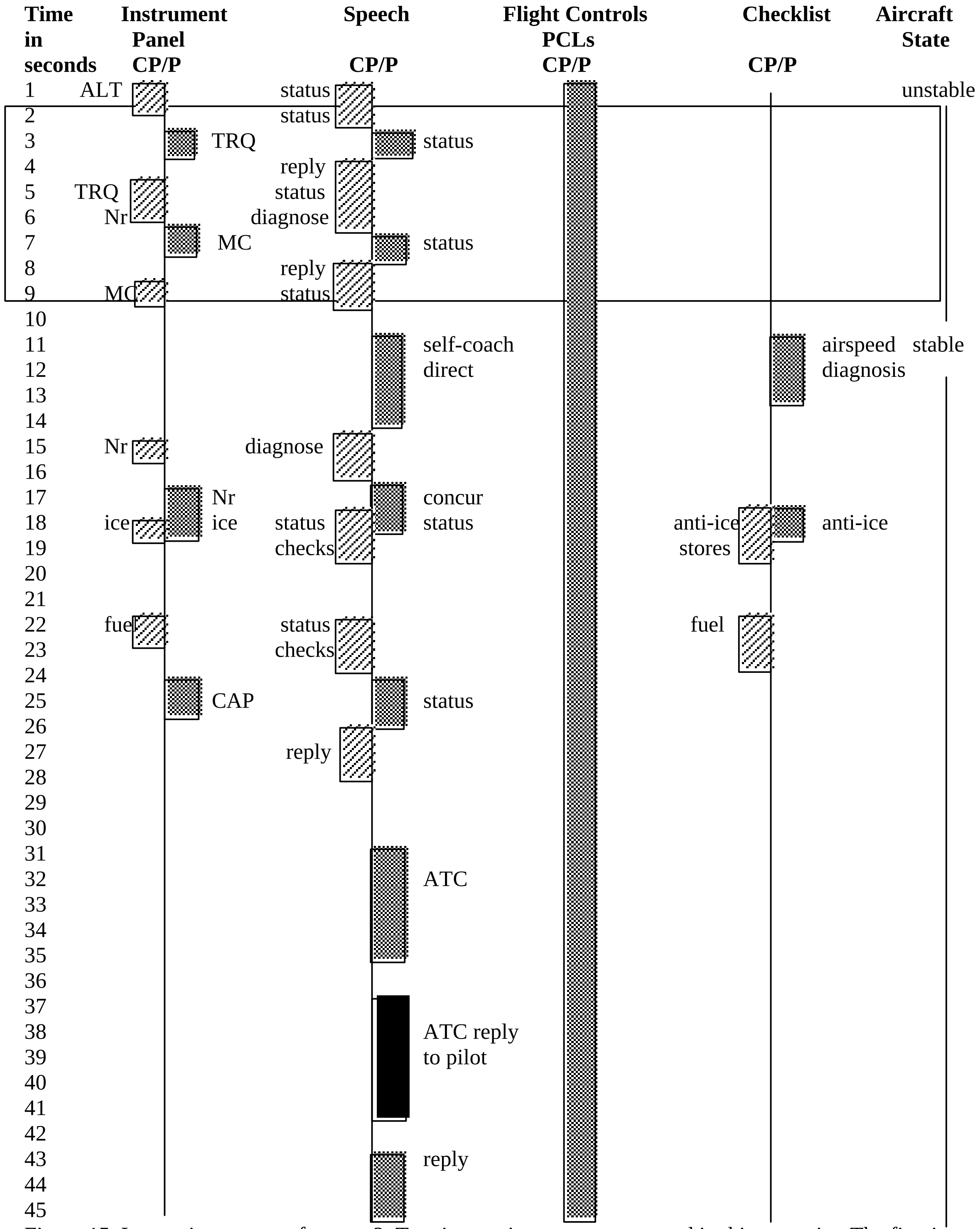


Figure 15. Interaction patterns for case 2. Two interaction patterns emerged in this scenario. The first is an intersubjective interaction during the detection of the malfunction and is indicated by a box beginning at time 2. The coaching interaction pattern occurred as the crew approached the runway for a landing beginning at 1:59. This crew coordinated their activities and established an equitable division of cognitive labor.

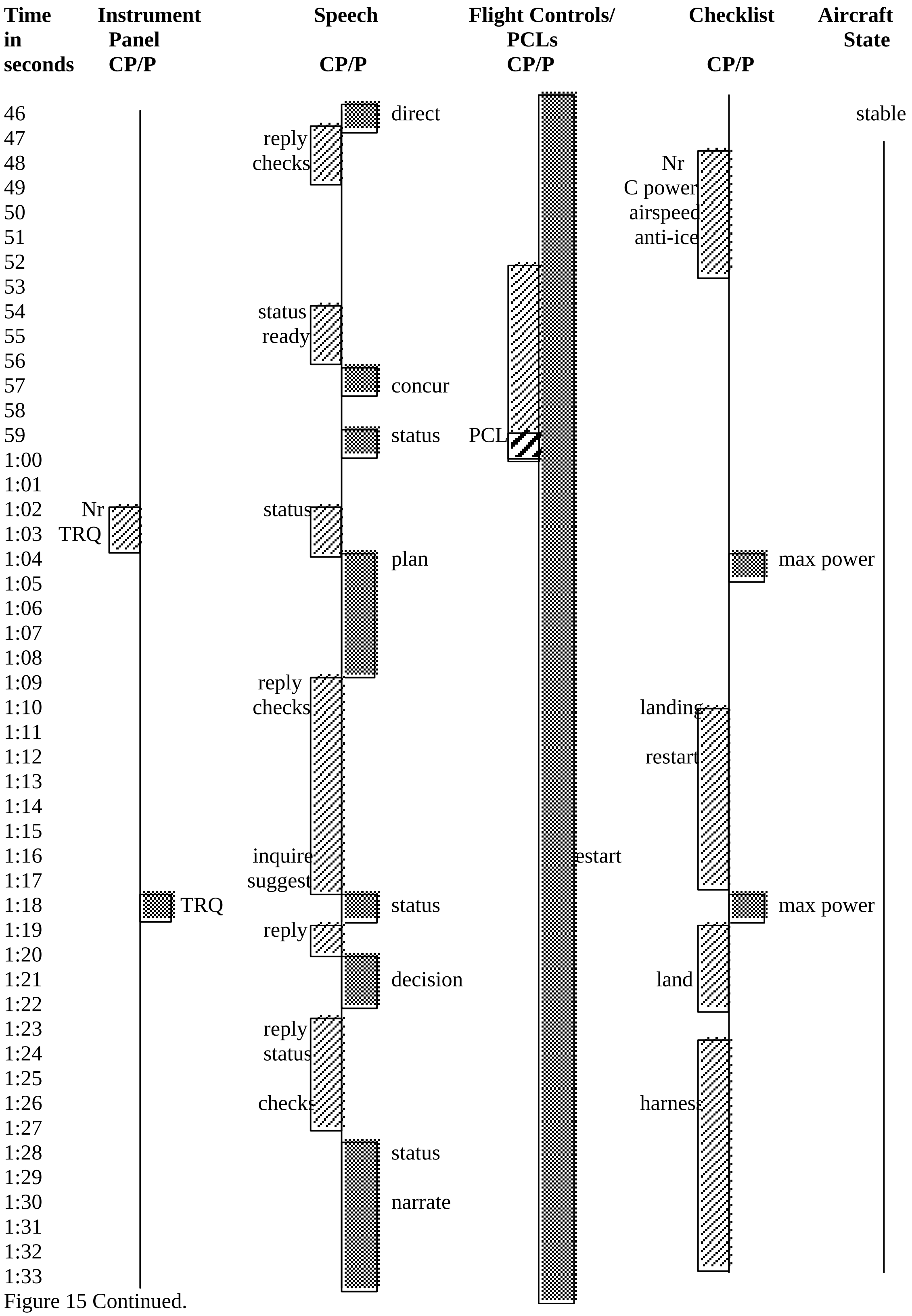


Figure 15 Continued.

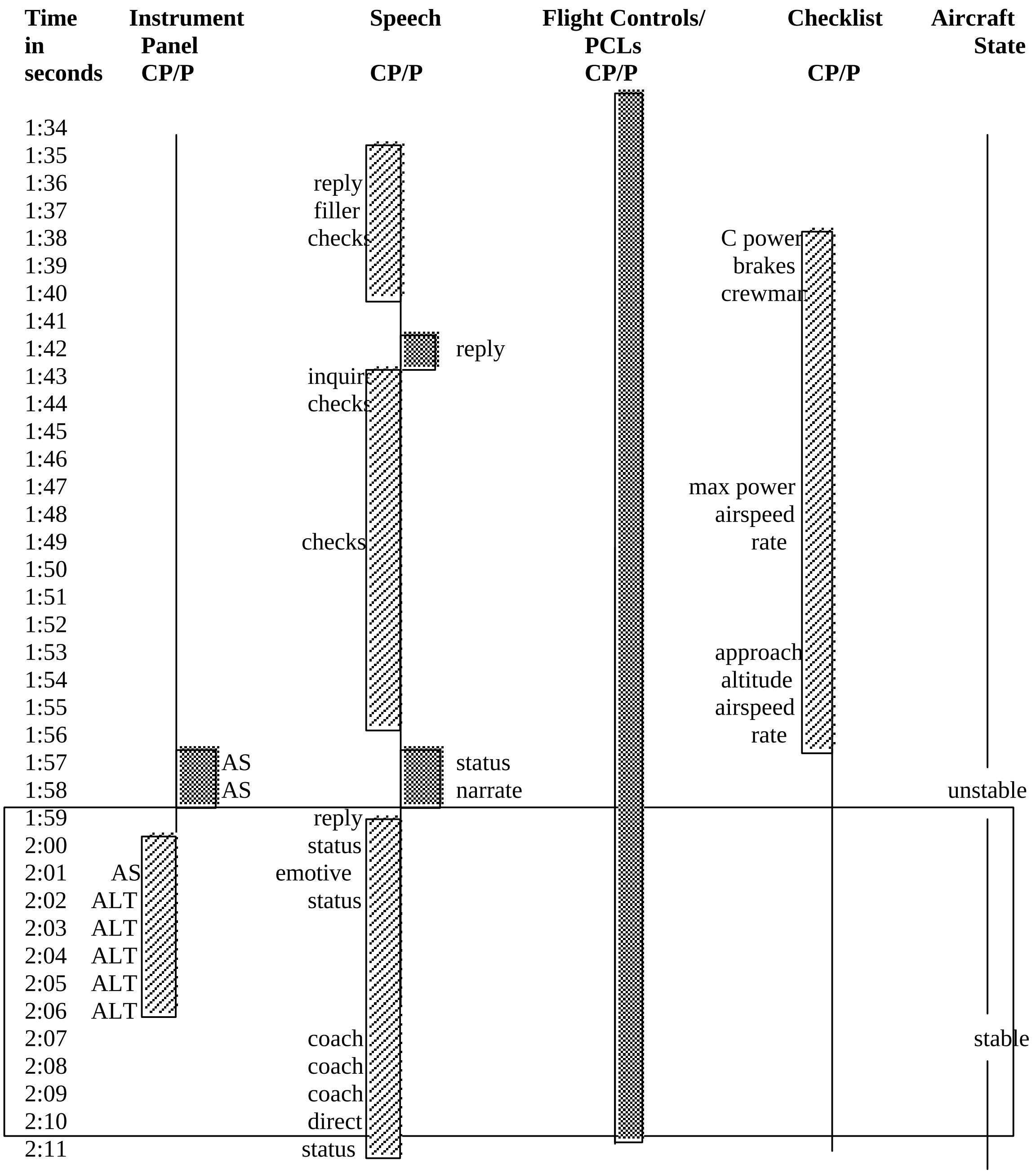


Figure 15. Continued

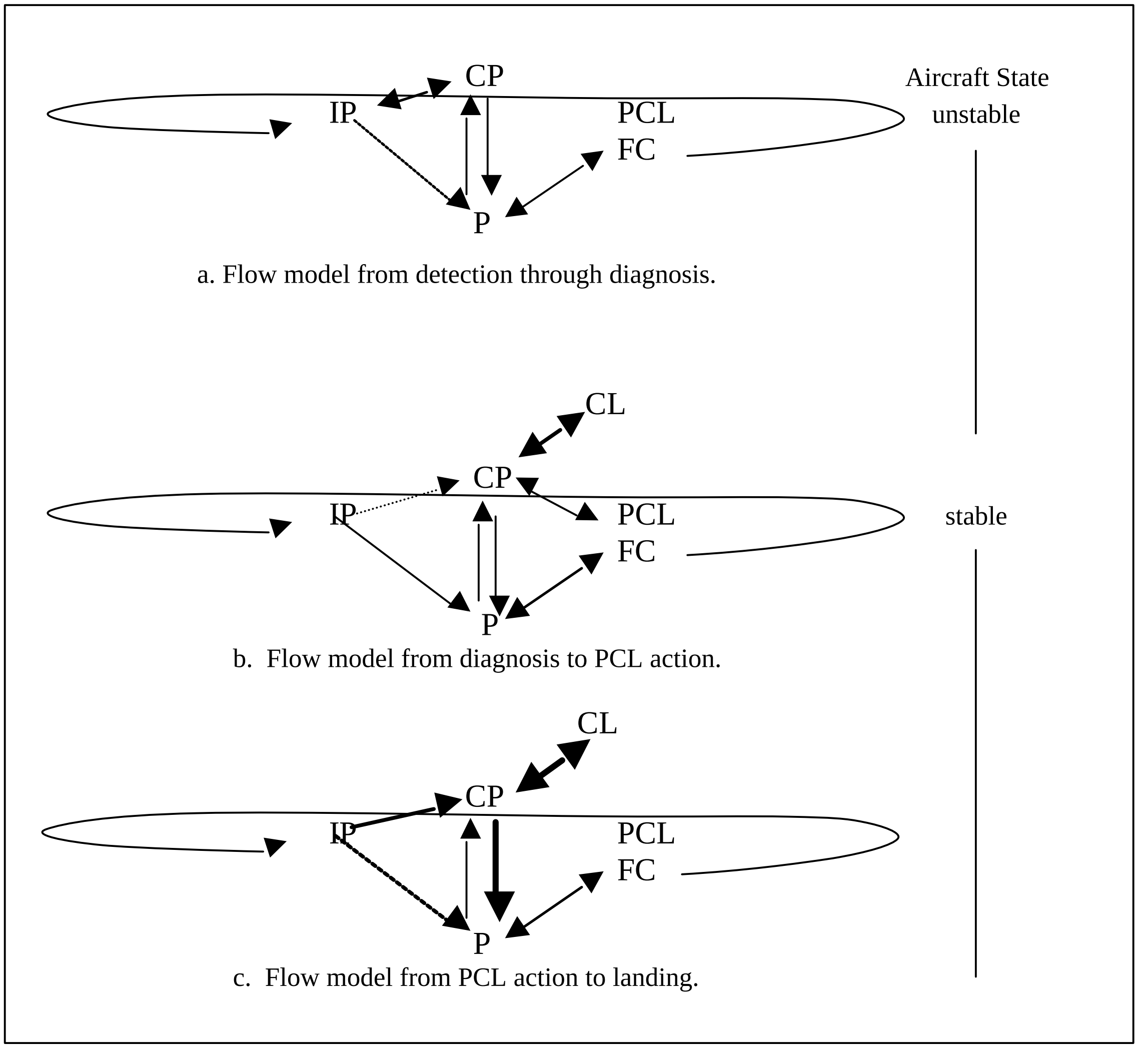


Figure 16. Flow patterns for engine case 2. Aircraft state remained stable throughout the response, however the representation flow changes to meet the immediate demands of the flight. The representation processing workload is equitable from the beginning (a). As the system moves to configure the aircraft the copilot's task load shifts to the checklist and PCL coordination. Consequently the pilot processes representations from the instrument panel and filters them to the copilot (b). As the aircraft approaches the landing phase, the checklist interaction increases. Then the copilot initiates a verbal scan for the pilot and the aircraft lands (c).

Case 2 Summary

In this case the crew executes a model response to an engine failure. Several coordinating interaction patterns emerged during the response. At the first sign of mechanical failure, there was increased communication between pilots about aircraft status and diagnosis. Pilots narrated their actions and plans and coordinated the power control lever movement. At the end the copilot coached the pilot during the approach and landing. The pilots were able to establish periods of intersubjective understanding and that facilitated their coordination.

Even though there was a difference in rank between the pilots, (pilot LT/copilot LTJG) a dominance interaction did not emerge in this system indicating that asymmetries in rank are not necessarily detrimental to crew interaction.

Case 3: Low Side Engine Failure

In this example both pilots rank Lieutenant (LT.) and so does the flight instructor. The crew was conducting a simulated rescue in a low hover when an engine failure occurred. Immediately after they lifted a survivor from the water with the rescue hoist. The pilot regained full control of the aircraft and voice communications from the air crewman (during some operations, like rescue, the enlisted air crewman may have partial hover and voice control). The copilot immediately detected the power loss and communicated that loss to the pilot with the statement “you’re losin power”.

Time in Seconds		Speech	Gestures and Displays
01	P:	Roger I have the |controls	
	CP:	|Hup,	# 2 engine displays low power
02		you're losin power dude	P moves cyclic forward
03		Get that nose	CDU indicators go high on #1, drop #2, VSI 500 fpm drop
04		over	P moves cyclic laterally
05	P:	Collective comin down,	P moves cyclic forward
06	P:	Emergency depart	P moves cyclic neutral
	CP:	Emergency depart	
07	CP:	Little bit of power	P moves cyclic back Master Caution light on
08	P:	-kay there's thirty	
	CP:	You've got something	
09		to play with there	CP puts hands over cyclic, follows it, #1 power displays high, #2 low

When the power loss occurred, the copilot immediately informed the pilot and began giving him flight instructions such as "get that nose over". This statement marks the beginning of the crews establishing joint control of the aircraft. Both pilots communicated status to each other and acknowledged the other's contribution verbally or through action. In this case the pilot informed the copilot of his actions while the copilot observed the pilot and gave aircraft situation and status statements. Here an intersubjective interaction emerges as they decide to fly the aircraft rather than ditch.

Thirty feet was the altitude limit established in the brief at which the crew would decide to either ditch the aircraft in the water or try to fly out immediately. The pilot noted the altitude and the copilot encouraged him to fly out. As long as they have close to 100% Nr it is possible to fly the aircraft out on a single engine. This exchange was based on a prior agreement made during the brief and represents shared knowledge. As the pilot attempted to "scoop it out" the aircraft tapped the water.

