WHAT PILOTS LEARN ABOUT AUTOFLIGHT WHILE FLYING ON THE LINE

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ABSTRACT

We are conducting a longitudinal study to investigate how pilots acquire expertise in the operation of the autoflight and flight management computer systems in the Airbus A320 airplane. We interview and observe pilots in the first stages of their line experience to discover how pilot's understanding of flight deck automation develops. Pilots appear to use a small set of simple conceptual models to understand how the automation controls aircraft behavior. These basic models are not presented to pilots in training. Pilots appear to use their conceptual models as resources for constructing an understanding of how the automation controls airplane behavior. We discuss the models and our efforts to incorporate them into training.

INTRODUCTION

There is ample evidence suggesting that when airline pilots leave training they do not have a complete or accurate understanding of autoflight system functioning [2, 5, 6]. Airline training programs often emphasize the procedural knowledge needed in operations and gloss over the conceptual knowledge needed to understand and predict airplane behavior in a wide range of flight situations. Most airlines accept this lack of conceptual depth in their pilots' knowledge because they expect the pilots will gain a deeper understanding of the automation in their first year flying in revenue service.

In collaboration with a major U.S. airline we are conducting a longitudinal study to investigate the processes by which pilots acquire expertise in the operation of the Airbus A320 airplane with particular emphasis on the operation of the autoflight and flight management computer systems. We are particularly interested in discovering how pilot's understanding of flight deck automation develops over the course of initial training and through early stages of operating experience.

INTERVIEWS

We interview pilots flying the A320 for a major U.S. airline at regular intervals. The initial interview was conducted during the pilot's the first week of training. The second interview occurred after the pilot's initial operating experience (IOE) evaluation[1] given by a check airman. Subsequent interviews were conducted at 6 months, 12 months, and 18 months of operational experience.

The initial interview questions were designed to probe for the preconceptions about the airplane that pilots bring to training. We also collected experience data and asked pilots about their impressions of training so far. In Post IOE interviews we probe specifically for training issues, particularly what they thought was lacking in their training and areas they didn't understand. In subsequent interviews we probe for how they use the automation when they fly and how they use the automation to handle difficult flight situations. We ask pilots to describe the last leg they flew and how they used the automation in all phases of flight. We found that reviewing the last flight flown provides the pilots with a rich context for talking about automation use and areas of difficulty. We also observe pilots from the jumpseat to assess how pilots use the automation in flight. The jumpseat provides an opportunity to talk with the pilots while they fly[2] and it provides a rich setting for discussion about autoflight functioning. We use field notes from jumpseat observations to complement pilot descriptions in the interviews.

TRAINING

In training pilots are told to use as much automation as possible. For example, they are instructed to engage the autopilot at 100 feet AGL on takeoff and to disconnect it at 100 feet AGL on landing, and they are instructed to leave the autothrottles engaged at all time[3]. Pilots are

[1] The IOE period ends approximately when 25 hours of operational flight time has been accrued.
[2] All conversations abide by the constraints of safety and sterile cockpit rules.
[3] AGL refers to above ground level. If the autothrust is inoperative, the airplane may not dispatch.

ecouraged to use the highest level of automation available in all flight contexts, but are told that pilot judgement dictates the appropriate level. Pilots are taught how to use the automation for simple tasks that are flown in and around familiar airports. Simulator sessions are devoted primarily to simulating emergency conditions and are not used to instruct pilots on the intricacies of managing the automation during the various phases of flight. Pilots are told to fly the airplane the way it was designed to be flown; with the automation fully engaged from 100 feet after take off to 100 feet before landing. When pilots enter revenue service they report a very different pattern of automation use.

Most of our pilots report 'hand-flying' the airplane with the autopilot disengaged up to 10,000 feet or up to higher cruise altitudes. Depending on the terminal environment at the destination, pilots will often choose to hand-fly the airplane down from 18,000 to 8,000 feet to landing. Most of our pilots report no difficulty in their understanding of how the automation controls airplane behavior in the climb and cruise phases of flight. Many of our pilots report difficulty with the automation in the descent phase of flight.

