

PILOT ERROR IN THE 90S: STILL ALIVE AND KICKING

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ABSTRACT

In this keynote address, I will describe the notion of human- and pilot-error. I will show, given actual examples, why it is still alive and kicking, and what can be done to ameliorate this problem. The main thesis of this talk is about going beyond the mere classification of pilot-error into a detailed analysis of the events and a thorough consideration of all other factors that have contributed to the mishap. I will argue using three examples: The first example describes a certain crew interaction that, from the outset, appears problematic, yet once the details are revealed, all falls into place. The second example is about a pilot-error that is actually due to deficiency in the design of a "Before Landing Checklist" procedure. The last example describes problems that pilots encounter while operating an autopilot.

INTRODUCTION

Ladies and Gentlemen, members of the flight safety foundation staff, I would like to thank you for inviting me here to Cincinnati to open the Flight Safety foundation 44th annual corporate aviation meeting. I consider that an honor. The title of my talk is "Pilot Error in the 90s: Still alive and kicking."

A keynote address is an opportunity to go beyond the data, numbers, and facts into opinions and projections. I intend to make full use of this opportunity in order to challenge you, for going beyond. Going beyond the mere "pilot-error" classification. For searching below the surface for the complex and multiple factors that lead to pilot errors. I want to show you why pilot error in the 90s is still alive and well. And I want to challenge you to think about it in a different perspective, a more scrupulous one, as we are launched into a new and technologically exciting century.

I will tell you today three stories. Stories about interactions. About pilot-pilot interaction and a touch of CRM. About pilot-procedure interaction and errors, and about pilot-automation interaction. In each one of these stories, what you will initially observe from the outside is very different from what you actually see when you look into the... inside. You will be surprised at what you'll find.

Let me start with the first story....

Not too long ago, I was on a jumpseat of an Airbus A-320 flying from San Francisco to Detroit. I walk into the cockpit, on cold and rainy morning, and the captain, I estimate he was in his late 50s, looks back at me and says... “strap in, shut-up until 10,000 feet, and talk to me at cruise!” I kind of knew it was going to be an interesting flight...

The flight itself was uneventful. But something was unusual about the interaction between the two pilots. The co-pilot, I guess she was about thirty-something, seemed quite rude to her captain—anyone would have sensed that something here was out of line.

In this cockpit, you see, there was no “can you please give me the frequency for maintenance” or “would you do me a favor and put the sun visor down?” Instead, it was a raw and direct “do this, do that.” And there were the debates: about airports, layovers, food...you name it. Apart from that, everything else was fine. They were doing their thing—but I was very uncomfortable.

At some point, the discussion was about some high-performance aircraft I was not too familiar with. Somewhere in this debate, they showed me a picture: The two of them standing in front of a small slick aircraft. Now I was really confused. Noticing my daze, the first officer leaned back, looked me in the eye, and said: “Well, if you did not figure it out yet—this is my dad!”

It turns out he was on his last year before the mandatory 60-year retirement. His daughter delayed her move to become a DC-9 captain so she could fly with her father for the year. On the surface, the interaction in this cockpit was very uncomfortable, perhaps somewhat problematic. However, once I became aware of the hidden context, of the intricate relationship between the captain and his first officer daughter, everything fell into place. What appeared from the outside was very different from what really was going on.

This was a small cockpit family. And I feel, standing here in front of you this morning, the same way. Yes, there may be people here with different backgrounds, different perspectives, different agendas, and maybe, this talk will spur some arguments -- but we all share the same concern for flight-safety, a commitment to work together to achieve this goal. And in a way, belong to the same family.

INTRO TO PILOT ERROR

Now, I would like to introduce the notion of human error, because that is the focus of the rest of the talk. Human error, or pilot error in this case, is a very complex topic and I seriously doubt if anyone has the complete picture. Instead, I would like to give you my view on it, my view of its past, the problems it causes now, and if I may, its future.

You see, pilot error is a big white-wash. It’s a catch-all term that excites the imagination and suppresses thoughtfulness. There is no such thing as pilot error because the pilot does not stand in the middle of nowhere and commit an error. Instead, he or she is surrounded by a cockpit and its instrumentation, procedures, other crewmembers, an aircraft, ATC, dispatchers, a company, peers, past experiences, and... you can fill the rest of the list on your own.

