Chapter 1

Constructing Meaning from Space, Gesture, and Speech

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Abstract

Face-to-face communication in the workplace is often conceived of as consisting mainly of spoken language. Although spoken language is clearly a very important medium for the creation of representations, in complex work settings, it is one of several such media. Gestures and the space inhabited by speakers and listeners are normally thought of as providing context for the interpretation of speech. In this chapter we show how space, gesture, and speech are all combined in the construction of complex multilayered representations in which no single layer is complete or coherent by itself. We examine a brief explanation given by one worker to two others. We show how the meaning of the explanation is carried in the coordination among the spatial organization of specilized artifacts, the positioning of gestures with respect to those artifacts, and the words that are spoken.

Face-to-face communication in the workplace is often conceived of as consisting mainly of spoken language. Although spoken language is clearly a very important medium for the creation of representations, in complex work settings, it is one of several such media. Gestures and the space inhabited by speakers and listeners are normally thought of as providing context for the interpretation of speech. In this chapter we show how space, gesture, and speech are all combined in the construction of complex multilayered representations in which no single layer is complete or coherent by itself. We examine a brief explanation given by one worker to two others. We show how the meaning of the explanation is carried in the coordination among the spatial organization of specialized artifacts, the positioning of gestures with respect to those artifacts, and the words that are spoken. Our inspiration for this analysis comes from the work of Charles Goodwin on situated seeing and the cognitive uses of spatial organization (Goodwin, 1994a, 1994b; Goodwin & Goodwin, in press) and of Eleanor Ochs and her colleagues on the layering of speech and gesture over graphic displays (Ochs, Gonzales, & Jacoby, in press).

The computational properties of a cognitive system are in part determined by the patterns of communication within the system. This is true whether the system is contained in the mind of an individual or distributed across a number of individuals (Hutchins, 1991, 1995). The representations that are created depend on the resources available for their creation. What can be represented? How can it be represented? When a team is engaged in joint reasoning activity, communicative resources can be seen as media for creating the representations that move information around inside the system. Communicative behaviors *are* the representations by which a socially distributed cognitive system does its work.

Data Collection

The setting for our study is the cockpit of a commercial airliner. This is a complex high-technology work setting in which the crew engages in event-driven, high-stakes activities. The quality of the crew's performance depends on their ability to coordinate their actions with one another and with the dynamic behavior of the airplane (Hutchins & Klausen, in press; Hutchins, in press). The data were obtained from a videotape of a simulated flight. The simulation was performed in a Boeing 727-200 high-fidelity simulator in the Manned Vehicle Simulator Research Facility (MVSRF) at the NASA-Ames Research Center in Mountain View, California. Flight in a high-fidelity simulator is very close to the experience of flying a real airplane. The simulator used in this study provided full visual displays with dusk lighting conditions and six-degrees-of-freedom hydraulic motion. A real airline crew composed of pilots employed by a major air carrier flew a simulated flight approximately one hour in duration from Los Angeles to Sacramento. The flight was designated NASA 900 in order to hide the identity of company with which the pilots were employed. As part of the scenario, a dangerous fuel leak occurred midway in the flight.

There are three cockpit crew members on a 727-200: a captain, a first officer (F/O), and a second officer (S/O) who is sometimes called a flight engineer. Either the captain or the F/O actually flies the plane, typically alternating with each flight leg. This person is designated as the pilot flying (PF). The pilot not flying (PNF) handles radio communications. For the flight examined in this chapter, the captain was the pilot flying, and the F/O was the pilot not flying. The S/O monitors systems such as the fuel and the hydraulic systems on the S/O panel. The S/O also trouble-shoots and refers to the airplane operations manual for procedures in non-normal situations when necessary.

A low-light infrared camera was positioned behind the crew facing forward. All three crew members could be seen, as well as most of the main flight instrument panel and some of the second officer's controls and instruments, including the fuel panel.

The S/O in the NASA 900 flight discovered the fuel leak by monitoring the fuel gauges located on his panel. The fuel panel is described at length in the following section. The interactions that ensue between the crew members upon the S/O's notification of the problem are the focus of this chapter.

