Autopsy of an airplane crash: a transactional approach to forensic cognitive science

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Abstract In considerations of cognition in complex, technologically enhanced work environments, the question often concerns the boundaries of the phenomena to be researched. In classical cognitive science, the boundary of cognition is the brain case. More recent approaches, including distributed cognition and joint cognitive systems, draw the boundaries so that human operators and aspects of their environment are included; and the foci of the inquiries are interactions and representations that are passed around between players. This study makes a case for a transactional approach, which acknowledges a unity/identity of agent and environment. To understand the effect of agent characteristics in performance requires knowing the environment characteristics; and to understand the effect of the environment characteristics on performance requires knowing the agent characteristics. The approach is exemplified in the analysis of key instants of the spectacular and widely publicized crash of TransAsia Flight GE 235 in which 43 lives were lost. The transactional analysis exhibits the internal cognitive dynamic in the cockpit that actually explains why agents acted as they did (rather than what they did not do because situation awareness lacked). It is better suited as a foundation of forensic cognitive science than the classical view on human error.

Keywords cognition; joint cognitive system; self-action; interaction; transaction; situation awareness

1 Introduction

On February 4, 2015, TransAsia Airways Flight GE235 crashed into Keelung River (Taipei, Taiwan). The aircraft was destroyed upon impact leading to the death of 43 (3 pilots, 1 cabin crew, 39 passengers) of the 57 people on board. The crash was spectacular and became widely known because several dash cams and a rooftop CCTV recorded parts of the final moments of the flight, including a collision with a taxi (Fig. 1). The aviation occurrence report later would conclude that following a problem with engine 2 (right), the pilot flying the aircraft had shut down the remaining live engine 1 so that the aircraft was without any power. When the crew eventually discovered that both engines were off, it was too late to get engine 1 started again for a successful recovery of the aircraft. In the cockpit, the information available stated, consistent with instrument readings, that there had been a flameout of engine number 2. Even though the official occurrence report begins with quotations from a national act and the International Civil Aviation Organization directives that the purpose of an occurrence report is not to lay blame, the text of the report does so implicitly by noting many things that the pilot should have done but had failed to do. This includes that the pilot flying and in command (a) *did not* initiate a brief pertaining to a possible engine out, (b) *did not* comply with company procedure to reject the take off when the automatic takeoff power control system did not arm, (c) *did not* identify the engine malfunction, and (d) *unnecessarily* disengaged the autopilot after the master warning (ASC 2016). The report also states that the same pilot has had difficulties with this procedure during recurrent training. Key features of the official occurrence therefore concern actions not done. The report therefore fails to account for the unfolding of the actual cognitive processes inside the cockpit that actually led to those actions and the decision-making that left the aircraft crashing into the Keelung River.

««««« Insert Fig. 1 about here »»»»»

An important part of the report included a lengthy review of the literature on situation awareness with repeated references to the works of the scholar M. Endsley known for her work on the topic. Some aspects of the crash, thereby, are described in terms of the *lack* of situation awareness. Because this construct is widely used (cf. Carsten and Vanderhaegen 2015), scholars might not be surprised. Some go as far as suggesting that the concept of situation awareness is part of a "blaming game" (Dekker and Hollnagel 2004), exemplified in a particularly drastic case where a human operator was convicted because of a "'loss of situation awareness' that caused an accident" (Dekker 2015a). Although Dekker also provides examples, he does not actually look at the second-to-second unfolding of pertinent events, through the lens of the operators, which would allow the scholarly community to come to grips with the phenomenon of "drifting into failure." This requires understanding what the human agents perceive and what the motives are for their actions, that is, it requires an inside ("tunnel") perspective (Dekker 2014). One form of inside perspective into complex cognitive systems exists in interactional approaches that focus on the back-and-forth of the information (representations) exchanged within the system and the mutual effects that the constitutive agents have on each other (e.g. Hutchins 1995b). A very different, seldom adopted approach considers the system in *transactional* terms, which is based on the recognition (a) of an irreducible unity/identity of agents and environment and (b) that neither actions nor agents can be defined independently when the understanding of behavior is at issue (Dewey and Bentley 1999; Roth and Jornet 2013). The purpose of the present study is to make a case for the transactional approach to forensic cognitive science, which allows uncovering the internal dynamics within a joint cognitive system. The approach is exemplified in an analysis of two key instants of the ill-fated TransAsia Airways flight.

2 Self-action, interaction and transaction

A review of research that considers the role of the situation in cognition provides a useful (exhaustive) classification of approaches to modeling cognition: self-action, interaction, and transaction (Roth and Jornet 2013). In self-action models, human behaviors are explained in terms of independent actors, minds, mental models, knowledge, memory, mental representations, or forces; these are taken to be the drivers of events. Entities are treated as elements, as if they could be understood on their own, separated from the environments in which they normally appear. Most social sciences, and most approaches within each science, employ the *self-action* approach (Dewey and Bentley 1999; Roth and Jornet 2013). When research concerns the knowledge of agents, the experimental design involves some form of read-out to achieve the externalization of knowledge in the mind. The behavior of an agent can be predicted on the basis of the internal characteristics.

2.1 Self-action

In the self-action perspective, each action is considered in itself together with the intentions of the person articulating it. Any action and related cognition is completely understood once the mental model, internal representations, situation awareness, goals, plans, and scripts are understood (e.g. Endsley 1994a, b; Martins 2016). This self-contained explanation of actions and the cognitive activity producing it is symbolized in the closed circles; interactions are modeled in terms of three independent agents the effects of which add up to make the system (Fig. 2a). Consider fragment 1, which involves a pilot monitoring (PM) and a pilot flying (PF)[1]:

Fragment 1
01 PM: Engine flameout check
02 PF: check
03 PM: check uptrim . . . Yes

Here, the statement "Engine flameout check" may be termed to be an announcement irrespective of the function it has in and the effect it has on the unfolding event. In self-action models, this action is entirely explained by saying that the pilot has perceived engine flame out as the issue, built an internal model, called up the script for engine flame out emergency procedures, and now acts accordingly. Similarly, the "check" in turn 2 is termed a reply independent of its function. These actions are attributed to individual agents. The system then consists of the addition of these (verbal) actions. To be able to communicate, both agents have to have an internal model of the situation. The events in a cockpit from this perspective constitute a "weak form" of interaction because they are modeled entirely from the perspective of the individual (Agre 1997). The classical models in control theory and cybernetics are of this kind, for each component of a system are fully specified on its own; and all elements are then connected together to form the system through inputs and outputs from one element into another.

««««« Insert Fig. 2 about here »»»»»

2.2 Interaction

In interactional approaches, the *relationship* between agents is the focus of the analysis. The term interaction, in the strong sense, is used to mark that "two entities are acting reciprocally upon one another, back and forth, continually and symmetrically" (Agre 1997). Agent and environment still are understood as different things. Whereas there is recognition that each agent (broken circle, Fig. 2b) computes, the system is the result and understood in terms of the representations exchanged (sold lines, Fig. 2b). The agents and system are understood in terms of interaction sui generis, and analyses focus on those representations that are exchanged and their histories. Studies that employ distributed cognition or joint cognitive systems perspectives therefore investigate the information that is passed around and, thus, also connects the different agents (Hutchins 1995a; Woods and Hollnagel 2006). With respect to situation awareness, interactional approaches critique its use at the individual level and instead emphasize the performances of the system as a whole, leading to concepts such as collective, distributed, or team situation awareness (e.g. Millot 2015; Salas et al. 1994; Salmon et al. 2015).

The interactional approach generally is exemplified and used to exhibit well-functioning cockpits, where things work as intended (e.g. Hutchins, 1995, analyzes procedures that "come straight from the pages of a major airline's operations manual"). Thus, the "check" (turn 2) is recognized to be a reply because it is directly related to and arises from its position with respect to the "Engine flameout check" in the preceding turn, perhaps acknowledging the receipt of a piece of information. The functioning of the system is understood in terms of interactions that cannot be reduced to the individual agents because the analyses focus on the things that are exchanged, thus always involving at least two actors. But this approach places emphasis again on the individual player, who will have to take responsibility for misinterpreting what others (accident investigators) may take to be the obvious and self-explanatory representation transmitted.

[1] The tasks in a two-pilot aircraft have one pilot responsible for flying the aircraft (PF), whereas the non-fling pilot (here denoted by PM) must monitor and crosscheck management and operations of the PF.

Interaction models suppose the mutual forces of two or more agents or agents and their environments. The agents are modeled independently. When they collaborate, they are then said to somehow construct something together—e.g. negotiate "meanings"—and then internalize whatever has been constructed in cooperation with others. A main problem in interactional approaches is the establishment of common ground, or intersubjectivity, which is a result of the independent contributions of individual agents—e.g. see special issue on "awareness" in *Comput Support Coop Work 25*(6). The studies on the cockpit as joint cognitive system belong into this classification (e.g. Hutchins 1995b). Such studies focus on the information or representations that are passed between the different agents, thus recognizing three cognitive systems when (a) a *captain* reads values, which (b) the *first officer* records, and (c) the *information transfer* between the two (Henriqsen et al. 2011).

2.3 Transaction

Interactional approaches, such as realized in social constructivism and constructionism, have been subject to recent critiques, which point out that interactionism tends to focus on the social in a weak sense (togetherness of things and people) but fail to capture the social in the strong sense (the social as essence of things and people) (e.g. Latour 2013; Livingston 2008). These and other authors emphasize instead the transactional nature of life generally and social situations in the making specifically, where the unity of an act includes "its actual becoming and self-determination" (Bakhtin 1993). In transactional approaches, the organism and its environment constitute a single, irreducible system; "mental" activity is characteristic of this system rather than of any one of its component, e.g., the organism (Il'enkov 1977; Järvilehto 1998a, b). Transaction operates "without final attribution to 'elements' or other presumptively detachable or independent 'entities,' 'essences,' or 'realities,' and without isolation of presumptively detachable relations' from such detachable 'elements'" (Dewey and Bentley 1999). Some cyberneticists point out that even characteristics traditionally attributed to individual personality are to be understood as products of relations so that "it is nonsense to talk about 'dependency' or 'aggressiveness' or 'pride,' and so on. All such words have their roots in what happens between persons, not in some something-or-other inside a person" (Bateson 1979). In such models, it is impossible to cleanly separate the parts: neither actions and nor agents can be understood on their own (Bateson 1979; Snow 1992; Vygotskij 2001). They are all *part* of the systemic whole; and, as parts, they entirely reflect the whole. In a way, because each agent designs communicative acts *for* the other, thereby taking into account the other, it "reaches into" all other agents (see endpoints of transactional relations, Fig. 2c). Such "reaching *into*" another agent is apparent when we consider that the PM does not just say something, here "Engine flameout check," but indeed speaks *for* the other (i.e. has the other in mind, designs the message for the other), *in order to* get this other do something, using language that has come *from* the generalized other. Each act of speech therefore has the characteristics of speaker, recipient, and situation it pertains to. The italicized are examples of terms—including prepositions, adverbial phrases, and conjunctions—that manifest transitive relations rather than the connection between independent facts (James 1890). The transactional perspective thus challenges the idea of the bounded individual: " 'Inside' and 'outside' are not appropriate metaphors for inclusion and exclusion when we are speaking of the self" (Bateson 1979). Temporally and spatially, there are no boundaries because the trans-boundary flux of materials itself is constitutive of life (Järvilehto 1998a, b); mind is an effect of this coming and going (Mikhailov 2001). Similarly, "the boundaries of the individual, if real at all, will be, not spatial boundaries, but something like ... the bubbles that come out of the mouths of the characters in comic strips" (Bateson 1979). The transcriptions used here take into account this presence of the other in the self (see also Fig. 2c).