Pilot error always happens within some context. And this context is context is *the* key for any serious examination, understanding, insights, and possible resolution of the problem, so that it will not happen again.

In a family, when someone acts out, misbehaves, everyone is unhappy. Most of the time, what happens is that the person who has acted out is somehow disciplined, “taken care of.” We all do it—me, you, the FAA does it, your company does it, and our peers do it, too. But, we hardly ever look at our own contribution to the acting out, the list of other factors that triggered the event, the context. Why? Because this requires self-examination, honesty, detailed and highly dedicated work. It is very very hard, and time consuming. Especially after an mishap that did not add much credence to our collective reputation.

But if we do look beyond the smokescreen called pilot error, we see many contributing factors: equipment failure, faulty cockpit design, poorly designed SOPs, fatigue, and more. The distinction between pilot error and a design error (for a lack of better word) is always blurred, murky, and as a consequence, highly arguable.

A case in point is the recent Boeing/NTSB debate on the probable cause of USAir flight 427, the second Boeing B-737 to crash after a mysterious hard roll. The focus was on the Rudder. Was the first officer standing on the left rudder from the start of the event to the crash, as Boeing claims, or is there a dormant problem with the Rudder’s PCU, as the NTSB claims? Pilot error or design error? It’s a very, very, fine line. And this one involved eight years of intensive investigations, experts form left and right, and many millions of dollars.

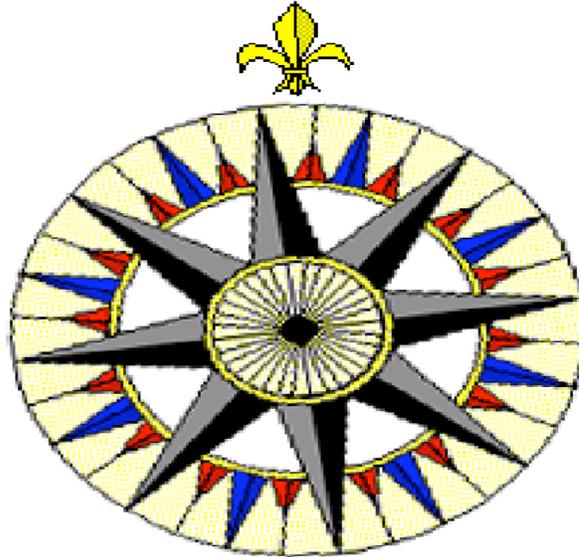
COCKPIT AIDS

In aviation there is always a sort of confusion between the things that help the pilot to do the work, and pilot error. Are these cockpit aids necessary ,or can the pilot do without them? Map displays, HSIs, and CDI are all aids to reduce pilot error. They are considered aids because the functionality of the system has not changed: A VOR signal is a VOR signal. But the presentation of the VOR signal changed when we moved from CDIs to HSIs—it made the task of intercepting a radial a lot easier.

When you use an HSI, you reference radials to the HSI’s lubber line. You all know what a lubber line is. That’s that little line, or indicator, that tells us where the nose of the aircraft, or ship is. Here is a 15th Century nautical compass rose, and a rather medieval-looking lubber line at the top.

Compass Rose

and a Lubber Line



Now I know what a line is, but what's a lubber? A lubber, according to the dictionary, is a 'clumsy' or a 'rookie' seaman. You see, the "old salts" did not need to use the indicator, they could hold a course just fine by running an imaginary line from the bow of the ship to the compass. This was their reference line.

But the rookies, the clumsy, the non-experienced sailors needed an aid to navigation. Today, no avionics vendor would dare build any directional device without a lubber line. Now granted, navigation has become more precise since the 15th century, but that's not the point. The point is that we consider the lubber line, an aide, a necessary display feature. Period

And here is the confusion. We put in the aid, we use it, but when an incident takes place, the "old salts" laugh. "You should have been able to do it without the aid," they say. "These kind of errors, we 'salties' never make." And if you make them, you are no longer part of this group. But the fact is, that everyone makes errors: pilots, designers, engineers, mechanics, and controllers. The real task is to identify and correct them...before something worse happens.

You all encounter the "salties" in your everyday work: "Why should we invest money in a strong safety program," they say. "We have a good training department, and all we need is few good pilots...." Ladies and gentleman, coated with vanilla and other excuses, this is still the prevailing thought in many, many places, today!