The Arrangement of Pilots in the Cockpit

In a three-person cockpit like the 727-200, the captain's and the F/O's seats face the front windows of the aircraft. The main flight instrument panel is directly in front of the captain and F/O. Additional controls are located on an overhead panel. The S/O's seat is mounted on a swivel behind the F/O's seat. The S/O can sit facing forward or can turn the seat to face the S/O's panel, which is on the right-hand side of the cockpit behind the F/O's seat. The main panel is just close enough to the S/O so that he can physically reach the center portion of it between the F/O and the captain. The captain cannot reach the S/O's panel, although the F/O can with difficulty. Both the captain and the F/O can see most parts of the S/O's panel.

The 727-200 Fuel System

The System

The three engines on the 727-200 are fed by three main fuel tanks and an aft auxiliary fuel tank. The main fuel tanks are located in the wings and the wing center section. Tank one is located in the left wing, and tank three is located in the right. Tank two is in the center of the plane between the wings. The aft (rear) auxiliary tank is located in the forward section of the aft cargo compartment. Each engine has a corresponding fuel tank: Tank one has a direct feed line to engine one, tank two to engine two, and tank three to engine three. The aft auxiliary tank also has a direct line to engine two.

Fuel from each tank can be fed to other engines as well. Cross-feed valves control the flow of fuel between tanks and engines in the fuel lines. There are three cross-feed valves, one for each main tank and engine combination. The fuel from the tank feeds a manifold, and from there the fuel goes to the engine. If the corresponding cross-feed valve is open, the fuel also feeds into another manifold, the cross-feed manifold. This manifold can supply all the engines with fuel, depending on the configuration of the other cross-feed valves (see Figure 1). When all three cross-feed valves are open, the fuel is free to flow from all tanks to all of the engines. Direction of flow is determined by the pressure in the fuel lines and by check valves that permit fuel flow only in one direction. When the cross-feed valves are closed (the default setting), the configuration is called *tank to engine,* because each engine is fed by only its own tank. The crew can control how much fuel is burned from which tanks by using the cross-feed valves to direct the fuel flow.

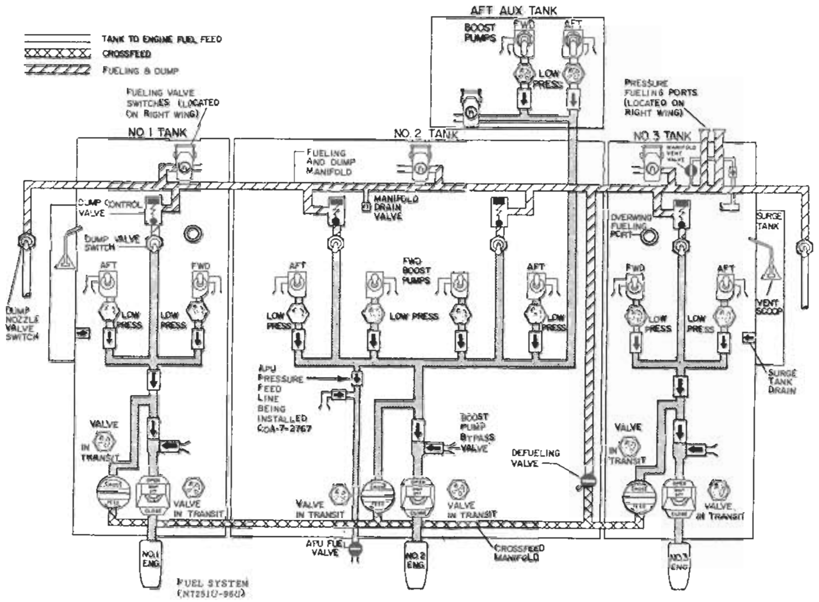

Fig. 1.1. A model of the fuel system as it appears in training and operations manuals.

Boost pumps also control fuel flow by supplying the pressure necessary to move fuel to the engines. Tanks one and three and the aft tank each have a pair of boost pumps located in the tanks. Tank two has two pairs of boost pumps because the

tank is divided into sections, two of which are located over the root of each wing. Boost pumps can be turned on or off. When the boost pumps are on, they extract fuel from the tank and feed it into the fuel manifold and to the engine. When the pumps are off, the fuel remains isolated in the tank.

Fuel Instrumentation

The fuel system gauges and switches are located on the lower left section of the S/O panel on the 727-200. The fuel panel in the simulated airplane displays four fuel quantity gauges: one for each of the main tanks and one for the aft auxiliary fuel tank. The corresponding boost pump toggle switches, the low pressure indicator lights, the cross-feed valves, and the engine shutoff valves are also displayed on the panel (see Figure 2).