In this characterization, the transaction model therefore emphasizes the interpenetration of parts and actions (Fig. 2c). Mathematically, the system cannot be reduced to the independent description of the parts (agents, agents and environment) because the description of any one part always involves a feature of another part. Psychologically, this means that to understand how agent characteristics affect performance requires knowing the environment characteristics; and to understand how environment characteristics affect performance requires knowing agent characteristics (Vygotskij 2001). The environment samples from the agent, requiring and conditioning the latter's response; but each agent also samples the environment, reacting to and selecting specific aspects (Snow 1992). In a strong sense, therefore, the characteristics of actions cannot be ascribed to the agent, whose "characteristic, whatever it be, is not his but is rather a characteristic of what goes on between him and something (or somebody) else," that is, is a result of the "*transactions* between the individual and his material and human environment" (Bateson 1987). No models of situation awareness from a transactional perspective have been found in the literature.

2.4 Interaction vs. transaction

In the literature, the term "transaction," if used at all, tends to be employed in the interactional sense to account for the interplay between actors (e.g. effect of child on parent as much as parent on child) but do not question the nature of these actors (e.g. Gibson 1986). In contrast, transactional approaches emphasize the unity/identity of organism and environment (Järvilehto 1998a; Vygotskij 2001). The boundaries between the two approaches sometimes become blurred. Thus, scholarly texts may claim to go beyond interactionist ecological psychology and then make statements that clearly have no place in a transactional approach, such as the difference and independence of organism and environment (e.g. Agre and Horswill 1997; Bateson 1979).

3 The transactional approach: theory and method

The transactional approach here is exemplified in the context of a verbal exchange: the translocution is a special case of transaction (Ricœur 1986). Consider the retranscription of Fragment 1, which in addition to speaking also includes the fact that conversation participants are actively attending to speakers and receiving (are given) statements (individual words, phrases) the nature of which is initially unknown to them (Fig. 3). The first locution, "Engine flameout check," materially is the same for the participants all the while it differs ideally (Rossi-Landi 1983); this double view not only is characteristic of transaction (translocution) but indeed constitutive of the relation itself (Bateson 1979). To have any conversational and situation relevance, a thing or statement has to be common to speaker and recipient (Mead 1938). The minimal condition includes that the sound wave connects the vibrating vocal cords of the speaker with the vibrating eardrums of the recipient. This takes into account the psychological insight that in an exchange relation, the thing exchanged—here the word—is a reality for two but impossible for one (Vygotsky 1987). The saying therefore also is hearing. From the perspective of the listener, to hear what is said means both actively attending and receiving something that cannot be grasped as a whole until everything is said and done. Thus, we term this unit *corresponding*. It consists of *speaking for*, *actively attending to*, and *receiving from* another: corresponding = {speaking for | actively attending to | receiving from}.[2] We may therefore also speak of a translocution composed of two counter-flows. In corresponding, not only is there something transferred but also the interlocutors come to be a little more alike. Corresponding is a true transactional event: it involves active participation of both agents. In each constituent part of a transaction, therefore, there are afferent and efferent flows.

««««« Insert Fig. 3 about here »»»»»

The second part of the transaction is termed *responding* (Fig. 3, horizontal, solid boxes). Responding includes and flows from (i) *actively attending to* while *receiving from* the other to (ii) *replying to* in *speaking for* the other. Thus, responding = {actively attending to | receiving from | speaking for}.[3] This takes into account that the behavior of the subject defines the perceptual field, perceptual gestalts, and changes in the environment that may act as stimuli an act (Järvilehto 1998a). Concerning the first part, the sound-words do not just arrive as a package taken as is or interpreted once it is received. Instead, life is durational, which means that statements are not given as a whole but reveal themselves in time (see time axis in Fig. 3). As the words unfurl (e.g. "E n g i n e . . .") they are transformed in preparation of a reply (Vološinov 1930). The second part of the responding event is replying. In a strict sense, in replying the current speakers not only speak to others but also come to know the results of their own thinking: it is in speaking that thought becomes itself (Merleau-Ponty 1945; Vygotsky 1987). A transaction therefore includes two events, corresponding and responding, each of which is transactional. These two are not independent because they have one part in common. Each of these parts common to the two transactional events is itself transactional because oriented in two directions simultaneously. If a thing exchanged is ambiguous (e.g. the verbalization "check"), then this is not because of different interpretations

[2] Philosophers characterize units that have a gap within themselves or being spread over different parts by means of the adjective *dehiscent* (Waldenfels 2006).

[3] Philosophers characterize temporally dislocated units, which fall apart but remain connected, by means of the adjective *diastatic* (Waldenfels 2006).

("meanings") but because of the (transactional) nature of the thing (Marx and Engels 1962). Consider part (b), which refers to the pilot flying (PF) actively attending to the PM and receiving what he says: while attending to and receiving from the other (PM), the PF is oriented toward replying.

The analysis actually requires a further step. From the perspective of the PF, to know whether his reply has had any effect, he needs to *monitor* the reply (turn 3, f). That is, the "check" (turn 2, d) originates in turn 1 (a), and the result of that verbal action is available to the PF only in turn 3, f. Any thinking related to the "check," therefore, has its genetic origin with an event outside the PF and ends with something that is happening outside of the PF (cf. Agre and Horswill 1997; Il'enkov 1977). Once considered in this way, the "check" (turn 2, c) is part of a transaction that also includes actively attending and receiving (turn 1, b; turn 3, f). To understand the dynamic of a situation, why an event evolves in a way it does, why participants say what they do requires such an endogenous perspective—though the effects and the conditions also require an outside, third-person perspective of the kind that shapes the analysis of the self-action and interaction approaches.

With respect to communication, transactional approaches accept as premises that (a) only a limited part of what is happening is available to the consciousness of participants; (b) everything that is happening fits into one of a range of sense-giving contextures, and thus are taken to be non-accidental; (c) communication is recipient designed; (d) the lived-in situation is taken as the common ground; and (e) participants in communication presuppose a shared understanding of the signal (Bateson 1996). This framework now may be extended without limitation to include not only words but also other forms of signs, such as hand/arm gestures. A second extension includes the machine player[4] and the environment. Thus, for example, whether pilots attend to a hand gesture or work-related movement, an instrument, the rattling produced by the stick shaker, or a feature visible outside the window, it is treated as something given in and to their perception. In addition to hearing (Fig. 3, b, d, f), seeing, feeling, and smelling (in case of fire) are pertinent receptive events. The machine player, too, has a variety of sensors oriented toward the pilots or parts of the aircraft (e.g. torque sensors).

One important issue in the "blaming game" is the inappropriate comparison of (i) what is available to agents while things are happening and (ii) what is known with hindsight (Dekker 2015a). Before replying (action, talk) begins, there is an *in-order-to* motive (Schütz 1932)—unless there is a simple stimulus–reaction chain. The in-order-to motive has the function of a plan for what is to come. Humans act in view of something to be achieved, and this something does not have to be fully articulated at the instant that the action begins. But such plans do not have causal force. Instead they constitute an orientation and disposition toward the action to come (Suchman 2007). It is only after the fact that the agent can justify the past action by means of a *because* motive, which is selected *in light of the outcome* (Schütz 1932). That is, causes are always implied after the fact from the actual (historical) course of events. A transactional analysis of the physiology of the stimulus–response event shows, the stimulus is only part of a systemic organization that realizes perceptual results and responses (Järvilehto 1998a).

4 Empirical background

The purpose of this study is to make the case for a *transactional* forensic cognitive science. To exemplify the method, an extended case study is provided to show the inner workings of the cockpit system of TransAsia Flight GE235.

4.1 The data sources

The data for the exemplifying analysis include: the transcriptions of the flight data recorder (ASC 2016, pp. 187–190), the cockpit voice recorder (ASC 2016, pp. 166–186), additional information provided in the 299-page report, and relevant information from Google 2D and 3D maps. The analyses take into account the discussion of the flight data recorder (FDR) materials by pilots and aviation technicians in a relevant online forum.[5] During the flight, the GE235 pilots used both English and Chinese words and statements. The report provides a transcription of the original audiotape together with a complete translation into English.

[4] The term "machine player" is used to highlight that some of the events in a joint cognitive system occur in computers and computing systems (Henriqsen et al. 2011).

[5] https://www.reddit.com/r/aviation/comments/2uyy3n/engine_flightdata_readout_for_the_ crashed/

4.2 Data analysis and analytic background

The study situates itself in the literature on complex cognitive systems that include human beings (e.g. Bateson 1987) and draws on an associated empirical toolbox dealing with verbal, proxemic, gestural, and intonational dimensions of communication (Bateson 1996, McQuown et al. 1971). The approach to the data analysis is exemplified in Section 3. The method reconstructs from the transactions and translocutions what was salient to and transacted upon by the different parts of the system. In many instances, it may be impossible to reliably reconstruct the contents of awareness.

From an analytic perspective, one shortcoming of the CVR transcription is that it only marks the timing of the beginning of a turn at talk; it does not mark its extent or the pauses between words and between speakers. This makes it impossible to conduct analyses of cockpit communication that are standard in the fields of applied linguistics and pragmatics (e.g. Nevile 2004b, 2007). But the two transcriptions provided below (Figs. 5, 7) physically render the approximate length of each turn at talk. The accident report provides precise beginning and end times of events, whereas only marking the beginning of others (e.g. a single chime).

This author has conducted research on debriefing and pilot assessment in airlines using the same aircraft but with the older analog cockpit that the crash pilots also had been trained on. As part of this research, the author has had numerous opportunities to accompany pilots on regular duty (i.e., sitting in the same jump seat that the observing pilot used in the crashed aircraft). The author also has flown the full-motion simulator of this aircraft, conducted observations in the simulator during biannual recurrent training and assessment sessions.