DIFFICULTY IN THE DESCENT

An analysis of the interview data suggests that when conceptual problems arise they are most often associated with the descent and approach phases of flight (Table 1).

Table 1. Number of reported difficulties by phase of flight

Ground	Climb	Cruise	Descent	Landing
6	6	1	48	2

The following interview excerpt is a representative sample of reported difficulty pilots experience in the descent selected for a corpus of 37 interviews:

Pilot: as far as what mode to be in at what part of flight and everything else. um the biggest problems I had were // the // descending into-to the terminal area? a-a-after // after you might fly fly the arrival and be down around sixteen thousand ten thousand feet, and then they just clear you down to an altitude figurin' out how to get down-how to get there-how to plug everything in to get the airplane to go down, slow down, and be able to configure, for the-for the approach.

To understand why the descent phase of flight might be problematic for pilots we performed two kinds of analysis. First, we completed a careful analysis of the training materials. These materials included the pilot handbook, CBT, displays guide, lights and switches guide, course syllabi, and IOE training guide. We examined the materials line by line to identify individual concepts, the presentation and descriptions of concepts, and the relations between concepts. We represented the results of this examination as an inventory of the autoflight concepts presented.

Second, we analyzed the interview data for conceptual models pilots use to describe aircraft behavior in the descent. Pilots appear to use a small set of simple conceptual models to understand how the automation controls aircraft behavior. Some of these models are basic models of airplane control that any instrument-rated pilot would know, such as "pitch to control speed with constant thrust," and others. These basic models are not presented to pilots in the training materials at the airline. The data suggest pilots bring these models to the airplane and use them to construct an understanding of how the autoflight system controls the aircraft's behavior.

Conceptual Models

People use conceptual models to establish the meaning of events, to understand why things work the way they do, to infer unobservable states, and to predict what will happen in the future [1, 3]. Pilots use simple conceptual models in their descriptions of how the automation controls airplane behavior. In this section we present an interview excerpt in which a pilot uses and contrasts two simple conceptual models to describe his own confusion about how the managed descent mode controls the airplane. The models he uses are "use pitch to stay on a path while maintaining speed (by unspecified means)" and "use pitch to control speed with idle thrust". The key components of our conceptual analysis are underlined in the discourse. The pilot is describing the difficulty he experienced in a recent descent.

Pilot: you <u>have to keep in the back of your head</u> that <u>if you're in a managed descent</u>, the <u>airplane's going</u> to go ahead and <u>go down whatever computed</u> // uh <u>// the vertical path has computed?</u> and it-and it's also gonnam-uh <u>maintain</u> that that <u>descent airspeed</u> you have."

The pilot reports that the managed descent mode selection must be remembered, suggesting that other (conventional) airplanes are not like this one. He continues with a description of managed descent mode as a pitch to path mode in which descent airspeed will be maintained in an unspecified manner. However, the flight mode annuciation (FMA) for thrust reads "IDLE" in the first segment of a managed descent. When conventional airplanes descend with thrust at idle pilots use pitch to control speed, so this FMA may suggest to pilots that speed is on pitch. The pilot continues:

Pilot: You'll be high, and you'll be wantin' to get down, and you're in a managed descent, like if-if-if you're flying an arrival and all of a sudden they change an altitude on ya? They want you to get down a little bit sooner?"

He expresses a desire to increase the descent rate to get down sooner while flying in managed descent mode. This leads to an automation surprise.

Pilot: Well you look at it and see where you're gonna level off and see if-see if that's gonna be enough and if it's not then it's kinda like (1.5) um you know y-you may increase the speed, and all-all this thing does it just spools the engines up and not increase the rate of descent. And you're sittin' there going why is it doing that?"