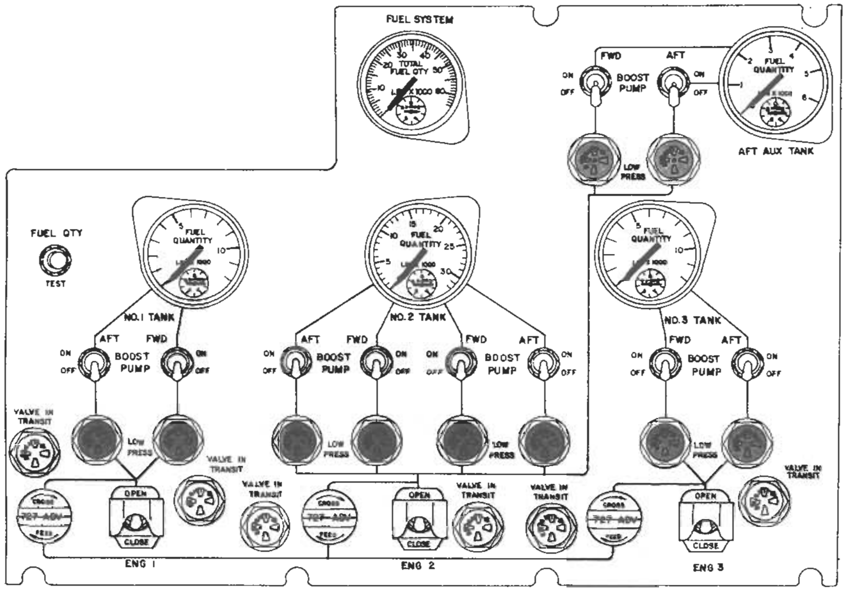

Fig. 1.2. The fuel panel. The second officer constructed his gestures in coordination with the spatial organization of this panel. The number three tank gauge and boost pump control switches are on the right side of the panel. The fuel quantity test button is at the far left.

Signs of a Fuel Leak

A crew uses the cockpit instrumentation and cues from flight controls and other aspects of the environment to monitor the status of the aircraft. The following are some of the signs that may be available to a crew when there is a fuel leak in tank three.

Flight Controls. A leak in tank three, which is located in the right wing, should cause the plane to roll to the left as the right wing becomes lighter than the left wing. This condition is called a lateral weight imbalance. In order to maintain a wings-level attitude with such a lateral weight imbalance, the control yoke would have to be tipped to the right. The need to adjust the control yoke is a cue to the pilots that something may be amiss. If the aircraft is on autopilot, however, the autoflight system would make the required control correction without notifying the crew. Although the autopilot system still physically tips the yoke, this visual cue is subtle, because the amount of displacement of the yoke may be small.

Instruments. Another sign of a fuel problem would be a greater decrease in one of the fuel tank quantity gauges relative to the other gauges as indicated by the gauge needle levels. On the 727-200, this information is available most readily to the S/O because the instrumentation is located on his panel.

What to Do in Case of a Fuel Leak

When a fuel leak is suspected, a typical response for the S/O is to press the fuel quantity test switch to confirm that the fuel quantity gauges themselves are operating properly. This test confirms that an irregular gauge indication is a result of the physical state of the fuel system and not a result of a malfunctioning gauge. Pressing the fuel quantity test button moves each of the fuel tank gauge needles simultaneously to different positions to test for responsiveness. When the fuel quantity test button is released, the needles return to their original positions.

Once the S/O confirms that the gauges are working properly, the next step is to locate the fuel leak. A leak could be in one of two places: in the tank itself or somewhere in the fuel line.

To determine if the leak is in the tank, the fuel must be isolated in the tank by turning off the boost pumps in that tank. If the gauge still indicates a decline, the leak is in that tank. If there is no decline in fuel quantity when the boost pumps are turned off, the leak may be somewhere in the fuel line. This is an even more dangerous situation than a leak in the tank, because the fuel may be escaping into the fuselage where it could ignite and destroy the airplane. An additional action that can confirm a fuel leak is to perform a visual check outside a cabin window

to look for fuel escaping from the wing. In a simulator, a visual check is simulated by asking an experimenter if fuel can be seen from the wing.

Another action must be taken before the diagnostic of turning off the tank three boost pumps is performed. An alternate fuel supply to engine three must first be established so that the engine will not stop working when the fuel it normally receives from tank three is no longer available. To do this, the cross-feed valves in the fuel lines between the new fuel source and engine three must be opened. Once this step is taken, the tank three boost pumps can be safely turned off.