4.3 Brief history of the flight and location of analytic objects

The analyses focus on two brief, but after the fact crucial episodes of TransAsia Flight GE235 (Fig. 4). These occurred when, soon after the master alarm and information in the cockpit consistent with an engine 2 (ENG2) flameout, the pilot flying (PF) reduces the power of the live engine (see below). At the time of the second episode, the aircraft heading was 120°, as specified on the departure chart for the Songshan Airport. At the end of the second episode, unbeknownst at that time to the pilots, the aircraft is without power. The map of the flight shows that the aircraft follows the river for a while at a magnetic heading of 50°, then rolls to the right until heading 110° before rolling left again and eventually crashing into the river (Fig. 4). During the remaining time, the pilot monitoring (PM) calls ATC to announce mayday the flame out. They turn the autopilot on (10:53:46–10:53:50), but then repeatedly turn it on and off (10:53:58–10:54:04). Stall warning and stick shaker come on. At 10:54:07 the PM states, “No flame out … we lost both sides,” to which the immediate reply is a command to restart the engine. The crew attempts seven times to restart engine 1 (ENG1), without success. At 10:54:27, the captain states a realization: “Wow … pulled back the wrong side throttle.” Only 9.5 seconds later, the cockpit voice recording ends, terminated by the crash. Immediately preceding the crash, the aircraft, having entered aerodynamic stall, increased its bank angle from 10° to 80°. The dashcam recording shows that its left wing struck a taxi and then the fence next to the highway (Fig. 1).

««««« Insert Fig. 4 about here »»»»»

4.4 The human players

On that flight, there are three pilots present in the cockpit. The pilot in the left-hand seat has the rank of captain and has accumulated 4,915 hours of flight time, 251 of which were on the ATR 72-600 (twin-engine turboprop with digital instruments). Before he has flown the same aircraft with the analog cockpit (ATR 72-500, same twin-engine turboprop but with analog instruments); according to the manufacturer, the two aircraft are equivalent so that pilots require only differences training but not a new type rating (i.e. full training and licensing on a new aircraft). He commenced his upgrade-to-captain training in April 214 but failed the simulator check. Among others, the examination report states insufficient knowledge of procedures with respect to engine flame out at take off, failure to follow standard operating procedures for engine fire, and shortcomings in cockpit management and flight planning. During line training, the instructor also noted “insufficient knowledge leading to hesitations in . . . ‘engine failure after V1’ situation during the oral test” and “hesitant when facing situations that require making decisions” (ASC 2016).

During the differences training (i.e. between -500 and -600 versions), the instructor noted problems with the engine failure after take off and task sharing.

The pilot in the right-hand seat also is at the rank of captain. He has accumulated 6,923 hours of flight time, 795 of which were on the ATR 72-600. He passed all previous checks successfully, instructors and examiners always noting “satisfactory” and “good job.”

The third pilot sits on the jump seat (behind and between the other pilots) and is on the flight for training purposes. He is first officer and has 8 flight hours on the ATR 72-600. But he is a very experienced pilot having accumulated 16,122 flight hours as captain on another aircraft type. In 2008, he completed his training on the ATR 72-500. Initially failing the simulator check, his subsequent performance was rated satisfactory. During the training on the -600, it was noted that he should be paired with an experienced captain.

5 Transactional analysis of two segments of TransAsia Flight GE235

The purpose of this study is to make a case for a transactional forensic cognitive science, a discipline investigating the operation of complex cognitive systems during events that end in accidents with or without fatalities. In this section, the transactional approach is exemplified in the analysis of what after the fact turn out to be two crucial segments of the event.

5.1 Analysis of a system’s initial response to a master warning

In this section, an analysis is provided of the moments surrounding a master warning signal that is associated with the information that the machine player (MP) makes available to other parts of the cockpit system.

5.1.1 Data for flight fragment 1: pull back of power lever PL1

The materials provided here include the transcription of the cockpit voice (and sound) recorder (CVR) and some information from the flight data recorder (FDR), in part represented precisely in the way it was available in the cockpit environment (Fig. 5). Thus, for example, the transcription features the top part of the engine and warning display including the torque, NP (propeller speed), and ITT (temperature) gauges (top right, Fig. 5). Also featured are the power levers after a first reduction of power has occurred (Fig. 5, bottom right).

««««« Insert Fig. 5 about here »»»»»

The transcription shows that the master warning begins while the pilot monitoring (PM) talks to the control tower. There is a verbal exchange over who has control. The pilot flying then pulls back power lever PL1 all the while the panel shows that ENG2 has no more torque. ENG2 has been feathered and the power of ENG1 has been increased (up trim), changes that are brought about by the automatic takeoff power control system (i.e. part of MP). Following the pull back, the PF *formulates*[6] the action, leading to the request to wait. But the system is carried away by an immediately following identification of the flight mode to be used that leads into the formulation of future action as “continuing.” The accident report calls the action of the PF inappropriate because it is inconsistent with the standard operating procedures, and it identifies the source of the failure in a lack of situation awareness: pulling back power lever PL1 in the face of the malfunctioning ENG2.

5.1.2 The perception and resultant “mental model” of a machine player (MP)

In this crash, the master alarm is associated with a sequence of events initiated by the automated take off power control system (ATPCS): the auto feathering of propeller 2[7], shut down of ENG2, up trim of

[6] The verb *formulate* is part of the theoretical discourse in the discipline of conversation analysis to mark when social actors describe what they are doing for the purpose of making this action salient to other actors. In the aviation community, the same is referred to as *verbalizing* an action.

[7] Feathering refers to the movement of the propeller blades parallel to the flight to reduce their spinning and the friction.

ENG1[8], and an engine flame out message on the engine and warning display (see Fig. 5). That is, the machine player has begun to act and communicated based on the assessment that ENG2 has a flame out. However, the accident investigators found no sign of any malfunctioning in ENG2. Indeed, they found that broken soldering joints in autofeather unit 2 (connecting it to the one of the two ENG2 torque sensors) may have been responsible for the autofeather request and a low torque reading. They knew from the cockpit voice recorder that the ATPCS had not armed while accelerating, but then came on just upon take off. That is, the ATPCS worked intermittently. The report therefore notes that “an intermittent discontinuity in engine number 2’s auto feather unit (AFU) *may have* caused the automatic take off power control system (ATPCS) sequence which resulted in *the* uncommanded autofeather of engine number 2 propellers” (ASC 2016). As a result, the machine player “perceived” an engine flame out when there actually was none. At that stage of the flight, the internal representation (mental model), as read out to the pilots, is “ENG2 FLAMEOUT AT TAKEOFF.”

One may be tempted to lay blame with the soldering point in the autofeather unit where the discontinuity occurred, suggesting that it triggered the event. But the signal is signal only in the overall organization, involving the subsequent “interpretation” on the part of the autofeather unit and what it sent to the cockpit instruments. The “interpretation” is the result of the design, itself the endpoint of a response to issues in the history of building aircraft. That is, the mental activity—sensing and mental modeling of a failure and corresponding with the pilots—is the result of an organization of the system as a whole. Fragment 2 shows how the pilots take up the master alarm part of the MP’s report.

Fragment 2

Agent	**Turn 1**	**Turn 2**	**Turn 3**
ENV:	ENG2 working		
MP:	(perceives) ENG2 flame out	(says) continuous repetitive chime [CRC] (writes) ENG2 FLAME OUT (does) autofeather ENG2 (does) up trim ENG1	
PM:		(hears) CRC	(does) turn off CRC
PF:		(hears) CRC	(hears) turn off CRC
MP:			(feels) turn off CRC

The fragment shows how what was happening in the cockpit during Flight GE235 actually gets started: The machine player (MP) perceives an ENG2 flameout, which begins the event of responding, the second part of which are an aural signal (continuous repetitive chime, CRC) and a written announcement (“ENG2 flameout”) on the engine and warning display (Fig. 5). Hand in hand with the announcements go an autofeather of ENG2 and an up trim of ENG1. Both PF and PM are attending to and receiving the correspondence, the former acknowledging it with an expletive and the latter by stopping the chime. That stopping arises from a communicative action (pushing button) that “asks” MP to turn off the chime. MP is responding by turning it off. From the push of the button, the MP also “infers” that a human player has taken note; and the PF can know from the silencing of the master alarm that the PM has acted and, thus, is aware that something is going on. In this way, the situation is unfolding.

From the perspective of the self-action model in this expanded approach that also accounts for the machine player (MP), the faulty perception on the part of the system is at the origin of a sequence of events. The interactional approach focuses on the information received on the part of MP. The transactional model does not attribute unique status to the information exchanged but emphasizes the commonness in the material (sensual) dimension that goes together with the difference in the supersensual dimension. From the perspective of MP, it has acted consistently with what was given in its perception, and it has received information that at least one human player has acted upon its communicative act. Just as an inexpensive

[8] Up trim means that the torque on the engine increases from the 90% it is operating at to 100%, thereby compensating for the lost power of the other engine.

malfunctioning O-ring was part of the events in the Space Shuttle Challenger disaster, malfunctioning solder joints are part of the events that end with the crash of GE235.

5.1.3 Faulty perception, misinterpretation, trigger

The occurrence report—taking a self-action approach that does not account for the machine player in the way Endsley (1994a) models such situations—lays blame by stating what the PF did not do or inappropriately did. For example, it states that the standard operating procedures "required the PF to announce the failure . . . however, the PF *did not* command 'engine flame out at take off memo items'" (ASC 2016). At the same time, the report fails to state that the standard operating procedure states that for the "first CM [command] who detects the engine failure calls loudly 'ENGINE FAILURE'." Following the call, the PF is to order, "Engine flame out at takeoff memo items." The pull back is the visible reply to the situation, which includes the master warning and the confirmation that he (PF) is in control of the aircraft.

As part of his reply to the master alarm, the PF pulls back PL1. Replying does not originate in "a lack of situation awareness." From a transactional perspective, whatever the pull back is replying to is a "disturbance in the environment … [that] is *an integral part of* the behavior" (Järvilehto 1998a). We may not know with any precision what the pilot is attending to—unless he lets it be known in some way—but decrease or lack in situation awareness does not explain the pull back. The master warning may have been a trigger that is itself part of the system behavior (Järvilehto 1998a), setting off an evolving transaction sequence that will be leading into the shut down of ENG1. Thus, the accident report notes that in recurrent training and assessment, flight examiners more frequently fail ENG1 than ENG2. In this way, triggering and pulling back ENG1 is part of a patterned way of responding of systems that include this PF. It has been noted that pilots do not represent and process information. Instead, when triggered, entire aviation-related kinetic sequences unfold in the way a melody unfolds (Roth et al. 2015). In this case, no further internal processing—interpretation or other cognitive process—needs to be invoked for understanding and explaining what has happened. That the signal may remain a simple trigger is the result of the context remaining the same (Learning II), whereas transcontextual learning (Learning III, learning to learn) is stimulated when the triggers continuously change (Bateson 1987).

