Chapter 4
The Real: Flight Operations Add Complexity and Variability

In the previous chapter we summarized the tasks of the flight crew as described in FOMs and concluded that those manuals and the associated training convey cockpit work as linear, predictable, and controllable. In this chapter we examine the degree to which that characterization accurately captures the real world of routine flight operations. Our discussion of this real world is based on an ethnographic study in which we observed a substantial number of scheduled, passenger-carrying flights from the cockpit jumpseat at two airlines. In this study we took detailed notes of events and crew actions throughout the course of these flights and, whenever possible during cruise or after the flight, we asked the pilots to comment on these events and actions. (See Appendix A for methodological details.) We have also conducted a large number of less formal observations from the jumpseat of diverse aircraft at several other airlines; these observations helped inform the formal study and provided a broader context for our formal observations.

Our jumpseat observations focused on perturbations that forced the crew to alter the sequence of execution of tasks described in the FOM, disrupted the flow of work, or increased the complexity of work. From these observations we constructed a realistic portrait of crew work in actual flight operations. It is not surprising that the real world is far more complex and dynamic than the simplified portrayal of the FOM, but by comparing the real with the ideal of the previous chapter we lay a foundation for understanding the vulnerability to error of skilled pilots when performing routine tasks. This in turn makes it possible to redesign operating procedures and training to address the demands of actual flight operations more effectively.

Although all of the observed flights followed the general schema of the FOM, no two flights were the same, varying dynamically with unscripted task demands and because of differences in pilots' responses to these demands. The real operating environment is far more interactive than indicated by the FOM. In each phase of flight, the cockpit crew must interact with a wide range of human agents on the ground and in the air; these agents provide critical information to the crew, require information from the crew, and impose demands that affect the structure and timing of the crew's other tasks. (See Appendix B for a list of these agents and their responsibilities.) Weather conditions and air traffic conditions also greatly increase the dynamic complexity of the crew's work.

How crews responded to perturbations hinged on subtle variations in the timing and the nature of competing task demands, and their responses were also undoubtedly influenced by personal preferences, experience, and work habits. Consider, for example, the frequently-occurring situation in which the first officer attempted to contact the Ground controller to obtain the required departure clearance but found the frequency occupied and had to monitor the radio for an opportunity to break in and make the request. We observed one instance in which the captain asked the first officer to request departure clearance while the first officer was still entering data into the FMC. This first officer chose to continue entering data while simultaneously monitoring the radio for an opportunity to make the request. In a very similar situation another first officer chose to suspend entering data until she was able to contact the Ground controller and receive the clearance. In still another instance the first officer had finished entering data before the captain asked him to obtain the clearance.

One might be tempted to interpret the perturbations we describe in this chapter simply as increased workload for the crews. Indeed they do increase workload, but on most flights the crews' workload, as we shall see, was clearly within their capabilities, was easily managed by experienced crews, and rarely did they seem rushed. In this book we develop a new perspective, going beyond traditional concepts of workload, to argue that these commonplace perturbations have a larger and more subtle significance than the simple volume of work. These perturbations, which permeate pilots' work, require both pilots to manage

> Mr. and Mrs. M, a married couple, were brought into the emergency department for medical care after their vehicle was struck by a truck. The two patients were placed in the same trauma bay, next to each other. They were both going to be requiring blood so samples were typed and cross-checked for each, separately. This process involves drawing blood samples from each individual, identifying the blood group, and running a quick cross-check to determine compatibility. Mrs. M was quickly assessed to be less stable than her husband and therefore more urgently in need of a transfusion.
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> The emergency department is a crowded, noisy, stressful work place that increases the risk of errors. Personnel have to be sensitive to, yet not allow themselves to be distracted by, the concurrent demands that suddenly arise with the arrival of a new patient. The situation becomes ever more complex with the simultaneous arrival and urgent need for stabilization and assessment of more than one patient. The commotion that forms in the trauma bay may lead to labeling blood tubes away from the patients. Patients with the same surname (as in this case) further add to the potential for error. In the hubbub following the arrival of Mr. and Mrs. M., the blood typing tube for Mrs. M was confused with that of her husband, and therefore inadvertently mislabeled. Fortunately for Mrs. M, a blood bank technologist happened to notice the discrepancy, after checking with records of a previous admission of Mrs. M. to the hospital. The error was corrected and the potentially fatal incompatible transfusion was narrowly averted.
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> (Agency for Healthcare Research and Quality, 2004)

multiple tasks concurrently, interleaving performance of some tasks, deferring or suspending other tasks, responding to unexpected delays and unpredictable demands imposed by external agents, and keeping track of the status of all tasks. The cognitive demands imposed by managing concurrent tasks in this fashion, play a central role in pilot's vulnerability to error, especially errors of inadvertent omission, as discussed in the next chapter.

Appendix C lists a large number of perturbations observed in these flights. Rather than discuss each perturbation in detail, we have selected seven examples from the complete set. The examples do not represent distinct categories of perturbation situations—rather, they illustrate the wide continuum of perturbations and provide a representative cross-section of the sum of our observations. For each example we discuss the context of the perturbation, the source, and the consequences for the crew and the flight. We explore each example to illustrate the large range of perturbations observed, their diverse nature, the varied contexts in which they occur, their diverse sources, and the many ways in which they influence the flow of work, increase the complexity of the flight operation and require crews to manage multiple tasks concurrently. After presenting these examples, we contrast the real characteristics of actual flight operations with the ideal characteristics portrayed by FOMs.

In each of the seven examples, the crews dealt with perturbations successfully, without error, which was generally the case in our jumpseat observations. Crews are able to manage diverse perturbations effectively in the great majority of instances. Still, perturbations increase vulnerability to error, as is illustrated later when we contrast these seven examples with similar perturbations pilots themselves reported to have occurred on other flights, and which were *not* dealt with as successfully.

We have taken a small journalistic liberty in discussing the selected examples: We describe pilots' thoughts in response to the situations they encountered. Of course, we do not know, in a rigorous scientific sense, what the pilots were thinking in these specific instances, but from many observations, later discussions with the pilots observed, discussions with many other pilots, as well as our own personal experience as pilots (K.D. and I.B.), we feel comfortable characterizing how pilots typically understand these types of situations.

"Chain of mounting pressure"

Context: The aircraft was at the airport gate and the crew was busy preparing for the next flight. A load sheet containing the latest figures on weight (passengers, fuel, and luggage) on board had already been delivered by the gate agent to the first officer, who had entered the data in the FMC, as required. This enabled him to determine that the aircraft weight and balance were within limits and to compute critical takeoff data (rejected takeoff speed, rotation speed, etc.). The captain, having verified the first officer's actions and calculations, requested the Pretakeoff checklist, which the crew proceeded to perform in the standard challenge and response fashion. Just as the two pilots were completing the final two items of the Pretakeoff checklist, the gate agent re-appeared at the cockpit door holding a revised load sheet. Additional luggage, which previously was assumed would not arrive from a connecting flight on time, had just been loaded in the aircraft cargo hold. The first officer used the new load sheet to begin revising the data he had previously entered into the FMC. To expedite the programming task and to guard against inadvertent mistakes, the two pilots spent the next few minutes bent over their respective computer screens, making keyboard inputs and talking to each other. A radio call from the company dispatcher, however, interrupted the crew right as they were about to compute and enter in the FMC the new operating speeds. The dispatcher informed the crew that another aircraft from the same company had just arrived at the ramp area and was now waiting to pull into the gate their aircraft was currently occupying.