The Second Officer Explains His Diagnosis

From the detection of the problem with the fuel system to the safe landing of the aircraft, the crew engaged in many kinds of activities. We examine the 24 seconds during which the S/O notified the captain and the F/O of the problem and explained how he had diagnosed the problem. The following is a transcription of the verbal behavior of the crew during this brief episode.

Transcription symbols:
\2\ Indicates a pause (here, a 2 second pause)
xxx Indicates an uninterpretable utterance

12.00.43	S/O	well it looks huh like a funny situation. we have a fuel leak or something \2\ in number three tank
12.00.50	Capt	hmmm
12.00.51	F/O	ohhhh
	F/O	xxx
12.00.56	S/O	I don't know we must be losing it very quickly you see right now I-\2\I turned the pumps off ok I tried to feed from number one to both engine one and three but we're still losing in number three quite a bit

In a previous analysis of the S/O's announcement of the problem and explanation of his actions regarding it, we began with the transcript of the verbal behavior and tried to show how the gestures supported the speech. It became clear to us, however, that this separation of speech from gesture and the removal of the gestures from the space in which they were performed distorted the phenomena. In the following analysis, we therefore try to show how space, gesture, and speech interact with each other, giving none of them precedence over the others.

The S/O turned in his seat to face the front of the airplane while addressing the captain and F/O. No gestures other than body orientation accompanied this announcement.

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12.00.43  S/O   well it looks huh like a funny situation. we
                have a fuel leak or something \2\ in number
                three tank
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The S/O's opening announcement was a call for the attention of the other crew members. The language the S/O used was explicit but indicated some uncertainty. A fuel leak is a potentially flight-threatening situation and requires the immediate and coordinated attention of all the crew members. After the S/O's announcement, the crew members collectively knew what the S/O suspected (a fuel leak) and where he thought the problem was located (in fuel tank three). With that information, the crew members prepared to attend to the problem.

Fig. 1.3. A frame from the video tape showing the 727 cockpit. The captain, first officer, and second officer are all attending to the fuel panel that is on the instrument panel at the bottom right.

By focusing their attention collectively, they created an environment that enabled them to collaborate and develop a shared understanding of the fuel problem. We

assume that the crew members' mental models of the fuel system were similar because they all received similar company training for the 727-200. Additionally, they all have access to the same manuals that describe the operation of the fuel system and fuel system procedures. Still further, typical airline career trajectories start in the S/O position and move to the F/O position and then finally to captain. In most cases all the crew members have had S/O experience.

A salient part of a pilot's understanding of a fuel leak is that it is a situation that must be dealt with quickly. In response to the S/O's announcement, the captain and the F/O turned in their seats to face the S/O and the S/O's panel (Figure 3). Each of them also produced a contentless verbalization with a rising intonation.

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12.00.50
Capt      hmmm
12.00.51
F/O       ohhhh
F/O       xxx
12.00.56
S/O       I don't know we must be losing it very quickly you see
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The very act of the captain and the F/O turning around to face the S/O and the fuel panel indicates that they heard the S/O's announcement and realized that their attention was needed. Once the captain and the F/O were situated, the S/O began his explanation of the problem without further prompting. As the S/O spoke, he turned in his chair to face the fuel control panel.

SPEECH	GESTURE IN SPACE
right now	placed index finger on, but did not depress the fuel quantity test switch

With the fuel system, there is always a question of whether what is observed is really the behavior of the fuel system or if it is simply a gauge malfunction. The S/O began by gesturing to (placing his finger on, but not depressing) the fuel quantity test switch while saying "right now."

There was nothing in the S/O's words about the fuel quantity test button. Pressing it in the context of a suspected fuel leak would have been a meaningful action. But the S/O did not press it. He only touched it. We believe that the other crew members interpreted this as an indication that the S/O had already tested the gauges (in fact, he had).

The words "right now" gave a sense of immediacy to the situation. They place something in the present time, but what it is not yet clear. The speech and the gesture seem to be working independently of each other here, each conveying a different sort of information about different topics.