CHECKLISTS

A checklist is another aid. It costs about 2 cents a copy, but its contribution to flight safety is priceless. The first formal checklist probably was only written in the late 20's or early 30s. Here is the oldest one on file. It came from the Smithsonian museum in Washington, and it's a checklist of a B-32 Dominator, a World War II bomber.

B-32 CHECK LIST

Suitable For Use With 100 Octane Fuel Only

BEFORE ENTERING AIRPLANE

Visual Inspection of Airplane
Pitot Head Cover Removed
Tire and Oleo Inflation
Wheel Chocks in Place
Trim Tabs Neutral
Crew Inspection

Carburetor Air Filters—AS RE-
QUIRED
Carburetor Heat—OFF
Anti-Icers, Wings and Props—OFF
Electrical Hyd. Pump Switch—ON
Parking Brakes—ON
Hydraulic Brake Pressure—CHECK

BEFORE STARTING ENGINES

Landing Gear Switch—NEUTRAL
Forms I and IA
Fuel and Oil
Loading, WITHIN C.G. LIMITS
Ignition OFF
Props PULL THROUGH 6 BLADES
Control Movement FREE
Altimeter—SET
Battery Switches—ON
A.P.U.—Start, Equalizer Switch OFF
Inverter Switch—MAIN ON
Prop. Feather Switches—NORMAL
Prop. Reverse Safety Switches—SAFE
Prop. Reverse Pitch Switch—
NORMAL
Prop. Selector Switches—AUTO-
MATIC
Prop. Speed Control—2800
Prop. Master Motor Switch—ON
All Circuit Breakers—ON
Throttle—1000 R.P.M. Position
Turbo Boost Selector—0
Mixtures Controls—IDLE CUT-OFF
Intercooler Flaps—AUTOMATIC
Oil Cooler Flaps—AUTOMATIC

STARTING ENGINES

Fuel Selector Valves—TANK TO
ENGINE
Booster Pumps—ON LOW
(No Fuel Pressure Ind. until Mixture
Control is Moved)
Fire Guard and Call CLEAR
Master Ignition Switch—ON
Ignition Switch—ON AFTER TWO
PROP. REVOLUTIONS
Mixture—AUTO RICH AFTER
ENGINE IS RUNNING

WARM UP

Fuel and Oil Pressures
Booster Pumps—OFF
Vacuum and Flight Indicator
Generators—ON, 28V
A.P.U. Equalizer Switch—ON
Inverter—CHECK
Wing Flaps—OPERATE
Prop. Control—CHECK R.P.M.
CHANGE
Magneto—CHECK at 2000 R.P.M.

Were there informal checklists before that? Sure, but they were considered “lubber-lists” by the “salties”—*they*, of course, did not need checklists and SOPs. They knew them by heart. Some of them still do it today! But I would like to see the person who can perform this checklist of a modern wide-body airplane from memory, day in day out, without omitting an item.

BEFORE STARTING ENGINES

- CIRCUIT BREAKERS CKD
- FLT RECORDER* ON
- VOICE RECORDER* TESTED
- OXY ON & 100%, SPKRS CKD
- ANTI-SKID* TESTED & NORM
- EVACUATION SIGNAL ARMED
- COMPASSES CKD
- ANNUNCIATOR LIGHTS TESTED & BRIGHT
- LO SPD AIL NORM & AUTO
- RUD TRAV/PITCH FEEL ON
- EXTERIOR LTS* ON (OR OFF)
- SERVO CONTROLS ON
- ENG START PANEL* CRANK/START ABORT
- FIRE HANDLES up
- NO SMOKING* ON
- EMER EXIT & MIN CAB LTS ARMED & ON
- ICE PROTECTION* OFF
- WINDOW HEAT* LO & ON
- RADIO MASTER SWS ON
- AUTO FLT/NAV CKD
- INST SWS CKD & NORM
- FLT INSTS & ALTMS* CKD & SET
- GPWS TESTED
- ENG INST/N₁ COMPUTER* CKD & TESTED
- GEAR LEVER* DN, 3 GREEN
- OMEGA* CKD
- FLAP/SLAT LEVER W/GAGES
- SPEED BRAKES RETRACT/DISARMED
- FUEL LEVERS OFF
- PK BRKS & PRESS* SET & CKD
- RADAR & TRNSPDR* STBY
- TRIM CONTROLS* SET
- MAN DEPRESS VLV CLOSED
- ELEC PANEL* CKD & SET
- BATTERIES* NORM
- FUEL PANEL CKD & SET
- FUEL QUANTITY* ___ LBS, CTRS RESET
- HYD PANEL* CKD & SET
- OIL QUANTITY* ___ QTS
- APU* CKD
- FIRE & SMOKE DETECTION TESTED
- AIR COND & PRESS* CKD & SET
- RAM AIR INLET SWITCH* NORM CLOSE
- VENT PNL* CKD/BLOWER OFF
- TEST PANEL NORM & OFF
- PROBE HEAT CKD & OFF