Time in Seconds		**Speech**	**Gestures and Displays**
10	CP:	We’re gonna hit!	P pulls cyclic full back fast
11		Nose level	Cyclic full forward, Cabin goes dark, master caution lights on
12			Cyclic back past neutral
13			Cyclic full back
14			Cyclic full forward
15	P:	Still airborne?	Cyclic back
16	CP:	Yeah	
17		we’re airborne but we’re	Cyclic moves back
18		right on the water,	Cyclic neutral, VSI at 0 fpm
19		just settle down	Cyclic neutral

When they settled on the water the pilot controlled the aircraft and prevented a water entry. Being absorbed in aircraft control, the pilot asked the copilot "still airborne?" The instructor reported his observation later in the debrief that the pilot was so preoccupied with flying that he was unaware of the aircraft's position and commended him for using the copilot as an information resource. The instructor described the crew’s actions to control the aircraft as exceptional crew coordination. So while the instructor did assess the pilot’s individual performance he also recognized the crew’s performance as a team, which is a departure from the instruction we saw in Cases 1 and 2.

The copilot confirmed they were indeed still airborne but right over the water. When the copilot said “just settle down” he was referring to the pilot's radical control inputs. The pilot was over controlling, pulling too far back on the cyclic and dropping the collective creating an unstable aircraft attitude, which is particularly undesirable at a low altitude. The pilot’s status response to the copilot regarding collective inputs is an acknowledgement of the copilot’s directive to “settle down”.

Next the copilot transformed the flight instruments (altitude, vertical speed, and attitude) into general flight directives, "watch your rate of descent" and "don't bring back the airspeed" which are all coaching statements. The pilot remained occupied with aircraft control. Once the pilot regained control he told the copilot to stop issuing flight directives, "I got it, I know". With that statement the pilot communicated that he no longer needed coaching and the coaching interaction ended. These statements suggest the pilot had awareness of the coaching and was not blindly following the copilot’s instructions.

Time in Seconds		**Speech**	**Gestures and Displays**
20	P:	I’m lettin it out	
21		lettin it out	
22		collective comin out	
23	CP:	-Kay keep that	Cyclic neutral
24		airspeed comin in	Cyclic neutral
25		watch your rate of descent	Cyclic back
26		Now don’t bring	Cyclic forward
27		back the airspeed now	Slowly moves cyclic neutral
28		you’re okay,	
29		you got it, now	
30		just nice and easy	
31		okay now start lettin out	
32		some collective	
33			
34	CP:	You got it now,	
35		keep that	
	P:	I know	
36	CP:	---nose high	
37	P:	I got it,	
38		I know	
39			
40			
41	P:	there we go	TRQ evens out, power displayed on #1 is high, CP rubs his eyes

Forty-one seconds into the emergency the pilot recovered from the power loss and from hitting the water with the copilot's assistance. Once recovery was established the copilot shifted his focus to assessing any damage to the aircraft that may have resulted from the water tap. While the copilot made an assessment the pilot diagnosed the cause of the engine problem and offered his initial diagnosis, a high side failure, which was incorrect.

Time in Seconds		**Speech**	**Gestures and Displays**
42			
43	CP:	Okay	CP puts both hands in lap
44		We got safe speed	CP reaches toward stabilator
45		stabilator is programmed	indicator
46		I think we tapped	CP holds right hand over lower console
47		but we're alive.	hands in lap
48			
49	CP:	I got uh	CP raises right hand under
50		generators kicked off	overhead console
51		uh turn	touches CAP and front panel
52		right to about	
53		zero six zero	
	P:	are we high on one?	
54		We're high on one	
55	CP:	Yeah,	CP reaches for checklist
56		lemme get everything done	and puts it in his lap
57		let's make sure	
58		we're flying here first.	

The pilot's diagnosis was phased first as a question, "are we high on one?" and then as a statement, "we're high on one." The question presented an opportunity for negotiation. The second statement was an explicit diagnosis of a number one engine high side failure. But the copilot responded with, "Yeah, lemme get everything done, let's make sure we're flying here first". That was a critical moment in the event because the copilot suspended concurrence until he finished configuring the aircraft. The pilot agreed to wait and then turned his attention to flying. The copilot continued to monitor and direct the pilot while he proceeded to configure the aircraft.

Time in Seconds		**Speech**	**Gestures and Displays**
1:08	P:	All right there's three hundred	
1:09		coming back to the left	CP turns on flashlight and begins flipping through checklist
1:10		Hit on my AFCS for me	CP hits switch on lower panel
1:11	CP:	Okay and	
1:12		Make sure you're TACAN mode	
1:13	CP:	there so you got navigation |point	
1:14	P:	|right	
1:15	CP:	Watch your rate of descent	
1:16			

Time in Seconds		**Speech**	**Gestures and Displays**
1:17	P:	Roger	VSI stabilizes
1:18	CP:	Okay	CP looks at P’s instruments and points
1:19			across panel to Nr
1:20		Control Nr	
1:21		Contingency power	CP points down to collective
1:22		safe single engine	over to cyclic
1:23		airspeed	CP's head down to checklist

Once configured, the copilot initiated the checklist and confirmed that each item was completed. As the copilot progressed through the checks he used speech and a pointing gesture to establish joint attention to the cockpit indicator that confirmed each item was complete. Next they diagnosed the malfunction together. In their discussion, they established an intersubjective understanding of the failure by coordinating the displays with their knowledge and with their speech. The pilot did not maintain his original diagnosis. With the diagnosis completed they coordinate action to secure the malfunctioning engine. Both pilots concurred on which PCL to move.

Time in Seconds		**Speech**	**Gestures and Displays**
1:24	CP:	Looks like the number two	CP looking at instrument panel
1:25		engine is still on	
	P:	yeah	P looks left then forward
1:26		number two is still on I think	
1:27	CP:	we’re |low on	
	P:	|low on	P looks left then forward
1:28	CP:	two right?	
1:29	P:	Yeah, low on two.	
1:30	CP:	Okay	CP reaches up to PCLs
1:31	P:	Go to lockout	
1:32	CP:	I got my hand on	CP grabs right PCL with right hand
		the number two	
	P:	You have the	P looks left and up to CP's hand on PCL
1:33		number two let’s	P looks forward
1:34		let’s go to lockout	
	CP:	here we go	
1:35		now, now now	CP moves PCL forward then back
1:36			releases PCL but keeps fingers
1:37			on PCL

With safe single engine flight established, the pilot declared an emergency to the control authority. The instructors always perform the role of control authority with varying authenticity. This instructor merely responded with "roger" to acknowledge the request was made. Meanwhile the copilot set the functioning engine. The Nr continued to fluctuate more than normal but within normal ranges so they decided that was good enough to land on.

Time in Seconds		**Speech**	**Gestures and Displays**
1:38	P:	Okay back up	
1:39		and controlling	
1:40	CP:	Okay I'm settin it	
1:41	P:	Mayday, mayday, mayday	
1:42			
1:43		Island ruler zero one	
1:44		we have an engine failure	
1:45		in the alphas	
1:46		we are requesting	
1:47		immediate landing	
1:48		Imperial Beach	CP taps PCL
1:49			
1:50	ATC:	Roger	
1:51			
1:52			
1:53			
1:54	CP:	Okay it's a little squirrelly	CP slowly backs his hand away
1:55		but we got it under control	from the PCL
1:56		there I think	
1:57	P:	Okay	
1:58			
1:59	CP:	Okay we're in there,	
2:00		I'm gonna pop out the checklist	
2:01		keep it comin out	CP looks at pilot, then to
2:02	P:	Roger	checklist, uses a flashlight to read it

2:03 (ten seconds go by as the copilot flips through the checklist pages)

The pilots continued flying over the water toward land. The pilot became slightly disoriented and asked his copilot for assistance in locating Imperial Beach airport where they had planned on landing.

Time in Seconds		Speech	Gestures and Displays
2:12	P:	Where's IB?	CP looks at P
2:13			
2:14			
2:15			
2:16	CP:	Come a little bit left,	
2:17		still got five miles	
2:18		to go there.	

In the debrief, the instructor reported he observed that the pilot was focused on maintaining control of the aircraft and dropped navigation from his immediate task hierarchy. The question "Where's IB?" was reportedly a technique the pilot used to enlist the copilot's assistance with navigation. The pilot successfully re-negotiated the established workload with this question to task the copilot with monitoring navigation and the copilot accepted without hesitation. As a system it was easy to adapt to a local failure in the pilot's understanding of their location in relation to Imperial Beach airport.

Time in Seconds		Speech	Gestures and Displays
2:19	CP:	-Kay control Nr,	
2:20		stay single airspeed	Going throughout the checklist
2:21	CP:	Identify malfunction,	
2:22		we did,	
2:23		Looks like that did	
2:24		fix the immediate problem.	
2:25	P:	I'm staying up here	
		at eight hundred feet	
2:26	CP:	I got about ten percent	
2:27		below torque,	
2:28		a good engine	
2:29		land as soon as practicable,	
2:30		and	
2:31		there we are	CP puts down single engine land checklist

The pilot communicated his intention to remain at 800 feet. When pilots are below 1000 feet the pilot is required to verbalize his altitude and state his intention to remain there or to deviate from it, for example a pilot might say, "at 800 descending to 500". This technique alerts other crewmembers to monitor the change in altitude so the pilot doesn't go too far and fly into the water. The navy adopted this technique after several pilots inadvertently flew into the water and later was institutionalized in a NATOPS procedure to reduce the incidence of controlled-flight-into-terrain accidents. The copilot completed the checklist and the flight continued with no further incident.

During the response the pilot had difficulty controlling the aircraft but the crew was able to recover because they dynamically adjusted their workload (Figure 17). The copilot assisted the pilot with aircraft control through coaching and offering status statements. The pilot became disoriented twice during the response but was able to use the copilot as a resource for assistance. The pilots developed an inter-subjective understanding at key decision points: the decision to fly out and not ditch, which was the right decision even though it made aircraft control an issue, and the diagnosis. Both pilots focused their attention to aircraft control and then later jointly worked through the diagnosis. There is also some negotiation when the pilot tried to make an early diagnosis and they agreed to wait to diagnose later.

Aircraft state was immediately unstable because the aircraft was in a low hover when the failure occurred, but the representation flow immediately changed to support aircraft control. The copilot processed representations flowing from the instrument panel while the pilot managed representations from the flight controls. As the system transitioned to aircraft configuration, the copilot's task load shifted to the checklist and configuration. As the aircraft approached the landing phase, the checklist interaction increased and the workload was heaviest on the copilot.

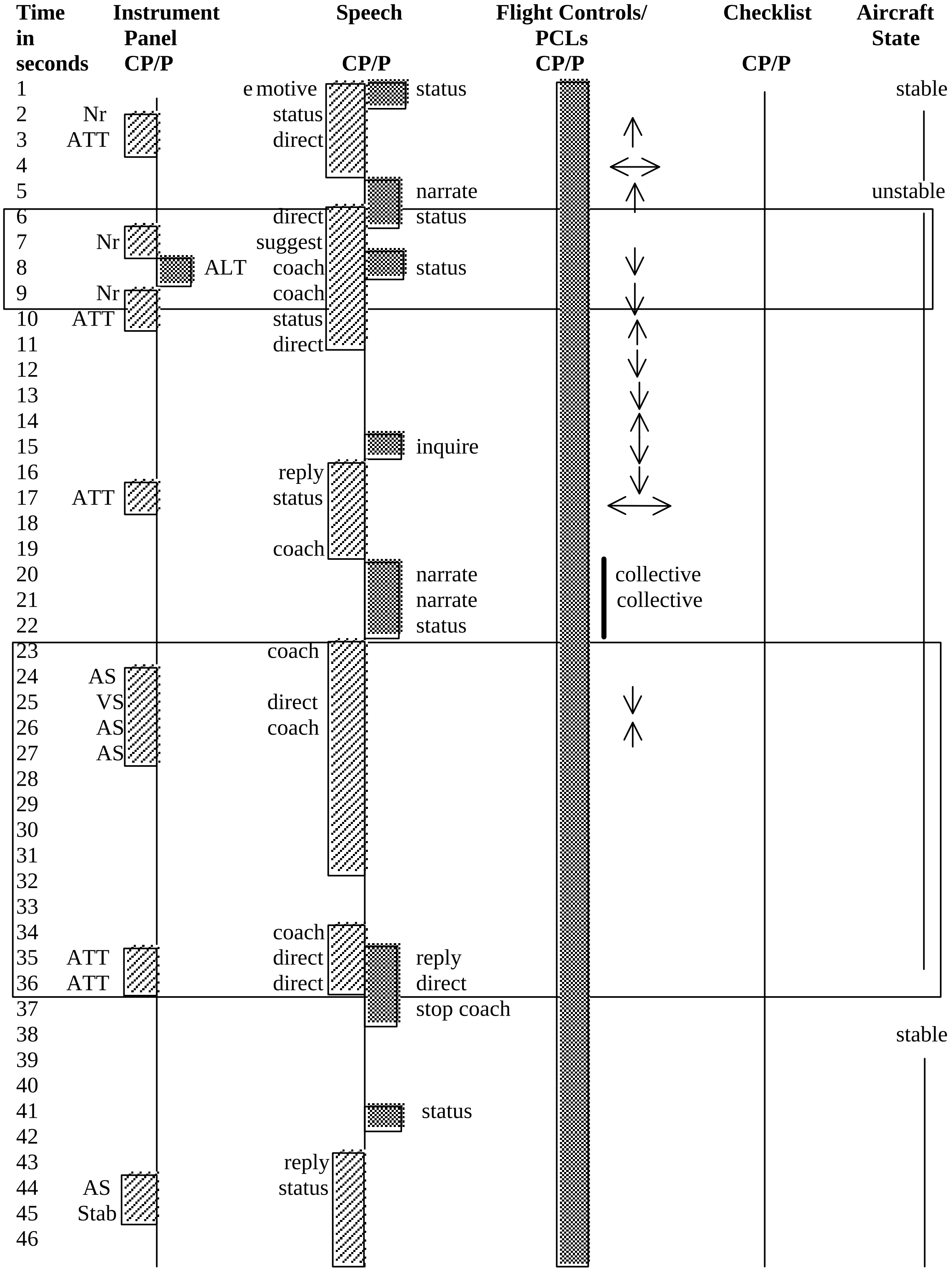


Figure 17. Interaction patterns for case 3. At time 6 through 9 an intersubjective interaction pattern emerged. Later at time 22 through 36 a coaching pattern emerged as the crew established joint control of the aircraft. Notice the aircraft becomes stable when coaching stopped. During the formal diagnosis at time 1:24 another intersubjective pattern emerged and the flight proceeded without further incident.

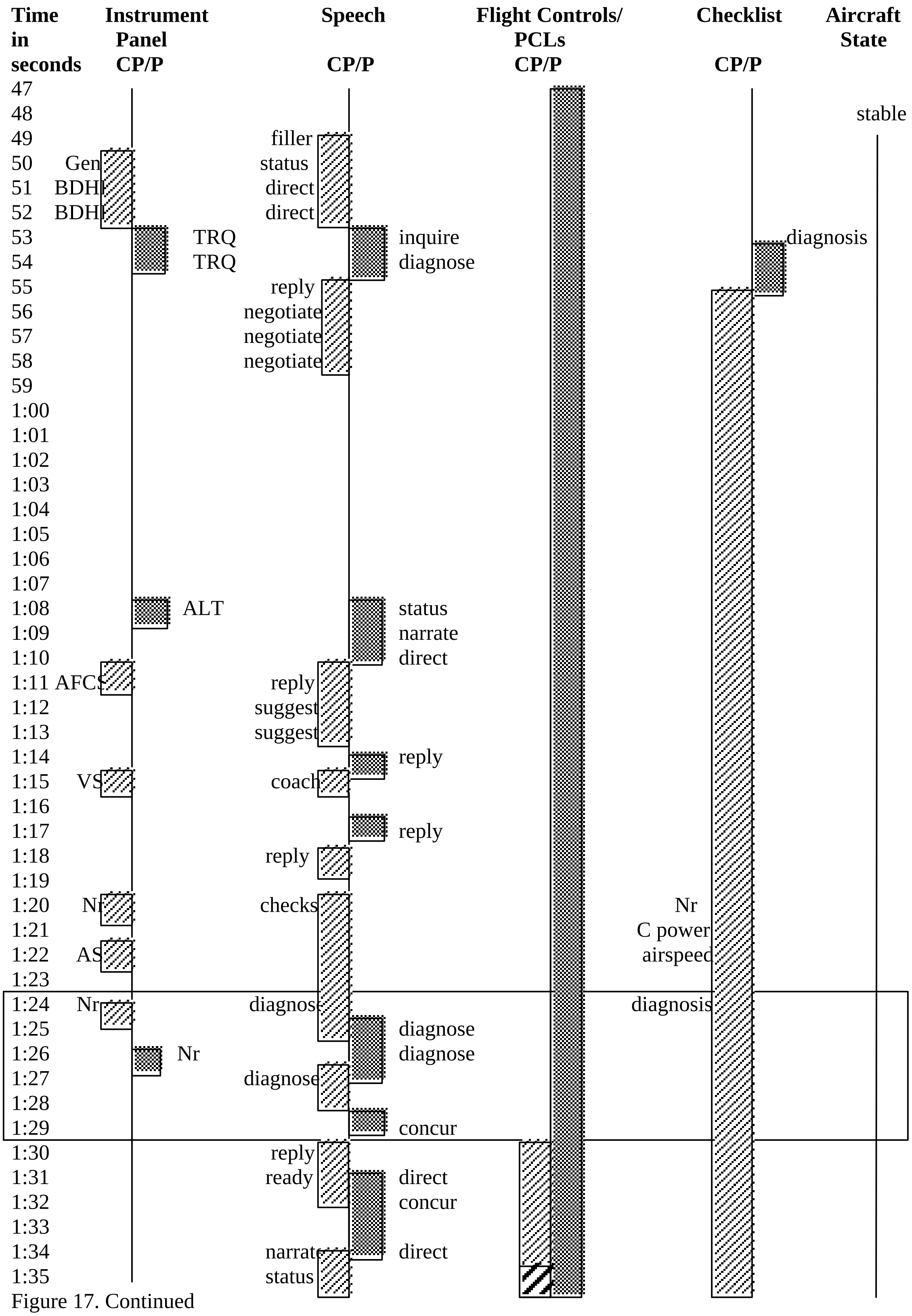


Figure 17. Continued

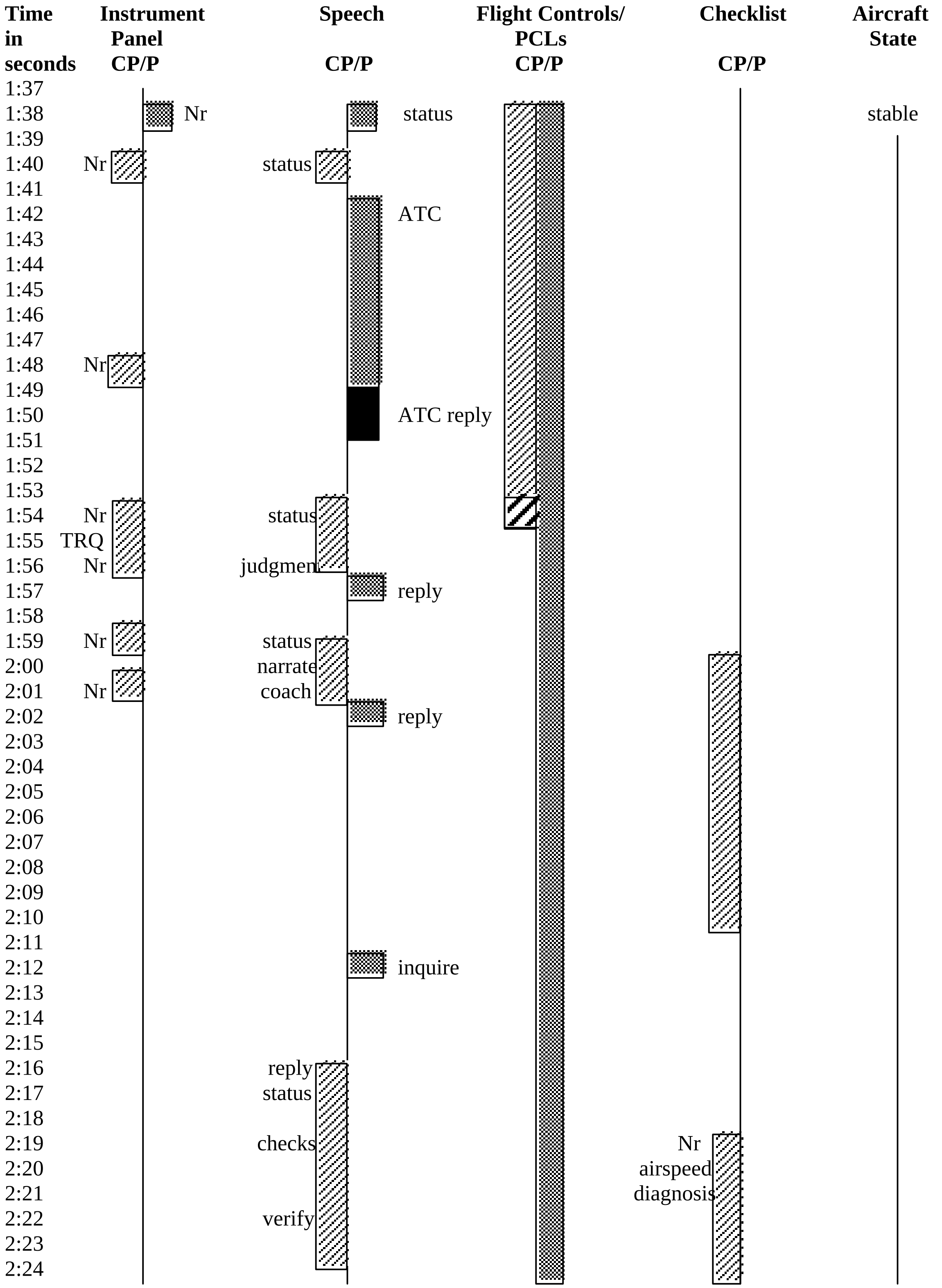


Figure 17. Continued.