SPEECH	GESTURE IN SPACE
I-\2\I turned the pumps off ok	brought index and middle fingers down onto the tank three boost pump switches which were in the off position

The S/O next made a motion over the number three tank boost pump switches that mimicked the motion used to turn the pumps off. The switches were already in the off position. The combination of the gesture and the state of the panel and the knowledge that boost pumps are normally on in flight made this action unambiguous. The words redundantly expressed that which the gestures had described, but the words also included information about temporal relationships that cannot easily be represented in gesture. Speech marked the gestures as a reenactment of what the S/O had already done. The verbal statement did not indicate which pumps had been turned off, but the fingers did. The location of the gesture in the space of the fuel panel resolved an ambiguous reference in the verbal stream. The verbal component provided temporal markings that were lacking from the gesture, and the gesture provided aspects of indexical reference that were ambiguous in the S/O's words.

If the pumps were off, one may wonder where the fuel for engine three was coming from. The topology of the panel facilitates certain inferences about the functional behavior of the fuel system, and the S/O next moved to demonstrate these inferences to the other crew members.

SPEECH	GESTURE IN SPACE
I tried	moved hand from the tank three boost pump switches **to the area** of the tank one boost pump **switches**

The S/O changed topics at this point and his gesture directed attention to the other side of the fuel panel where subsequent events would be described. He was now beginning to explain how he established an alternative fuel source for engine number three. The use of the past tense placed the action referred to in the past with respect to the present course of action.

SPEECH	GESTURE IN SPACE
to feed from number one	moved index and middle fingers up and down between the tank one quantity gauge and the boost pump low pressure indicator lights

Here the gesture and the speech were almost completely redundant. The gestures indicated the states of the controls that feed fuel from tank number one as the fingers moved along the lines painted on the panel that depict the pipes in the system that move fuel from the number one tank, through the boost pumps, and to the engine one fuel feed valve.

SPEECH	GESTURE IN SPACE
to both	hand raised away from the sufrace of the fuel panel

The S/O's hand lingered a moment near the controls for tank number one.

SPEECH	GESTURE IN SPACE
engine one	moved hand across the fuel panel to the area of the controls for tank and engine number three

The S/O pointed to the area of the engine number three cross-feed valve and main fuel supply valve while saying "engine one."

SPEECH	GESTURE IN SPACE
and three	moved hand back across the fuel panel to the area of the controls for tank and engine number one

In the brief statement, "I tried to feed from number one to both engine one and three," the S/O explained that he had remembered to feed fuel to engine three before he turned the tank three boost pumps off. The gesture accompanying this section was complex and quickly executed. The S/O pointed to the tank one gauge, to the tank one pumps (which were on), then to the engine three cross-feed valve controller, and to the engine one cross-feed controller. These gestures drew attention to the controllers that indicate that the valves were open and supplying fuel to engines one and three from tank one. Some of the motions of the hand also followed the flow of fuel through the system.

SPEECH	GESTURE IN SPACE
but	pointed with index finger to the engine three fuel gauge

Having established the alternate source of fuel for engine three, the S/O pointed to the engine three fuel gauge. This was the locus of the problem. The S/O marked with gesture a return to the topic of the fuel level in tank three and, with speech, a return to the present tense. *But* signals a logical disjunction. The elements that stand in disjunction are not yet clear but will be made clear by what follows.

SPEECH	GESTURE IN SPACE
we're	flicked the face of the engine three fuel gauge with middle finger

The S/O flicked the gauge with his finger. This is a common technique among pilots to free a gauge needle that is believed to be stuck. From a strictly functional point of view, this is a useless action. The S/O detected the fuel leak by observing the rapid movement of the fuel gauge needle. The fact that it was possible to detect the fuel leak is evidence that the needle is not stuck.

This flick was not performed in the S/O's original diagnosis and was not a report of a previous action. Rather, it was a new action performed while the other crew members looked on. Because this action was not functional, we might ask what other kind of role it might be playing here. For one thing, it returned the narrative to the temporal present. It was a way of emphasizing that the fuel level shown by the number three tank gauge is the salient problem. At a more abstract level of description, flicking a gauge is a way to produce an expected reading when an unexpected reading has been encountered. In that sense, this action could also be read as a assertion by the S/O that he would have liked the behavior of the gauge to be other than it was.

SPEECH	GESTURE IN SPACE
still losing	repeated jabbing motions at the face of the tank three gauge with the index finger

The S/O then emphatically gestured to the tank three gauge, while he said, "still losing." This last gesture drew attention away from the function of the needle (that which the prior gesture, the flick, demanded) to the actual fuel quantity level that the needle was indicating.