Perturbation sources: The arrival of new data having a direct influence on aircraft takeoff performance is not an uncommon occurrence. This perturbation requires re-computing and re-entering the data into the flight computer, and the crew, knowing this to be a time-consuming, head-down activity, realized this was best accomplished before pushing back. The crew collaborated to respond to this new task demand when it was notified of the company aircraft waiting to pull into the occupied gate. The captain realized they needed to expedite preflight preparations so he could signal the ground crew to push the aircraft away from the gate. Once that was accomplished the crew could start the engines, obtain taxi clearance, and taxi their aircraft away from the ramp area to allow the company aircraft to move in and de-plane its passengers. The captain wanted to support the company's goals for on-time departures and arrivals and wanted to accommodate the passengers of both his aircraft and of the other company aircraft. From his experience with the tempo of operations at this busy airport, he had grown accustomed to this type of situation, and had often initiated pushback before completing FMC programming to expedite operations, resuming programming after his aircraft had cleared the gate. Today he made a conscious decision to repeat this strategy; he established contact with the ground crew, interrupted the first officer's programming, and directed him to assist in the engine start sequence.

Consequences: Ideally, as portrayed in the FOM and described in the previous chapter, the first officer would have completed all pretakeoff tasks by the time the captain directed initiation of the pushback and engine start sequence. However, like the captain, the first officer had flown in and out of this busy airport many times, and was not surprised by this situation or the captain's request to proceed with pushback before completing re-programming.

Interrupting his programming meant that the first officer would have to remember to return to it and resume where he had left off, as soon as possible after pushback and engine start. Should this not be possible until after the captain had already started taxiing, he would have to make sure to complete the programming task no later than when the captain called for the Taxi checklist because that checklist required verifying that the necessary data had been entered into the FMC. In such a case, the first officer would also have to interleave his monitoring of the taxi progress with his programming of the FMC.

The first officer may have subconsciously counted on a number of things to help him remember to resume the suspended task. He kept open in front of him the laptop performance computer used to calculate critical operating speeds and other takeoff data, and left the display on the screen with the takeoff speeds. He also left the FMC on the screen that displayed the fields into which he would later copy the new speed data. Of course, both computer screens still displayed the previously-entered speeds, but the first officer still may have hoped that the screens could serve as reminders of the need to compute and enter the new speeds. Further, he knew that the captain would later be reviewing all the relevant FMC pages as part of his own duties, and that would perhaps serve as another reminder. If all else failed, the Taxi checklist would provide a final layer of protection against forgetting because one of the challenge items required verification that all programming had been completed

After pushback and engine start, the captain directed the first officer to request taxi clearance and, upon receipt of the clearance, started taxiing the aircraft to the departure runway. The first officer resumed re-programming as soon as he confirmed that the captain had acknowledged the taxi instructions and had started moving in the right direction. He looked back down at the performance computer still in his lap, and, keeping a watchful eye and ear to monitor taxi progress, resumed re-programming.

The crew on this flight successfully dealt with the perturbation caused by the nearly simultaneous arrival of new load data and a company aircraft waiting to pull into the gate their own aircraft was occupying. The programming task was suspended, and later re-initiated in time to complete all takeoff preparations. The captain's strategy to expedite preparations accommodated the desires of the company's passengers and helped maintain a good on-time departure and arrival record for the company. Thus the outcome of this strategy seems entirely positive, yet this strategy has a hidden downside, for it increased the crew's vulnerability to error to some degree.

Interrupting a habitual task for an appreciable period exposes pilots to the risk of forgetting to return to the interrupted task, especially when the pilots are later caught up in other attention-demanding tasks. In this case, the first officer suspended re-programming the FMC to complete not just one, but several other tasks before returning his attention to the FMC. Checklists are, of course, a safeguard against errors of omission, but checklists are themselves sometimes forgotten or imperfectly executed, so the risk is not negligible. Still another risk was engendered when the crew started taxiing before completing programming: the first officer's attention was directed down to the FMC, making it more difficult for him to monitor outside the aircraft during taxi, which is one of his responsibilities and an important safeguard against costly collisions. Unfortunately, it is difficult to quantify the increase in risk in these situations.

Some pilots and airline managers may feel that re-arranging the normal sequence of tasks to expedite operations does not increase risk as long as workload remains within manageable limits. However, the risk is not necessarily a matter of workload but of disrupting the processes of attention and memory that enable correct performance. Several major airline accidents have resulted from such disruptions (Dismukes et al., 2007).

Our comments here are not meant as criticism of this crew. Nor do we argue that airlines must never allow these sorts of procedural deviations. Deciding whether to allow procedural deviations to expedite operations should be a matter of management policy based on explicit cost-benefit and risk analyses. This book is meant to inform management in the conduct of such analyses.

"Visitor"

Context: The crew had executed a normal takeoff, retracting the flaps and landing gear on schedule. After takeoff, the air traffic controller had instructed the crew to climb to and maintain a cruise altitude of 22,000 feet. This was exactly what the crew had expected from their experience with this particular airport, the airspace surrounding it, and the traffic patterns usually flown in the area. The cruise altitude assignment matched that of the departure clearance given the crew during preflight preparations. The crew had used this cruise altitude to compute flight-relevant data and to program the flight profile in the FMC.

During the initial portion of the climb, the flying pilot had selected the appropriate autopilot mode, per company procedures, and the aircraft was now in a normal climb, tracking the FMC-programmed route (speed, altitude, and waypoints) on the way to the assigned cruise altitude. The crew was monitoring the altimeters and the aircraft's progress as it followed the autopilot's commands, and the cockpit was quiet as the two pilots put away their charts and other paperwork.

Perturbation source: The sound of a chime in the cockpit interrupted the silence. The first officer recognized the chime as the cockpit "doorbell", which meant that the flight attendant was requesting permission to enter the cockpit. She knew to expect the flight attendant at about this time—per company procedures, he would be checking to see whether the pilots needed anything before starting the passenger cabin food and beverage service. The first officer pushed the cockpit door button to unlock the door to let the flight attendant in.[1]

1 Cockpit doors, although variable in other design features, remain locked during flight for security purposes. Non-emergency access to the cockpit can only be gained by "requesting" permission to enter (i.e., notifying the crew via interphone (a chime sounds in the cockpit)). The cockpit crew can either grant or deny access by controlling the door lock from the inside.

Just then, the air traffic controller issued a new instruction to "climb and maintain flight level two-seven-zero [27,000 feet]." This was not an unusual instruction, and the higher altitude would save fuel, but it required the crew to take several actions to set up the climb to the new altitude. The flight attendant entered the cockpit, unaware of the just-received communication from air traffic control, and began to ask the pilots whether he could be of service.

Consequences: Normally, pilots would have welcomed the flight attendant's arrival to inquire how things were going in the passenger cabin and perhaps to ask for something to eat or drink. However, in this case, the flight crew did not respond to the flight attendant, remaining focused on the new task demands posed by the controller's call for a higher cruise altitude. The first officer acknowledged the air traffic control instruction by "reading it back" to let the controller know that the instruction was correctly understood and would be followed. The captain, with his hands on the yoke and the thrust levers, asked the first officer to replace the previously-entered altitude (22,000) in the Mode Control Panel (MCP) with the new altitude (27,000), which she did, verbally verifying the entry by announcing "27,000" while pointing to the altitude window on the panel. The first officer then turned around to face and greet the flight attendant.