Normal descents in non-FMS equipped airplanes are flown at idle thrust with airspeed and vertical rate controlled by airplane pitch attitude. Lowering the nose will increase airspeed and increase descent rate. This mode of operation is also available in a so-called "tactical" or "selected" mode in FMS-equipped airplanes[4]. These modes do not make use of FMCS path computations. While in such a mode, pilots increase the speed target to increase the vertical rate. In a managed descent mode[5], an increased airspeed target causes an increase in thrust, because descent airspeed is being controlled by thrust *and* thrust is at "IDLE". The airplane's behavior violates the pilot's conceptual model of using pitch to control speed when thrust is idle.

Speed can be controlled by thrust while thrust is at idle *only* if the vertical path has been constructed such that idle thrust *is* the amount of thrust required to produce the target speeds. This computation cannot be done by any human pilot. But, it is exactly what a managed descent in an Airbus or a VNAV path descent in a Boeing does. Many pilots see it as magic because they literally cannot imagine how it is done.

Pilots have difficulty understanding how the automation controls airplane behavior in a managed descent because the automation violates their most basic conceptual understanding of how airplanes fly. This is a training issue. Pilots need to be taught how the autoflight system controls airplane behavior in a managed descent, a topic we address later.

DIFFICULTY WITH THE APPROACH

The transition from the descent phase of flight to the approach phase of flight is another area of difficulty for pilots new to the Airbus. The terminal environment is a challenging flight environment. The Airbus A320 was designed to be flown from top of descent to the final approach fix with the highest levels of automation fully engaged. If the flight environment is unconstrained, pilots can program the entire descent and arrival in advance. This can lead to a welcome lowering of workload in the arrival. However the reality of flying in North America often does not permit the transition from descent to approach to be made at high levels of automation.

Several things interfere with flying the full descent path as computed by the flight management computer. Pilots may receive vectors, last minute runway changes, speed restrictions, or be "kept high." Each of these conditions may interfere with the computed descent path/speed profile, which engineers (but few pilots) think of as a schedule for energy dissipation. Pilots experience the results of these clearances as difficulties getting the airplane to arrive at assigned fixes at appropriate airspeeds. The A320 is an aerodynamically clean airplane and pilots report "it doesn't like to slow down". Others call it "vertically challenged." Thus a feature that was intended to reduce workload can increase workload when the aircraft must depart from the programmed descent and arrival path/speed profile. Furthermore, pilots get no experience in training solving these problems. When they apply conceptual models that were developed in conventional airplanes to the problems encountered in a modified arrival, they often encounter automation surprises. Training does not provide pilots with the conceptual understanding needed to effectively use the automation in the transition from descent to approach. First, the disparity between what they learned in training and the reality of line flying encourages pilots to avoid the highest levels of automation. Thus they never give themselves the opportunity to learn to trust the automation. Second, they may use the "selected" automation modes inappropriately.

In the following segment the pilot describes having to turn off the flight directors on the approach. Some of the other pilots in our study also report not knowing the circumstances when the flight directors must be turned off.

[4] In the Airbus airplanes, this would be the OP DES or OPen DEScent mode. In the Boeing airplanes, this would be FLCH or Flight Level CHange mode.
[5] DES in the Airbus, VNAV-PTH in the Boeing.

Interviewer: so how's it going on the airplane?

Pilot: uh good. good. um of course everything they say you know that can happen with the-as you remember the um flight directors when you're going visual you know that they ***have*** to come off. the airplane starts doing goofy stuff. in fact it was my first trip, uh IOE, going into Pittsburgh, and the traffic in front of us slowed down too much, so we got off the ILS, and uh S turned a little bit, and uh forgot to turn the flight directors off, and the speed started going real low on it

In training, pilots are told to keep the automation (including autopilot and flight directors) engaged until 100 feet AGL. However that was not an option because of the requirement to slow for traffic. In retrospect, the pilot can see that the problem was caused by his failure to turn off the flight director when he needed to fly away from the guidance it was providing. Having raised the topic of flying away from the flight director, the pilot offered another what he considered to be another example of the automation doing something goofy as a result of the crew deviating from the flight director guidance. In fact, the following is a description of a misunderstanding of an autoflight mode.