5.1.4 The increase in complexity of environment and information for the human players

A master warning comes with an explosion in the informational complexity that the cognitive system has to deal with. In the case of an ENG2 flameout, there are master warning signals in aural and visual form. The master warning light illuminates and the master warning sound, a continuous repetitive chime comes on. On the engine warning display, just below the engine instruments, there is a red display stating "ENG 2 FLAME OUT AT TAKE OFF" (Fig. 5, top right). Associated with the engine flameout, there are changes in the engine display, which are the consequence of an action sequence initiated by the ACTPS that is armed during the acceleration phase on the ground. The torque of the affected decreases to $TQ = 0\%$. There is an issue, however, with the torque of ENG2. The aircraft systems manual from the manufacturer shows that the autofeather unit controls the pointer, whereas the engine electronic control, which receives its signal from the second torque sensor, controls the digital display. On Flight GE235, the torque gauge for the right ENG2 may thus have featured different values for the pointer and digital displays. In this case, therefore, the MP would have produced a contradiction on the engine and warning display. While the ENG2 torque reading decreases, that of ENG1 increases to 100%. This increase is referred to as the "up trim." Together with the changes in torque are associated changes in the angle of the propellers; this change is referred to as "auto feather" and results in the rotation of the propeller. These changes in propeller rotations are denoted as NP; the NP value of the live engine remains at $NP = 100\%$, while the affected engine drops to around 10%. The engine warning display, in addition to showing the actual instrument readings, also have additional visual information that the auto feather and up trim have occurred (Fig. 5, top right).

5.1.5 Actions increase workload and information

Some actions, rather than dealing with the increased information and complexity contribute to further augment it. Actions within the system have communicative functions (Nevile 2004a, b). These therefore contribute to the complexity of a situation already more complex than normal, which then requires further cognitive processing (Roth and Mavin 2015). As these authors note, observers (e.g. assessors of pilot performance) of such cockpit events then are led to describe them as “messy” and “untidy,” often invoking “loss of situation awareness” for describing and explaining what is happening.

The transcript shows that while pulling back PL1, the PF also turns off the autopilot (Fig. 5). As a consequence, the PF now hand-flies the aircraft. Hand-flying is particularly challenging in this situation, because a stalled engine makes the aircraft want to yaw (horizontally deviate from its course); this tendency is decreased by the “auto-feather function,” which turns the blades parallel to the flight direction and thereby decreases air resistance. Hand-flying the aircraft forces the pilot to attend to correcting the aircraft’s yawing tendency. He therefore has to attend to aspects of flying that the autopilot part of MP could have done. This limits the attentional and cognitive resources of the PF available for other aspects of the flight and communication. The transactional perspective shows the complexity of what is happening on the inside of the system as a whole.

The AP may be turned off with a button on the control column. That is, when the PF pushes the autopilot button, the effect is that the MP receives the signal and replies in turning off the autopilot. The MP’s reply also includes an aural announcement that the autopilot is disengaged in the form of an auditory cavalry charge. The occurrence report does not state how long the sound of the autopilot disengagement can be heard. If it were only short, this would mean that that the warning signal was turned off, which the PF may do by a second push of the autopilot (AP) button or which the PM might do by pressing the button on the AFCS panel. In addition, a visual “AP OFF” appears on the advisory display unit (ADU), and the green triangular lights left and right of “AP” on the automatic flight control system (AFCS) control panel go off.

The cavalry charge, the AP/OFF, and the green arrows next to AP on the advisory display unit are available to be perceived on the part of the PF, who, in pushing the AP button again, requests the MP to turn off the AP/OFF light and the cavalry charge. The MP accepts the request by implementing the requisite actions. This again exhibits the transactional nature of responding and the inner connections between attending, receiving, and replying. We observe here an event in the system as a whole consisting of the unity of a range of actions. MP turns off the autopilot, but this turning of has its origin outside of this cognitive agent, and the end result is available outside of this agent—information is available to all three pilots that the AP is turned off now. The initiating action is unavailable to the other pilots of Flight GE235 given the geometry of the situation. But the results clearly are available in the public arena. On the part of the PM, the situation becomes more complex when the sound of the autopilot disengagement and the associated visual information overlaps with the articulation of “you have control,” which itself is in reply to, and confirms, the PF’s earlier announcement that he has control.

In the case of the AP/OFF, the MP enacts the command and reports back in aural and visual form. But there is no additional feedback (reply). The PF already knows he has turned off the AP, and the aural and visual signals are confirmation to him that he has done it. He hits the AP button a second time, which turns off the signals. In the contexture of the cockpit designers, the AP/OFF red light and the cavalry charge may have the function of alarms, as if saying, “Do you really want to turn off the AP?” Within the cockpit, a different figure/ground contexture may exist, where the AP/OFF red light and the cavalry charge function as forms of communication. In this instance, the PF pushes the AP button on the control column, which the PM and observer cannot see. But they know that this event has happened when they hear the cavalry charge and see the AP/OFF red signal; and they can see the two green arrows next to the AP button on the AFCS go off. Thus, we are in a situation where neither the system nor the two other pilots present question the AP disengagement. The cockpit as a whole just carries on. In such instances, the unfolding silence itself is a confirmation that what has happened is unproblematic (Roth 2004).

5.1.6 The communicative dimension of actions

Actions not only get things done and change the environmental part of the situational whole but also communicate. Thus, when the PM sets the heading mode near the end of the transcription (Fig. 5), this movement is available to others present, who, thereby, also come to know that the action has occurred. This also is the case with the pull back of PL1, which will turn out to be integral part of the fate of the aircraft. Thus, fractions of a second after turning off the autopilot, the PF pulls back PL1 (Fig. 5). He begins the verbal articulation of a power pull back just as the pull back is completed. Further information on such a change is apparent from the engine warning display, where the torque has returned to TQ = 90%. He does so in the presence of information that ENG2 is shut down and ENG1 is operating at more than normal power (Fig. 6). This does not mean, however, that the PF disserves blame. The pull back is available to the MP, who only replies in reducing the power of ENG1 from 100% to 90%. The pull back also is available to the two other pilots (Fig. 6); and it therefore also constitutes a form of communication and information (e.g. Hutchins and Palen 1997; Nevile 2004a). We do not know which of these multiple gestalts available to be perceived originate the PM's reply; but in saying, "Wait a second. Cross check," he completes the response as a translocution. There is no evidence, however, that this verbal action is taken up. In the pause prior to the next pilot statement, there is a single cavalry charge (Fig. 5), which is normally associated with an AP disengagement. On the FDR plot, however, there is no change in the AP signal to show whether the AP might have been turned on and off again. In this way, even if at that moment the PM has a private sense that something is not right, it does not come to be available as information within the cognitive system as a whole.

««««« Insert Fig. 6 about here »»»»»

5.1.7 Attending to emergent issues

In the classical approach to cognition, the individual pilot builds an internal model of the external situation (e.g. Endsley 1994b). Alternative approaches exist in artificial intelligence research, where the situation is taken as its own representation and the situation is transformed from one state into the next (Agre and Horswill 1997). These are "prepositional and conjunctive states of mind [that] are not remembered as independent facts," and they exist on their own rather than through representation (James 1890). In a transactional approach, this means a self-transformation of the system in which one state is the condition and origin of the transformation into the next state. For better or worse, the system is attending to emergent issues. In the present situation, the transcription shows no apparent reply to the statement "wait a second, cross check" (Fig. 5). The PM does not continue or follow up—e.g. by announcing the type and source of failure (i.e. ENG2 flameout) and doing the checks normally to be done (and visually available on the engine and warning display below "ENG 2 FLAME OUT," Fig. 5). Instead, the next verbal articulation has the PF say: "heading mode." We do not know the origin of the statement, the actively attending and receiving to which it is replying. That is, we do not know what the PF attended to and received, so that the "heading mode" was the most reasonable reply. Indeed, "heading mode" is one of the autopilot modes, which, when activated, makes the aircraft head in the specified magnetic direction. We do not know how the PM responds, whether it is with decreasing pitch as in an affirmation and confirmation or with a pitch so that it can be heard as a question. The reply begins with an "okay," which thereby also makes a statement that all is right given the circumstances, leading into a statement of an in-order-to motive: let us continue. When the PM replies without adding, modifying, or even contradicting, what is said can thus be heard as confirmation/affirmation. At that point, then, nothing and nobody has told the PF that the action to reduce the power was inappropriate. It *is* the current state. Within that perspective, it therefore makes sense to note: "okay, let us continue." This is again a simple transformation of the state of the cockpit-in-flight in that it contributes a formulation of the in-order-to motive for what is to be done in the impending future.

5.1.8 State of the cognitive system at the end of the flight fragment

The preceding analyses feature that fragment of Flight GE235 in which begins the shutdown of what we *now* know to be the live engine. Classical situation awareness scholars may suggest—as insinuated and implied in the incident report (ASC 2016)—that the PF has lost or lacks situation awareness. Critics of the classical position will quickly note, however, that the PM and the observing pilot do nothing about the pull back of PL1 even though it is an apparent part of the events in the cockpit. The transactional analysis above shows how, in not acting, the other parts of the system produce confirmations for the PF. There is one part of the cognitive system that is indeed "aware" of the ENG2 flameout, auto feathering, and up trim of ENG1: the machine player (MP). But the MP "says" nothing when the PF pulls back the power lever and, therefore, counteracts the immediately preceding up trim that the ATPCS sequence has triggered. The MP "sits back" and watches without doing or saying a thing, just as the PM and the observer do.

The analyses show how the event gets under way when the MP perceives information consistent with what it knows to be an ENG2 flameout and reports this interpretation to other parts of the cognitive system. The analysis emphasizes that everything contributing to beginning of the ENG2 flameout response are "aspects of the organization and dynamics of the whole organism—environment system" (Järvilehto 1998a), which ranges from the engine 2 and the associated sensors of MP to the human players. In the organization of the system, the different “nervous (sub-) systems” (neurons in humans, electrical circuitry in machines) are but integral part of the whole (Järvilehto 1998b). It is only because they contribute to the transactions of *responding* and *corresponding*, that is, to transactional events, that they come to be active parts in shaping the system to produce behavioral results.

The events are under way and it will be known only later that the system has set itself up for its own destruction. In the analyses thus far, there is more than can be found in the accident report and the content of self-action and interaction analyses; but there is also less. Ungrounded assumptions about situation awareness do not appear here; indeed, the notion of situation awareness no longer has a function because both corresponding and responding involve actively attending to and receiving data that another actor produces to be received and understood. It is precisely because the human players are attending to and receiving from the environment that the situation is continuously transformed leading to new gestalts to be attended to and received. The situation is of the system’s own making. But rather than a lack of situation awareness—which may equally be attributed to the MP when it perceived an ENG2 flameout that likely did not exist—researchers might invoke the human factor *management*. In this situation, turning the autopilot off is a critical aspect of managing the situation. As the research on debriefing in aviation shows, flight examiners tend to emphasize the crucial role that the autopilot may play in high workload situations and thus the need to make use of it so that pilots are freed up to attend to the many other issues which arise (Roth 2017). One might therefore anticipate that it is very important from the systems design perspective to include an extra step between the human and machine players to verify that turning off the autopilot in an engine flameout situation is indeed the desired action. The same is the case for the pull back of PL1, because the extra power, here delivered by the up trim, is especially important in single engine situations.