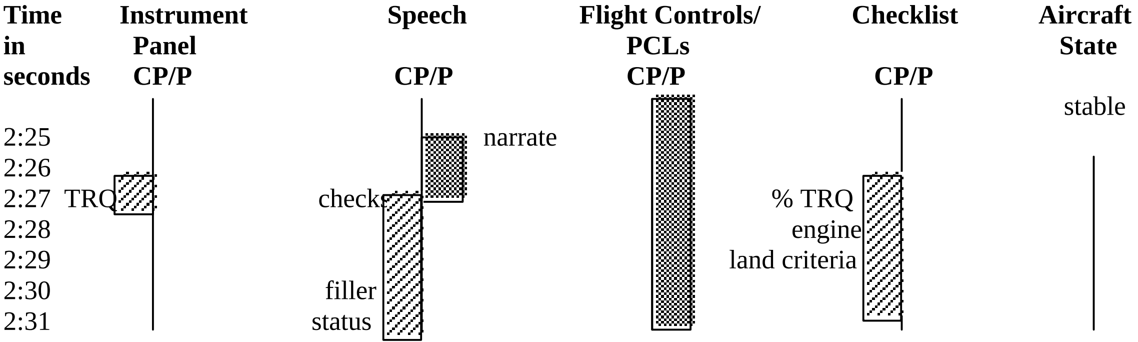


Figure 17. Continued.

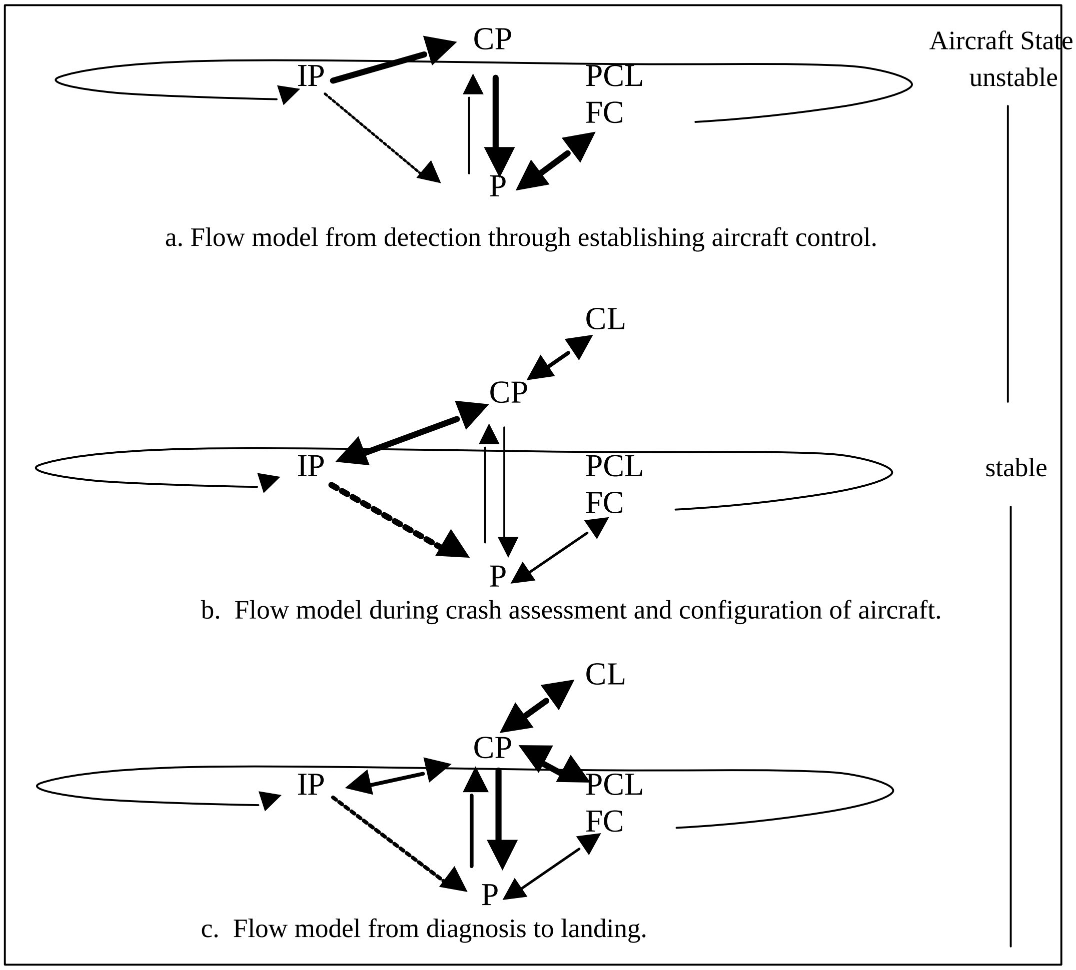


Figure 18. Flow patterns for engine case 3. The state of the aircraft became unstable immediately, but the representation flow changed support aircraft control. The copilot processes representations flowing from the instrument panel while the pilot manages representations from aircraft behavior and the flight controls (a). As the system moves to configure the aircraft, the copilot’s task load shifts to the checklist and configuration (b). As the aircraft approaches the landing phase, the checklist interaction increased and the workload is heaviest around the copilot (c).

Case 3 Summary

This case is an excellent example of a system recovery to a serious failure under difficult circumstances. Recall that the failure occurred while the helicopter was in a hover. That loss in power caused the aircraft to descend to just over the water. The pilot controlled the aircraft and prevented water entry by dedicating most of his cognitive resources to that task. Meanwhile the copilot supported the pilot in decision making and with maintaining aircraft control by offering aircraft status and coaching statements.

They also engaged in several intersubjective understandings during their response. These exchanges emerged at critical points in the response when they decided to fly the aircraft instead of ditching and during diagnostic reasoning. Each pilot ranked LT. and rank did not appear to be a factor in their interactions.

Chapter Discussion

As I stated earlier, there is an unusually high incidence of incorrect high and low side engine failures among pilots of all experience levels and the consequences of such can be catastrophic. The case studies presented in this chapter point to reasons why that incidence is so high relative to other mechanical failures.

The data suggest that display properties have a serious role in diagnostic reasoning and in the development of situation awareness. This finding supports other findings that representational characteristics of displays have consequences for the cognitive demand they levy on the interpreter (Hutchins, Hollan, & Norman, 1986; Zhang, 1997). Therefore human performance cannot be assessed independent of the technology in the setting. This finding relates to the theoretical stance that cognition is inseparable from it natural context.

Crews bring substantial background knowledge to the cockpit. A lot of knowledge is shared between members of the crew that may be utilized in building expectations and developing intersubjective understandings (Hutchins & Klausen, 1996). Expectations and understandings may emerge in parallel or they may be co-constructed through interacting partners. The interaction patterns that emerged in these case studies were coaching, dominance, and intersubjectivity.

Finally, flight instructor assessment of the crew's performance is usually oriented to the pilot. Except for the last case, flight instructors assessed only the pilot and did not make reference to crew performance. This instructional style does not promote teamwork in the cockpit instead it emphasizes individual performance. This practice is problematic for multi-crew cockpits that require crew coordination to safely respond to mechanical failures.

CHAPTER 4

Tail Rotor Drive Failures

The Seahawk has a single main rotor and a tail rotor that counter balances the torque generated by the main rotor. When the tail rotor fails, it can no longer oppose the main rotor and the aircraft may begin to spin. Consequently power supply to the main rotor must be significantly reduced and the aircraft cannot sustain flight. Helicopters are inherently unstable flying machines and unlike airplanes they cannot glide to a safe landing, but they are capable of an autorotation, a complex maneuver that permits the aircraft to descend much like a leaf gently falling to the ground. When a loss of tail rotor drive occurs, pilots have two options for a maneuvering a safe landing: autorotation or spinning cut gun.

If there is sufficient altitude for an autorotation, the pilot lowers the collective and enters an autoroatation at 80-100 knots. At about 150-200 feet above the ground the pilot should establish a flare by moving the cyclic back without changing the collective position except to keep Nr within limits. This decreases the airspeed and rate of descent and increases Nr. During an autorotation, the point when the PCLs should be pulled off depends on the characteristics of the landing terrain. It is the pilot’s responsibility to direct the copilot to pull off the PCLs.

The procedures for a tail rotor drive failure at an altitude and airspeed insufficient to establish an autorotation (below 1000 feet, 80 knots) are to lower the collective and decrease altitude to thirty feet. The maneuver is called a "spinning cut gun" because the aircraft is usually spinning fast and the copilot “cuts” the power at 30 feet. Response to a loss of tail rotor drive is inherently difficult and it is one of the few emergency conditions that require an immediate response. The loss of tail rotor drive is often practiced in the flight simulators during training sessions because it is too dangerous to practice in the aircraft.

Unfortunately, tail rotor malfunctions are a reality for pilots. Recently, four tail rotor failures have occurred in the SH-60B fleet. Pilots who have experienced a tail rotor failure in flight reported g forces in the spin pinned them to the wall of the cockpit.

In this chapter I present the data from four cases of tail rotor drive failures I recorded in the flight simulator. I begin by describing the standard procedure and then I present the four cases in detail, and conclude with their implications.

Standard Procedure

The standard procedure is an idealized response that prescribes a division of labor (Table 3), communication patterns, and decision markers. The loss of tail rotor drive is one of the few emergency conditions that require an immediate response and since the pilot is the one flying, he is tasked with detecting and diagnosing the failure, and for directing action.

When a failure is detected the pilot must immediately arrest the aircraft's yaw rate with the flight controls to prevent a severe spin. Once the failure is diagnosed the copilot "backs up" the pilot by monitoring the instruments making it possible for the pilot to shift his attention outside to select a landing site. The copilot reads instrument panel display representations to the pilot. At this time the pilot must decide how to descend, in either an autorotation or a spinning cut gun. This decision is based on the altitude, airspeed, and available landing terrain. In either case the aircraft is placed in a steep, controlled descent and at thirty feet above the ground the pilot directs the copilot to move the PCLs off. The aircraft may or may not sustain damage depending on the terrain and the descent rate, but the crew will likely survive.

Table 3. Division of labor for tail rotor failure.

Pilot	**Copilot**
Detect and diagnose	"Backup" pilot on instruments
Arrest aircraft yaw rate	PCLs off when directed
Decide on a maneuver	
Maneuver to a safe landing	

The procedures for an autorotation landing as they appear on the checklist are presented in Figure 19. The checklist procedures for a spinning cut gun maneuver are presented in Figure 20. All steps are to be completed without reference to the checklist.

ALTITUDE AND AIRSPEED SUFFICIENT TO ESTABLISH AUTOROTATION

***1. Collective……………………………………..DOWN;**
Tail rotor pedals…………………………CENTERED
***2. 80- to 100-kt autorotation………………ESTABLISH**
***3. Immediate Landing/Ditching checklist…………………………………COMPLETE**
***4. Drive failure…………………ATTEMPT TO VERIFY**
***5. ENG POWER CONT levers…………………………………………….OFF WHEN DIRECTED**

Figure 19. Checklist items for an autorotation maneuver. All items are to be performed from memory as indicated by an asterisk.

I used the standard procedure as a technical point of reference for making across-case comparisons in the analysis. The procedure represents a model of response pilots learn in training and the standard by which their performance is graded. Thus the procedure is a resource pilots may use to help organize their response.

ALTITUDE AND AIRSPEED NOT SUFFICIENT TO ESTABLISH AUTOROTATION

***1. Collective………………………DOWN,**
DECREASE ALTITUDE
***2. Copilot………………HANDS ON ENG**
POWER CONT LEVERS
***3. ENG POWER CONT**
levers………………………………..OFF
(ABOUT 30 FEET)

Figure 20. Checklist items for spinning cut gun maneuver. All items are to be performed from memory as indicated by an asterisk.

Figure 21 illustrates that the critical instruments for the descent are altitude (ALT) and vertical speed (VS). Note that the copilot processes instrument panel displays specific to the malfunction and propagates the representations to the pilot. Meanwhile the pilot manipulates the flight controls using input from the copilot and his own instrument scan patterns.

Moving down the diagram through time, the event unfolds with the pilot detecting and diagnosing the failure. The copilot acknowledges the pilot's diagnosis and initiates a verbal scan of the instrument display readings that are pertinent to the response. Next the pilot decides on a maneuver and narrates his actions. The copilot continues monitoring aircraft state and reports display readings to the pilot.

Because the pilot is busy maintaining control of the aircraft, he is focused on the flight controls but acknowledges the information the copilot gives him. This kind of coordination keeps both pilots focused on aircraft control and keeps each other informed of the other's understanding of the situation. As the aircraft nears the ground the copilot informed the pilot he is ready on the PCLs and the information focus shifts to altitude because the descent rate has been established. At thirty feet above the ground the pilot directs the copilot to move the PCLs and the copilot pulls them off

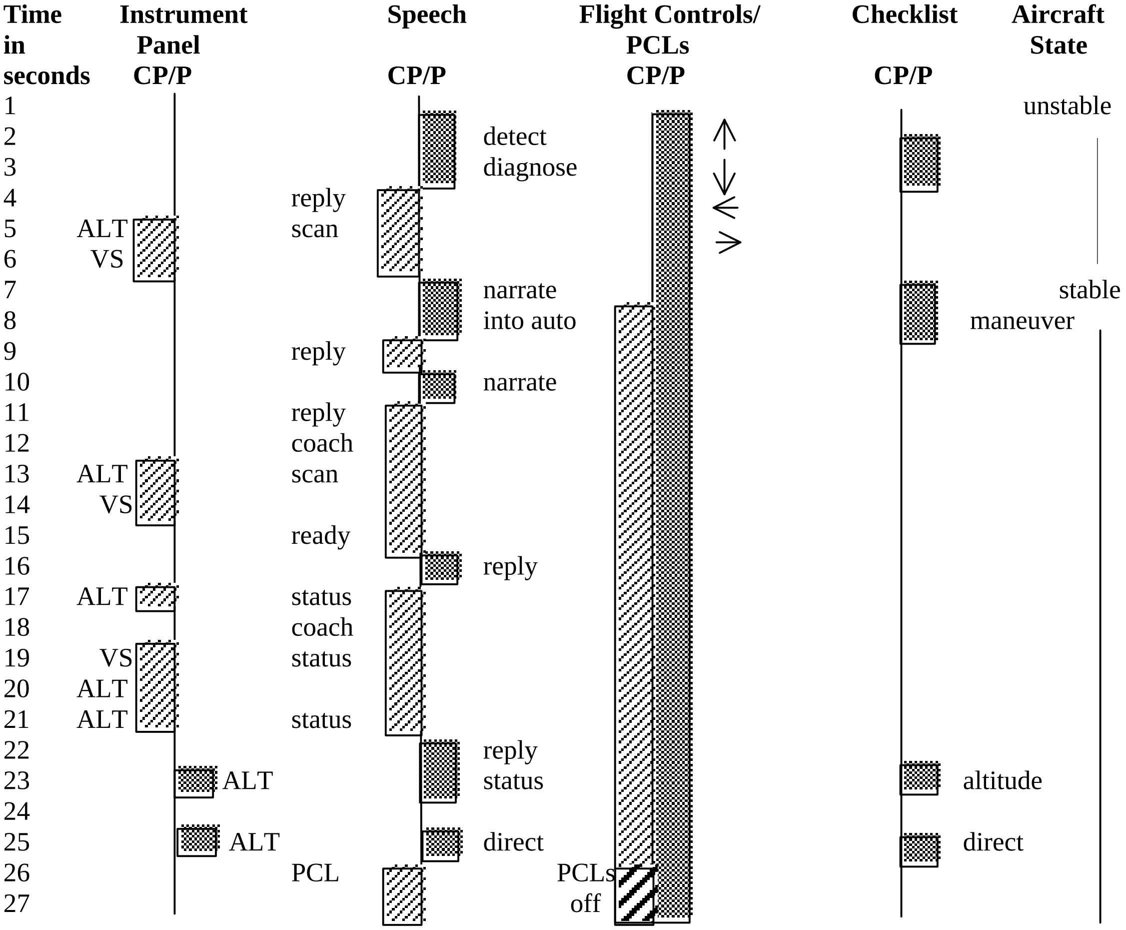


Figure 21. System interactions for responding to a tail rotor failure.

and the aircraft lands safely. We do expect real flights to deviate from the standard because flight environments are dynamic and sometimes deviations from procedure are needed for a safe outcome.