Pilot: the other one was we were leveling off coming out of Pitt-*((unint))* out of Pittsburgh, and there was traffic at six thousand, and we were taking off to the west right into the traffic coming into Pittsburgh, and that's why they held us at five, so when we got to about, I was hand flying it, we got to about I don't know, forty five hundred or so, you know thing's climbing at like eighteen hundred or two thousand feet a minute,

Interviewer: right

Pilot: I didn't want the Tcas to go off, so I start shallowing out the uh level off, to hit five at you know like two hundred, three hundred feet a minute. once again the flight directors are looking at-hey you need to be climbing at eighteen hundred or two thousand or whatever, it doesn't realize-it doesn't think far enough-you know it can't think for you so it doesn't know that you're just trying to avoid a Tcas alert.

Interviewer: yeah

Pilot: well what happened was it said well obviously you're not-you're not climbing fast enough to make me happy, so the airspeed started zooming to uh it got-it went through two fifty I mean it was probably up to around three hundred.by the time we uh reached up and grabbed the VSI.

Here the pilot was climbing in open climb mode. Open climb mode is a pitch to speed mode. When open climb is engaged autothrust commands climb thrust and the flight director pitch bars command an airplane pitch attitude to maintain a speed target. The pilot had the expectation that when the airplane leveled, the thrust would decrease to maintain the speed target, and indeed it would have, if the autoflight system had been permitted to make the automatic mode transitions to altitude capture (ALT*) and then altitude hold (ALT) mode at 5,000 feet. However, while still in OP CLB, and thus still pitching to a speed, the pilot pushed the nose down. This did two things. With climb thrust set, it caused the speed to increase dramatically. Second, by decreasing the rate of climb, it delayed the transition to ALT mode that would have given the control of airpspeed to the autothrust system in SPD mode. Putting the airplane into vertical speed mode was an appropriate solution to the problem of the overspeed, but the problem was caused initially by a misunderstanding of the behavior of the guidance modes.

INCORPORATING PILOT MODELS INTO TRAINING

Pilots use simple conceptual models to describe how the automation controls airplane behavior. These models seem to be ones that originated early in their flying experience and are then adapted to the Airbus. One way to productively use this knowledge is to train pilots by grounding the explanations of automation behavior in the conceptual models pilots are known to use.

In our analysis of the training materials, it was obvious that the training materials were not giving pilots the conceptual framework they needed to understand how managed descent mode worked. Our objective was to identify the concepts that pilots needed to know to understand managed descent mode functioning and to develop a computer based training (CBT) module that presented those concepts clearly so pilots could construct a coherent understanding of the relations and dependencies between concepts.

The entire set of concepts is too large to present here, however in Table 2 we present several descent concepts a pilot must know to understand how the flight management computer computes the descent path and how the airplane will fly that path. Notice that there are some generic automation concepts (i.e., managed versus selected modes), but there are also Airbus specific concepts that pilots must learn when they transition to this aircraft for the first time (i.e., descent speed target range).

In addition to a set of concepts pilots must also learn a set of conceptual models to understand how managed descent mode affects the aircraft's behavior when it flies the computed descent path (Table 3).

Table 2. Descent Concepts

Idle descent path
Geometric descent path
Bottom of descent point
Top of descent point
Vertical restrictions
Speed restrictions
Speed targets
Pilot modification of speed targets
Descent speed target range
Deceleration point

These are, for the most part, models any instrument-rated pilot would know. A few of these basic models must be elaborated to understand specific managed descent mode functioning, such as the consequence of exceeding the upper or lower limits of the descent speed target range. We found that these models were missing from the training materials but pilots regularly used the models during interviews to describe how the auto-flight system controls airplane behavior.

Table 3. Conceptual Models for Descent

Use thrust to control speed
Use pitch to control speed
Use pitch to maintain path
Relations between wind path and speed
Relations between speed, thrust, and pitch
Relations between thrust, speed, constraints
Relation between drag, speed, pitch, thrust

A New Managed Descent Module

We used the concept inventory as a basis for redesigning the airline's computer-based trainer (CBT) module for managed descent mode. The conceptual content, representation of concepts, and order of presentation are critical to establishing a solid conceptual understanding of the relations between concepts. Thus in designing the CBT, we adhered to a set of pedagogical principles presented in Table 4. The principles are based on a theory of incremental construction of conceptual understanding that is embodied and situated [4].