5.2 A system shuts down its power and (unknowingly) destines itself to failure

In this section, the events on GE Flight 235 that led to the ultimate shutdown of the live engine are analyzed. To exemplify the transactional perspective, any stretch of the flight could have been chosen. This particular fight fragment is of interest because it is only with hindsight that one can say with certainty that what was unfolding will have been part of the history of a doomed flight. This knowledge was not available to the pilots at the time. To understand why the pilots have acted in the way they have requires us to take the transactional perspective, and look at the events *from the inside* so to speak.

5.2.1 Data for flight fragment 2: complete shutdown of engine

There are 17 seconds between the two flight fragments analyzed here (see Fig. 4), together containing the events around the pullback of power lever PL1, which, as known to the pilots only later, shut down the remaining live engine. During the time between the two fragments, the pilots attend to the heading mode, check the speed, and the PM finally announces an engine flame out check, without actually naming the affected engine. He conducts the up trim and autofeather checks, as described in the standard operating procedures, and receives an “okay” from the PF. It is at this point that the second fragment begins (Fig. 7).

««««« Insert Fig. 7 about here »»»»»

In the course of the second fragment, the power lever of ENG1 comes to be reduced from 66° to 49°, then 40°, and finally to the flight idle position at 35° (Fig. 7, center right). At the beginning of the fragment, the engine and warning display still features ENG2 in auto feather and ENG1 in up trim. The transcription also shows that the PF advances the power lever PL2 from the 75° mark to maximum power at 86° just after the stall[9] warning and stick shaker come on (Fig. 7, center panel shows final power lever positions). The stick shaker is a mechanical device that moves the control column rapidly and noisily, thereby warning the pilots of an imminent stall. Three seconds later, the system activates the stick pusher, an electromechanical device designed to move the control column forward and thereby to pitch the nose of the aircraft down in the attempt to prevent the imminent stall. The aircraft pitches down, as seen in the primary flight display (bottom panel, Fig. 7), where the aircraft symbol (2 dark L-shaped configurations on the side) stays at -7°. At the same time, the flight director still points the aircraft to be flown to a pitch of +8° (see green horizontal line), thereby providing contradictory information to the pilots. This contradiction, though it is recognized by the occurrence report as not likely to have contributed to the crash, is pointed out in the

[9] In a stall, there is no longer sufficient lift on the wings to pull the aircraft upward; among others, a stall may occur when the speed of the aircraft is too slow for a given angle of attack.

report as an item to be addressed by the manufacturer. The cockpit voice recorder (CVR) transcription shows the exchange mainly between the PF and PM, announcing the pull back (PF), confirming ENG2 flameout (PM), and an issue with the terrain (PF, PM). The PM twice says, “wait a second,” and twice articulates the word “throttle.” It is apparent from the CVR and flight data recorder (FDR) that the different players in the physical cockpit are presenting each other with forms of communication that others do not act upon or act upon in unexpected ways. It is *as if the agents are talking past each* other without noticing it, leaving the system without control. As a result, *the system is carried away* by the events of its own making.

5.2.2 Agents talking past each other

The transcription shows that the PF pulls back the power lever PL1 in the face of ENG 2 already being shut down (Fig. 7, torque $TQ2$ = 0%). As shown in the preceding section (Fig. 6), the pull back is visible (though not necessarily seen) from the right and jump seats. There is no reply from the system; and the reply from the PM makes the speed part of the accented visible, which has by that time dropped to 100 kts from the maximum climb speed of 135 kts. There is no apparent uptake of the speed issue on the part of the PM or the observing pilot. The aircraft system replies by reducing the torque to about $TQ1$ = 28% just prior to the stall warning (Fig. 7); and the MP announces the reduction on the engine and warning display. Instead, the PF now announces a further pull back, which, however, has already begun nearly two seconds earlier. Language having the function of bringing something into the accented visible (El’konin 1994; Heidegger 1977), the announcement further contributes to the visibility of the pull back. Prior to the next turn on the part of the PM, the PF does not have further input that might have encouraged a more reflective action.

The analyst-observer’s sense that the agents are talking past each other without being aware thereof further increases when the PM announces that the flame out of ENG2 now is confirmed, bringing the current situation on the engine and warning display (bottom right, Fig. 7) into the accented visible; and this is acknowledged on the part of the PF. The excerpt supports the hypothesis that the PM and the PF do not reply to one another. We do not know what their turns are replying to, and thus we do not know the genetic origin of the corresponding event of responding (there would be question marks in the reception part of the transcription, see Fig. 3). In two consecutive turns, the PF announces pulling back PL1 and the PM says that the number two engine has had the flame out. We do not know whether the PF actually hears the acknowledgement “Okay,” but if he does, he has to assume that the PF knows ENG2 is inoperative. It would be reasonable for the PM to assume in this case that pulling PL1 back was okay, especially if the PF, as captain, is taken to “know what he is doing.” There is no reaction momentarily on the part of the PF. Thus, from the perspective of the PM, it is quite possible that he actually heard what the PF said and had done, that is, pulling back PL1 and still not be conflicted.

The FDR shows that during the entire time since the master warning sounded and ENG2 was shut down, the captain has exerted force on the control column in an apparent effort to deal with the lack of power on the right side of the aircraft. But here he acts on ENG1 by pulling back PL1 and, as a result, he shuts ENG1 down. The other human agents do not or not clearly object even though they have access to all communication on the part of the machine player. The machine player, too, initially does not object to the reduction of power to the live engine.

5.2.3 The system carries on, thereby getting carried away by events partially of its own making

The different agents act upon issues emanating from the situation, sometimes prior to bringing about a completion to an ongoing issue that has started earlier. As a result, the system moves from issue to issue as these emerge so that the events carry the system away. Already in the preceding subsection, the verbal exchange concerning the heading mode is taking attention away that may have existed with respect to waiting and cross checking. This is quite apparent for the MP, who, after the PF has reduced PL1 to 40°, turns on the stall warning sound and stick shaker as an immediate reply to an imminent stall. In turn, the PF completes responding by advancing PL2 from 75° to 86°, as if it were the live engine. That is, from the beginning to this point, the replies of the PF are corresponding to a faulty ENG1 and a live ENG2. But these replies have their genetic origin in what the PF has been attending to and receiving from the other players and the environment.

Between the human agents, undetected contradictions may be observed. Thus, shortly after the exchange over the pull back of PL1 (PF) and the confirmation of ENG2 flameout (PM) ends, there is a stall warning and then PM states: “wait a second … it” (Fig. 7). But the PF pulls the PL1 back further, pronounces an expletive, and notes “terrain ahead.” To avoid a stall, the speed needs to increase, which may be achieved by increasing power or by pitching the aircraft down. But heading down conflicts with the elevation issue. Yet the PM simultaneously says, “okay lower” and 1.5 s later invites the PF to “push back.” The two statements may have been invitations to (a) lower the pitch (nose down) and (b) push the control column forward consistent with the first stall warning and confirmed by the second stall warning and the additional stick shaker.

Here, the PF apparently makes available that he is visually attending to and receiving an environmental feature: the terrain. The terrain now has entered the accented visible while the requested “wait a second” still is operative. There is clear evidence that the PF attends to the terrain, but it is unclear whether he hears the PM or what he hears the latter to say. The transcription shows that situationally emergent issue of the terrain ahead now is salient, requiring some form of transformation. In actively attending to what the PF is saying, the PM and OBS accept the invitation to attend to terrain and altitude. These issues now take center stage. We see in this fragment of the transcript how the unfolding event moves away from whatever was to come during the wait. That is, rather than completing whatever might have followed the “wait a second,” a new issue is emerging to which all three pilots then attend. But already the events have evolved and the stall warning and stick shaker come on. The two turns that follow (PM, OBS) both take up the altitude, which, by that point, no longer has been increasing—which would be visible on the right-hand side of the primary flight display (bottom panel, Fig. 7).

During the talk about the terrain, changes in the power lever positions are brought about. That is, these changes happen (are brought about) while the currently salient public issue—to which the transcription shows the PM and the observer are oriented, confirming the aircraft to be low—is the terrain. At that time, the aircraft no longer is climbing, flying level at about 1,650 ft (500 m). The terrain map shows that the pilots would see at that time higher elevations of 400 m about 10 km ahead of them (to the south east, Fig. 4). Whereas the departure chart indicates a heading of 120° until the aircraft has reached 2,500 ft, the GE 235 aircraft has rolled to the left. At that time the stick shaker and stall warning sounds come on, and it is therefore not apparent to what situation or talk the PM replies when saying (in Chinese), “Okay, push … push back.” But there is no reply. In the context of being too low, it would make sense to pull the control column to gain altitude; but it might also be heard as pulling back on the power lever. This is announced verbally by means of a “shut” call, followed by a pull back of PL1 to 35°. The PF apparently replies to the stall warning and the stick shaker (which can be felt and comes with considerable noise) by increasing power to ENG2. The two other pilots do not (further) object. The MP now adds warning and action: the stick pusher. This is a direct reply to the action of pulling back PL1 (Fig. 7). The stick pusher moves the control column forward, which decreases the pitch of the aircraft making it head downward and, in so doing, making it gain speed for the purpose of escaping the imminent stall. It is at that time also that the PM states, “wait a second,” and then adds, “throttle.” Two seconds later, the PM states again “throttle.” In this, the throttle is brought into the accented visible. This might be taken as an invitation to increase the power by moving the lever forward; but while the PM is talk, the PF is actually retarding PL1. At the same time, PL2 is already advanced to maximum power.

At this point, unbeknownst to the human players, the aircraft is without power. When the captain subsequently discovers and comprehended the situation (“Wow … pulled back the wrong side throttle”), it is too late to turn the situation around. Seven attempts at restarting ENG1 fail and the aircraft crashes.

5.2.4 Understanding the internal dynamic

The analyses in this subsection show how a bystander might have discovered that the participants (human and machine players) communicated past one another. Even though they produced communicative expressions, the players were not actually *corresponding* with one another. The players were indeed responding, but what they were receiving differed from what was offered. As a result, the players did not enter a state of correspondence. An appropriate metaphor may be a musical ensemble where the players each follow and produce a tune without noticing that others follow and play different tunes. In the enchainment of one thing is leading to the next, following an inner logic that leads to an apparently inescapable sequence of events that ends in system failure. It is this inner logic that leads to a disaster not something (like situation awareness) that is absent. The actors are indeed aware of a variety of issues; and they act upon (reply to) what they perceive.