The representation flow model is another way to characterize the organization of the system and to make comparisons across cases. The system configuration presented in Figure 22, shows the copilot processing all the key representations from the instrument panel whereas the pilot is only processing a subset of available representations. The copilot transforms and propagates the representations to the pilot via status statements. The pilot integrates the representations, manipulates the flight controls, and the aircraft's response is reflected in subsequent instrument panel display readings. Ideally, the system should move from unstable to stable and remain stable, however that is not always the case, sometimes the system moves in and out of stable configurations throughout the course of the response.

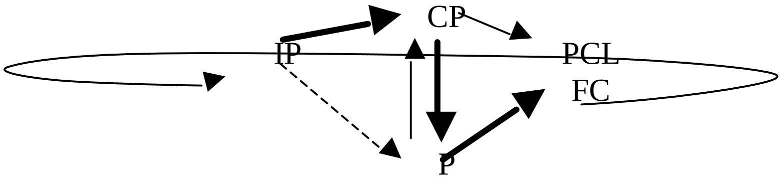


Figure 22. Flow model representing a stable system configuration. The arrows represent the direction of representation flow. Bi-directional arrows represent an interaction that changes the state of media in the cockpit. The girth of the arrows represents the density of flow. Dashed arrows represent degraded flow of representations when key representations are not processed.

Tail Rotor Cases

In this section four cases of tail rotor failure and the crews responses are presented. Three of the cases resulted in a simulated crash that would have been catastrophic in a real aircraft and one of the cases ends with a controlled landing. First I present a narration of the event in conjunction with the full transcript and then I present the interaction analysis and system configuration models. I conclude with a discussion of all four cases.

Case 4: Tail Rotor Drive Failure

The tail rotor malfunction occurred as the crew prepared to land. The pilot and copilot both ranked Ensign and are peers. They had the same number of hours in the aircraft and simulator. The loss of tail rotor drive occurred as the pilot made a right turn to approach the runway. The turn masked the sensation of the loss so the pilot's detection was delayed until the aircraft leveled. Once the aircraft leveled, the pilot immediately detected the problem.

Time in seconds		**Speech**	**Gestures and Displays**
01-05			CP/P looking forward
06	P:	It's abeam	
07		I'm comin down on	
08		right?	CP looks at P
09	CP:	Right	
10	P:	running landing	CP looks at instrument panel
11			
12			
13			
14	P:	And, I've got	P begins moving cyclic laterally
15		something	then back, then forward
16		wrong with the	BDHI indicates slow left turn
17		tail rotor here	
18		I'm uh	BDHI indicates faster left turn
19		completely losing	
20		control	P moves cyclic back
21		I'm not gonna get	P moves cyclic forward
22		an autorotation	
23		at this altitude lets go for	
24		a spinning cut gun	

Because they were approaching the runway for landing they were already low and slow at seven hundred feet, seventy knots. Upon detection of a tail rotor problem the pilot decided to perform a spinning cutgun maneuver. The copilot did not acknowledge his decision or contribute status statements. The aircraft stopped spinning, but then turned left, and then stabilized. The pilot interpreted the behavior as an indication of a tail rotor *control* loss and directed the copilot to verify his diagnosis by turning on backup hydraulics to the tail rotor. A loss of tail rotor control differs from a loss of tail rotor drive in that the tail rotor still produces torque but the pilot has no means of controlling the tail rotor blade pitch. A total loss of control results when both tail rotor control cables break or when there is a hydraulic fluid leak in the tail rotor system. Indications of a tail rotor control loss are the illumination of caution advisory lights: tail rotor quadrant caution light; number one hydraulic pump or backup pump on; and number one tail rotor servo, none of which illuminated in this case.

Time in seconds		**Speech**	**Gestures and Displays**
25			
26	P:	and I uh	BDHI stops turning, CP reaches for PCLs Puts hand over both
27		going back the other way now,	BDHI indicates slow turn to right
28		must be	
29		loss of control	BDHI stops turning
30		Go-switch	
31		the tail rotor servo	
32		to backup	CP removes hand from PCLs
33	CP:	Roger	RAWS sounds, BDHI indicates left turn, cyclic forward
34		goin to back up	CP reaches across lower console
35			turns on backup hydraulics switch
36	P:	eh uh	hydraulics lights on, P moves cyclic back, VSI and Alt indicate rapid loss of altitude
37	CP:	Backup hydraulics	P moves cyclic lateral
38		comin on	
39	P:	okay	CP puts hands in lap
40		I still have no control	P moves cyclic laterally
41		let's get---aircraft impacts ground	
42			

The copilot turned backup hydraulics on, and although the pilots were interacting they were not in coordination and neither pilot was certain of the specific problem. When backup hydraulics came on, the pilot detected no difference in tail rotor control and at that moment the aircraft crashed to the ground.

In this case it was not necessary to specifically diagnose the malfunction or complete all the configuration checks because the aircraft was so close to the runway. In fact it is surprising that the pilot didn’t just put the aircraft on the ground. Instead he became engrossed in verifying the failure and did not process vertical speed or altitude. The pilot made all the decisions, judgements, and contributions to the task while the copilot sat there. The copilot did turn on the hydraulics and verified their operation, however he did not support the pilot in the descent. In the next passage the pilot and instructor discuss what they think happened.

Line		**Speech**
A	P:	And, I guess I didn’t notice that descent comin in
B	I:	I guess not, wow ground deck impact exceeded structural limitations at
C		touchdown yes, uh V/N envelope limits exceeded, yes and what do you think
D		happened?
E	P:	At first I thought there was a complete loss of drive but for some reason
F		the nose seemed to stabilize or maybe a loss of control so I was testing the tail
G		rotor and I uh was not paying enough attention to the rad alt.
H	I:	Absolutely correct, and so we went from uh, you were at about seven
I		hundred feet down to the ground at a fairly rapid rate of knots and of course your
J		copilot at that stage was uh trying to turn the tail rotor servo to backup. Crunch.
K	P:	Was that a loss of control or drive?
L	I:	Drive. Your initial reaction was quite reasonable for me um being at uh let’s see
M		you were at seventy knots, seven hundred feet I would have gone for an auto
P		initially uh um mainly because my experience level I might have been able to
Q		recognize it in time. But basically once the nose has gone through ninety degrees
R		your airspeed just drops off to zero so you’re decision to go for the spinning cut
S		gun was correct. All that happened after that was you just didn’t do the right
T		thing. You uh got distracted and you have to use the rad alt. The biggest thing you
U		have is the scale change on the rad alt—you know when you were up at seven

V hundred feet you'd look at how much of the rad alt scale there is between seven
W hundred and four hundred then it expands between four hundred and one hundred
X and then from one hundred down its going at ten-foot increments and man that comes
Y very, very quickly.

The pilot admitted full responsibility for not monitoring rate of descent (Line A) and then (Line K) asked the instructor for clarification of the failure type. The pilot reported that because he was unsure of the problem he focused on verifying the malfunction and dropped the radar altimeter from his scan. The instructor agreed and then blamed the pilot for improperly directing the copilot to focus on the hydraulics (Lines I-J). The instructor told the pilot his action decision (spinning cut gun) was fine, but said he would have recognized the problem and maneuvered into an auto because he is experienced (Lines M-Q). The instructor praised the pilot’s decision to do a spinning cut gun , but after that noted the pilot became distracted (Lines S-T). The instructor continued with a discussion about the display properties, specifically the scale change on the radar altimeter, and how the scale change makes it difficult to readily perceive altitude (Lines T-Y). The instructor attributed the crash to the pilot not using the radar altimeter. His comments indicate an implicit understanding, on the instructor’s part, of the role display properties contribute to the information processing capabilities of the cockpit. The instructor’s entire evaluation was directed at the pilot, no instruction was given to the copilot, and there is no discussion about their coordination problems. The instructor did not say what are suitable coordination practices for this scenario or how to develop coordination skills for managing these kinds of situations in the future.

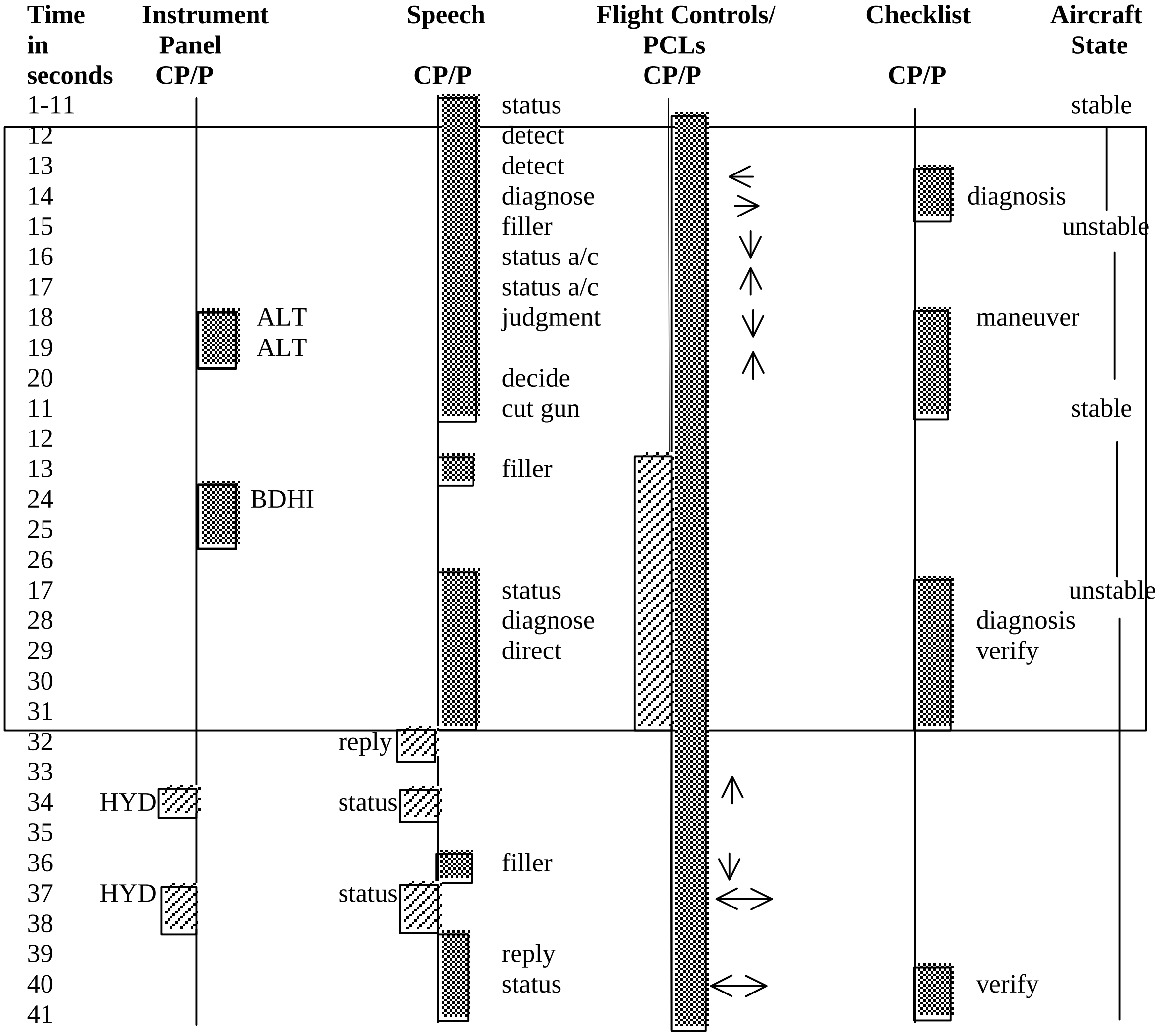


Figure 23. Case 4 interaction patterns. In this case the dominance patterns emerges marked by the box. Notice that either pilot did not process vertical speed.

Moving down Figure 29 we see an immediate deviation from the interaction patterns of the standard case. The pilot detected and diagnosed the failure but the copilot did not acknowledge the diagnosis or initiate a verbal scan and we see the emergence if the dominance interaction pattern. At this time the pilot had difficulty controlling the aircraft, indicated by the heavy input on the cyclic and he was processing representations from the instrument panel while the copilot reached for the PCLs. The pilot made a critical decision to verify the failure and directed the copilot to assist him. This marked the first time the copilot and pilot coordinated their actions and the end of the dominance interaction. The representation flow gets divided between verifying the failure and controlling the aircraft. Both pilots worked in parallel on independent activities. Shortly after the copilot turned on backup hydraulics, the pilot flew the aircraft into the ground. There is no evidence that either pilot processed vertical speed in the descent. The configuration models indicate degraded representation flow from the instrument panel to both pilots. Note the heavy flow of speech from pilot to copilot and light flow of speech from copilot to pilot and the pilot’s dominance of the interactions. The copilot manipulated the tail hydraulic system through the instrument panel, as well as the PCLs however interaction with the PCLs was not sustained.

System configuration C featured in Figure 24 represents the final system organization with the pilot processing most of the representations. This system organization differs from the standard procedure in that the flow of representations from the instrument panel to the pilots was degraded, that is, the critical representations were not processed. There was sustained interaction between the pilot and the flight controls suggesting that the pilot had difficulty maneuvering the aircraft. Over the course of the scenario the pilot processed most of the representations. Unstable system organizations, like this one, introduce another layer of complexity to the task and demand more responsiveness from the pilots.

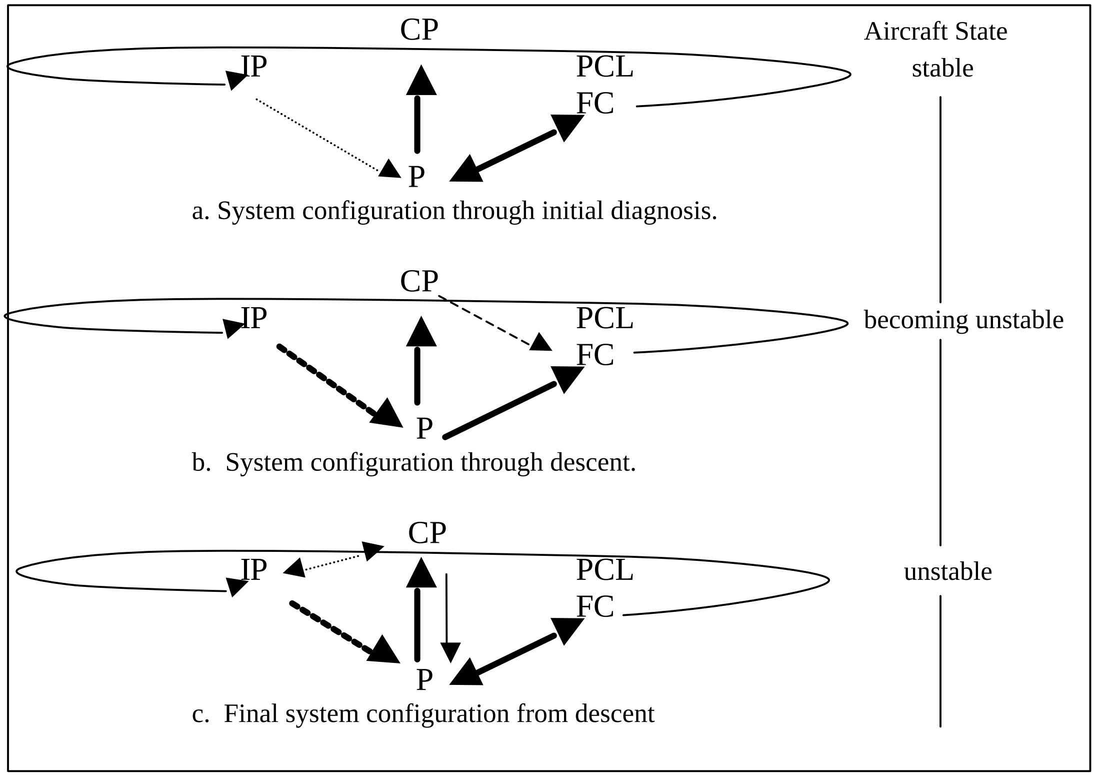


Figure 24. Case 4 system configurations during the response. The initial configuration illustrates heavy workload on the pilot, particularly with the flight controls and communication with the copilot. In second configuration the copilot joins the response by reaching for the PCLs while the pilot regains control of the aircraft. In the final configuration, the copilot is focused on the instrument panel and is not interacting with the PCLs while the pilot is also interacting with the instrument panel and the flight controls.

Case 4 Summary

When the pilot detected the loss of control he immediately began to dominate the cockpit interactions. The copilot was cooperative but passive in that he made no cognitive contribution to the scenario and went along with the pilot. The flow of critical representations from the instrument panel to the pilots was degraded and neither pilot processed vertical speed. Conflicting cues led the pilot to misdiagnose the drive failure for a loss of control and waste valuable time attempting to verify the diagnosis.

Case 5: Tail Rotor Drive Failure

While the crew was flying straight and level the tail rotor failed. The pilot ranked LT. J.G. and his copilot ranked LT. When the pilot detected a yaw control problem, he diagnosed a loss of tail rotor control when it was actually a loss of drive. Many pilots loosely refer to both emergencies as a “loss of control” even though the procedures for the two failures are different. Once the diagnosis was made, the copilot initiated a verbal scan of aircraft altitude.

Time in Seconds		**Speech**	**Gestures and Displays**
17	P:	And looks like we	BDHI begins to spin slowly left
18		got a loss of	P moves cyclic left, forward, aft
19		tail rotor control	Master caution light illuminates
20			
21	CP:	Got two hundred feet	
22			

Then the pilot directed the copilot to be ready on the PCLs, which he verbally acknowledged and then reached for the controls. The pilot narrated his actions and intentions to the copilot that helped to establish a set of expectations for the response. Again the copilot acknowledged the pilot and started to coach him at 30-31seconds he began monitoring the pilot's actions and continued reading the altitude. Then the copilot announced his readiness on the PCLs (34-35) which also serves as a request for direction. This demand is consistent with the standard division of labor, the pilot flying and directing, the copilot monitoring and setting up to follow directions.

The pilot called out thirty feet but the aircraft hit the ground before the copilot could move the PCLs. The copilot reacted with the statement, "that's pretty quick". The instructor attributed the crash to both pilots' failure to monitor rate of descent and the pilot's failure to arrest rate of descent below one hundred feet.

Time in Seconds		**Speech**	**Gestures and Displays**
23	P:	Kay get your hands	BDHI spins faster
24		on the PCLs	
25	CP:	Okay	CP reaches for PCLs
26	P:	and I'll just try to keep it	CP places hand on both PCLs
27		level bring it back down	CP's hand remains on PCL till
28	CP:	Roger that,	impact
29		two hundred feet	
30		Still quite--	
31		even it off there	
32			
33		two hundred feet,	
34		I'm ready to go	
35		when you are	
36	P:	Okay	
37	CP:	Hundred feet	
38			
39	P:	There's thirty	
40		(aircraft impacts ground)	
41			
42			
43	CP:	That's pretty quick	
45			

Line		**Speech**
A	I:	Kay, on that one you have to check your rate of descent. One of the
B		two of you has to for sure keep that or, hopefully both of you, keep that
C		in check um so that you can get that under control down around a
D		couple hundred feet lower. You probably want to pick up five hundred
E		feet per minute or less rate of descent and um as you come through
F		thirty either momentarily slow down and stabilize for a second or just
G		pick a slow rate of descent and then pull it at thirty but either way you
H		have to check your VSI (vertical speed indicator).