You see, there is a certain limit on how much a human, even the most conscientious one, can recall. We ask pilots to remember, flawlessly, many sets of procedure items, numbers, sequences. At some point we hit a limitation of our memory abilities. And this is where an aid, like a checklist, comes in handy. But that very aid can become your enemy, if we are not very careful in designing it.

DC-9 INCIDENT

Now I would like to tell you another story—a story about pilot-procedure interaction. Just as I was confused, at first, about the interaction between the captain and his first officer earlier, the incident I’m about to tell you now was at first labeled pilot error. Pilot error with capital letters.

A year ago, around midnight, a DC-9 was pushing its way into a large Mid-Western airport. It was a dark night, with rain and scattered clouds from 200 feet and up. Poor visibility and a tiered crew. “Left 140 degrees into base” – “roger heading 140.” “Slats extend, flaps 5” – “set.” “070 until established, three thousand feet, cleared for the ILS 6R,” radios the controller.

“Flaps 15” calls the first officer, while hand-flying the aircraft. “Localizer alive, going to join you now.” “flight director – ON.” “Roger.” The captain, Pilot Not Flying, notices first – “Glide slope alive” and the first officer, Pilot Flying on this leg, immediately calls “Gear Down, before landing checklist.” All per standard company procedure and by the book.

The PNF grabs the gear handle and pulls it down, accompanied the by the usual vibrations. Next, his hand moves above the glare shield and beyond the annunciator panel to set the ignition switch to override. He picks up the checklist, which looks like this.

BEFORE LANDING - PNF	
1. IGNITION.....	.....OVERRIDE.....PNF
2. LANDING GEAR.....	.....DOWN, 3 GREEN.....PF
	.....PRESSURE, QUANTITY CHECKED.....PNF
3. SPOILERS.....	.....ARMED.....PNF
4. SLATS, FLAPS.....	.....EXTENDED, 40.....PNF
5. ANNUNCIATOR PANEL.....	.....CHECKED.....PNF
6. BEFORE LANDING CHECKLIST.....	.....COMPLETE.....PNF

And then starts reading:

Before Landing check:

- ignition override
- Landing gear...

The needle is 1 dot above the glideslope, and the first officer replies, “down three green, flaps 25.” Descending, gust from the right, and now the needle is dead center. The first officer calls “glideslope capture, flaps 40.” More rain. The captain watches the flaps needle slew to 40 degrees and speed depleting below 160. Annunciator panel – one light is still missing. And he calls, “Flaps extend 40, set, annunciator panel to-go.” Altitude-alerter goes off—aircraft just passed through 1,300 feet—decision altitude. “Disregard,” says the captain.

Speed 150 knots. Now “rudder light” comes ON and the captain calls, “Annunciator panel checked, Before Landing check complete.”

While going through the checklist motions, he realizes Approach Control did not switch them to tower. One thousand 200 feet and splatter of rain on the windshield. He calls Approach-Control, quiet.... “Approach....you want us to go to tower?” More quiet. “One thousand above minimums,” he calls to the F/O. Now ATC replies, contact tower on such and such. Frequency change. “With you on ILS 6R,” and tower responds sharply – “clear to land.”

The captain makes a last scan of the cockpit. Looking down, he notices the auto-spoilers are not in the arm position—darn—skipped the item and missed it on the checklist. Aircraft passing through a dark cloud, two beaming lights one flickering strobe. “100 above minimums,” he calls and rehearses to himself, “when we touch down – I reach, pull up, back, and up.” To manually get 60 degrees, full deflection, on the spoilers. Because, remember, he forgot to set the autospoilers.