6 Discussion

Forensic cognitive science is concerned with understanding the cognitive processes at work during events that turn into accidents. The common approach to accidents is the self-action perspective, where cognition is understood in terms of processes in the neural circuitry of the human brain. One cognitive factor often invoked in accident reports[10] is situation awareness in its classical sense (Endsley 2015). In such reports, a deficit of situation awareness is used to explain error. Self-action perspectives generally take a deficit approach, as exemplified in the occurrence report of TransAsia Flight GE 235 (ASC 2016). Even though the executive summary notes that the "accident was the result of many contributing factors" it then descriptively names specific human failures, referring to everything else as "a range of contributing and other safety factors" relating to the autofeather unit, TransAsia management and operations, and the regulator. The explicitly stated errors on the part of the human players include: (a) flight crew *did not* perform according to the operating procedures for abnormal flight situations; (b) the PF (*inappropriately*) retarded power and shut down the live engine; (c) the crew *did not* detect the loss of power from both engines; (d) the crew *did not* timely respond to stall warnings; (e) the crewmembers *did not* prioritize their actions; (f) the crewmembers *did not* correctly identify the propulsion system malfunction; (g) flight crew coordination, communication, and management were *less than* effective; (h) the PF *did not* appropriately respond to or integrate input from the PM; (i) the PF was *confused* about identity and nature of malfunction; and (j) the crew *did not* reject take off when discovering while accelerating that the ATCPS was not armed. To understand why the cognitive system has acted in the way it has done requires the actual inputs to which it has replied or that have triggered certain kinetic melodies (Roth et al. 2015). Here, that cognitive system (mental activity) is understood as an organization and dynamic of the whole organism (player)–environment system (Järvilehto 1998a, b). This inherently means taking an inside perspective on complex cognitive systems (Bateson 1979; Dekker 2014; Vygotskij 2001). Taking an inside perspective takes us toward a transactional forensic cognitive science that is concerned with identifying the properties of the actual phenomenal field that makes for the logical properties of situated actions and talk (cf. Garfinkel 2002; Ricœur 1986). The environment as perceived by the agent is an irreducible part of the unit that already includes conscious awareness of the human player (Vygotskij 2001). The following subsections elaborate on those three points.

6.1 For an inside perspective on complex cognitive systems

Forensic cognitive science attempts to understand the cognitive processes involved in accidents. Accident occurrence reports and other forms of analysis tend to focus on what agents do not do for the purpose of explaining what has happened (Dekker 2015a). Little can be learned about cognition from the list of things that the system at hand *has not done*. Such lists do not tell us *why* the system—and therefore its parts—has exhibited the particular behavior. Actions are not explained by reasons (causes) attributed after the fact; instead, actions need to be understood as having their genetic origin in what agents have received, which contributes to constituting their in-order-to motives (i.e., what they intend doing). These motives exist in the face of an inherently uncertain future not only of the situation but also the actions of the players. To understand the behavior and cognitive activity of complex systems requires an inside ("tunnel") perspective (Dekker 2014). Pursuant this goal, the question addressed here is: What are the actual inputs that become the in-order-to motives for the agents act in the way they do? The question for the forensic cognitive scientist then is to find out what the agents actually attended and replied to, that is, what was salient at the time and provided the grounds for the rationality of their actions.

This approach is exemplified in the present analyses, which focus on (ex post facto known to be) crucial aspects of the doomed flight. The first excerpt begins immediately prior to the engine flameout and the events during the first few instants that followed. The second excerpt covers a 14-second period during

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[10] In addition to GE235, situation awareness is used as explanation for the crashes of a DHC-8 near Palmerston North, New Zealand (June 9, 1995), a Boeing 737 near Dubrovnik, Croatia (April 3, 1996), a Fokker 100 near Heho, Myanmar (December 12, 2012), an ATR-72-600 near Pakse, Laos (October 16, 2013), and an ATR 72-500 near Magon, Taiwan (July 23, 2014).

which the live engine is completely shut down. At the time, nobody on the aircraft knows the ultimate outcome of the flight. To understand actions and talk, the analysis needs to retain the inchoate nature of that situation in its unfolding. Any hope to understand why the pilots have acted in the way they have comes from taking an endogenous, "shop-floor" perspective. Any explanation that invokes references to what the pilots should have done or should have not done—while letting us know that these may have contributed to the crash—actually miss the *internal* dynamic and thus the logic of the cognitive processes of the situation as a whole. Contradictions may be said to exist when looked at from the outside. If the players do not attend to and perceive contradictions, they do not act on these. Some part of the complete system, human and non-human, may be "aware" of contradictions but do not or cannot communicate in a manner that allows the contradiction to become visible in the public forum. This goes in both directions. Thus, the machine player may be "aware" that there are issues (e.g. the pull back and shutting down of the live ENG1) but may be unable to initiate an intelligible reply; or human players may verbally articulate certain issues that remain unavailable to the machine player.

The analyses show how the different components (human and machine players) attend to different aspects of the flight and display forms of communication that we now (after the fact) know as not having been taken up by other players. The different players appear to act like independently functioning eyes of a single organism that do not come to see and act upon the same information let alone compute the different inputs to arrive at the perceptual equivalent of a stereoscopic image. For example, the PM does not appear to attend to the reduction of the power or the specific problem announced on the engine and warning displays, and therefore does not compute the difference nevertheless available in the cockpit at the time. Furthermore, the PF reduces the power of the live ENG1 even though the MP makes available perceptually that ENG2 is not operating. But, as shown, the perceptual differences begin at the machine level, when an engine failure is detected although the available evidence suggests that there was none. Moreover, given that the second torque sensor was found to have no problem, the engine electronic control would have received normal torque signals. Thus, within the MP there existed different readings of torque (i.e. in the autofeather unit and the engine electronic control). But the MP did not "comprehend" and thus act on these differences. Now, we can read almost daily about the efforts to completely automate transportation systems to eliminate the possibility of human error. But the present analyses show that what turn out to be problems emerge from the MP part of the whole system. A further instance of this is the case of the stick shaker and stick pusher warning and actions, which provided the human agents with incorrect information in instructing the aircraft to be pitched up to 8° and opposite to the action of the stick pusher. In the initial phase of reducing ENG1 power, the machine player said or showed nothing—though one can easily imagine some form of double check in the form of "Do you really want to reduce power on the live engine?" That is, the machine player clearly "was aware" of what was the case and what was happening, but did not seem to process this difference and provide any additional warning.

6.2 Toward transactional forensic cognitive science

In the introductory part of this study, the related but distinct natures of interactional and transactional approaches are described. In the interactional approach, the representations *between* the players are the foci of analyses. But those representations, while being materially the same for the different players, are not the same on the ideal plane. This is so not because of differences in some presupposed "meaning" but more importantly, because of the different function it has. Thus, in an exchange, the material thing (commodity, representation, word) has ideal exchange-value for one person, but use-value for another person (Rossi-Lani 1983; Roth 2006). When the GE 235 PF says, "Engage autopilot," he makes a statement that is to be received and transformed into an action (i.e. it as "an order"). For the PM, prior to acting, it also functions as an in-order-to motive for what he is about to do: it is a plan of action. He then acts. But whether the plan accurately describes the situated action that follows can be ascertained only after the fact (Suchman 2007). The PM uses it as a design for acting. When the PM reports back, "Okay, autopilot okay," then he communicates a current state; and the PF can use it to update his knowledge of the current state. Indeed, the PF and PM then state, one after the other, "a-p green." The transcription does not indicate the intonation. But in many conversations when two speakers articulate the same phrase, the intonation rises in the first (i.e. "AP ↗green") but falls in the second ("AP ↘green") thereby producing a {query | reply-affirmation}. Thus, we can hear the phrase in the first case as glossed by "Are the arrow-shaped lights next to the button marked 'AP' lit green?" The second instance can be heard in the constative form, "Yes the green lights next to the 'AP' button are lit green." A falling/falling sequence of intonations (together with some other voice qualities) may constitute an {order/instruction | confirmation}. The function of the same locution clearly is different, in part the result of the different intonations and to another part because of the different responding units in which they are part.

Inherent in the transactional approach is that the material fact—aspect of situation, instrument reading, or verbal statement—is different ideally. It is materially the same, part of the world that the agents inhabit. The difference at the ideal (supersensual) level is not to be taken as a deficiency but instead constitutes the condition for the “double view” or “double description” required for human consciousness (Bateson 1979). The self-action and interaction approaches can be thought of as two eyes, each having a monocular view; at best, the two organs exchange information. When there is take up of the information from one eye by the other eye and when the two differences (appearing in the left and right part of the brain) come to be computed, then information of a *new* logical type is created (Bateson 1979). But if those eyes, for one reason or another, come to operate independently, then the stereovision disappears. This way of looking (interpreting) the GE 235-related events shows that the players did act upon certain states of the situation. But more important than what each of the players attended to and took into account while acting may have been what falls into the human factors areas of *management* and even more so *communication*. Thus, communication requires actively attending to what others say, processing it, replying, and monitoring the effect of the reply. Because actions and messages are inherently ambiguous, agents need to monitor how their emanations are received to discover precisely what they have said and done (Bateson 1996). The analyses show that the communication was such that the PF could continue shutting down ENG1 because, disregarding for the moment the other information available, the PM could be heard as assenting to and confirming what the PF was doing.

In this study, only the contents of the words could be taken into account because of the nature of the data available. For a forensic cognitive scientist with direct access to the CVR, additional information is available that may be crucial to understanding what information the cockpit system processed. For example, pauses and prosody—e.g. intonation contours, pitch, speech intensity, and speech rate—are important, constitutive aspects in the unfolding of communicative exchanges (e.g. Couper-Kuhlen and Selting 1996). Prosody not only changes the grammatical function of speech (e.g. a statement is heard as a question with rising intonation but as a constative or confirmation when intonation falls) but also makes available emotional states and processes that affect the internal dynamic of events (e.g. Collins 2004). Access to such records further increases the viability of the results from a transactional approach.

The transactional approach takes into account that when one player communicates something by auditory or visual means, these are *designed for* the other, *in-order-to* be understood, and *for the purpose of* bringing about some action on the other’s part. That is, the communicative act cannot be described solely in terms of the communicator’s internal characteristics because the latter takes into account the recipient. On the part of the recipient, any (communicative, practical) action is situated in at least six sense-constituting contextures: (a) those things and events that are the referents of the communicative sign; (b) the sign system in which the sign is a constitutive part; (c) the sign-producing act as an expression of the communicator; (d) the sign-producing act as a communicative act; (e) the communicative act as an invitation to act and reply; and (f) the very appearance of the now, here, and thus of the communication (Schütz 1932).

