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# Cognitive Mismatches in the Cockpit: Will They Ever Be a Thing of the Past?

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## ABSTRACT

The introduction of the glass cockpit redistributed, rather than reduced flight crews' workloads. Pilots now spend more resources managing the various systems in the cockpit. The specific problems of using cockpit automation are well documented; the more generic problem of cognitive mismatches is considered here. A taxonomy of the types of cognitive mismatches is defined before considering how to manage them. Allowing the glass cockpit to continue to evolve in the same way will not help. A call is made for the development of a new integrated cockpit architecture that better supports the task of flying an aircraft.

## KEYWORDS
Cognitive mismatches, flightdeck systems, design, human-machine interaction.

## INTRODUCTION

Mastering a complex skill, such as flying an aircraft, takes of the order of 1000 hours [16]. During their training aircraft pilots used to be taught that to fly the aircraft they needed to aviate, navigate and communicate. This was before the advent of glass cockpit aircraft. It was hoped that their introduction would reduce the amount of training required by pilots, but this has not been the case [12]. Some of the burden for handling of safety and efficiency has been passed to the automation, but the pilots instead have to spend extra time and effort on learning how to manage these systems. Indeed, the introduction of technology has changed the nature of training such that pilots are now taught to aviate, navigate, communicate *and manage systems*.

As more and more technology continues to be added, the emphasis on managing systems continues to increase accordingly. There are already several well-documented examples of the problems that the new automation has introduced, such as automation surprises [15], where the technology in the cockpit does something that the pilots were not expecting. In this paper, the more general problem of cognitive mismatches—a disparity between the operator's mental model of the system, and the way that the system is really working [e.g., 14]—is discussed, and some consideration given to how they can be managed.

## AVIATION AS PROCESS CONTROL

The way that crews fly an aircraft is generally considered as a typical control loop activity. The pilots have some sort of mental model of how the socio-technical system—pilots, aircraft including computer-based systems, air traffic control, the airline, and the regulators—works, which enables them to reason about its behaviour [e.g., 11].

The pilots monitor the system variables and interpret the data to formulate a representation of the current state of the system. They then compare this with the expected state, and then make adjustments as necessary to try and ensure that the current and expected states match. This process can be summarised by the simplified loop shown in figure 1.

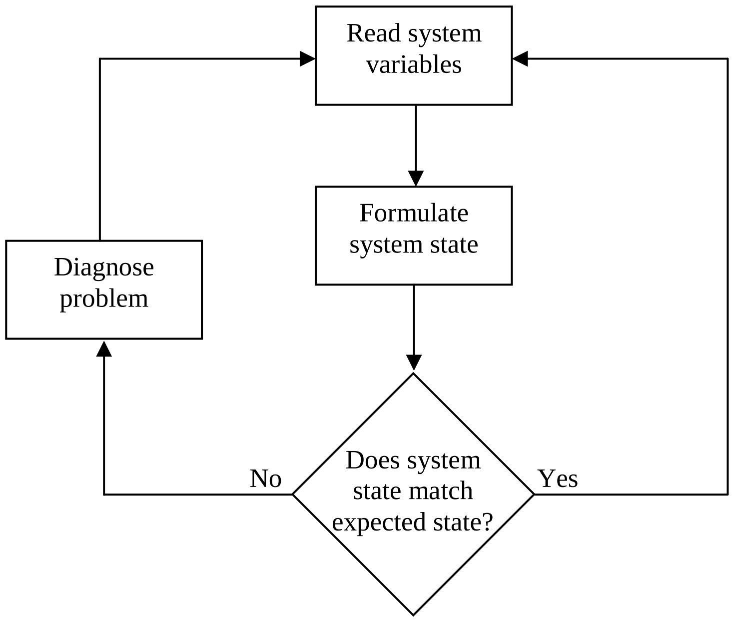


**Figure1:** Simplified overview of pilot's control task

In many modern process control systems there are usually too many variables for the operators to be able to check them all individually whilst still controlling the system or process in a timely manner. This state of affairs is certainly true of modern glass cockpit aircraft. The pilots deal with the problem by learning which of the variables can normally be used to reliably predict the current state of the system, and then monitor that subset of variables. In other words, the pilots rely on their perceived state of the system, rather than the real state [6]. Generally, this works well, but where it starts to break down, system state misinterpretation can occur and give rise to subsequent problems [3].