Normally, social conventions and neurobiological orienting mechanisms cause people to immediately turn their attention to an individual who comes into their presence and addresses them. Consequently, although distractions such as a flight attendant coming into the flight deck do not involve essential flight duties, they are likely to divert attention in much the same way as more flight-relevant interruptions. Both interruptions and distractions can cause pilots to lose their place in an ongoing task, overlook a required action, or forget to resume a suspended task.

Perhaps recognizing the danger of distraction from previous experience, the crew kept their attention focused on responding to the controller's instructions, deferring interacting with the flight attendant until a break occurred in the demands of their flight duties. Correctly interpreting the situation, the flight attendant waited quietly until the pilots completed their ongoing tasks.

Although the crew managed this situation optimally, one should note that distraction was inevitable, at least momentarily, when the flight attendant entered and made his query. Salient intrusions such as this automatically divert individuals' attention, and attention is further required to assess the situation and re-direct attention to the more important task. It is difficult to assess the degree of distraction involved when crews such as this one are well-disciplined in maintaining their focus, but it is reasonable to assume that vulnerability to error increases slightly, albeit momentarily. A far greater risk occurs if crews are not so disciplined, and allow their attention to be diverted for longer periods by distractions that are not critical to flight duties.

"Flaps to go!"

Context: The crew was on an instrument approach to their destination airport. Visibility was poor and the pilots could not yet see the airfield, but the aircraft was steady on a descent path that would bring it to the runway. To begin the process of configuring the aircraft for landing, the flying pilot asked the monitoring pilot to set the flaps to 5 and to initiate the Landing checklist. The flaps extension would begin the process of slowing the aircraft, and the Landing checklist would ensure that items critical for the impending landing (e.g., landing gear extended, speedbrakes armed) were accomplished before reaching about 1,000 feet above the ground.

Perturbation source: The monitoring pilot directed his attention away from his ongoing task of monitoring the aircraft and its progress along the approach path and began the actions directed by the flying pilot. He remained on the Approach controller frequency, continuing to monitor for radio calls. While setting the flap lever to 5 and tracking the corresponding gauge to confirm that the flaps had been set in motion, he also reached up to the glareshield to pull out the checklist card, which he now kept in his hands. As soon as the flap gauge indicated the flaps had reached the commanded position, he turned his attention to the Landing checklist. He challenged each item in turn by reading it off the checklist card and verified the correct setting of the item before responding, as required by the FOM. In this manner he performed the first four checklist items. When he reached the fifth item, which called for ensuring the flaps are in the desired setting for landing, he recalled that, during the approach briefing the crew conducted before starting descent, they had decided this landing would be executed with flaps set to 30. This decision was based on performance data, computations, and company guidance.

The monitoring pilot knew that several minutes would pass before the flaps could be extended to their final setting of 30.[2] Specifically, he anticipated two more calls from the flying pilot for intervening flap extension settings (flaps 15 and flaps 25) as the aircraft was gradually slowed for landing. He could not complete the checklist until the flaps were at the final setting, however this was not at all an unusual situation—it occurs on almost every flight involving 737s and many other airliners. The Landing checklist procedure is written in a way that requires the monitoring pilot to complete the first part of the checklist (typically three or four items), then suspend the checklist until the flaps can be set to the final position for landing. Then the monitoring pilot must remember to resume the checklist to complete one or two additional items before announcing completion of the checklist.

2 Aircraft flaps must be extended and retracted according to a manufacturer-prescribed schedule that defines safe flap surface exposure as a function of aircraft speed. Abrupt extension of flaps into excessive wind stream can damage the flaps and severely impair handling of the aircraft.

Consequences: Normally, after completing a checklist and announcing it complete, the monitoring pilot returns the checklist card to its storage slot on the glareshield, an action signifying that the checklist has been accomplished and no longer requires attention. However, in this situation the monitoring pilot returned the card to its slot but left it sticking out partially to indicate that the Landing checklist was not yet complete and would have to be resumed. Also, at this time he announced "flaps to go" as a way of reminding himself and the flying pilot that further action was required.

The monitoring pilot resumed his role, focusing on attending to the aircraft flight progress by alternately checking the instruments and the view out the window, and monitoring the radio for further instructions from the Approach controller. When the flying pilot called for the intervening flaps settings as expected (flaps 25, and a few seconds later, flaps 30), the monitoring pilot moved the flap lever to the appropriate position and reached for the checklist card still protruding from its slot. He challenged the last two items on the checklist (final flap setting and autopilot set as desired for landing) and announced "Landing checklist complete" to indicate that the sequence was complete. He then immediately stowed the checklist card, this time pushing it all the way in its slot to indicate that all checklist items had been addressed and the aircraft was properly configured for landing.

Deferring an action step from a habitual task exposes crews to the risk of forgetting to perform the deferred action later when they are busy with other tasks. Further, landing flaps are typically set at a time when both pilots are busy with other duties such as monitoring aircraft speed and altitude and making required callouts, looking outside the aircraft for the runway or for conflicting traffic, responding to radio calls from ATC, and being prepared to respond to TCAS (Traffic Collision Avoidance System) alerts. These competing task demands increase crews' vulnerability to forgetting to resume the suspended Landing checklist.

This crew did remember to resume the suspended Landing checklist, and in fact, crews remember to do this in the great majority of flights. Two actions taken by the monitoring pilot—positioning the checklist to stick part way out of its slot and calling "flaps to go"—probably helped the crew remember to resume the checklist. Also the flying pilot's commands for further flap extensions served as indirect reminders because flap extension, through experience, is associated in memory with execution of the Landing checklist. It is fairly common for pilots to develop personal techniques to help remember deferred items such as suspended checklists; although these can be quite helpful, they do not eliminate vulnerability to errors of omission, especially in high workload situations. In fact, several major accidents have occurred in which crews forgot to complete a suspended or interrupted task in the face of multiple, concurrent task demands. For example, one of the factors in the 1999 landing accident of an MD-80 at Little Rock, Arkansas was the crew's failure to resume an interrupted Landing checklist during a very busy approach (NTSB, 2001; see also, Dismukes et al., 2007).

"Please call back later"

Context: The aircraft was parked at the gate as the crew prepared for departure. The first officer was in the process of performing his Pretakeoff procedure actions, as prescribed by the company FOM. The captain, having already finished his own pretakeoff tasks, was ready for the Pretakeoff checklist, which would verify that both pilots had performed all actions critical for this Pretakeoff phase of flight.

Perturbation source: Turning to the first officer to request that he initiate the Pretakeoff checklist, the captain found him still busy verifying the numbers on the load sheet and typing the data in the FMC. He saw that the first officer had not yet finished his own Pretakeoff procedure actions.

Consequences: The captain recognized that interrupting the first officer to ask for the checklist could be problematic for several reasons. First, the crew would be unable to complete the checklist anyway, as that would depend on completion of programming of the FMC; further, interrupting the programming task would risk their forgetting to resume programming or making other types of error. Pushback was not scheduled for 12 more minutes, so there was no immediate time pressure.

The captain decided to give the first officer time to finish programming. He looked around his own area and saw the papers he had been handed when descending the jetway to the aircraft. He remembered that the weather report contained information about winds aloft that could potentially affect later stages of the flight. He had already reviewed the weather while waiting for the incoming aircraft to pull in, but now took the opportunity to look over the papers again and refresh his memory. This would come in handy when he later conducted the departure brief before pushback. The captain made no attempt to create any special reminder to call for the deferred checklist, apparently assuming he would automatically remember when the first officer finished programming. Indeed, once the first officer looked up from the FMC and put the load sheet on the control panel for the captain to review, the captain called for the Pretakeoff checklist, which the crew accomplished together.