6.3 The transactional perspective and situation awareness

The transactional approach requires rethinking classical takes on cognitive issues. In the following, situation awareness is taken as a proxy for cognitive issues more generally. The declared interest of cognitive studies is the understanding and modeling of cognitive processes. Self-action models exclusively focus on the brain case of the individual players participating in a complex system. But, as seen in occurrence reports and in the scholarly literature, such models are used to focus on what cognitive agents do not do relative to some ideal behavior. These approaches thus do not sufficiently acknowledge that there tend to be more than one (prescribed) way to achieve some goal. Indeed, flying according to the standard operating procedures does not guarantee the best conditions for flight operations. Observations during debriefing shows that flight examiners sometimes note that a pilot failed to “change [move] things around” when the conditions within the cockpit or outside change so that strict adherence to the standard operating procedures worsens the current state (Roth 2017). Flight examiners then admonish pilots, saying that they “mechanically go through what needs to be done regardless of where it is leading them.” Flight examiners critique pilots for not adapting procedures and thereby ensuring that the procedures actually flown and decision-making are adequate to the circumstances at hand.

Interaction models instead take the whole system as the relevant site for understanding cognition, which, in the aircraft, is the cockpit joint cognitive system. Human and machine players constitute such joint cognitive systems (Henriqsen et al. 2011). Such studies investigate the information (representations) passed from one player to another and at the transformation of information (representations) that human and machine players bring about. The present study shows that it is problematic to think about information being passed around when in fact different players attend to different available information.

The transactional approach goes one step further in acknowledging the irreducibility of the individual parts, each of which is taken to be part of the definition of the other. Thus, the cognitive system does not only involve the different players (as in Henriqsen et al. 2011; Hutchins 1995) but the player–environment unit (Dewey and Bentley 1999; Järvilehto 1998a, b; Vygotsky 2001). As a consequence, if the PF were to be taken as the current focus, everything else—the other players, the cockpit as a whole, the state of the aircraft, and the outside world—is part of the environment. The transactional approach treats person and environment as an irreducible unity/identity. Transactional approaches recognize that typically human behavior cannot be explained on the basis of internal factors or external learning (Bateson 1979; Vygotsky 1989). Indeed, it has been noted that concepts such as situation awareness are circular; and the attention to "factitious" inner tendencies or principles can only hide the real origins of behavior (Dekker 2015a). A transactional approach avoids such circularity because it recognizes that "only if you hold on tight to the primacy and priority of *relationship* can you avoid dormitive explanations" (Bateson 1979). The real origins of complex system behavior lie in part-whole relations of relations, a fact that is quite apparently represented in the alternative transcriptions that also account for the active attention and reception that constitute the second part of *corresponding* and the first part of *responding* both of which consist of efferent and afferent events (Fig. 3).

In the introduction to the most-recent special mini-issue on situation awareness in this journal, the editors pursue the question whether the construct of situation awareness is valid or fallacious (Carsten and Vanderhaegen 2015). The authors do not however provide an answer to the question; instead, they point out that many critics have highlighted the various difficulties (e.g. related to measurement or operationalization) associated with the construct to explain anything at the individual level. Standard approaches to situation awareness fundamentally define the concept in terms of the difference between what is known after the fact and what the agents attended to (knew) in situation and before the fact (Dekker 2015a). First, it is quite apparent that used in this way, the concept explains nothing. The underlying assumption is that a successful (non-crash) flight occurs when the human agents act such that the standard operating procedures constitute appropriate descriptions of what was done. But there are many other system trajectories possible that are successful even though they are not (precisely) according to the description (prescription). Thus, one study analyzed how experts (first officers, captains, and flight examiners) assessed a flight scenario where the PF was uncertain about the direction of a flight during an emergency situation (Roth and Mavin 2015). Unsurprisingly, situation awareness was the main human factor invoked by some of the assessors. However, although the PF was uncertain, and although the crew acted in ways that many observers deemed to be "messy" and non-standard, the cockpit eventually extracted the aircraft safely. That is, the flight was successful even though it did not follow standard operating procedure. Not following standard operating procedure explains little, for in most cases it still leads to unproblematic flights. Instead of explaining accidents in terms entities located in or missing from the brain cases of human players, transactional forensic cognitive science takes phenomena such as perception, memory, or comprehension to be manifestations of the organization and dynamics of the player–environment system. It describes such systems from the inside for the purpose of exhibiting the inner logic that leads such systems to failure. Understanding this inner logic may then lead to new designs, which may inhibit certain (self-destructive) behaviors. The transactional approach does not mean, however, that standard operating procedures decrease in importance. Instead, the approach understands what the procedures state as in-order-to motives (plans) that orient actors but are not the causes of their situated behavior.

Safety practitioners will be interested in how a theory (method) leads to and materializes in better or smarter safety recommendations. The analyses from a transactional perspective conducted here show how a cockpit system carries on, gets carried away by events partially of its own making, and ultimately destines itself to failure. The most-common self-actional approach emphasizes deviations from standard operating procedures and lack of pilot skills (any one from whatever list of human factors used). The transactional approach, recognizing that breakdown is possible anywhere in complex systems, would likely focus on recovery and resilience, especially how to deal with contradictory information within and across different parts of the cognitive system. The recurrent media reports on accidents of self-driving systems show that engineers have not yet solved the question of how to prevent accidents when human factors cannot be invoked to explain what has happened. The focus then becomes one on get things right once some form of breakdown has occurred (cf. Dekker 2014), that is, on the dynamics of recovery. Throughout the analyses, suggestions are provided where the machine player could have acted in some way to move the system into a different trajectory.

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Captions

Fig. 1 Three instants of the TransAsia Flight GE235 while crashing into Keelung River, leaving 43 people dead

Fig. 2 Three models of cognition involving two pilots (pilot flying, PF, and pilot monitoring, PM) and the aircraft system (SYS): (**a**) self-action of self-contained agents (solid circles); (**b**) interaction, focusing on the information shared between any two agents (solid lines) understood as open to the environment (broken circles); and (**c**) transaction, where each part of the system, "reaching" into any other part, reflects the system as a whole (the relation to the environment is of the same kind as that to other agents, and here is shown only for one agent)

Fig. 3 In the model, transaction is reflected in its parts, *corresponding* and *responding*, the parts of which (a–f) are in themselves transactional in nature

Fig. 4 Flight path of GE235 reconstructed from the information provided in the report and the approximate location of the aircraft position during the two episodes transcribed. Circles mark the occurrences of the master warning and triangles those of the stall warnings. (Credits: Imagery ©2017 GeoForce Technologies, DigitalGlobe, CNES/ Astrium Map data © Google)

Fig. 5 Transcription from the cockpit voice recorder (CVR) together with the the display of the upper part of the engine warning display and the power lever positions reconstructed from the flight data recording. The dashes ("—") mark the precise point in time when an event begins or a fact was recorded; "*" signals an expletive. (© author, used with permission)

Fig. 6 The pull back of the power lever PL1 is visible (though not necessarily perceived and consciously processed) to other human players and sensed by the machine player. (© author, used with permission)

Fig. 7 Transcription from the cockpit voice recorder (CVR) together with the display of the upper part of the engine warning display (top), the power lever positions (center), and the primary flight display with information—all reconstructed from the flight data recording. The dashes ("—") mark the precise point in time when an event begins or a fact was recorded; "*" signals an expletive; the triple click, according to the flight crew operation manual, is the warning that an autopilot capability downgrading has occurred. (© author, used with permission)