SPEECH	GESTURE IN SPACE
in number three quite a bit	moved hand away from panel and into lap

Finally, the S/O returned his hands to his lap indicating that his turn was completed.

The Multilayered Representation

The actions of the S/O produced a multilayered representation. Gesture was superimposed on the physical structure of the fuel panel itself, and the S/O's verbal account was superimposed on the gesture. If we want to understand what the crew members do, we must take into account the production and use of such complex structures. We will try to show what each layer contributed and why we cannot entirely separate the layers from one another.

None of the layers was completely coherent by itself. The panel provided a coherent depiction of the fuel system, but it was neither a representation of what the S/O had done nor even a representation of the state of the airplane. The fact that fuel was leaking from the wing tank was not represented in the instantaneous state of the fuel panel. It could only be inferred by comparing the rates of change of the tank indications over time.

The gestures performed on the panel nearly provided a complete account by themselves. They certainly formed a more complete and meaningful description of what was done than the S/O's words did. How can this be?

The Panel

First, the spatial organization of the panel is a central element of the usefulness of the panel as a communicative resource. The spatial layout of the panel is topologically (but not metrically) identical to the spatial layout of the fuel system that it depicts. Table 1 shows correspondences between components on the fuel panel and components in the fuel system.

IN THE SYSTEM	ON THE PANEL
Fuel tank	Quantity gauge
Fuel line	Painted line
Pump	Pump control switch
Pressure sensor	Pressure indicator
Valve	Valve control switch
Fuel flow established by valve position	Position of valve control with respect to painted lines

The topological relations among panel components (e.g., the quantity gauges, painted lines, and pump control switches) are the same as the topological relations among the system components (e.g., fuel tanks, fuel lines, and pumps). The actual mapping of the space of the fuel system onto the space of the panel is complex. Components that are higher on the panel generally correspond to fuel system components that are forward in the airplane. Components that are to the right on the panel generally correspond to fuel system components that are on the right of the airplane. But there are exceptions. The gauge and pump switches for the rarely used aft auxiliary fuel tank have been placed out of the way so that they do not interfere with the depicted relations among the main tanks and the engines. The panel is further simplified by omitting depictions of check valves that cannot be controlled from the panel.

The topology of the painted lines and switch positions creates a representation that permits the crew to do conceptual inferences with simple and robust perceptual skills. For example, figuring out where fuel will flow can be accomplished by visually following lines on the panel. The valve controller has a line painted on its top surface. When the controller is in the cross-feed position, this line appears to connect the painted lines that depict the fuel line arriving at and departing from the valve. The rotational action of the cross-feed valve controllers, combined with the shape of the controller knob, makes the open and closed states of the valve "look like" flow through or blocked flow. These may seen to be trivial design features, but they have important cognitive consequences.

Imagine valve switches of a different kind (e.g., toggle switches) and a readout that lists the name of the valve and its state in text format. With such a representation, it would be impossible to use simple perceptual skills to reason about the behavior of the system.

The simplified topology of the panel as a representation of the fuel system itself permits the pilots to reason about the state and behavior of the fuel system by "seeing" the panel in a particular way (C. Goodwin, this volume; Goodwin & Goodwin, in press). The fuel system itself as a collection of physical components cannot actually be seen from any real vantage point, but the pilots can "see" the fuel system by seeing through the fuel panel. In fact, only through seeing fuel panels and diagrams such as Figure 1 do pilots have any experience of the topology of the fuel system. As with any materially instantiated symbolic

representation, it is possible to see either the representation itself or to see the thing that is represented. Sometimes it is possible to see both at once. Understanding the S/O's performance requires several shifts in seeing. How do gesture and speech guide these shifts between the perceptual stance in which the panel is seen as a thing in itself and the perceptual stance in which the panel is seen as a representation of the fuel system?

Meaningful Gestures

The gestures superimposed on the space of the panel can be read as meaningful actions and courses of action on the fuel panel itself, or they can be seen as events in the fuel system. Seeing each of these things requires a different stance with respect to the panel. To see the gestures as actions on the panel, one must see the panel as a panel. To see the gestures as representations of events in the fuel system, the panel must be seen as the system that it represents.