The captain adapted to this situation, as he undoubtedly had many times before, by momentarily deferring a task when the conditions for its execution were not agreeable. In this instance, time pressure was not an issue, but that is not always the case—contrast this situation with the one encountered in the first example— ("chain of mounting pressure") in which there was immediate pressure to vacate the gate area, leading the captain to interrupt the first officer. As previously discussed, deferring a task with the intention of completing it later exposes crews to the risk of forgetting to perform the deferred task at the appropriate time, especially if they are busy with other tasks at that time. In the current example, the captain remembered to execute his intention to call for the checklist when the first officer finished programming, but in similar situations crews under time pressure have on occasion forgotten to conduct deferred checklists. This example illustrates one of the many reasons pilots cannot completely control the sequence and timing of their own tasks, a notion we explore more extensively at the end of this chapter.

"Eavesdropping"

Context: The aircraft was parked at the gate prior to departure. The captain of the observed flight (which we will call FictionAir flight 123) monitored the Company frequency while performing his preflight duties. Listening to that frequency is required by the carrier's standard operating procedures and serves to ensure that crews are informed of modifications to flight plans caused by changes such as in weather, airport traffic, delays in loading or unloading, or other factors.

Perturbation source: A number of communication exchanges occurred between the company dispatcher and another aircraft of the same company (FictionAir flight 456), which was at that time parked at a neighboring gate and was also preparing for departure. All communications were appropriately prefaced with the flight number so the crews could identify which aircraft was being addressed. Flight 456 was experiencing some potential departure delays because of weather, as became evident by the dispatcher's call: "FictionAir 456, anticipate you will have to wait for the Albuquerque flight. They have 3 of your passengers and are running 14 minutes late." The captain of flight 123 monitored all of these exchanges. The captain's primary task at this point was to finish performing his pretakeoff flow. With only three more minutes before his flight was scheduled to push back from the gate, the captain had to press on with the flow and to execute the Pretakeoff checklist before pushback.

Consequences: Normally, monitoring the radio frequency to identify calls addressed to his aircraft, although performed in parallel with other tasks, required very little of the captain's attention because experienced pilots develop a skill in monitoring for and detecting their own call signs automatically. However on this day the captain found himself having to pay particular attention to the content of communications with the other company aircraft in order to continue updating his mental picture of the overall situation in the ramp area. With only one pushback tug available at the four neighboring gates at this ramp, any changes to other flights' pushback time could directly affect his own flight, especially since flight 456 was scheduled to push first. Paying attention to the content of these communications, rather than simply screening for his own call sign increased demands on inherently limited cognitive resources (attention and working memory). Thus the captain was forced to continuously switch attention between performing the pretakeoff flow and monitoring communications to update his awareness of the situation.

In this instance, the situation was resolved when the Company controller decided to re-sequence the order of departure of the two aircraft and issued a command for flight 123 to proceed first. The captain asked the first officer for the

Pretakeoff checklist and prepared for pushback and engine start, and the flight proceeded without difficulty. Although this crew managed the situation effectively, switching attention between tasks for sustained periods exposes pilots to the risk of becoming preoccupied with one of the tasks to the neglect of the other task and in some cases forgetting to switch attention back to the other task at all. This happened in an accident at Guantanamo Bay in 1993, in which the captain, who was flying the approach, became preoccupied with trying to find a strobe light on the ground to avoid Cuban airspace and failed to control the airplane's turn to final appropriately (NTSB, 1994b). Then, preoccupied with regaining control of the turn, he failed to recognize the need to abort the approach and go around. Fatigue apparently exacerbated the captain's vulnerability to preoccupation. (The crew had been on duty for nearly 18 hours, and the captain had been awake for more than 23 hours.)

"No can do!"

Context: The flight was in the beginning stages of its approach to its destination airport. The crew anticipated landing on runway 17R, which was the most commonly used runway at this airport at this time of the year. The first officer, who was the monitoring pilot, announced "going off"[3] to acquire ATIS information, which she partially transcribed on paper.

Perturbation source: After reviewing the ATIS information, the first officer realized that the airfield was now directing aircraft to land on runway 17L. This change was probably made to accommodate the high volume of traffic arriving at the airport at this time of the day. Before saying anything to the captain, who was the flying pilot, she quickly checked the performance numbers and found runway 17L was not an acceptable option for their aircraft because this runway was too short to accommodate their aircraft with its landing weight on that day. She informed the captain and waited for his assessment.

Consequences: The captain responded that they would need to request a landing on the originally planned runway, 17R, which was long enough for the weight of their aircraft. The first officer was aware that the Enroute controller would very soon be directing them to contact the Approach controller who was the controller to whom the crew would have to make their request. She therefore deferred making the request, intending to make it immediately upon establishing contact with the Approach controller who would be able to coordinate this type of request with the airport. A short while later, when the Enroute controller directed the flight crew to

3 When a pilot announces "going off" he or she is indicating that they are going to stop monitoring the air traffic control frequency while they divert their attention to another task. This prompts the other pilot to take sole responsibility for monitoring and communicating with air traffic control, in addition to their other tasks.

switch to the Approach frequency the first officer happened to be glancing at the ATIS information she had previously transcribed on paper, and remembered to make the intended request for runway 17R.

Runway changes are certainly not unusual in today's flight operational environment. In fact, they are quite common, and pilots learn to expect them at certain busy airports. Changes in flight plans during descent, however, create additional tasks that pilots must integrate with their usual, expected tasks. This integration can be challenging, increases workload, and exposes crews to the risk of errors, especially errors of omission. Crews are particularly vulnerable when one of the tasks to be integrated inadvertently drops out of the focus of attention, and the surrounding environment does not provide effective cues to remind pilots of the unattended task. The observed pilot was fortunate in that a happenstance event (looking at the ATIS information at the moment the Enroute controller communicated with the crew) reminded her of the deferred intention, but that was merely coincidence. The haphazard noticing of a cue cannot be relied on to guard against inadvertent omissions. The risk of forgetting is further increased when the workload in the cockpit is already high, as it often is during an approach to a landing. A runway change was one of the factors contributing to the runway overrun accident at Burbank, California in 2000 in which the crew became preoccupied and overloaded trying to salvage an unstabilized approach (NTSB, 2002; see also, Dismukes et al., 2007) and this factor has been implicated in many incidents (ASRS, 2007).

"Everything changes"

Context: The crew was halfway down their assigned taxi route on the way to the planned departure runway (runway 7). They had set the flaps to the takeoff position before getting underway, and were just about to initiate the Taxi checklist. The captain was at the controls and the first officer was monitoring his actions and the traffic on the taxiways, as per standard operating procedures.

Perturbation source: The winds had shifted since the original flight plan had been approved, and the airport was now using another runway for departures. The Ground controller issued an instruction directing the crew to taxi to and depart from runway 14 instead. She also issued new taxi instructions that would get the aircraft from its current position to the new departure runway for takeoff.

Consequences: With more than half the distance to the runway already behind them, the crew would normally already have performed the Taxi checklist at this point. On that day, the crew realized they would have to give precedence to the task demands generated by the unexpected change in the departure runway while underway. The checklist would therefore have to be performed later than usual (but of course no later than reaching the runway). Instead of performing the checklist, the first officer started responding to the new task demands. He first acknowledged the instructions (repeating them back to the controller) and next, based on his familiarity with the airport layout, mentally assessed how immediate a response was required to comply with the new taxi route instructions. The new route showed they would need to turn at taxiway D, and he estimated they would reach that intersection within a minute. He realized that they would barely have enough time to perform the calculations necessary to verify that the aircraft takeoff weight was within acceptable limits to take off from the new runway. At the same time, he knew he must not neglect his normal duty to monitor the taxi in progress and to conduct the Taxi checklist before the aircraft arrived at the departure runway.