Figure 1 Click here to download Figure 01.jpg

Figure 2

Click here to download Figure 02.jpg

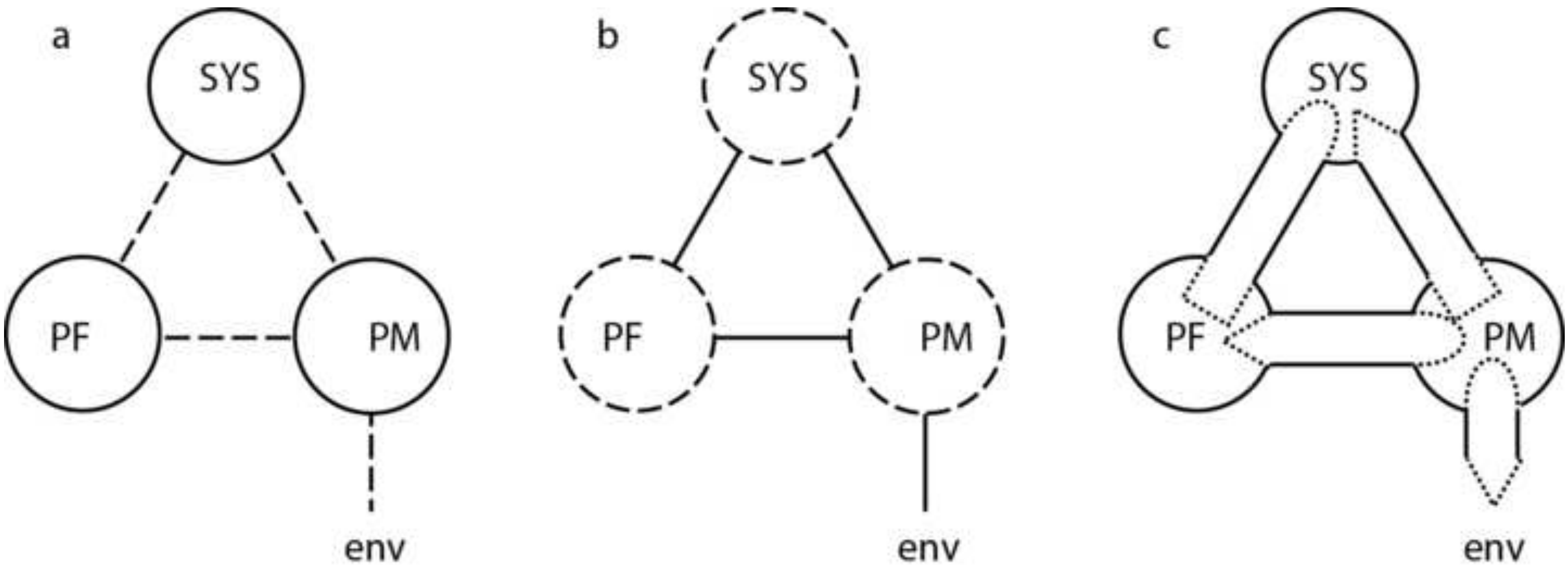

Figure 3 Click here to download Figure 03.jpg

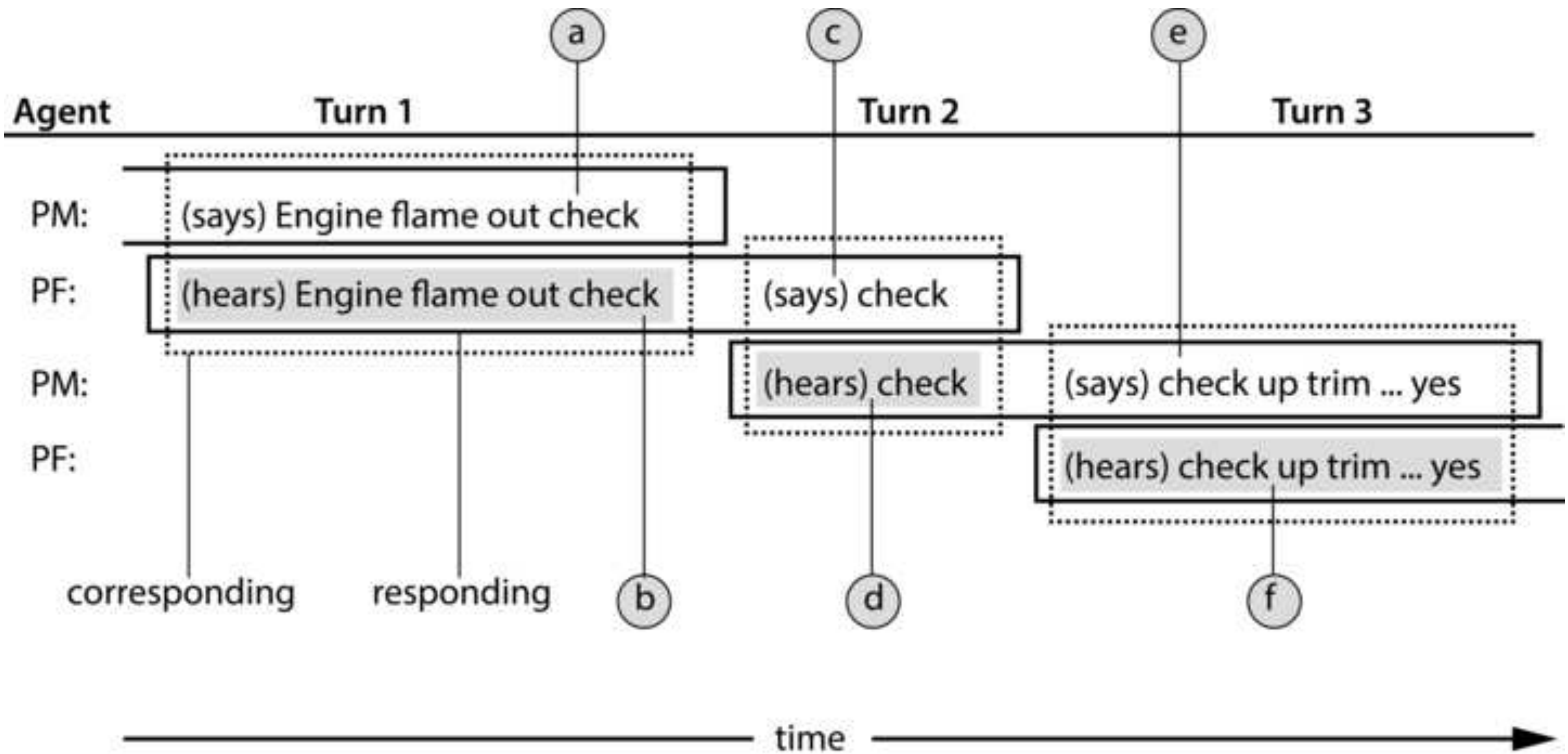

Figure 4

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Figure 5

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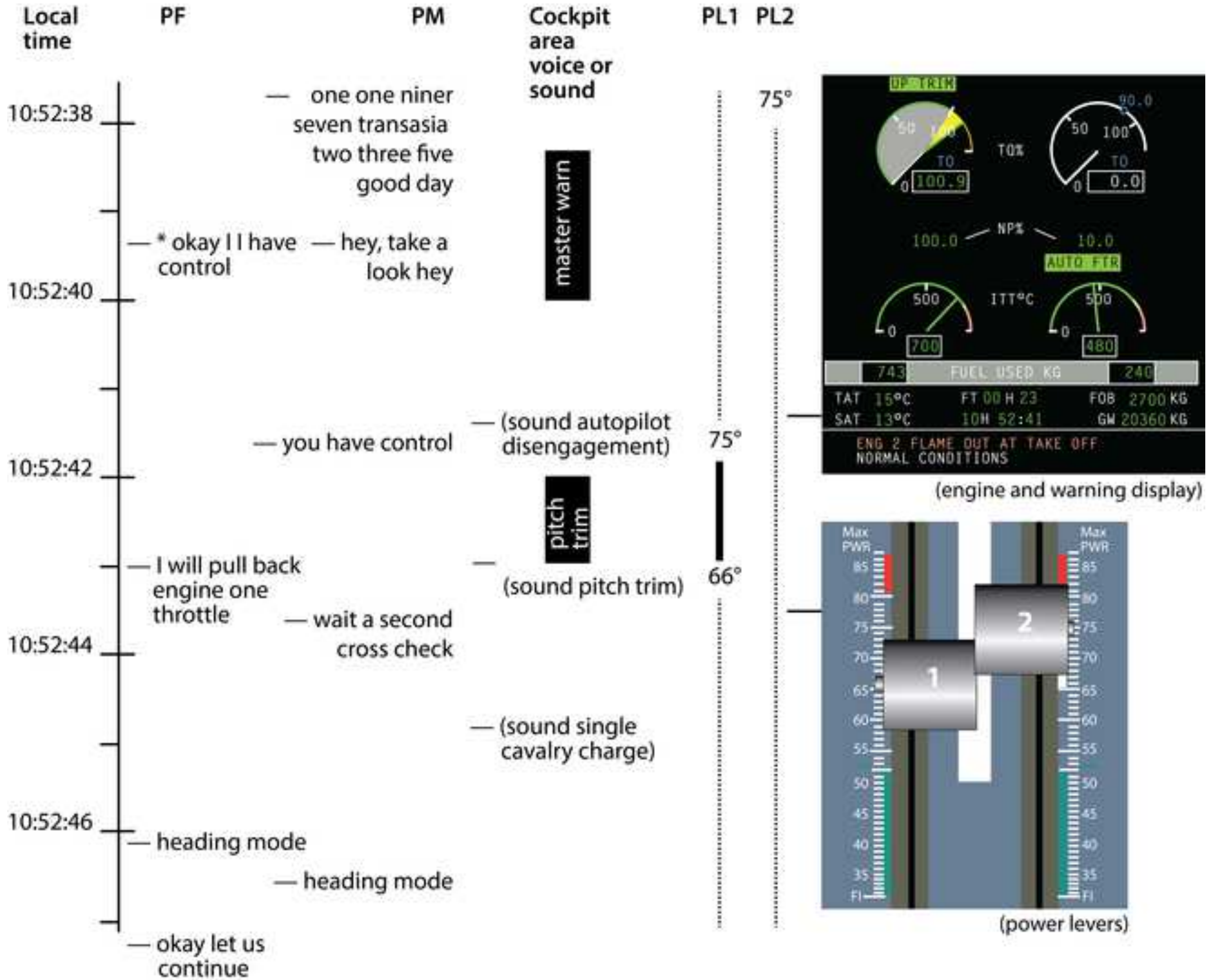

Figure 6

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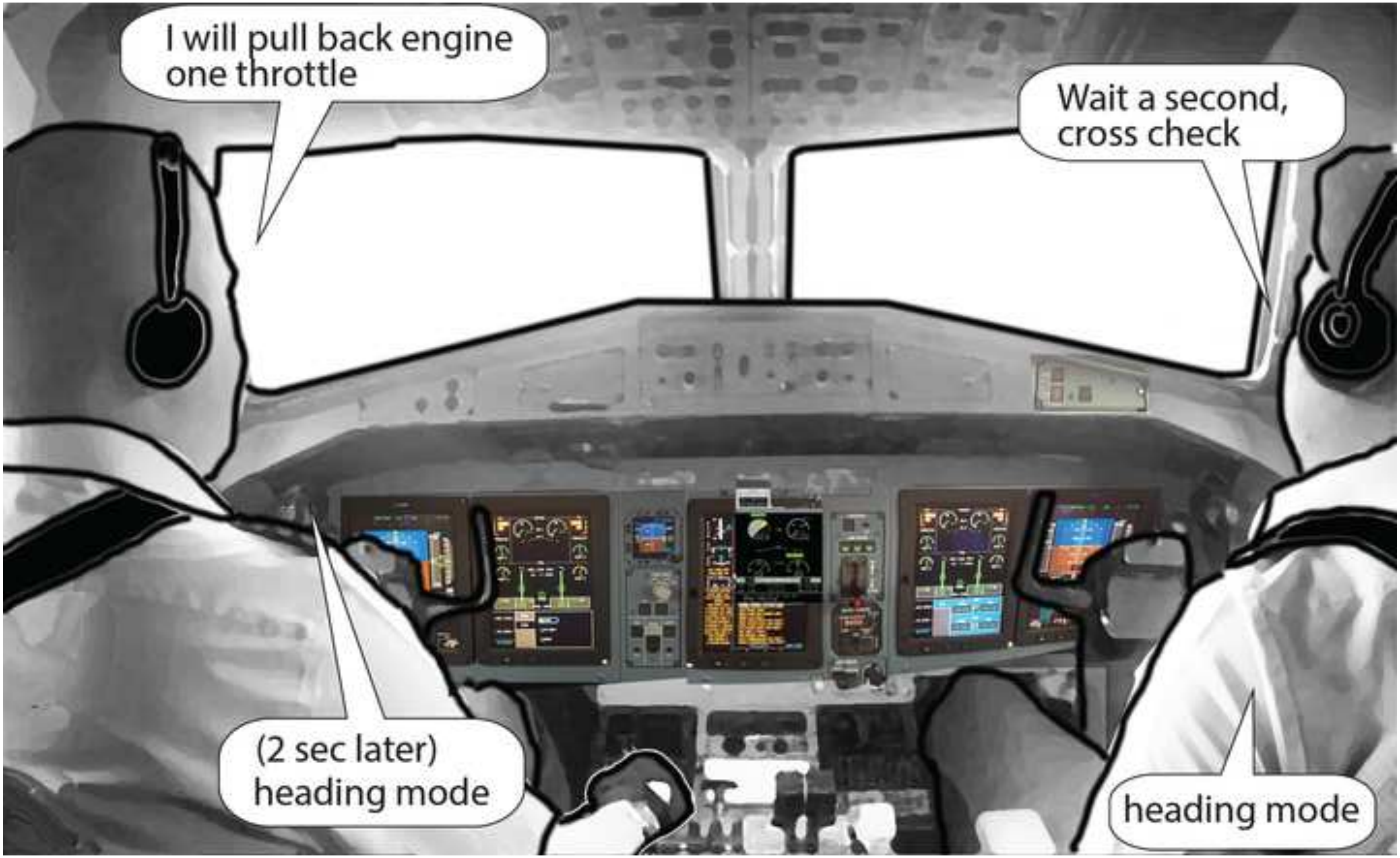

Figure 7

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