There is no evidence that either pilot processed vertical speed and this instructor's evaluation emphasized the need for one or both pilots to process rate of descent (Lines A-D, H). He doesn't designate who should process it, only that it is processed, thus the division of labor is left to the discretion of the pilots. The instructor suggested two options for controlling the descent rate, either slow to five hundred feet per minute and flare at thirty feet or pick a slower rate (Lines D-G). Through his review, the instructor promoted a team approach to aircraft control and response.

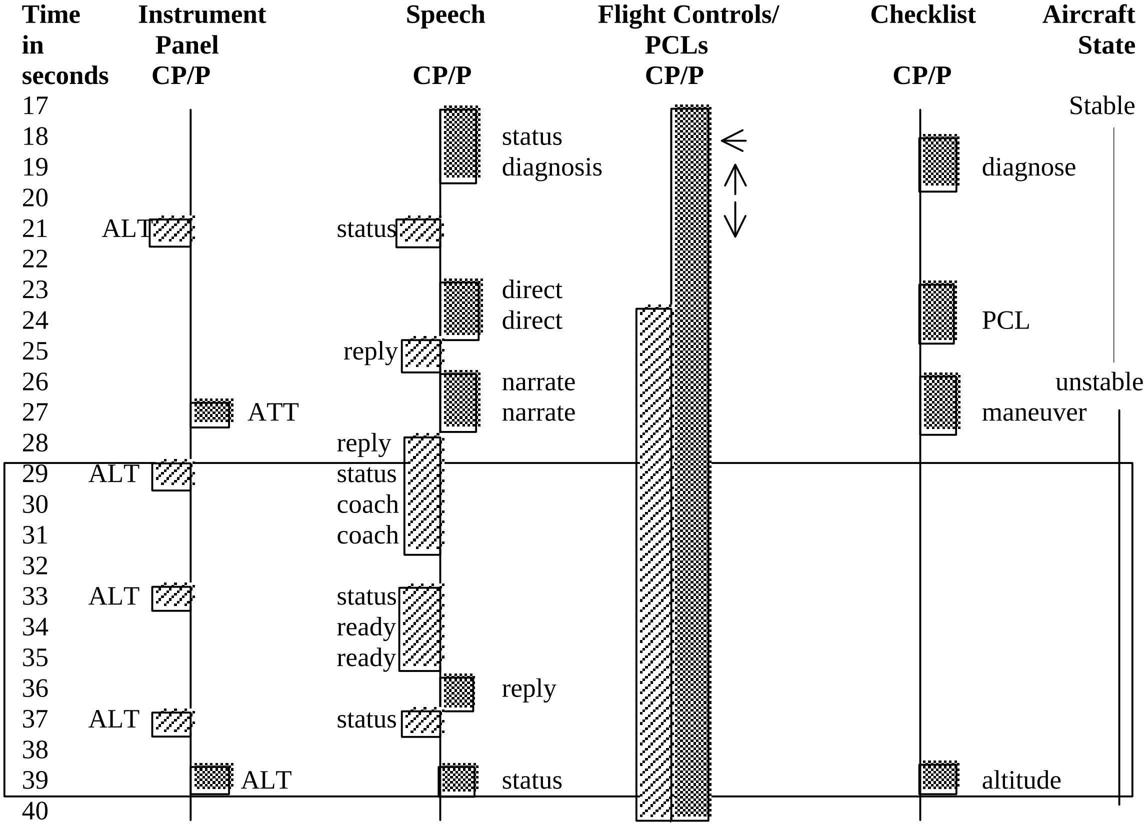
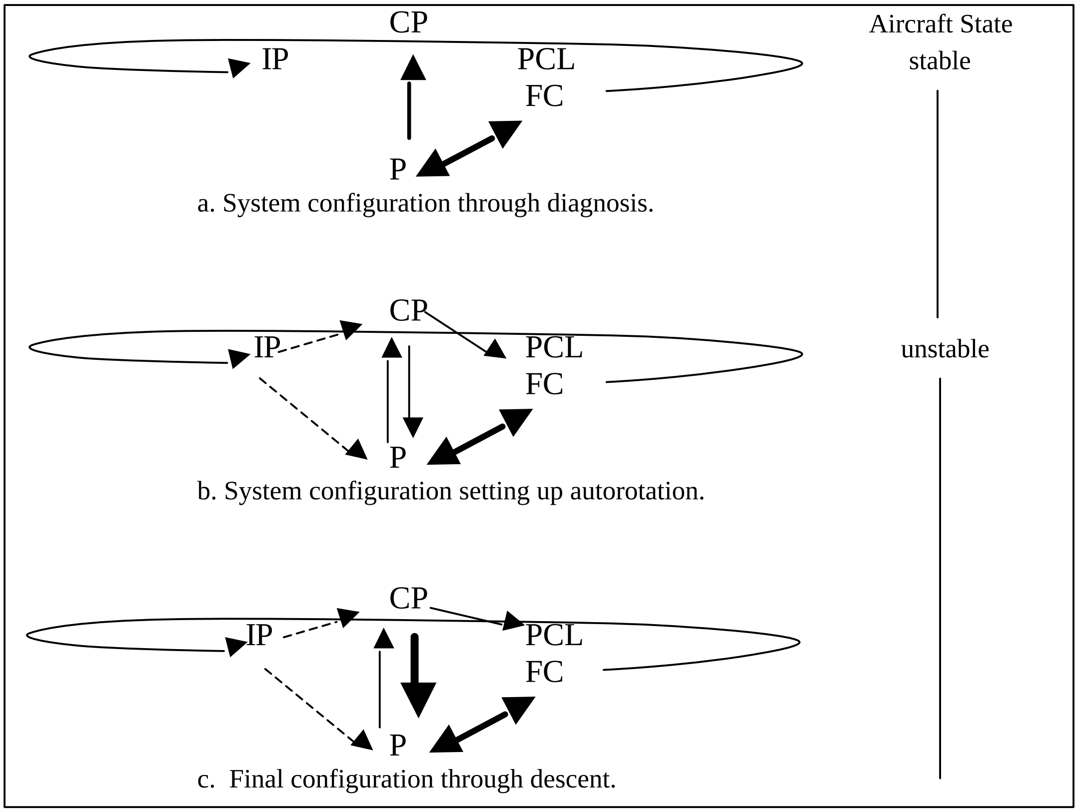


Figure 25. Interaction patterns for tail rotor case 5. Note that vertical speed was not processed by in the system. A coaching interaction pattern began at time 29 and ended at time 39.

In Figure 25, vertical speed is missing from the instrument panel column. Every other interaction follows the standard procedure except that the PCLs never came off. The copilot supported the pilot with a verbal scan, however it only included altitude. At time 29 we see an emergence of a coaching interaction. So even though this crew was working in coordination it was not enough to save them because key representations had not been processed.

The system configuration changed several times during its response to the tail rotor failure (Figure 26). As the pilot began having difficulty controlling the aircraft, the copilot increased the flow of status and coaching statements to the pilot. System configuration a shows heavy workload on the pilot through the diagnosis. Configuration b shows consistent communication between pilots, the copilot interaction with the PCL and both pilots are processing representations from the instrument panel. The final configuration illustrates increased communication between the pilots as the aircraft becomes unstable.



a. System configuration through diagnosis.

b. System configuration setting up autorotation.

c. Final configuration through descent.

Figure 26. Three system configurations for case 5. Note the critical representations are absent from the flow patterns between the instrument panel and the pilots.

Case 5 Summary

In this case the standard procedure was followed yet the aircraft still crashed. The copilot initiated a verbal scan of altitude but other key representations such as vertical speed were not processed. This case is one of many flight events I observed in which the crew coordinated their activity but missed critical flight information.

The crew must coordinate with the task-appropriate representations and integrate them into meaningful content that informs activity. The results of this event suggest flight safety depends on crew coordination, pilot coordination with other cockpit media, and how the system organizes representation flow. Even though coaching emerged, it alone cannot save the crew if key representations are not processed.

Case 6: Tail Rotor Drive Failure

The crew was flying along the San Diego coast from Imperial Beach to North Island when the loss of tail rotor drive occurred. The pilot ranked LT.J.G. and the copilot ranked LT. Upon detection, the pilot correctly diagnosed the problem as a loss of tail rotor drive. The copilot immediately acknowledged the diagnosis and read the current altitude of two hundred fifty feet. Next the copilot informed the pilot that the rate of descent was within a safe range for the flight condition.

Time in seconds		**Speech**	**Gestures and Displays**
1-2			CP reaches to upper panel P moves
03	P:	Kay	cyclic back then forward, lateral
04		looks like we got	BDHI begins to spin left
05		a loss of tail rotor	
06		drive	
07	CP:	Okay, you're at	BDHI speeds up
08		two hundred fifty	
09		That's a good rate	Caution lights on CAP illuminate
10	P:	Roger	Master caution flashes

The pilot gained control of the aircraft, but allowed it to climb. Instead of directly reading the altitude, the copilot transformed the display reading into flight status with "You're still climbing". A few seconds later the pilot established a descent of a thousand feet per minute, which is too fast for this situation. The copilot coached the pilot through the descent with "just try to set the power". Adding power is a technique for stabilizing the aircraft, but again the pilot let the aircraft climb. The copilot acknowledged the climb "goin up to two hundred feet" and the pilot began to re-establish a descent. During the short exchange that occurred between 20-28 seconds intersubjectivity is established between pilots. The pilot was trying to establish a steady descent however, he inadvertently climbed, over-corrected, and descended too fast. The copilot made suggestions that were appropriate to the immediate task. The pilots speech overlaps (26) and they complete each other’s sentences (27-28). The copilot understood what the pilot was doing and why. He knew the pilot was listening because the actions he took were sensible for the context. By coaching the pilot and the pilot being receptive to the suggestions the pilots jointly established control of the aircraft through coordination.

Time in seconds		**Speech**	**Gestures and Displays**
11	CP:	You're still climbing	
12		Still climbing	CP reaches for PCLs
13		Okay two hundred	CP grabs PCLs with right hand
14		That's settling down now	
15		You're descending, descending	
16		a thousand feet	
17		per minute now	
18		(Unintelligible)	P moves cyclic back
19		(Unintelligible)	
20		Hundred and fifty	
21			P moves cyclic forward
22		Just try to set the power	
23		That's it	
24		Okay goin up to	

Time in seconds		Speech	Gestures and Displays
25		two hundred feet	
26	P:	Okay	
	CP:	Okay now	
27		Just	
28	P:	Bring it down slowly	
29	CP:	Yeah we're ready on	
30		the PCLs and	
31		Bring it down	
32		nice and slowly too	

When a copilot interprets displays for the pilot, it frees the pilot to focus on controlling the aircraft rather than scanning the instrument panel. This is exactly the kind of division of labor that emerged in this case. The copilot continued coaching the pilot through the descent, then said, "Okay you don't have control" to initiate the failure verification procedure. The pilot confirmed the problem as a loss of tail rotor drive by testing yaw control with the rudder pedals.

Time in seconds		Speech	Gestures and Displays
33	P:	Okay	
34	CP:	Okay you don't have control	
35		now, let it come	
36		that's it natural descent	
37		Okay	
38		we're descending at four hundred feet	
39		we'll go down	
40		that's it	
41		just touch on the power	
42	P:	I got full left pedal	
43		and nuthin happenin	
44			
45	CP:	Roger	
46		That's still comin	
47		nice and gentle for ya now	
48		all ready to go	
49		Okay here it comes	
50		here it comes	
51		eighty feet	RAWS tone
52	P:	Bring a little	
53		power back in	
54	CP:	Okay	
55	P:	Get ready on the PCLs	
56	CP:	Yep, PCLs ready on	

The copilot continued to coach the pilot and calls out the descent at 10 feet increments as they approach the critical altitude of thirty feet. The copilot announced his readiness to pull the PCLs on the pilot's call. After passing through thirty feet the pilot ordered PCLs off and a few seconds later they landed.

Time in seconds		**Speech**	**Gestures and Displays**
57	CP:	your call	
58		Fifty feet—	
59	P:	There's fifty	
1:00			
1:01		Forty	
1:02			
1:03			
1:04			
1:05			
1:06		Kay, you can bring	
1:07		the PCLs off	
1:08	CP:	Okay comin off	CP pulls both PCLs back
1:09		Off	Hand remains on PCLs
1:10			Master caution flashes
1:11			
1:12		aircraft lands	

Line		**Speech**
A	I:	Okay real good
B	P:	Yeah that happened yesterday. I just, if you watch the rad alt, it's not a
C		good instrument to use for that.
D	I:	Uh the rad alt is not?
E	P:	Well, I mean it is but you bring the--like yesterday I bottomed out the collective
F		cuz we weren't comin down and then I was just lookin at the rad alt only.
G	I:	Oh, I see, yeah.
H	P:	And you know, then once you get to a hundred feet it just flies straight down.
I	I:	Yeah, well you're gonna have to check the VSI and then you'll notice that half
J		almost half of your rad alt indicator is a hundred feet and less.
K	P:	Right.
L	I:	So when things get to that point all of a sudden everything is happening real, real
M		hyper quick so you have to keep checking VSI on the way down and then get it under
N		control well below, you know, well before a hundred feet.
O	P:	Uh huh.
P	I:	And then at a hundred feet like you said you can use the rad alt.

In this case the crew landed safely. The discussion between the pilot and the flight instructor is about the practice of using the vertical speed instrument and the radar altimeter, with particular focus on the radar altimeter scale change which causes the needle to move too fast to effectively read (Lines B-H). The instructor suggested the practice of using vertical speed to set up the descent and then once it is steady, use the radar altimeter on the way down. The instructor's suggestion is an example of how display properties may promote an adaptive practice to compensate for cognitively demanding display characteristics.

In interviews, navy pilots and flight instructors reported they don't use the vertical speed indicator to set up the descent in autorotations and tail rotor responses because the instrument lags. The VSI is often used as a trend indicator until the instrument stabilizes and displays the actual rate of climb. The instrument produces unreliable readings under rough control conditions or turbulence, such as autorotations and tail rotor maneuvers. Experienced naval flight instructors reported that during these maneuvers they used the radar altimeter to estimate vertical speed, however only flight instructors claimed to do so reliably. When I asked the naval instructors how they learned to estimate vertical speed with the radar altimeter they replied it was a perceptual "skill they developed with experience".

The flight instructor in this case was a civilian and suggested the crew utilize the vertical speed display to acquire a safe rate of descent and then use the radar altimeter below 100 feet to inform action on the PCLs. I've never heard a navy instructor tell a

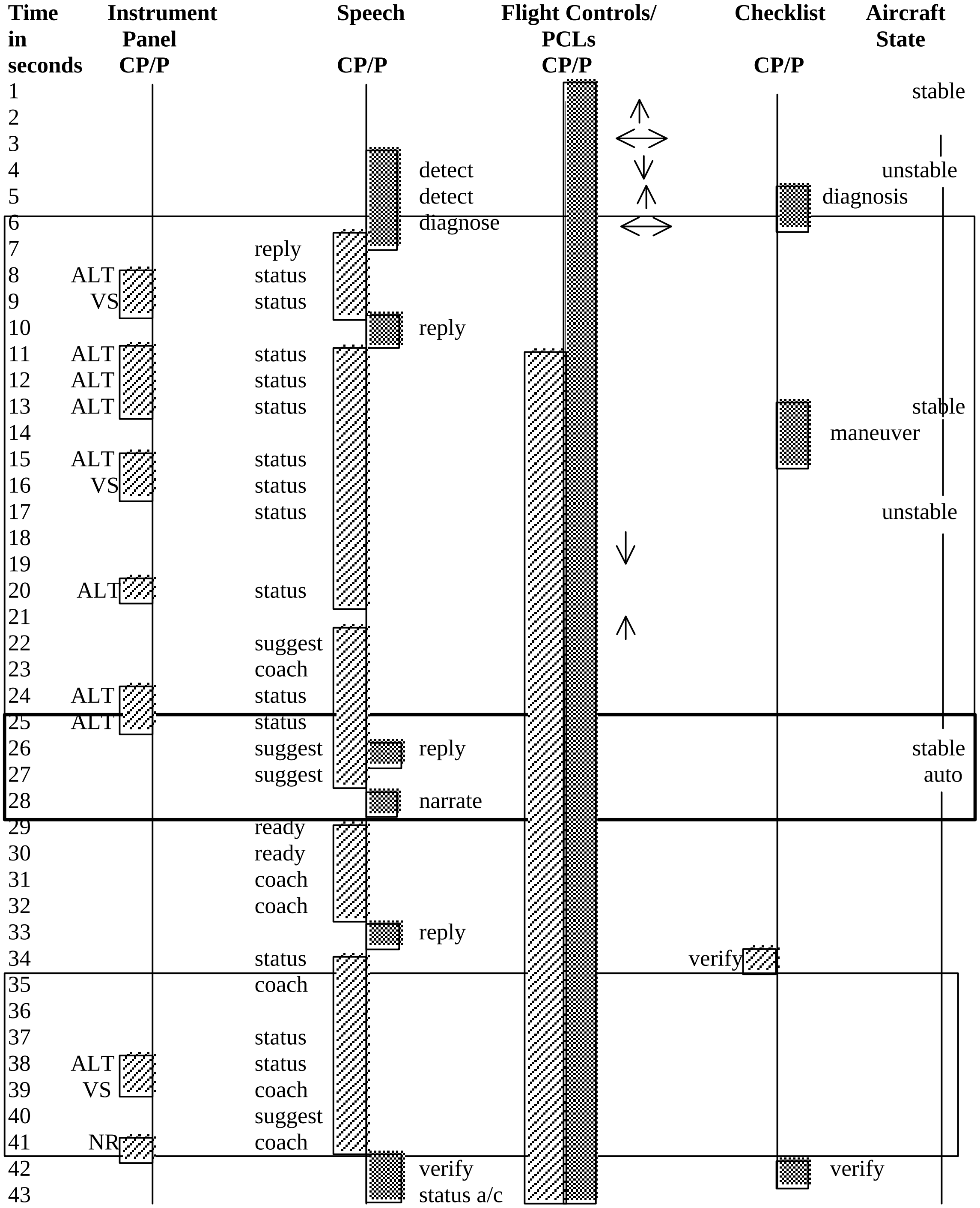


Figure 27. Interaction patterns for tail rotor case 6. The narrow boxes represent coaching interactions, the bold box indicates intersubjective understanding. These patterns led to the joint establishment of a stable autorotation.