The first officer advised the captain of the imminent change in routing, and the captain directed him to take care of the necessary calculations and preparations. Because these were all activities with which the first officer was quite familiar, he probably did not regard it as difficult to concurrently monitor the captain, switching attention back and forth between the head-down calculation task, and the head-up monitoring task. He was able to perform both these tasks that required his primary attention before reaching the runway by interleaving them, continuously switching attention from one task to the other. At the same time, he also monitored the radio frequency for additional changes that might require further action.

The change in departure plan before the aircraft reached the takeoff runway was certainly not an unusual occurrence, as airport conditions (e.g., weather and traffic) often change dynamically, necessitating runway changes for both landing and departing aircraft. When the operational situation changes and new tasks arise, crews have to find ways to integrate the new task demands with their normal tasks, and sometimes this requires interleaving steps of the new tasks with steps of the normal tasks. Thus, at a time when pilots would usually be able to devote full attention to a single task, they now must switch attention among tasks and execute tasks more rapidly.

Pilots usually accomplish this interleaving effectively; however, the cognitive demands of interleaving different types of tasks (in this case, monitoring someone else's actions, monitoring aural messages, entering data in a computer, engaging in simple mathematical calculations) are not at all trivial. This situation increases vulnerability to error, probably more than most pilots realize. Pilots may choose to reduce task demands to manageable levels by deferring or omitting lower priority tasks, which can be effective, but only if done in a deliberate, strategic fashion.

This handful of examples selected from the much larger set of events observed during routine flight operations (see Appendix C for a longer list) reveals the general flavor and the manner in which routine flight operations are actually conducted. The sources and effects of perturbations in pilots' formally prescribed tasks are numerous and variable. Some perturbations are momentary interruptions that can be acted upon quickly ("visitor"), but other perturbations require time-consuming actions to reach resolution ("everything changes"). Some come in the form of requests that can be dealt with by briefly suspending an ongoing activity ("flaps to go"), whereas other requests must be deferred until later ("no can do"). Perturbations may be single events ("please call back later"), or they may be compound strings of events, each incrementally imposing additional demands on the crew (“eavesdropping”). The source of perturbations is often external to the cockpit and can generally be traced to one of the many human agents who function within the same operational environment, or to ambient situational factors (e.g., weather changes). The timing and pattern of perturbations are unpredictable, and multiple perturbations sometimes occur simultaneously or in rapid succession.

Notably, all of the perturbations we observed occurred in the context of normal, routine operations—they did not arise out of an emergency or abnormal situation that required extraordinary attention or special handling by the pilots. Also notable is that perturbations were typically dealt with swiftly and effectively. Discussions with crews confirmed our impression that such events are considered part of “doing business” and are not normally cause for concern. Pilots generally feel confident that they are skilled at handling routine perturbations. (However, the next two chapters suggest that pilots may underestimate their own vulnerability to error in these situations.)

Simply listing perturbing events is not sufficient to convey the manner and extent to which they disturb the ideal execution of procedural steps listed in FOMs. Beyond analyzing the selected examples above, and in order to better convey the consequences of perturbations we turn again to time-and-activity figures. We now present a new set of figures, labeled “Real,” for each phase of flight. These are essentially revised or “populated” versions of their ideal counterparts because, in addition to the normative activities, they also depict perturbing events noted during our jumpseat observations.

Figure 4.1 is a populated version of Figure 3.2. We began with the ideal Pretakeoff phase, listing all the FOM-specified activities in the prescribed sequence and with the appropriate timing. On it, we have overlaid observations

> Early in the morning a maintenance technician performed an engine vibration evaluation on a Boeing 757 aircraft. This test involved running the engine on high power for a few minutes and testing for unwanted vibrations. When engines are operated while the aircraft is on the ground and not properly configured for takeoff (as is the case when an engine is powered up for a maintenance procedure and not in preparation for taxi and/or for takeoff), the takeoff configuration warning horn sounds. To avoid becoming distracted by the loud horn during the vibration run, and to ensure the clarity of communication in the cockpit, the engineer pulled the circuit breakers for the warning horn. This was common practice for this type of a test. The technician would be re-setting the breakers at the completion of the test.
>
> When the engine was shut down, the technician became preoccupied with having to find the engineer who had some documents necessary for the completion of the required paperwork. This distraction led the technician to forget his intention to re-set the warning horn circuit breakers. The flight crew discovered the omission during their preflight check.
>
> (U.S. Aviation Safety Reporting System, Report # 687309)

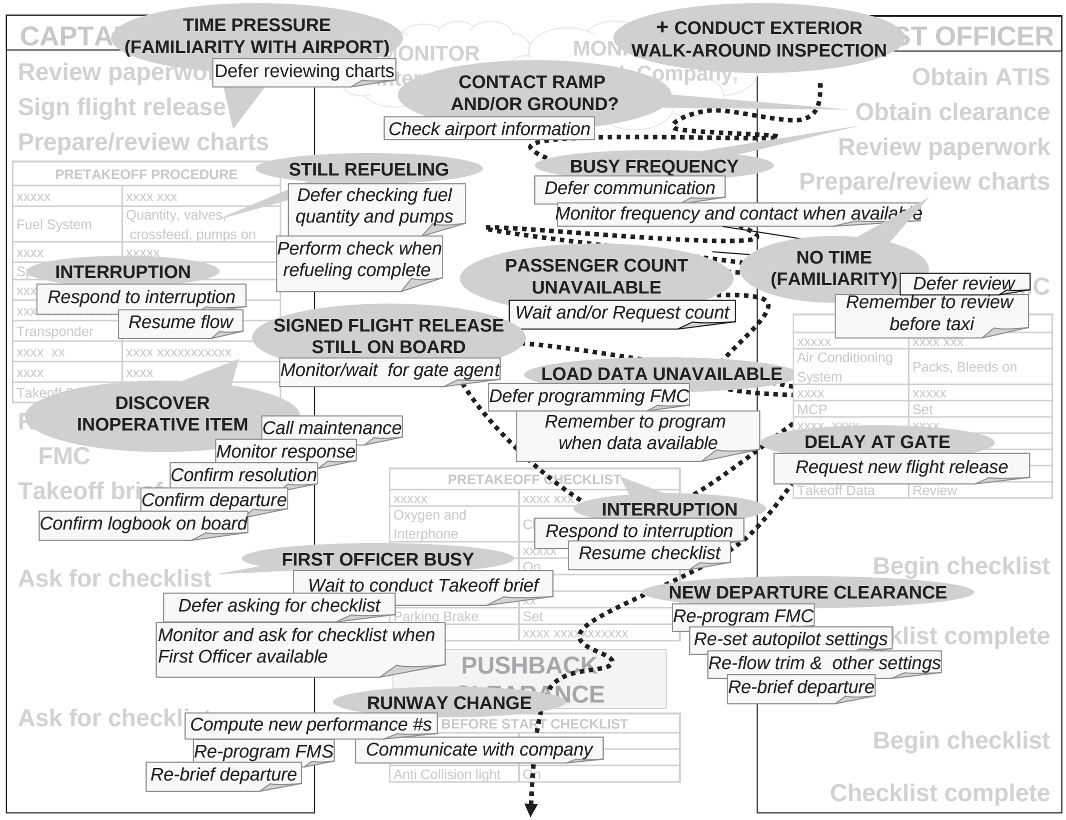

Figure 4.1 **Real before start**

of perturbing events from different flights. Each perturbing event is denoted by an oval-shaped text box (call-out box) describing the source and nature of the event and placed on the vertical axis to indicate the approximate time of occurrence. The cognitive demands associated with each perturbation are indicated in rectangular boxes below each call-out box. For example, the perturbation caused by a "busy frequency" when the FO requested pushback clearance forced the FO to keep trying until the frequency became free (Figure 4.1, top, center).