## COGNITIVE MISMATCHES

As the complexity of aircraft cockpits continues to increase, the chances of the pilot's mental model being accurate are accordingly reduced. Instead of being an isomorphic representation of the real system, the pilot's mental model takes the form of a homomorphic representation. In other words, the model only accounts for the states that the pilots have encountered, whereas an isomorphic model would require the pilots to either have to know or be able to generate all the system's possible states. The pilot's mental model is therefore a simplified representation of the real state of affairs, and as new situations and states are encountered, the failings of that model start to become apparent.

In aviation, a cognitive mismatch occurs when the pilot's mental model of the system does not adequately explain the way that the system is really working. The different types of cognitive mismatch can be categorised using two dimensions (see Table 1):

- *Type of mismatch*. A real mismatch occurs when there is a real discrepancy between the pilot's mental model and the way that the system operates. This state of affairs is normally indicative of a real flaw in the pilot's mental model. A perceived mismatch occurs when the pilot perceives that there is a real discrepancy between their mental model and the way that the system operates, when in reality there is not. In other words, this state of affairs represents a false alarm.

- *Detection of mismatch*. Once a mismatch has been detected, it provides a potential trigger for action, so that the mismatch can be corrected. Normally the detection of a mismatch should trigger some diagnostic activity. If a mismatch is undetected, this means that the pilots are unaware that the situation is deteriorating. Generally, the longer a mismatch remains undetected, the greater the potential severity of any resulting adverse consequences.

| | *Real mismatch* | *Perceived mismatch* |
|---|---|---|
| *Detected* | Real problem: needs to be diagnosed and fixed | False alarm: could be a problem if the pilots act and turns it an undetected real mismatch. |
| *Undetected* | Real problem that needs to be flagged to the pilots, so that it can be diagnosed and fixed | Not possible: "perceived" implies "detected". |

***Table 1****: The four theoretical types of cognitive mismatch.*

There is an implicit temporal dimension to cognitive mismatches. The pilots need to be able to detect the mismatch at a time when they can still diagnose the problem and take recovery action before any adverse consequences arise. Ideally, all real mismatches should be detected, or at least made apparent to the pilots so that they can be dealt with in a timely manner. Detection is not always straightforward, however, because cognitive biases can intervene, such as falsely attributing explanatory power to events which happen coincidentally [4]

Cognitive mismatches can take many different forms, and have a range of causes such as lack of attention, insufficient knowledge, high workload and so on. In many cases the cause is rooted in the design of the automation and the way that it has to be used by the pilots. Palmer [13], for example, highlighted the role of mode confusion in a particular instance of automation surprises, which are considered here as a type of cognitive mismatch.

## COPING WITH COGNITIVE MISMATCHES IN THE COCKPIT

The issue of cognitive mismatches needs to be considered carefully during the design of aircraft systems. Current cockpits are really an evolution of the original glass cockpit concept. More and more new automation has been introduced into the cockpit in an almost *ad hoc* fashion, without full consideration of the overall impact on all the other parts of the system, including the pilots.

Many of the new devices that have been added to the cockpit have had some sort of safety function. In other words they detect when an unsafe situation has occurred and indicate this to the pilots, generating warnings and alarms and potentially triggering automatic behaviours. For instance, some flights configurations (e.g. low altitude with gear up) will trigger several simultaneous alarms regardless of whether the pilot correctly realises and understands the situation or not. If the low altitude flight was unintended, then the Three Mile Island nuclear accident [9] teaches us that recovery can be hindered by the proliferation of alarms. If the low altitude flight was indeed intended, however, then the multiple alarms will be an undue distraction to the pilot.

Managing and programming flight systems is now an intrinsic part of the task of flying an aircraft. Pilots acknowledge that they spend more and more time typing data into the flight management computer, thereby spending correspondingly less time monitoring external visual cues. Each new piece of automation adds to the system management task and does not always reduce the workload on the other tasks in the cockpit. From this point of view, the move from classical to glass cockpits has shifted the workload rather than reduced it [18].

Given the current state of affairs in aircraft cockpits, the problem is how cognitive mismatches can be detected and managed in a timely manner or, preferably, prevented. Where prevention is not possible, they should be made obvious to the flight crew so that they can attempt to manage them. In other words, some effort should be made to ensure that the only type of mismatches are those that are real and that they are detected at the earliest possible opportunity. Some possible ways of dealing with the problems of cognitive mismatches are briefly outlined below.