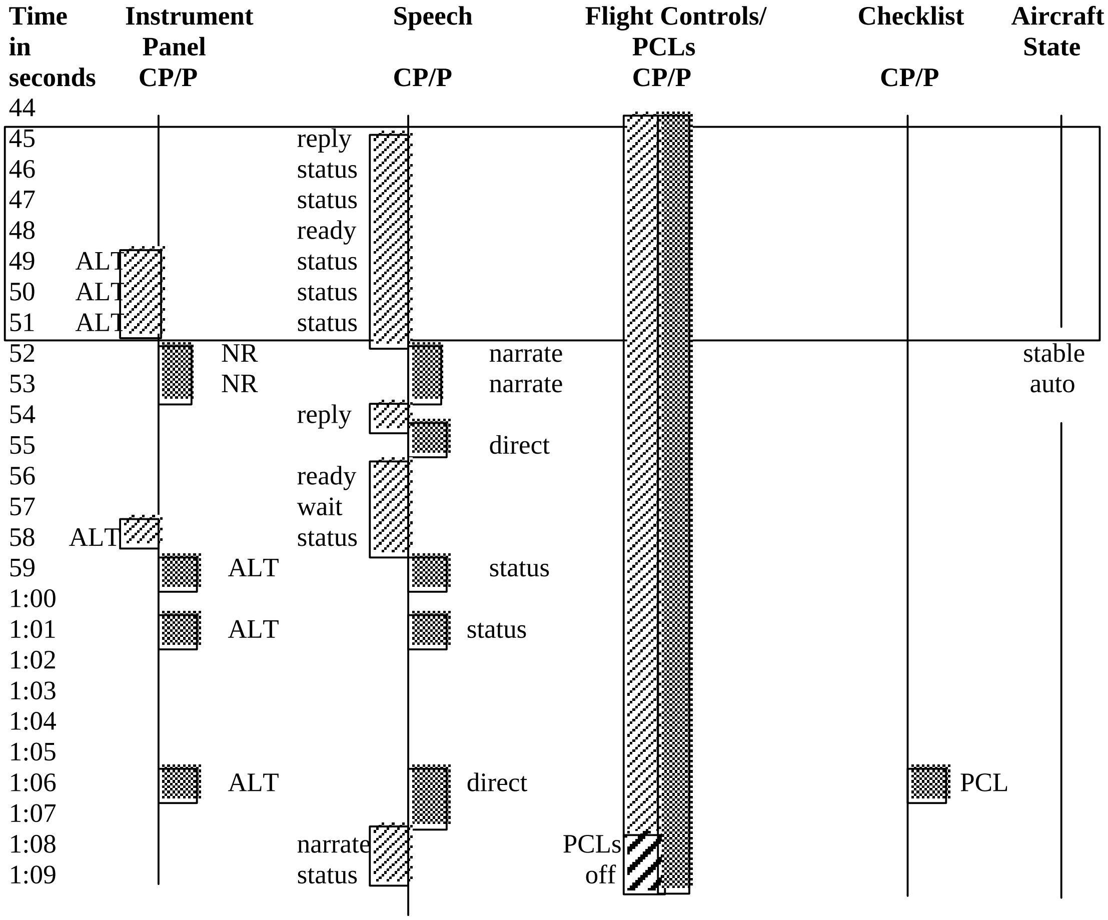
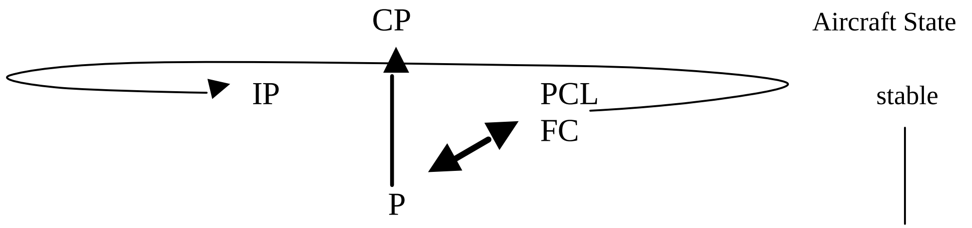


Figure 27. Continued.

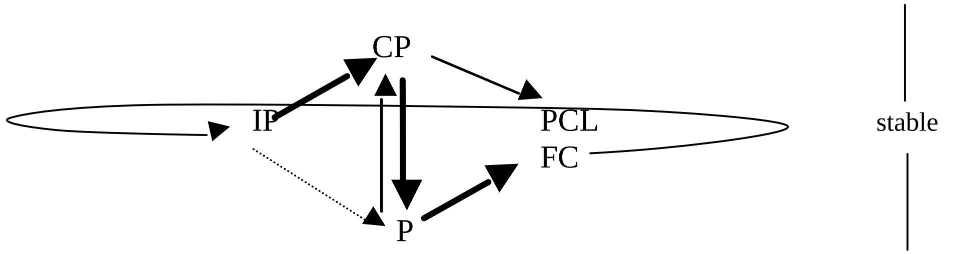
student to use the radar altimeter to judge vertical speed, but I have heard them emphasize use of the radar altimeter over vertical speed (for example see case 4). Consequently, pilots adapt their behavior to compensate for the scale design of the radar altimeter in different ways and that the scale change complicates an already difficult task.

In this case we see the coaching interaction pattern three times indicated by the boxes in Figure 27. Coaching began immediately after the pilot detected the failure. The crew transitions in and out of coaching to perform parallel, but complimentary tasks such as verify the failure. Intersubjectivity also emerged indicating that coaching and intersubjectivity are complimentary interaction patterns.

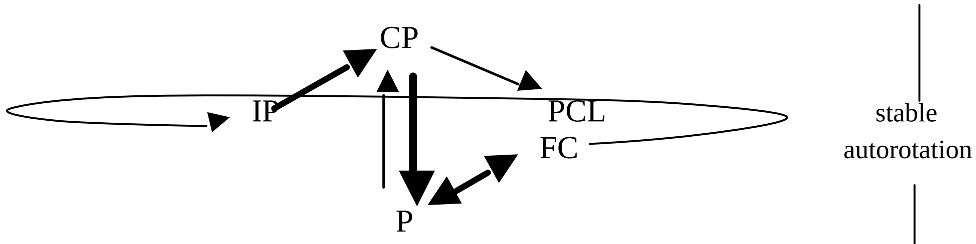
During this scenario the copilot transformed VSI readings into judgments about the appropriateness of the rate of descent and propagated it through the system. The rate was given in raw form when it exceeded safe conditions, "descending a thousand feet per minute now" and when it met safe conditions "we're descending at four hundred feet".



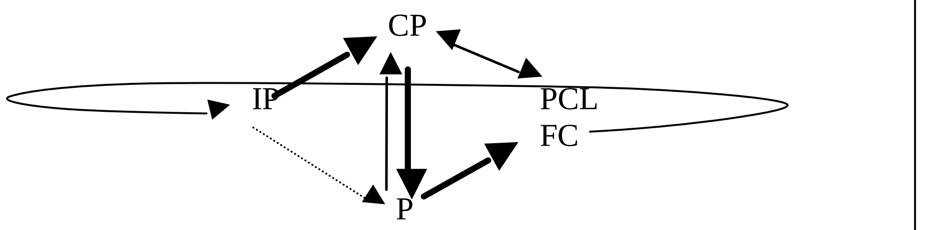
a. System configuration through diagnosis.



b. System configuration during initial aircraft control response.



c. System configuration during coordinated control of the aircraft.



d. System configuration during stable autorotation and landing.

Figure 28. Four system configurations for case 6. System configuration (a) shows heavy workload on the pilot through the diagnosis. Configuration (b) shows consistent communication between pilots, the copilot interaction with the PCL and both pilots are processing representations from the instrument panel. Configuration (c) shows increased communication from copilot to pilot and increased interaction between pilot and flight controls. The system focus has shifted to aircraft control. Note that no representations are flowing from instrument panel to pilot.

The copilot made other statements about the rate to communicate flight status or to help the pilot configure the aircraft for a safe rate of descent. Altitude was also propagated through the system, sometimes in its numerical form as a number “two hundred feet” and sometimes as flight status, "still climbing". The change from a numerical representation to a flight status representation appears to be linked to the criticality of a specific altitude and rate of descent. As the crew approached critical altitudes such as thirty feet, the altitude was processed in numerical form. The specificity of both the vertical speed and the altitude seem to depend on the specific task context. The copilot actively tailored the content of the displays, transformed them into a verbal representations that meet the specific task needs of the flight context. The safe landing depended on an establishment of equitable division of labor, joint attention to altitude with respect to rate of descent, and coordination of action.

Figure 27 illustrates the system interactions that occurred during the response and there is little or no deviation from the standard procedure. In fact these interactions so closely model the standard that its overall structure appears sound. The pilots interacted with each other and the key representations (vertical speed, altitude, and Nr) were processed and propagated through the system. One unique feature of this system was the intersubjectivity that emerged while the pilots established a controlled descent.

In Figure 28, we see four system configurations. Notice how they change according to the workload of the pilot. When the pilot processed representations from the instrument panel there was less interaction with the flight controls and when interaction with the flight controls increases, there was little or no interaction with the instrument panel. Thus the copilot picked up the instrument panel processing for the pilot. These pathways operating in coordination enable a safe response to a difficult maneuver. The final configuration of the system illustrates a stable system that models an ideal response. Critical representations were processed through coordination between pilots and between pilots and the cockpit media.

Case 6 Summary

In this case the crew successfully responded to the malfunctioning tail rotor. They coordinated with each other and with key representations utilizing several coordinating interaction patterns. The patterns that emerged were coaching and intersubjectivity and the crew established joint control of the aircraft. These patterns were also present in the successful engine cases suggesting that they could transfer to a range of emergency responses.

Case 7: Chip Tail Transmission Caution Light

The participants in this case are peers, both ranking LT.J.G. They were in the same class and had flown together during prior training events. The crew approached Imperial Beach at 800 feet when the chip tail transmission caution light illuminated. The copilot reset the master caution warning system, then the pilot directed him to review the checklist while he slowed the aircraft.

Time **in seconds**		**Speech**	**Gestures and Displays**
01			MW and CAP lights illuminate
02	P:	Kay uh	
03	CP:	Kay	
04		chip tail transmission	
05		reset mas-caut	CP clears MW
06	P:	Kay	
07		Break out the	CP grabs checklist from
08		checklist	between his seat and the lower
09			panel. Opens it and flips pages.
10			
11			
12	P:	Little bit fast	

Ten seconds passed while the copilot searched for the corresponding checklist. The pilot proceeded with an autorotation maneuver to put the aircraft on the deck.

Time **in seconds**		**Speech**	**Gestures and Displays**
23	CP:	Kay land	
24		as soon as possible	CP looks at P, BDHI spins left
25			P moves cyclic lateral
26	P:	Kay	forward
27		and goin	back
28		right into the auto	neutral, BDHI spins right
29			
30			
31			CP reaches for the PCLs
32			CP hands on PCLs
33			
34			
35			
36	P:	Kay	
37		We're in the auto	

The pilot announced an established autorotation, even though it was not yet established, and in response the copilot announced his readiness on the PCLs. At this point the crew was in coordination but the coordination was not sustained. The pilot made an unusual attitude to recover the autorotation (note severe right turn) meanwhile the aircraft rapidly descended. During the unusual attitude, the copilot asked the pilot for direction on the PCLS. On the third demand the pilot gave in and said “yeah”.

Time in seconds		**Speech**	**Gestures and Displays**
38	CP:	Standin by on	ALT drops
39		the PCLs	VSI falls
	P:	the PCLs	
40			
41		I keep the flare	P makes severe right turn
42	CP:	PCLs off?	
43	P:	And	
44			
45			
46	CP:	Do you want me to	
47		get em off?	P returns a/c to straight and level
48	P:	Yeah	CP pulls PCLs back
49			engine winds down
50			Nr drops off
51	CP:	PCLS are off	
52			RAWs tone
53			RAWs tone
54			RAWs tone
55	Aircraft hits the ground		Impact at 3000 fpm

The copilot's demand for direction on the PCLs occurred during an unusual attitude. They didn't crash because the pilot was a poor pilot, his recovery from an unusual attitude is a testament to his flying skill, they crashed because they did not coordinate their actions on the PCLs. When the copilot pulled off the PCLs, they were at 150 feet and fell to the ground at a rate of 3000 feet per minute. When the instructor replayed the event he accompanied it with a narration of what he thought happened. I have never observed a playback for a good performance.

Line		**Speech**
A	I:	I put crash override on, that one really hurt. Let's go back and take a look at that one.
B	CP:	What'd you say when I said standby on the PCLs? Did you say pull em off or --I
C		didn't hear what you said?
D	I:	Yeah hold on for a second.
E		Comin outta freeze. I gave you a chip tail transmission, gives you an idea somethin's
F		goin on back there. I've already given you the uh-tail rotor torque loss. Watch, see
G		your BDHI starts to come off to the right. You're feeding in left pedal, you're feeding
H		in left pedal, you shoulda checked the collective down, feeding in left pedal, you're
I		feeding in left pedal. You're at two seventy you've now gone thirty degrees (turn),

Line		**Speech**
J		you're sixty degrees, airspeed goes off, you've gone below forty-five degrees, you
K		make a nice aggressive maneuver to get back, a little unusual attitude. High Nr but
L		you're under control. You're comin back around to the right, I would have leveled out
M		with PCLs on into the flare holding the flare. You called for PCLs off here at this
N		point and now you're gonna crash at one hundred fifty feet with zero airspeed. Look at
O		your Nr.
P	CP:	Look at our VSI! (VSI at 3000 fpm)
Q		Ohhhh!
R	I:	Bam you're dead.

The instructor immediately told the crew their performance was poor (Line A). The copilot could not recall if the pilot had directed PCLs off (Lines B-C). I take the copilot’s statement as evidence that some pilots’ recollection of the events occurring during an incident may be unreliable. Despite some problems with Nr control (Lines H and K-L) and an unusual attitude (Line K), the instructor’s assessment of pilot’s performance was satisfactory. However the pilot did not ask for PCLs off with the standard nomenclature, he merely replied “Yeah” to the copilot’s third demand for direction. The instructor, in Line R emphasized the severe consequences of that action.

The instructor’s comments were directed at the pilot and this kind of instruction perpetuates an individualistic view of accountability. The copilot may leave the event believing that he had no role in the crash and it was pilot who erred. Unfortunately the copilot might carry the belief into the fleet. I disagree with the instructor’s comments because this crash was completely preventable had they coordinated the PCLs and that coordination is standard procedure.

The copilot demanded direction from the pilot and did not support the pilot in processing and propagating task-critical readings from the instrument panel. During the playback the instructor did emphasize PCLs came off too early, but again this comment was directed at the pilot and not at the copilot (Line M). Finally the instructor adds, “Look at your Nr” and the copilot replies, “Look at our VSI!” The copilot’s surprise is evidence that he had not processed rate of descent during his demand for direction on the PCLs and at the time he pulled them off.

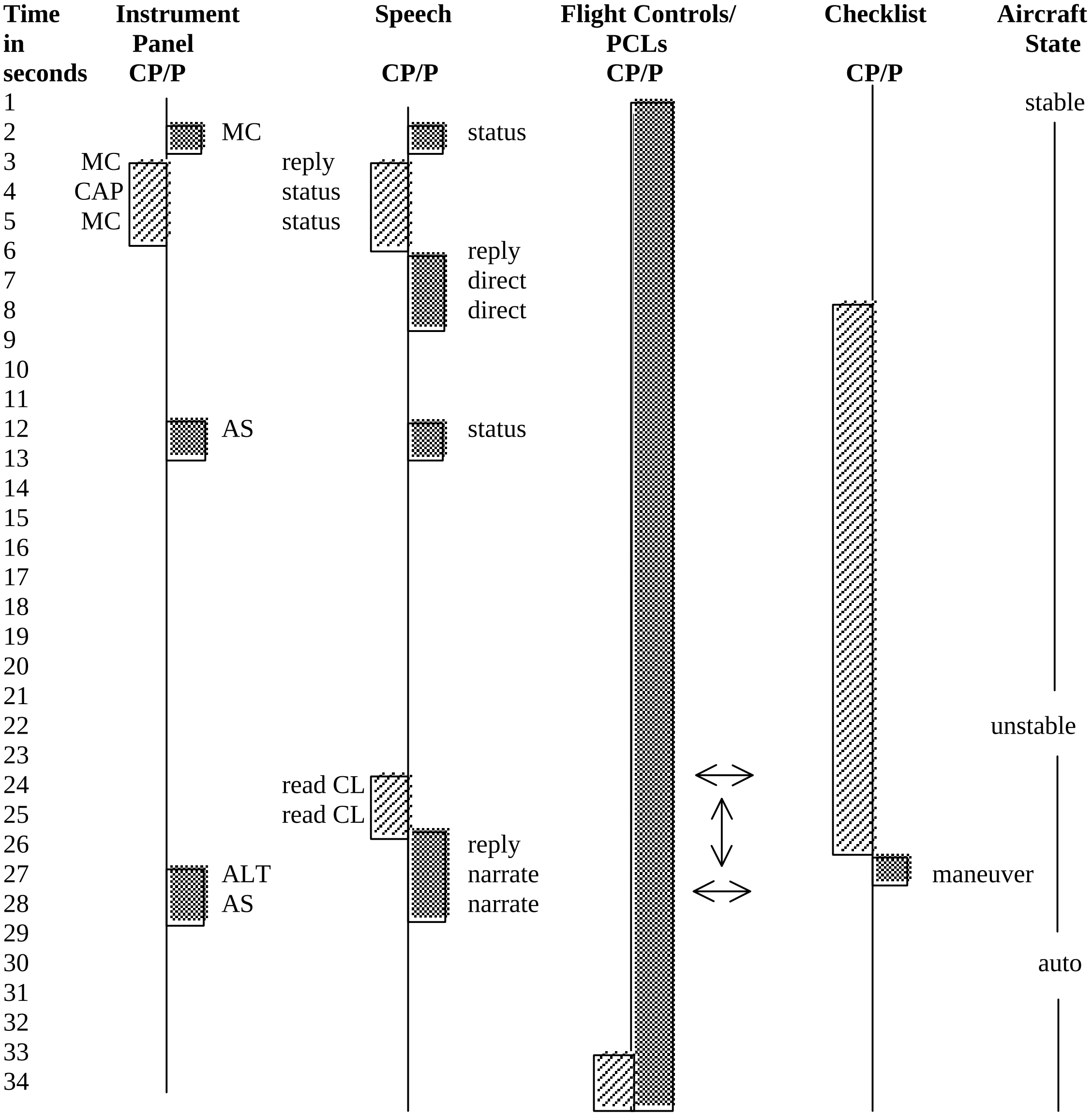


Figure 29. Interaction patterns for case 7. Note that either pilot did not process vertical speed and the copilot did not process any display readings after the diagnosis.