Figure 4.1 represents the entire data set collected during the Pretakeoff phase. It is important to note that the events depicted on this figure did not all occur on any one flight—they are the aggregate of many events noted in all the flights observed. (Similar events are collapsed into a single call-out box, even though they may have occurred at different times with somewhat differing repercussions.) Thus, the figure resembles a worst case scenario with perturbations along every step of the way. In reality, on most flights we observed only a few perturbations. However, the constraints of observing and note-taking undoubtedly prevented noting all perturbations that occurred on a flight. Also, perturbations surely show up in more forms than observed in our sample of about 60 flights, however, we feel this sample is large enough to be representative of routine flight operations nationwide. Using the same populating process, Figures 4.2, 4.3, 4.4, 4.5, and 4.6 show observed events for the other phases of flight and depict them superimposed on the corresponding ideal illustrations of Figures 3.3, 3.4, 3.5, 3.6, and 3.7.

Characteristics of the real operating environment

Comparing the two sets of figures (ideal and real), it becomes apparent that the real flow of activities is much more convoluted than its ideal counterpart and this observation is applicable to every phase of flight. Perturbations are generally not anticipated and are mostly acted upon as they appear, disrupting the habitual, practiced, flow of anticipated activities based on written manuals. Each perturbation entails additional cognitive demands that must be integrated with the demands of anticipated tasks. Graphically, the end result is that linear flow of events and actions depicted in the figures by straight arrows morphs into a winding path in the real figures.

The divergence between the real and the ideal time-activity graphs suggests that the picture of cockpit operations as pilot-driven, which emerged from analyzing FOMs in the previous chapter, is rather misleading. Rather than linear, predictable, and controllable, real operations are better described as:

Dynamic: Tasks do not always follow a prescribed order.

Pilots must often deviate from the linear flow of actions, A → B → C…, prescribed in FOMs. When A is completed the situation sometimes makes performing B impractical, and the pilot must move on to C with the intention of returning to B when the situation permits. Also, pilots must often respond to