### Do Nothing

The simplest solution is to maintain the status quo and do nothing. In other words, continue to rely on the pilots being able to detect, diagnose and fix any problems. This may be the only solution for existing systems, in which case pilots need to be continually made aware of any new potential problems with the new technology (through feedback from incident reporting systems, for example).

Keeping pilots in the loop has long been recognised as the best way to exploit human flexibility and adaptability [1]. As systems continue to get more complex, however, it may get even harder to keep the pilots fully in the loop, because they will require more complex mental models to appropriately represent the system's behaviour. This is likely to make it even more difficult to detect any cognitive mismatches in a timely manner. Under normal operating conditions, everything works fine. During busy periods, such as transitions between flight levels, however, if a problem is flagged up by the automation, this can often lead to problems. Re-introducing a third flight crew member into the cockpit may help, although it could also have an adverse effect on the dynamics of the system because of the need for extra communication, for example.

### Use Intelligent Assistants

The second solution is to utilise intelligent assistant technology. This approach is consonant with the notion of joint cognitive systems [8] in which the idea is to try to develop and maintain a synergy between the operator's mental model of the computer system's behaviour and the computer system's model of the operator's behaviour. This is achieved by the automation tracking the pilots' behaviour and using this to determine what it thinks the pilots are doing, and then offering appropriate support and assistance. Such ideas have been incorporated into systems such as Hazard Monitor [2], and CATS [7] although these have not yet been deployed in commercial aircraft.

### Patch the Existing Cockpit Design

There is often a long lead time in aviation between the initial design of a new technology and its introduction into the cockpit. Mode S datalink, for example, was originally designed in 1975. A radical overhaul of the cockpit is therefore unlikely in the short term. In many respects, the way in which new technology has been introduced into the cockpit can be regarded as patching the existing system, usually in order to improve safety, as already noted. In addition to this, however, as an interim measure, consideration should also be given to how to apply existing proposed solutions to several of the problems of human-machine interaction in cockpit that are already well documented [e.g., 5, 17].

### Design a New, Integrated Cockpit Architecture

In the longer term, however, a more radical solution may be required. Current cockpits are the result of the evolution of the glass cockpit in a bottom up manner. New pieces of automation are added which often bring their own sets of interfaces, displays and methods of interaction. It would therefore seem sensible to develop a top down integrated cockpit architecture that would provide a more structured, coherent basis for the next generation of cockpits. The new architecture would provide better support to the pilots in the task of flying the aircraft.

It is already widely recognised and accepted that it is important for pilots to "keep ahead of the plane". One useful facility of the new architecture would therefore be a feature that allowed the pilots to predict the future state of the aircraft. Ideally this would allow them to ask "what-if?" type questions about future possible situations. The answers to such questions could help in anticipating some of the problems of cognitive mismatches, because they would allow the pilots to be able to detect potential problems with particular courses of action.

Another useful feature would be the interpretation of pilots' intentions. This feature is already present in intelligent assistants, which attempt to infer the user's intentions on the basis of their actions. The sequence of actions is compared to a library of reference plans in order to try to identify what the user is trying to do. Such a facility would help to avoid the problems that arose in the A300 landing at Nagoya airport in Japan

[10] where the co-pilot had to fight against the climbing aircraft in order to land it. Such a facility would also help in the management of cognitive mismatches because the automation would be able to detect and flag up where it thought that the pilots were doing something that was not expected.

Even the notion of an integrated cockpit architecture has potential knock-on effects. If the new cockpit is radically different from existing cockpits, this would mean that the pilots would have to undergo extensive retraining to learn to use the new cockpit. This is not an insurmountable problem, however, since there are similarities to the situation when the glass cockpit was introduced.

## SUMMARY

The complexity of the aviation system is now at the level where it is very difficult if not impossible for pilots to be able to correctly mentally represent the current and future states of the system. The cockpit on its own is heavily populated with automated equipment that the pilots have to program and manage. Often each piece of equipment has its own way of working, and its own separate interface. The proliferation of equipment makes it harder for the pilots to understand what the system is doing and to predict what will happen next, leading to cognitive mismatches which the pilot has to detect and resolve in a timely manner. There is, however, no silver bullet that can be used to solve the problem of dealing with cognitive mismatches in the cockpit. It seems clear, however, that continuing to allow the glass cockpit to evolve further, by adding more automation that uses visual display based interface can only make things worse in the long run. The preferred solution is therefore to set in train the idea of developing an integrated cockpit architecture that can better support the pilots in the task of flying the aircraft through facilities that allow them to keep ahead of the plane and anticipate possible problems.

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