The first meaningful gesture in this sequence is the S/O placing his finger on the fuel quantity test switch. The fuel quantity test switch differs from all other elements of the panel. All the other elements are in some sense "about" the fuel system, but the fuel quantity test switch is "about" a set of components, the quantity gauges, on the panel. This gesture must be read as being about the panel rather than about the fuel system. In order for the captain and F/O to interpret the S/O's gesture to the fuel quantity test switch, more than a shared understanding of its function was necessary. It was not enough that they all have a similar model of the switch's function. They needed to know that the others had a similar model of the function as well. This kind of intersubjectivity underlies all of the meaningful actions on the panel.

The procedure for diagnosing the fuel leak involves two distinct courses of action. The first course of action establishes an alternate fuel supply for engine three. The second course of action is to turn off the pumps in tank three and to monitor the gauge for continued fuel loss. These courses of action were executed in this order by the S/O before he notified the crew of the potential problem. The explanation he gave of his action, however, interwove the two courses of action, placing all of the second course of action in between the elements of the first.

We find it interesting that, although the order in which the actions are reported is not the same as the order in which they were executed, it is the same order that would be encountered in a traditional problem-solving account. The goal of turning off the boost pumps for tank three cannot be accomplished directly because it will cause engine three to flame-out (quit running). This leads to the creation of the subgoal of establishing an alternate fuel supply for engine three. Once this has been accomplished, the pumps can safely be turned off and the gauge monitored for further fuel loss.

The gestures acquire their meaning by virtue of being superimposed on the meaningful spatial layout of the fuel control panel. The same gestures produced in the absence of the panel would, of course, be quite meaningless. Enacted over the panel, though, these gestures take on meanings such as "turning off the pumps" and "the newly established path along which fuel is flowing." The functional consequences of the actions re-enacted in gesture by the S/O are easily seen by the other members of the crew.

Speech

The verbal layer of the representation does things that cannot be done in the other layers. For example, it uses tense markers and other linguistic devices to indicate temporal relationships among actions. Gesture by itself is always action in the present. The verbalizations place the actions in a temporal framework. This is what makes it possible for the S/O's actions to be seen as a re-enactment of action already taken rather than as a proposal for action to be taken.

Speech is also used to indicate the S/O's relationship to the actions and to belief states derived from the actions. The use of personal pronouns is interesting here. The S/O speaks of (1) his own state of knowledge, "I don't know," (2) a condition shared by them all, "we must be losing it very quickly," and (3) a relation between the captain and F/O to the shared condition, "you see, right now." Responsibility for actions and even for the flight in general are often implicitly expressed in the use of pronouns in such settings.

In this excerpt, speech is used to control conceptual and temporal relationships. Consider the words, "but we're still." There is a conceptual disjunction in the "but" and a temporal disjunction in the "still." The conceptual disjunction marked by the use of "but" is between the expectation that the level in tank three will not decrease if the boost pumps are turned off (in normal operation) and the fact that the level is decreasing. The temporal disjunction is between the past action that should have put an end to the decrease and the present fact of continued decrease. These disjunctions, together with the S/O's action of flicking the gauge with his finger, move the discourse back into action in the present time. In addition to expressing the S/O's relation to the gauge reading and shifting attention momentarily from the fuel system to the panel, the flick gesture brings the account back into the present tense. It is the only action taken on the panel during the explanation. All of the other gestures depict an idealized set of movements that the S/O's hands might have made in doing the diagnosis.

Discussion

Does gesture support speech? Clearly it does, but no more so than speech supports gesture. This example demonstrates the creation of a complex

representational object that is composed through the superimposition of several kinds of structure in the visual and auditory sense modalities. Granting primacy to any one of the layers of the object destroys the whole.

The physical layout of the fuel panel and its relations to previously encountered representations of the fuel system permit the crew to see the panel as an object in itself and as the fuel system it represents. This allows the gestures performed over the panel to be interpreted as actions taken on the panel, or as events in the fuel system, or both. The speech is used in part to manage relations that are not easily expressed in gesture and also to move from one interpretive mode to another. In this way, the whole is a complex interwoven performance. The properties of the crew and cockpit as a cognitive system are in part determined by the patterns and richness of communication among them. The space of the panel, the placement of the crew with respect to the panel, and the availability of hands for gesture all have consequences for the communicative possibilities in the cockpit. In order to understand the operation of such systems, it is not enough to understand the properties of individual cognition or even of individual decision making with decision aids (although such knowledge may certainly be helpful). Real world decision making often involves the creation and use of the sort of complex multilayered public representation described here.

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