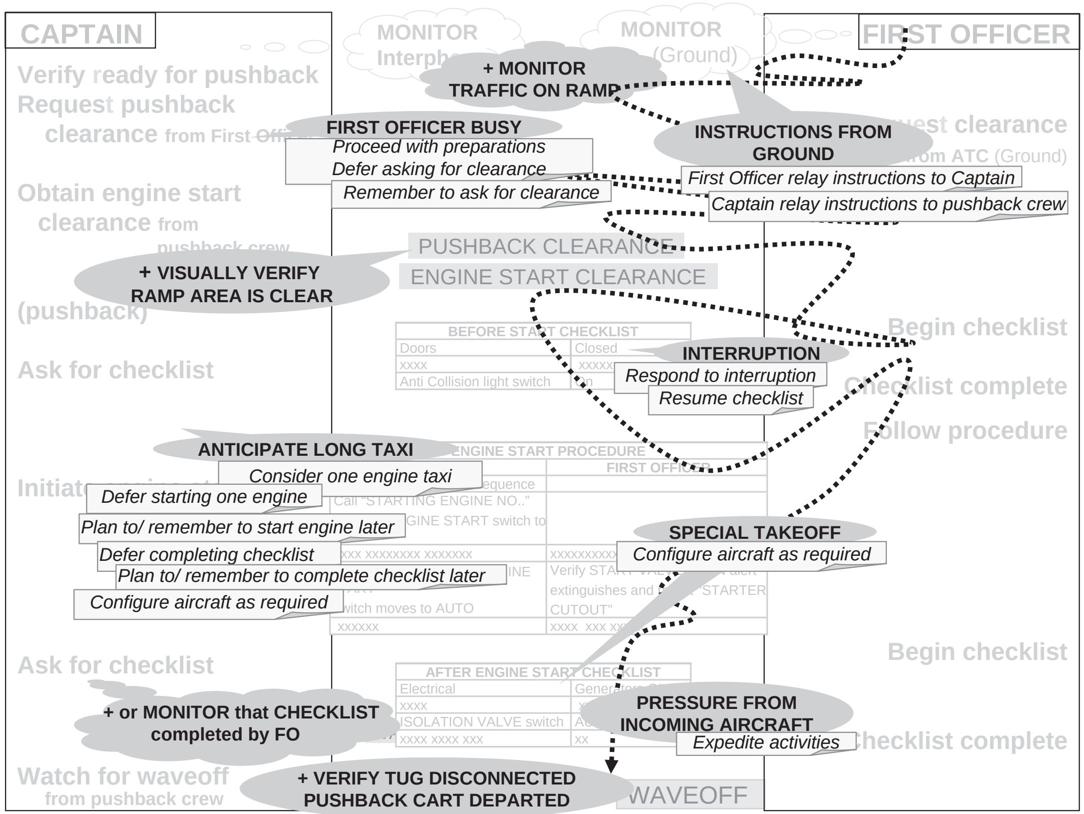

Figure 4.2 Real pushback

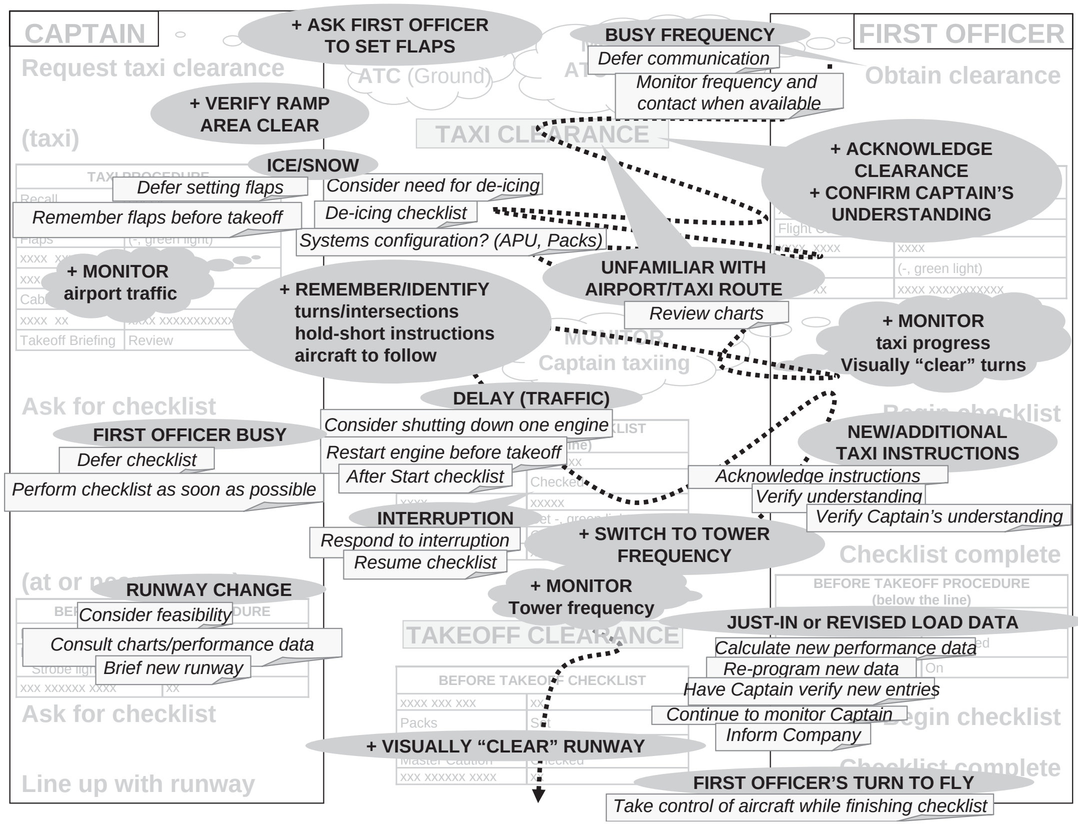

Figure 4.3 **Real taxi**

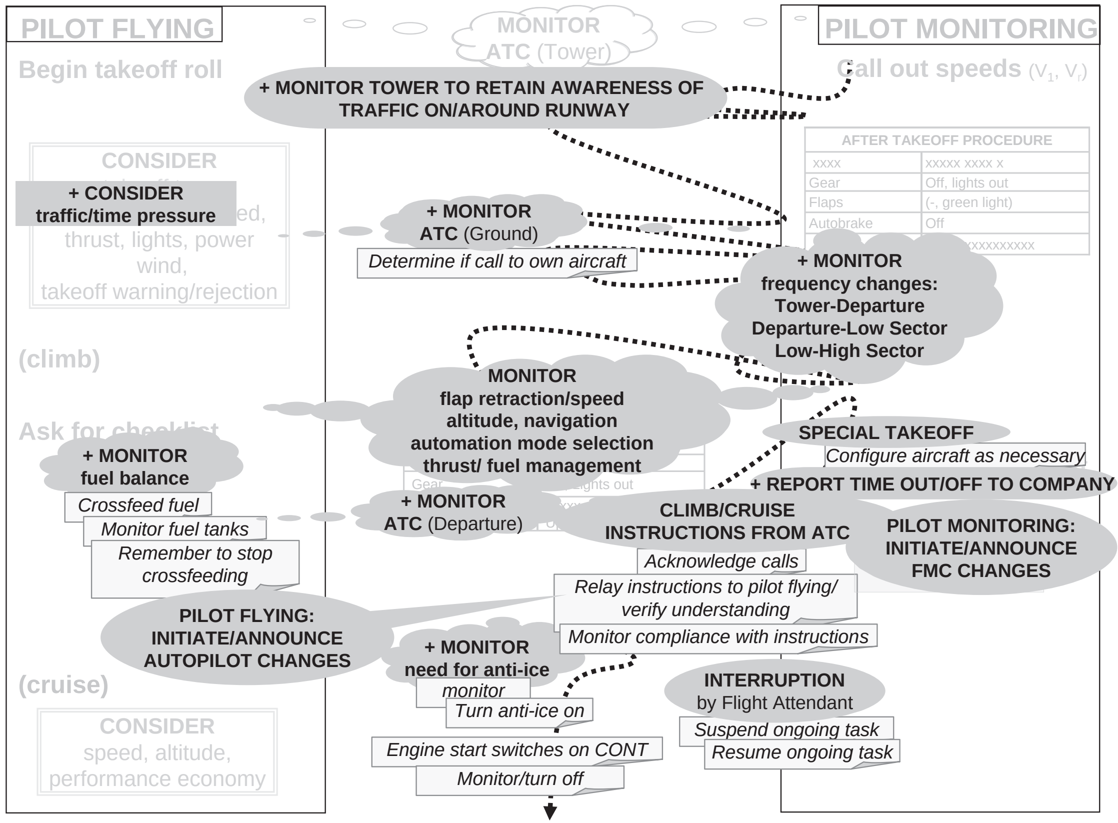

Figure 4.4 Real takeoff, climb, and cruise

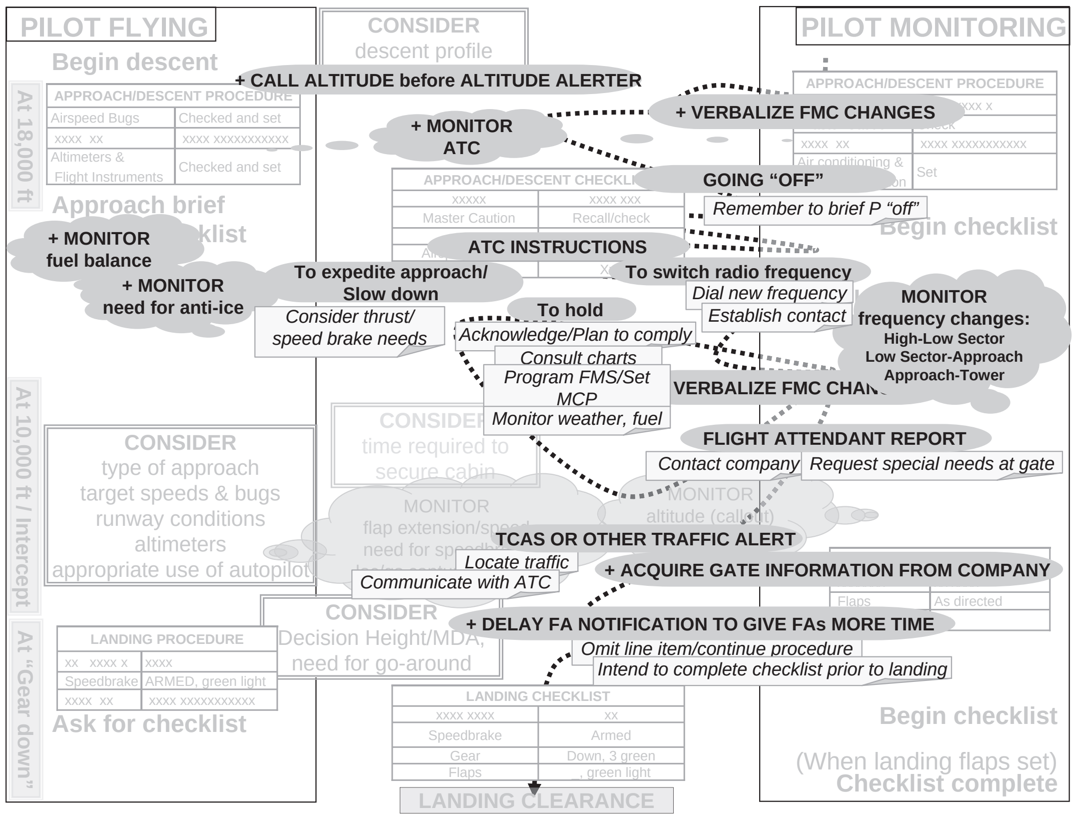

Figure 4.5 **Real descent and approach**

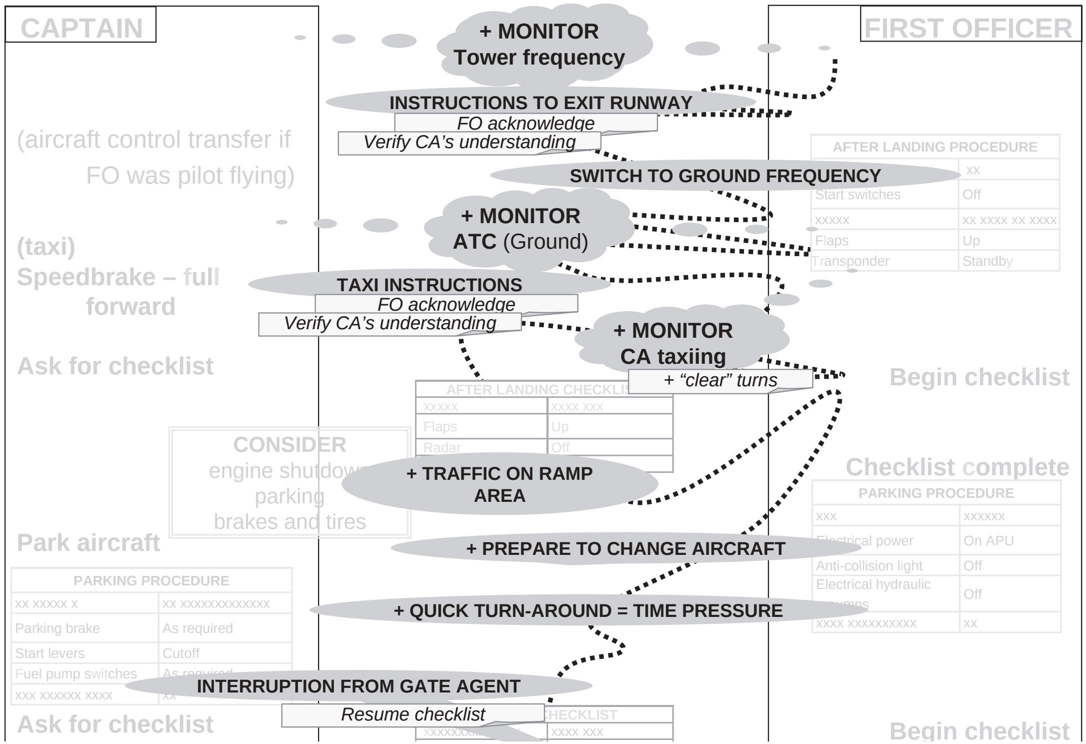

Figure 4.6 Real landing, taxi-in, and shutdown

unplanned demands, inserting new tasks, e.g.: A → B → X → C… Finally, tasks often must be performed concurrently, so the real sequence consists of alternating between elements, more like: part of A → part of B → part of A → part of B → part of C → part of D → part of C → part of D… Because of these variations, the flow of activities is dynamic rather than linear. Further, these situational-dependent deviations vary from flight to flight and even from moment to moment, which undercuts the automatic execution of habitual tasks; this increases vulnerability to error.

Semi-predictable: Tasks and events can not all be exactly anticipated (neither their nature nor their timing).

Predictability hinges upon the absence of unexpected events. Our field observations make it clear that real-life flights are inundated with unpredictable demands that generate unscheduled tasks for crews. Note that most of these events are unpredictable, but not truly unexpected. Because these events occur with some frequency in the course of operations, pilots have moderate to extensive experience handling them. However, pilots do not know when a given perturbation will occur or what tasks they will be performing when it happens, and thus cannot plan ahead how to manage it.

The availability of information necessary to perform specific crew tasks is also semi-predictable. Lacking required information disrupts the ideal flow of execution of tasks (e.g., lacking final weight and balance information, the first officer cannot complete FMC programming). Further, because each of the two pilots must juggle task demands that are not entirely predictable, they are not always immediately available to each other when they come to tasks that require them to collaborate.

Semi-controllable: Initiation of tasks is not entirely under pilot control.

Ideally, a pilot should be able to initiate a task when ready to devote full attention to it. In reality, it is often the case that circumstances or external agents require tasks to be initiated earlier or later than planned, at a time when other activities might be in progress. This pressure pushes crews from a role that is ideally proactive toward a more problematic, reactive mode of operating.

Because the timing and execution of activities is not entirely under crew control, the time available for executing tasks is sometimes less than desired or expected. The combination of lack of scheduling control and unanticipated additional task demands increases time pressure and workload, especially in critical phases of flight in which the crew is already quite busy. Further, FOMs portray the two pilots performing most of their tasks separately; however, unanticipated perturbations often require the attention of both pilots, increasing both workload and the need for collaboration.

In sum, situational constraints and unscheduled demands drive cockpit work to a significant degree, reducing the extent to which it is under crew control. This has important implications for captains' responsibilities. In his or her role as pilot in command, the captain is the one with whom most agents outside the cockpit interact, and the one who must make final decisions on handling all situations. To complicate matters, each group of agents acts in response to its own operating needs and pressures, communicates using its own language, and works with its own, often incomplete, mental picture of the overall situation. The ground crew, the cabin