Gray low laying clouds, more rain, “runway in sight 12 o’clock.” “Going visual,” says the copilot, small bank to the right. The copilot makes the transition: pitching up, flare, and the power coming back, engines whining down, clack, higher pitch, shake from the right. “Reach, pull up, back, and up”—the captain manually deploys the spoilers, believing the aircraft is on the ground. Thump! The aircraft hits the ground and rattles. A long ground roll on a wet runway, brake, stop, and taxi the aircraft to the gate.

Results: Hard landing with serious damage to the tail cone, skin, and parts of the fuselage. Consequence: The Captain was immediately removed from flying status.

What Went Wrong?

There were two procedural deviations here: not arming the spoilers after the gear check, and manually deploying the spoilers during the flare and 20 feet above the ground. The two events, as you all know, are linked: the captain inadvertently deployed the spoilers once he realized they were not armed for automatic deployment.

Let me focus here on the first deviation, a configuration and checklist deviation, which was the pre-condition for all that happened on that night.

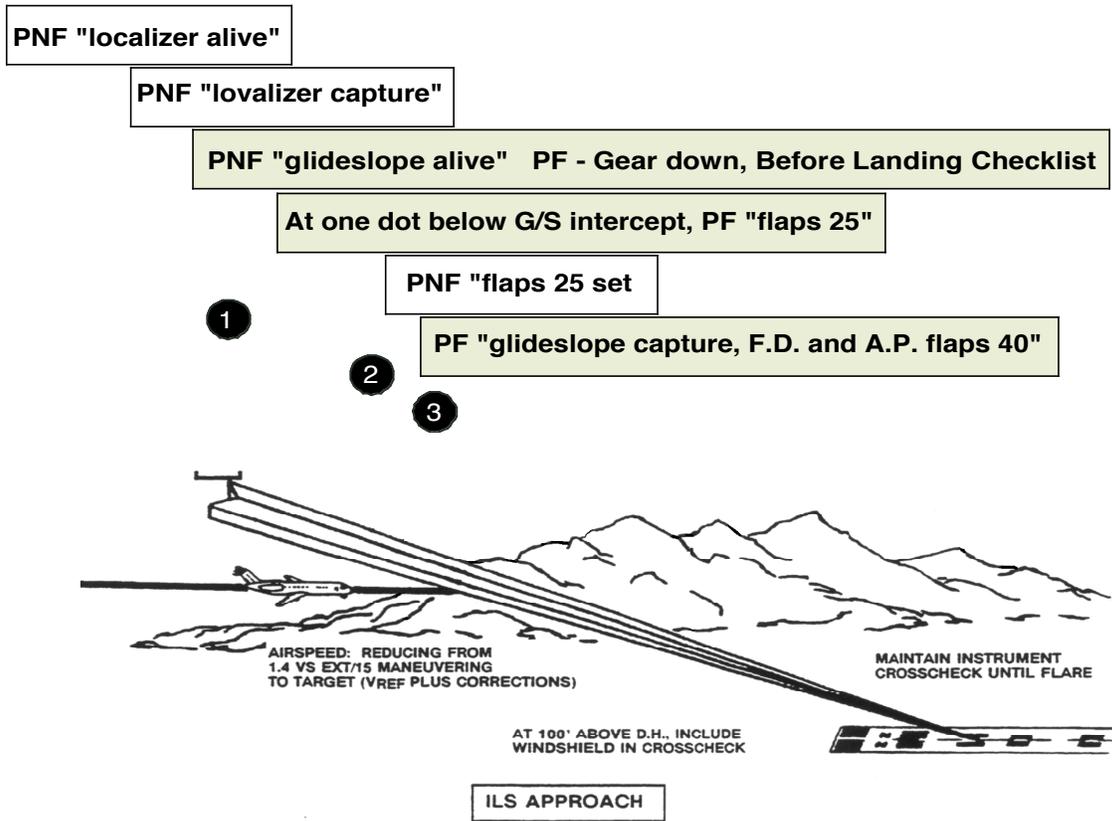
As you most obviously noticed on the checklist, the captain, following the ignition override and gear check, did *not* set the spoilers, nor did he verify this item using the checklist. He lost it here, twice. The question is, why? Why would a responsible crewmember fail to arm the spoilers?

From the facade, it looks like another of those so-called pilot errors. But I want to take you beyond. Let me take you along to the process that I went through in working this incident. Let’s analyze, together, the procedure, the events, and the pilot’s sequences of action.