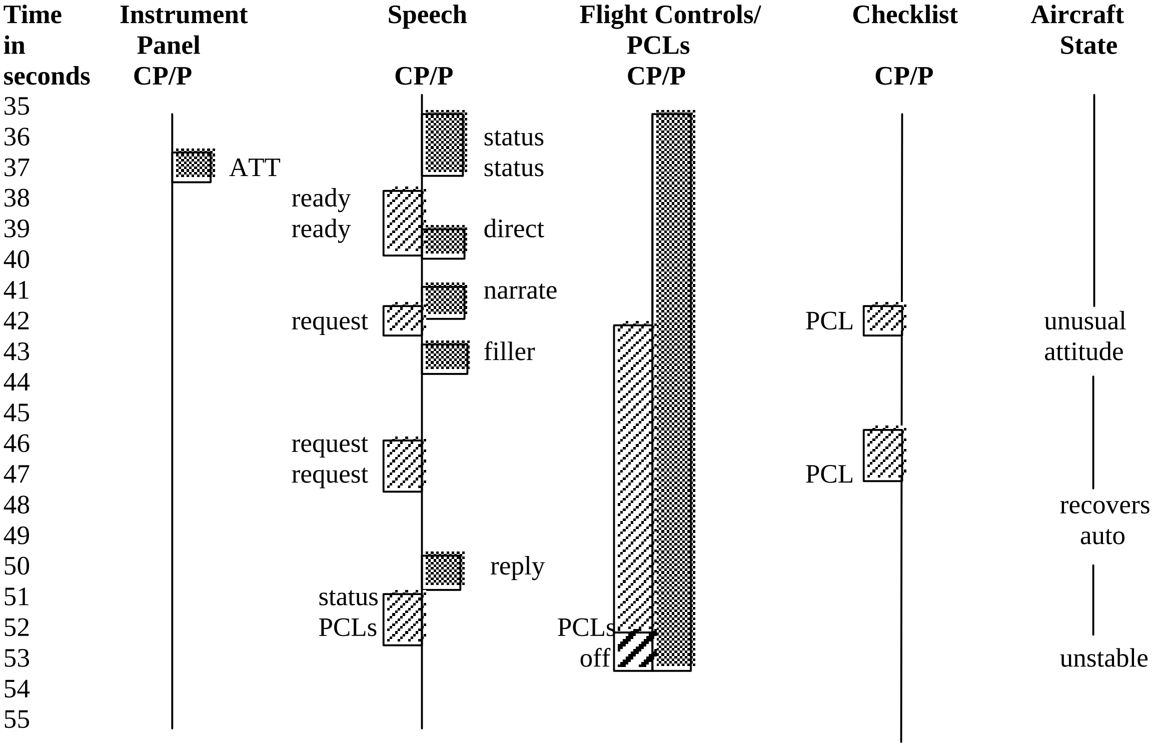
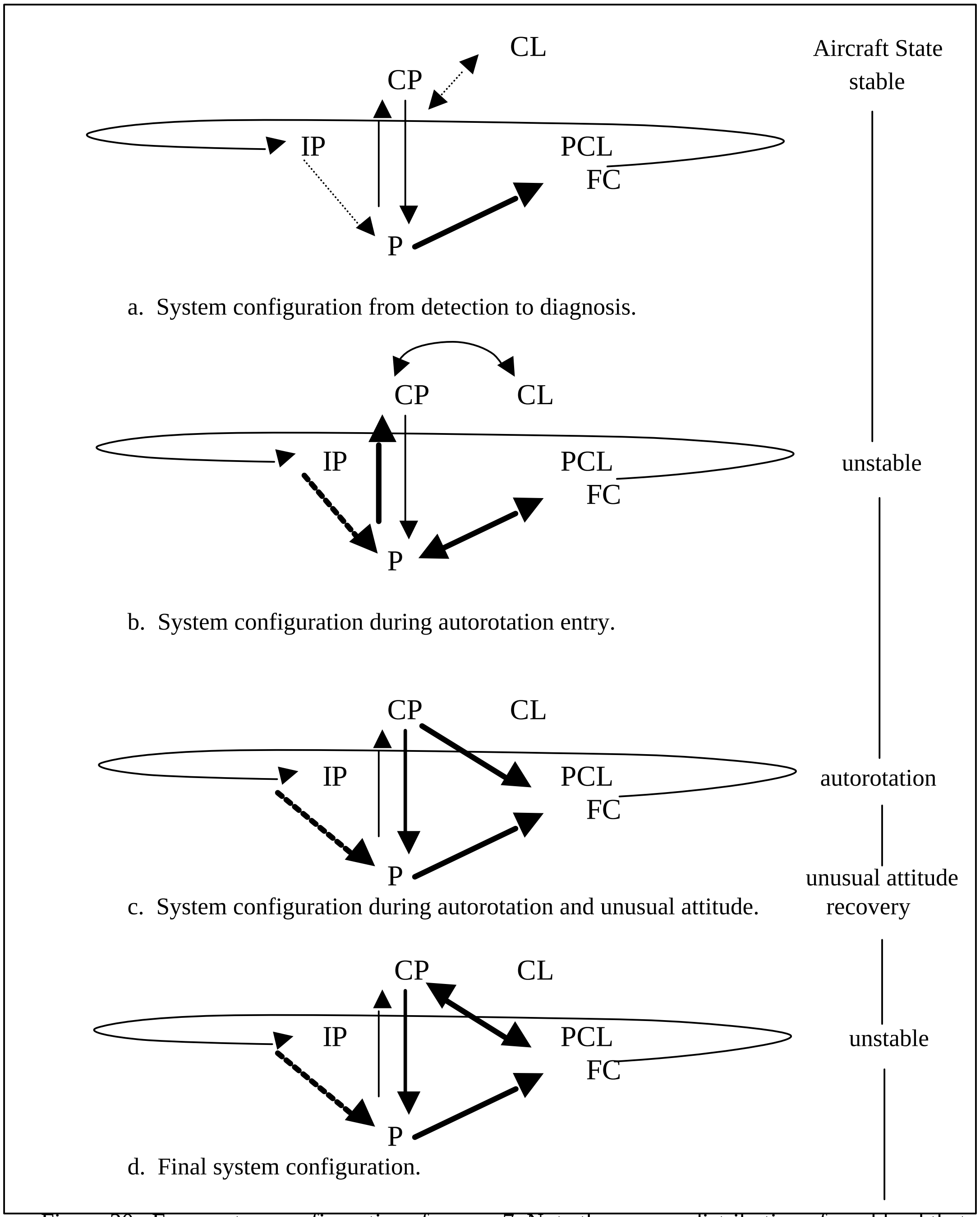


Figure 29. Continued.

Figure 29 shows the crew in coordination until the pilot directed the copilot to be ready on the PCLs. The copilot had his head down while reading the checklist and may have interfered with the flow of representations from instrument panel to copilot. There is no evidence the pilots processed vertical speed while establishing the auto and that may have contributed to the pilot’s difficulty in maintaining the maneuver. Altitude was not processed prior to PCLs off thus the decision to pull off the PCLs was an arbitrary one. Thus two critical representations, altitude and vertical speed, were not properly propagated through the system.

The system established four different configurations during the response (Figure 30). The pilot became an information-processing bottleneck because the processing pathway from the copilot was inactive; consequently key representations were not processed.



a. System configuration from detection to diagnosis.

b. System configuration during autorotation entry.

c. System configuration during autorotation and unusual attitude.

d. Final system configuration.

Figure 30. Four system configurations for case 7. Note the uneven distribution of workload that emerged between pilots with more demand on the pilot. The pathway of representation flow from instrument panel to pilot was severed early in the event (b). As the copilot turns his attention away from the checklist he does not process instruments (c). The information processing capabilities of the system are degraded with the pilot serving as the processing bottleneck (d).

Case 7 Summary

The crew was in coordination until the pilot tired to enter the autorotation. The pilot had difficulty maintaining the autorotation but does an aggressive maneuver and recovers. At that moment the copilot demands direction on the PCLs from the pilot. The pilot was focused on aircraft stability whereas the copilot was focused on establishing coordination with the pilot on the PCLs. The instructor's critique of pilot was especially harsh, and he did not critique the crew. This case illustrates that pilots need to learn *how* to establish coordination and that sometimes attempting to coordinate may disrupt aircraft control.

Chapter Summary

When comparing all four tail rotor cases, we see the same kinds of interaction patterns emerge that were present in the engine cases: coaching, intersubjectivity, and dominance. In cases 5 and 6 the primary pathway of representational flow was from instrument panel to copilot to pilot to flight controls. It is imperative that this flow pattern be established for an equitable division of labor between pilots and to avoid the representational flow bottleneck present in both cases 4 and 7. Furthermore when a flow pathway is degraded, the system either reorganizes the flow to other pathways or the channel is dropped from processing. Pathways that are not saturated may become saturated when representational flow is redirected there and results in the loss of signals processed. These cases, like the engine cases, support the role of attention in directing the flow of representations in the cockpit and that flow can affect workload distribution and system organization.

Response to a tail rotor drive failure requires the specific coordination of vertical speed and altitude. Vertical speed and altitude are more meaningful as an integrated representation than they are as independent representations. The aircraft's rate of descent in relation to the altitude is what matters here; a high rate of descent may be desirable at altitudes above 1000 feet but not lower. One pilot, but preferably both pilots, must process and communicate the aircraft’s current altitude in relation to vertical speed and with respect to the actions on the flight controls and PCLS. The data suggest that combined representations may be difficult to interpret and understand because it demands pilots integrate two representations into one meaning.

The cockpit is a complex system and a mechanical failure perturbs the system’s balance making it unstable. Under normal flight conditions the aircraft remains in a stable configuration and may readily adapt to small disturbances. But a mechanical failure, such as an engine failure or a tail rotor failure, makes the aircraft mechanically unsound and difficult to control. The failure causes changes in the cockpit displays indications and increases response demand on the pilots. Pilots must utilize coordinating strategies to manage the complexity. Studying systems in disarray can be informative for understanding the critical factors involved in the maintenance of system stability.

CHAPTER 5

Training and Culture

Introduction

In this chapter I discuss cultural aspects of HSL-41 and their relationship to training practice. I provided the squadron with a set of recommendations that were based on an analysis of case studies presented in the previous chapters. The recommendations represent the practical benefit of this study to SH-60B helicopter training (Table 4). In the sections that follow, I present my recommendations and findings from case studies in the context of the training culture based on my experiences and observations at the training center.

Table 4. Recommendations presented to the Navy.

1.	In terms of instructional philosophy, promote the idea that the cockpit is a team workstation.
2.	All pilots should receive instruction on how to be an effective pilot in command and copilot and how to coordinate as a team. Each pilot should be graded on his performance in each role and the crew should be graded on team performance.
3.	Explicitly teach pilots coordinating interactions.
4.	Describe how the procedures help crews accomplish task objectives give pilots a clear understanding of how to organize and manage cockpit workload.
5.	Make critical cues for each emergency explicit in training and emphasize understanding the system in terms of cockpit cues
6.	Design critical instruments so they are directly perceptible.

When a pilot walks into HSL-41 training he has had prior experience piloting a helicopter, but not a Seahawk. That pilot leaves the training center with his knowledge and skill changed by the experience of training. The pilot leaves equipped to fly the

Seahawk with practices and understandings that were constructed through his interactions with other students, flight instructors, and instructional media. Each of these, in some way, touches the actions and words that make up interactions in the cockpit.

A new class of incoming students arrives at HSL-41 every five weeks. Often the students in the class have met before or have heard about one another through a network of friendships formulated during their primary flight training or previous deployment. The first day of training was devoted to orientation and the students used break time to catch up on news of who got married, which squadrons they are going to after training, and so on. It didn't take me long to realize that the student pilot network has far-reaching consequences for distributing knowledge, both in and out of the cockpit.

Shared Knowledge

The students share knowledge in the form of *gouge*. There is gouge on everything from good restaurants to the hydraulic pump fluid levels. In orientation one of the flight instructors told us “If you buy me a beer, I'll give you the gouge on Japan.” One of the students in my class was going to a squadron in Japan after training and later told me he had shared a beer with the instructor and “got some good gouge.” Another time during a brief, one of the students drew an inaccurate diagram of the fuel system. The student explained that he had learned the system from a schematic given to him by students in the previous class. The instructor's response was “they gave you some bad gouge.” Unfortunately the students may acquire inaccurate knowledge on the basis of bad gouge.

The training syllabus is aggressive and there is a lot of material to learn. Training is commonly known as “drinking from the fire hose.” One way pilots cope with the workload is by learning gouge numbers and that can influence how they construct meaning in the cockpit. There are all kinds of gouge on the emergency procedures that pilot use when they study for the brief and when they fly in the simulator. An Australian flight instructor serving a tour at HSL-41 said American instructors place too much emphasis on book knowledge. In an interview before a hydraulics simulator event the instructor expressed to me this view:

> “When a pilot has trouble briefing the hydraulics system, usually he had a poor IGR of the hydraulics system. Some instructors are better than others and give better lessons and it shows in the brief. The Navy instructors tend to focus on the numbers instead of on conceptual instruction. They don’t teach them how to fly, they teach them the numbers. Back home we teach ‘em to fly.”

There are aspects of this excerpt that reflect the instructor’s perception of training’s emphasis on book knowledge as is inferior to the operational approach of his homeland. Second when a student has received poor instruction in a lecture it is reflected in the student’s poor discussion of the system during the brief and that there is variability in the quality of instruction given. Finally the emphasis on system operations instead of flying is an important distinction because it suggests, from the instructor’s perspective, that the training is not comprehensive. Consequently pilots learn aircraft systems and all their relevant limits and capabilities but aren’t taught how put everything together in flight.

One purpose of aircrew coordination training is to fill that gap. Aircrew coordination training consists of a lecture and completion of a series of computer based trainer lessons. In the lecture, we were asked to read a summary of an actual accident. Our task was to determine which of the seven crew coordination behaviors was missing from the scenario. Pilots were encouraged to talk about their own flight experiences where crew coordination was a factor and how to prevent safety incidents like this one in the future:

> The instructor listed the seven ACT behaviors on the board and then gave us a printed scenario of a real safety incident to read. We read it and then he asked us to identify the behavior that was missing from the scenario. In the scenario the crew pulled back an engine to the idle position to save fuel, but in the 60B the engine uses more fuel at idle. The instructor said to save fuel the engine must be shut down or in the fly position. The session went well and several students offered answers. "The copilot was in a cocoon, was how one student described the copilot saying he should have been more assertive. Another student said "sometimes you need someone to take you right out of the daze." Another student offered "The crew lost situation awareness of their fuel state." The instructor agreed saying "Their perception of the situation was 180 degrees off, way off."

This excerpt illustrates the kind of instruction pilots receive about crew coordination. Based on their explanations of the scenario, the pilots were able to at least recognize crew coordination factors that related to the scenario. But there was no instruction about how to establish coordination in the cockpit. The instructor ended the lecture by telling us "When one person gets wet, everyone gets wet." The importance of coordination is implicit in this statement, everyone knows it matters but there is no method in place for achieving it. The lecture like the instructional media was good at describing the behaviors and their consequences, but there is no standard procedure for establishing coordination such as coaching. The instructor's final comment points out that everyone is in the helicopter together so teamwork is important but the instruction on how to be a productive team is implicit in the training.

The flight instructor comments I presented at the end of cases 1-7 are representative of instruction pilots receive from both civilian and naval flight instructors. The instructors vary in their depth of knowledge, enthusiasm, and emphasis during simulator events and all the students know who runs the toughest brief.

Grading

For every event students are graded on their individual performance. For a simulator session two students are paired as partners for the session. If one student needs to complete a simulator event but there are no other students that need simulator time, that student is paired with a sandbag. A sandbag is a student that sits in on the event and acts as copilot but has no accountability for his performance as copilot.

During a simulator flight the pilot sits in the right seat and is the one being graded. After a two-hour session the pilots switch seats and the other pilot is graded during the next two-hour session. Each student's performance is recorded on a grade sheet that lists all the required tasks needed to successfully complete the event. Thus students are graded as individuals. The grading system creates an implicit division of accountability between the pilot and the copilot. In particular the pilot is both accountable and responsible for the safety of the flight and the copilot is not accountable, making individual accountability implicit in grading and instructional practices. This is an odd contradiction from what we learned in ACT: that in reality the pilot who crashes the aircraft takes everyone on board with him.

Interaction Patterns

The analysis of the data suggest that the outcome of a flight is a not due to the properties of an individual pilot alone but to the interactions between system components and their emergent properties. These critical interactions occur socially between crewmembers, physically between pilots and representations, and conceptually via pilot knowledge. This analysis was based on the distributed cognition principle that interactions within a system create emergent system-level properties.

The cases show that even in a structured environment outcomes may be influenced by social and cultural factors. The data suggest that safe flight was due more to the coordinating interactions and emergent properties of the system than to the pilot's individual knowledge, but that knowledge is essential to the interactions. This is something to keep this in mind when grading pilots and designing team environments like multi-seat cockpits. In addition, a more reliable predictor of flight outcome may be made on the basis of the interactive patterns that emerge rather than on individual actions.

The interaction analysis revealed three emergent properties of the cockpit system: coaching, dominance, and intersubjectivity. The navy also has its own terms for these patterns. Pilot talk about backing each other up which is the essence of coaching. The phrase "backing up" can mean different things depending on who you are and whom you ask. It is not a formal crew coordination term, but it is how pilots talk about coordination and teamwork. The identification of coaching will give the navy a concrete definition of "backing someone up" that works for pilots in this community. Thus it is a skill that can be taught in classrooms and practiced in simulators.

Dominance is other side of the assertiveness coin. Assertiveness is a formal crew coordination term and is a behavior that promotes a willingness to actively participate. Pilots are expected to assert their position, state their concerns, and offer solutions. But what happens when the other pilot does not acknowledge those assertions? Dominance occurs when an overbearing pilot makes decisions and judgements and performs actions without input or concurrence from the other pilot. This pattern is often characterized by a unidirectional flow of representations. Pilots construct an understanding of the situation independent of each other and the understanding of the dominant pilot may sway the understanding of the other pilot.

Intersubjectivity is the most difficult interaction pattern to define. The closest training term to it is synergy. The first time I saw this term was on a computer trainer in a crew coordination lesson. I never heard pilots or flight instructors use the term to describe behavior. Instructors did report that they could sense when a crew was in tight coordination but couldn't say why or how they did it. Both coaching and dominance have asymmetrical representation flow patterns that center on one individual. Intersubjectivity has symmetrical representation flow patterns making it less obvious to an observer. Perhaps that is why there isn't a clear training term for it and why instructors don't know how to talk about it.

In case studies 3 and 6 pilots established intersubjective understandings. These understandings are observable in the interactions between pilots, they complete each other's sentences, abbreviate words, and perform future tasks. The pilots understand each other's actions and abbreviation without having to ask for clarification. The emergence of an intersubjective interaction typically begins with both pilots working in coordination and it strengthens their coordination.

Crew coordination is a skill that needs to be conveyed to pilots in an explicit manner. Teaching pilots how and when to coach each other would be a good start and introducing team accountability into grading practice would soften the emphasis on individual achievement that is prevalent in navy culture.