crew, the air traffic controllers, for example, all have their own agendas. In pursuing their own operational goals and needs, they often create time pressure and impose operational demands on the flight crew. The captain (as pilot in command) must decide how to address these externally generated demands while also meeting the flight crew's own goals. At the ramp, for example, the ground crew might be under a tight schedule and anxious to push the aircraft back so it can report at another gate where another aircraft is waiting to be pushed. At the same time, the cabin crew may need more time to carry out a final passenger count because of a delay in boarding, while the Ground controller may be anxious to get the aircraft away from the ramp to accommodate other incoming aircraft. In the air, the Approach controller may push the crew to keep their speed up in order to maintain separation among airplanes in the busy airspace; the flying pilot may question whether this higher speed will allow enough time to slow down closer to the runway, while the lead flight attendant might still be anxiously waiting for the monitoring pilot to verify that her request for a wheelchair at the destination gate has been received by the gate agent on the ground. Quite often, groups of human agents are not in direct communication with one another and must rely on the captain to coordinate their respective demands.

There is danger that these pressures can push crews into a reactive mode in which the crew responds to each demand as it arrives, losing control of the situation and compromising safety. In principle, the captain is responsible for controlling the situation to ensure that the crew can manage the workload and have time to perform all tasks effectively. For example, the captain is empowered to respond "unable" to ATC instructions, if necessary, though this may not endear him to controllers. But strong organizational and self-imposed pressures work against crews' attempts to maintain control of the pacing and structure of their tasks. On-time performance and fuel costs are strong drivers in the hyper-competitive airline industry. Thus we suggest in the final chapter that airlines should explicitly train pilots to recognize the danger posed when they allow themselves to be pushed into a reactive mode, should provide realistic training in managing workload and competing task demands, and should emphatically support captains' efforts to maintain a proactive stance.

In closing the previous chapter, we argued that operating procedures designed solely from the ideal perspective are likely to be brittle and conducive to error in real-world situations. We also argue that training should help pilots develop effective ways of managing dynamic real-world task demands. Our visits to airline training centers (more than just the two that supported this study) led us to conclude that airlines provide very little training and guidance to help pilots manage these situations. Crew Resource Management (CRM) classes that focus on making efficient use of available resources (human, equipment, information) sometimes provide general guidance on workload management but rarely address the specific manifestations of real-world demands depicted in this chapter. Apparently, managing these manifestations is something that pilots are supposed to learn on their own during line operations, which they do, although it is far from clear that all pilots develop effective techniques.

In the next chapter we examine the consequences of the divergence of real-world cockpit operations from the ideal of the FOM and from pilot training. We describe pilot errors associated with real-world perturbations, analyze the cognitive processes that come into play when pilots respond to concurrent task demands, and develop a perspective on vulnerability to errors of omission.