In our redesign of the CBT we utilized the concepts and their relations to the conceptual models to build a coherent description of how managed descent mode controls airplane behavior in the descent phase of flight. We begin by describing how the descent path is computed and continue with an explanation of how the airplane will fly the computed descent path. Then we introduce exception cases. Thus we integrate the descent concepts with the conceptual models and autoflight functioning to give pilots a conceptual foundation from which they can understand airplane behavior in a variety of descent situations. In Table 5 we present the text from our CBT slide describing how the descent path is constructed.

New concepts being introduced are the focus of each slide. Concepts presented in an earlier slide of the CBT are reinforced before new concepts are introduced. Cockpit indications, pilot actions, the relationships between what pilots see, and what pilots do are linked by the underlying conceptual framework of descending an airplane. Our hope is that a strong conceptual understanding of how the automation controls the airplane will reduce mode *surprises* and *confusion* (see Sarter & Woods, 1994).

Table 4. Pedagogical Principles

- Incremental development of conceptual structure by providing component pieces first. Later complexes that make use of relations among the pieces are introduced.
- Place key concepts early. Introduce central concepts first. Then organize other concepts around key concepts.
- Key concepts are revisited in the context of newly added concepts as the instruction proceeds. This ensures that the student understands them.
- Present normal operation of the system before dealing with abnormal, unusual, or compensatory behaviors of the system.
- Ground the entire presentation in an operational framework that is meaningful to the pilot population. To best be able to use the knowledge in an operational context, it should be acquired in an operational context.
- Use consistent terminology throughout. The terminology should be consistent throughout the presentation and consistent with other usage in the instructional and operational environments.
- Where explanation of the behaviors of the system are provided, ground those explanations in the conceptual models observed in interviews with pilots discussing their understanding of the

behavior of the airplane. This assures us that the causal explanations we use are meaningful to pilots.
- Integrate the conceptual exposition with illustrations of the indications that will be present in the cockpit.

Table 5. Text from Redesigned Managed Descent Module

Text for Computed Descent Path Slide
The managed descent mode, DES, is built around a descent path that is computed by the FMGS before the descent phase becomes active. This path has two main parts: (1) an idle path, which extends from the top of descent to the first altitude constraint and (2) a geometric path linking segments between predetermined constraints to the point where the aircraft slows to approach speed.

CONCLUSIONS

Pilots seek conceptual understanding of the systems on which their performance depends. We developed a concept inventory method and applied it to training materials and to line interviews in order to track changes in pilots' conceptual models. We have identified several conceptual models pilots use to interpret how the automation controls airplane behavior. These models are simple. They are not elaborate energy models or engineering models. The models pilots use also have the interesting quality of being constructed from the perspective of the pilot from inside the airplane's cockpit and the conceptual components out of which the models are constructed are manifest in the material environment of the pilot.

While flying on the line, pilots learn to apply what they know about the behavior of conventional aircraft to the interpretation of the behavior of autoflight systems. In most circumstances, this strategy serves them well. However, managed descents are based on a computed descent path/speed profile that is a complex energy dissipation schedule. This descent profile cannot be flown in a conventional airplane, and is not captured by the conceptual models that pilots develop while flying conventional airplanes. Surprises and confusion result when pilots attempt to use conventional-airplane models to understand managed descent. Manufacturer's materials do not provide, and airline training does not deliver, clear conceptual models of this aspect of autoflight operation.

Having identified both the models pilots apply when they are learning how to use the automation and the functional properties of the autoflight system, we have designed a training module for managed descent that is meaningful to pilots. We give pilots the conceptual pieces needed to understand managed descent mode in terms of the models they currently use.

In the future we hope to empirically test the effectiveness of our managed descent training module in the development of pilots' conceptual understanding of managed descent mode.

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