Display Properties

It was not surprising to find that display representation properties have a role in processes of interpretation and meaning construction. There is a particularly high incidence of misdiagnosed high side and low side engine failures and the analysis indicates displays had a role in the incorrect diagnosis. If flight conditions or poor design make a display perceptually ambiguous, like when Nr and torque readings fluctuate, it can be difficult to perceive key representations and assign the proper meaning. It is possible for two pilots to interpret the same display differently because the interpretation also depends on knowledge and experience a pilot brings to the interaction.

When I asked pilots to describe the diagnostic procedure for a high side or low side engine failure most pilots responded correctly reporting to use Nr and to confirm the failure with secondary indications like torque. However in a flight context the diagnosis may not be so straightforward because of the dynamic properties of the Nr and torque displays and their placement on the instrument panel (see Chapter 3).

Pilots agree that high and low side engine failures are difficult to diagnose but tend to attribute that difficulty to inexperience. The following excerpt is between the training curriculum officer (who oversees both phases of training) and myself:

> This afternoon the curriculum officer stopped by my office to see how my research was progressing. I said I had only begun my analysis but I found it interesting that pilots regularly misdiagnose high side and low side engine failure. He replied, “Oh yeah that happens all the time.

> It’s a real problem especially with junior guys.” I asked why. “Because they either focus on the wrong instrument or they don’t cross check the torque” he said. CSI (civilian) instructors tell students over and over to use Nr not torque to diagnose engine problems (but NATOPS isn’t so explicit about that). The curriculum officer said the torque is positioned right in front of the pilot’s face and it has a dramatic split so pilots tend to look at it and don’t look at the other instruments.
>
> Then he talked about an actual high side failure he experienced with a student during a training flight in the aircraft. “In the hover I saw one red cube and thought gee that’s odd. Then we got just a little airspeed and about three seconds into forward flight we saw one engine go up then the aircraft just started shaking. I was pulling full collective and could not control Nr. Then I glanced at the TGT and saw it spike. I told the student to pull back the number one PCL to half and he did it. Luckily he did it right and we were okay but we had full fuel, we were at 150 feet at 30 knots. If he had gotten it wrong it would have been a disaster.”
>
> He said a less experienced pilot might not have pulled the engine off fast enough because the Nr was squirrelly and that students tend to focus on the wrong instrument then pull off the wrong engine, “but it’s not just a gauge problem it’s also a training issue. These students arrive at the FRS thinking their instructor or the more senior guy will save them in a dangerous situation and that’s bad.”

In these paragraphs the officer uses inexperience to explain the high incidence of misdiagnosis, but he also suggests that the displays have role. The data contradict the belief that pilots with less experience in the aircraft are necessarily poorer performers under stress. Even pilots who are considered experienced with over 1000 hours in the aircraft may still incorrectly diagnose a high side or low side engine failure (see Engine Case 3) for the same reasons the curriculum officer gave, focusing on the wrong instrument and not cross-checking. Then there are pilots with less experience who diagnose these failures correctly (Engine Case 2). So there is more to a response than experience in the aircraft, the displays have a role and so does the flight situation when the failure occurs. When an incorrect diagnosis does occur it is possible for the crew to negotiate a correct response through crew coordination and adherence to the standard procedure (Engine Case 3). It may be that more experienced pilots are better at recovering from an incorrect diagnosis because they have more knowledge resources in the form of experience.

Standard Procedure

The standard procedure serves as an excellent resource for pilots and it frees them from having to expend cognitive resources planning their actions. The navy structures activity and its primary means for providing structure in the cockpit is in the form of standard procedures.

Although pilots must use their own judgment when deciding to deviate from the standard procedure, the data suggest that adherence to the standard procedure equitably divides the cognitive workload between the two pilots and serves as a resource for pilots to organize and coordinate action. Following the procedure also discourages hasty diagnoses. In the analysis I tracked the density of representations as they moved through the system to identify processing pathways in the cockpit. The structure of the standard procedure helps pilots organize and manage cockpit tasks by giving them organizing structure for processing representations.

Flight procedures are knowledge pilots share and may utilize to build expectations about each other's behavior. Pilots need to understand the value of procedures and the work it accomplishes for the crew. I recommended that some part of training describe how procedures help crews accomplish their task objectives and would give pilots a clearer understanding of how to organize and manage cockpit workload. Obviously pilots should think for themselves because sometimes deviation from the procedure is the right thing to do. Pilots need to know how to dynamically organize their workload to meet the demands of the moment and the standard procedure is an excellent resource they can recruit for doing so.

Rank

I observed some interesting dynamics in the cockpit that were directly attributable to differences in rank between the pilots. In training pilots are more often paired with a peer, however in the fleet rank asymmetry in the cockpit is common. The data suggest that rank asymmetry can interfere with the interaction patterns that emerge between the crew, particularly the communication patterns (Case 1). Instructors have reported that junior pilots tend to “sit on their hands” when they fly with a senior officer. When a senior pilot’s interpretation of the flight situation contradicts that of a junior pilot’s interpretation, the junior pilot assumes the senior pilot is more experienced and therefore is probably correct. Consequently the junior pilot will not challenge the senior pilot and if he does it is implicit (See Case 1). The navy is a hierarchical organization and criticism flows down the chain of command not up. The hierarchical structure permeates the cockpit via rank, which is a such strong cultural pull making it difficult for junior officers to assert themselves even in the name of flight safety.

Mapping Meaning into Action

Student pilots are periodically tested on their “book” knowledge of operating limits, airspeeds, fuel quantities, time limits, and so on. However, the exams do not test a pilot’s understanding of how a particular aircraft system works and precisely how it affects aircraft performance and mission capability. Consequently there are student pilots who don’t know what the displays mean in terms of the aircraft systems and aircraft performance. The observed following exchange between a flight instructor and a student pilot during a simulator session:

> The instructor introduced a single engine failure and the Nr started to fluctuate. The pilot lowered the collective but the aircraft was in a climb and it drooped. The copilot was busy with the checklist and didn’t help her diagnose the failure. The aircraft developed a high sink rate and we crashed. After everyone caught his breath, the instructor asked the pilot what it meant to fly Nr. She gave the standard response: “95-110 percent”. “So then why did you stop flying the aircraft?” the instructor asked. After a pause she answered “I didn’t know what the display meant.”

This excerpt indicates the pilot knew the correct operational limits of Nr but did not know how to interpret the display fluctuations in the context of flight. I recommended making critical cues for each emergency explicit in flight training and that training documentation emphasize system malfunctions in terms of the display indications pilots see in the cockpit. It also suggests, as do the high incidence of misdiagnosis, that meaning is not present in the displays themselves. It is through the interaction of the displays with pilot knowledge that pilots construct meaning about the situation.

Pilots I interviewed reportedly understood aircraft systems one of two ways. Some they learn aircraft systems in terms of the cockpit by using the structure and organization of the cockpit to remember the systems and their functions. They learn what the cockpit cues mean in terms of how they affect aircraft functioning and maneuverability. This is an operational perspective that differs from the more ubiquitous approach of learning how the system operates on the basis of an engineering schematic. The civilian (CSI) flight instructors give each pilot a packet of aircraft system schematics and the pilots use them as study guides for exams and system briefings. One pilot I interviewed described to me how he learned each aircraft system:

> I use the CSI diagrams to understand the text written in NATOPS. I try to understand how the system works then break it down into system components. Once I understand it I draw each component and then put them all together. The way I keep things straight is by how things look in the aircraft.

This pilot learned the systems first by understanding how it worked and the relationships between system components. Then he took it a step further by mapping the cockpit cues to his understanding of the systems.

Some pilots simply memorize the system from the schematic and are able to describe it in a brief but have difficulty in the aircraft when they must construct meaning from cockpit cues. In interviews, student pilots reported they did not know what the displays meant, especially Nr, torque, and the caution advisory lights. When I interviewed pilots about how they learned aircraft systems they reported memorizing the system schematic because they are required to draw the system and describe it in the pre-flight briefs.

Conclusion

Through a systematic analysis of video and ethnographic data, I have presented what pilots do when they encounter an emergency condition. I have identified strategies pilots use to manage their workload, support each other in maintaining aircraft control, and why the standard procedures work to the benefit of the crew in their response. The next step for improving training (and possible for reducing the mishap rate) is to promote the idea of the cockpit as a team workstation. Evaluate pilots as a crew and give them a grade for their performance as a team, and offer explicit instruction for supporting each other using the strategies that were identified. Finally, meaning is not inherent in the displays, pilots construct meaning through a process of interaction that maps their knowledge to the display representations.

Change is never easy nor is it simple. However to move beyond the current paradigm in aircrew coordination the navy must shift the focus of its training program from that of the individual pilot to one that presents the cockpit as a cognitive system.

CHAPTER 6

Theoretical Implications and Speculations

I began this research with the express objective to understand how cockpits function as cognitive systems. I was particularly intrigued with comparing system configurations of cockpits that crashed to ones that maintained safe flight under emergency conditions. I verified the role of aircrew coordination (and crew resource management) in a crew's successful performance. I aimed to move beyond CRM and ACT by focusing on the cockpit as a functional system rather than on social coordination between pilots.

For obvious reasons I could not conduct this research in real aircraft. I acquired access to a naval helicopter training center equipped with full motion flight simulation. In chapters 3 and 4, I presented my observations and video representations of cases in which crews crashed the simulator and compared them to cases in which the crew recovered without incident. Utilizing principles from the distributed cognition theoretical framework, I described how the cockpit functioned in both cases.

In chapter 2 I discussed the theory, the data collection methods and analysis. I selected ethnographic methods and video recording to capture the system in action. In the analysis of data I had two theoretical challenges. First that I could model the overall flow of representations in a system during different stages of stability by tracking the trajectories of representations through the system. Secondly, if coordination is an emergent property of the system, I could identify it through an analysis of the individual-unit interactions.

I constructed a flow model of the representation flow within a system during different stages of aircraft stability. The data suggest that representation flow has a major role in establishing the cognitive division of labor within a system and that division has an influence on system performance. While divisions of labor are prescribed by the cockpit procedures, they are not fixed but dependent on the initial flow patterns that are established. The template for establishing flow patterns is largely determined by the social relationship between the crew. For example, differences in rank can negatively affect the system’s distribution of labor but not always, it depends on the crew. Like other complex systems, this system is sensitive to its initial conditions.

The flow models are of theoretical interest because they illustrate the dynamics of cognition in flight. A theoretical construct of distributed cognition is that the computational processes manifest themselves along pathways where representational state is propagated and transformed across media. An analysis of the flow dynamics reveals the anatomy of the system and its critical computational pathways. Sometimes the pathways become bottlenecks of representational processing which suggests these are cognitive limitations of the system. When the system is thrown into disarray, successful systems adapt the flow to meet the immediate processing needs of the system. These systems adapt and recover from the disruption. Systems that do not adapt miss critical representations and form bottlenecks that impede flow of representations. These are the systems that do not recover and result in a crash.

I developed an analysis of interaction dynamics to identify system-level properties. The analysis revealed three interaction patterns: coaching, dominance, and intersubjectivity. These patterns emerge from individual interactions in the system and are not produced by an individual pilot. The patterns are linked to the flow of representations and can perpetuate each other. Thus the flow of representations influences the emergence of these patterns and once the patterns arise they constrain the flow of representations through the system. These patterns can be seen as organizing computational properties of the system like representational flow.

These processes do not occur in isolation. They occur simultaneously across social, physical, and conceptual spaces that each pull on the interactions within the system (Figure 31). The physical aspects of the cockpit shape the computational properties of the system. The display representation and other cockpit media have a role in the perception and propagation of representations. Cockpit instrumentation that presents ambiguous representations may not be processed, such as the radar altimeter in the tail cases presented in Chapter 4.

The ways pilots relate to one another and the manner in which culture arranges those relationships also have an influence on system interactions. The training center tacitly emphasizes individual accountability through their grading practices, which has an effect on the pilot's sense of team accountability. Rank also has a role in the social interactions that emerge between pilots and between pilots and flight instructors.

The conceptual space includes pilot knowledge that also affects the range of possibilities for interaction. In chapter 5 I discussed how pilots learn to map meaning into action. Meaning construction is a complex interaction between display representation and pilot knowledge. The data suggest that meaning was not intrinsic to the displays, but that displays may have meaningful properties and individuals may have knowledge about those properties. Meaning is produced through interaction between the pilots' knowledge and the presence of display representations. We only know that a display representation is meaningful when it has an affect on the system outcome. In all engine cases and tail rotor cases pilots had to interact with display representations and that process was critical to the system outcome. In this system, meaning is created in an

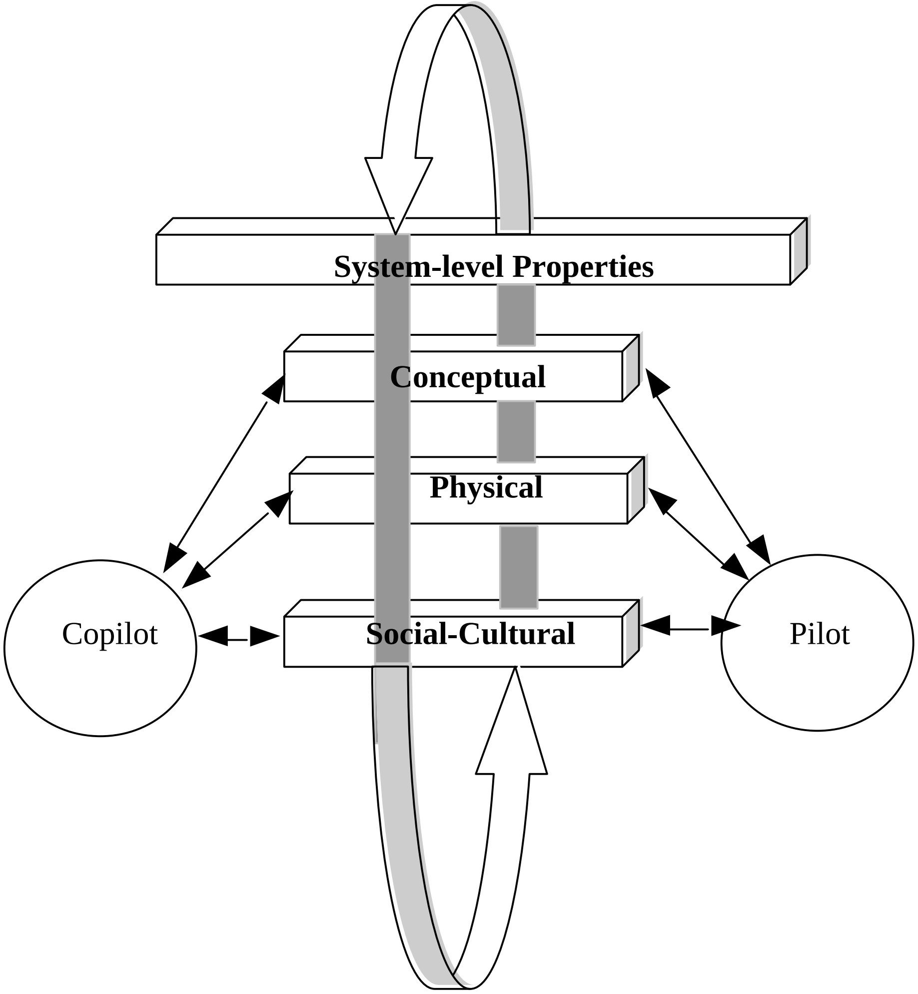


Figure 31. System interactions produce system-level properties. Conceptual, physical, and social/cultural pulls on the interactions and shape system behavior.

interaction between the situation and the internalized understandings of the pilots. Thus the cognitive properties of the system are woven into a fabric of complexity. When we pull on a single thread, it tugs at the entire fabric.

Finally, there is value in studying systems on the edge of stability. Others have also shown that studying systems in disruption is a productive enterprise for understanding how systems function (see Norros 1996, and Engeström 1996). When complex systems are moved to disruption, they begin to unravel and the parts that remain bound are the ones that contribute to maintenance of stable states. When systems are in equilibrium the components critical to maintaining balance are not always apparent because the system components are working in unison making them difficult to discriminate. Furthermore they force the researcher’s attention to process rather than outcome, which result from the interactive processes within the system. When systems are thrown into disarray, the critical components are highlighted and that is when the system exposes its underlying structure, its strengths and its weaknesses.

APPENDIX A

Speech Codes

Individual codes represent interaction units that arose in the stream of talk and action during tail rotor control and single engine failure responses. Individual codes were then categorized into interaction groups for analysis. The interaction diagram is coded with these speech codes. Examples of speech statements are presented in parentheses.

Status
Aircraft status (completely losing control,; going back the other way now; we’re in the auto)
Narrate--Narrate own activity (going to backup, I’ll just try to keep it level bring it back down, bring it down slowly, bring a little power back in, comin off, reset master caution, little bit fast, goin right into the auto)
Status-indicator light (backup hydraulics coming on, chip tail transmission)
Status-PCLs (PCLs off; Off, PCLs are off)
Status-altitude specific (got two hundred feet; hundred feet, there’s thirty; you’re at two hundred fifty; fifty feet; there’s fifty; forty,)
Status-altitude general (you’re still climbing; descending; goin up to; we’re descending; we’ll go down)
Status-vertical speed (a thousand feet per minute now)
Status-aircraft state (that’s still comin nice and gentle; here it comes here it comes; that’s settling down now)
Status-ready (we’re ready for the PCLs; all ready to go; standin by on the PCLs)
Verify status

Strong demands from other
Direct--Direct other’s action (switch the tail rotor servo to backup; get your hands on the PCLs; get ready on the PCLs; you can bring the PCLs off; break out the checklist)
Wait--Waiting for direction from other (I’m ready to go when you are; ready on your call)
Request--Request direction from other (PCLs off? Do you want me to get em off?)

Soft demands from other
Coach--Coach CP to P (even it off there; that’s it; bring it down nice and slowly too; now let it come that’s it;)
Suggest--Suggestion CP to P (just try to set the power; just touch on the power)
Inquire—A question (Are we high on one?)

Action codes
Decide--Decision made by P (Let’s go for a spinning cut gun)
Judgement--Judgment by P (I’m not gonna get an autorotation at this altitude)
Diagnose--Diagnosis (I’ve got something wrong with the tail rotor; must be loss of control; loss of tail rotor control; a loss of tail rotor drive)
Plan--Planned action (running landing)
Concur—Agree with partner

Reply
Reply to other (Roger; Right; Okay; Roger that; Kay; Yeah)

Filler
Filler statement (I uh; eh uh; and)
Emotive statement

Checklist
Checklist statement (land as soon as possible)

APPENDIX B

Instrument Panel Codes

Nr	Main rotor speed
TRQ	Torque output for each engine
AL	Aircraft altitude
AS	Airspeed
Ice	Aircraft anti-ice
MC	Master caution light
CAP	Caution advisory panel light
Fuel	Fuel remaining
VS	Vertical speed
ATT	Aircraft attitude.
Stab	Stabilator angle indicator
Gen	Generator display
BDHI	Bearing distance heading indicator
AFCS	Aircraft flight control system
HYD	Hydraulics light

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