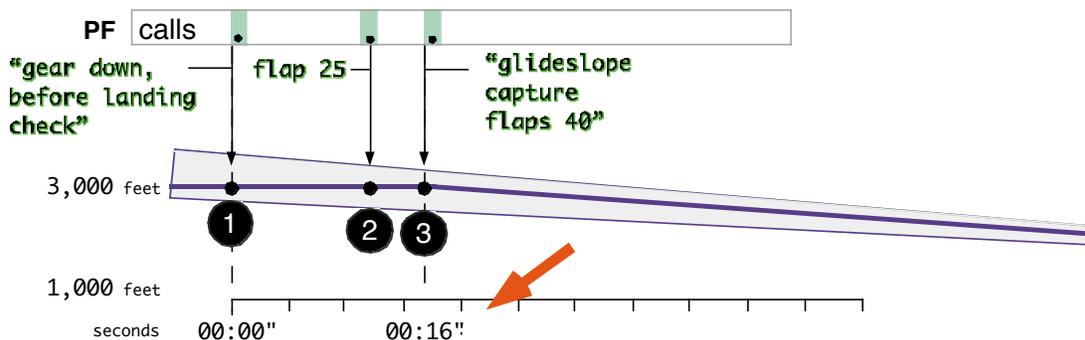
Analysis

Here is the ILS profile, from the book. It says that once the glideslope is alive and the aircraft is 2-3 dots below the glideslope, the PF should call for “gear down,” -> “Before

Landing Checklist.” This is the first point. Once the aircraft is one dot below the glideslope, the PF calls for flaps 25. This is the second point on the profile. The third point is at glideslope capture: here the manual says flaps 40.



For sake of clarity, let me draw this profile on a clean sheet of paper. I painted the PF actions and calls in green. Look at the three points. It takes 14 seconds (for a speed of 180 knots) and 16 seconds (for a speed of 160 knots) to fly from the start point to the third point, flaps 40. Flaps 40 is also the final flap setting for the landing and is an item on the checklist, something that we will get to shortly.



It takes the aircraft 14 to 16 seconds (for speeds of 160 and 180 knots) to fly from the start point to the third point, flaps 40. This you can compute from the ILS angle. Flaps 40 is also the final flap setting for the landing and is an item on the checklist, something that we will get to shortly. The rest is a standard ILS profile.

Now let's analyze the PNF's actions:

He first sets the gear, and then places the ignition to override. Then he picks up the checklist. Here is the expanded checklist.

1. Challenges ignition, and checks switch position.
2. Challenges gear, and checks 4 items:
 - Hydraulic pressure
 - Hydraulic fluid
 - Brake pressure
 - Gear door open light.....OFF

BEFORE LANDING - PNF	
1. IGNITION.....	.....OVERRIDE.....PNF
2. LANDING GEAR.....	.....DOWN, 3 GREEN.....PF PRESSURE, QUANTITY CHECKED.....PNF
PF CHECKS:	
Gear Lever.....Down Detent	
Left, Nose, Right, Green Down Lights.....on	
Left, Nose, Right, Red Unsafe Lights.....off	
PNF CHECKS:	
L/R Sys Hyd Press.....	.....Green Arc
L/R HYD Fluid Quantity.....	.....Above Red Arc
L/R HYD Brake Press.....	.....Green Arc
GEAR DOOR OPEN Light.....	.....off
3. SPOILERS.....	.....ARMED.....PNF
Pull the spoiler lever straight up to ARM. the lever should remain locked in position with the red "arming" band visible.	
WARNING: DO NOT ARM THE SPOILERS UNTIL THE LANDING GEAR INDICATES DOWN AND LOCKED. DO NOT ARM THE SPOILERS IF THE "AUTO-SPOILER DO NOT USE" LIGHT OR "GEAR DOOR OPEN" LIGHT IS ILLUMINATED.	
4. SLATS, FLAPS.....	.....EXTENDED, 40.....PNF
SLAT EXTEND Light.....On	
SLAT DISAGREEMENT Light.....Off	

Let's zoom in on the last item: Gear door light. It's an interesting item. The under-carriage in the DC-9 has two doors. These two doors open and the wheels come out. But the doors are longer than the wheels, and therefore must be closed at the end of the gear cycle.

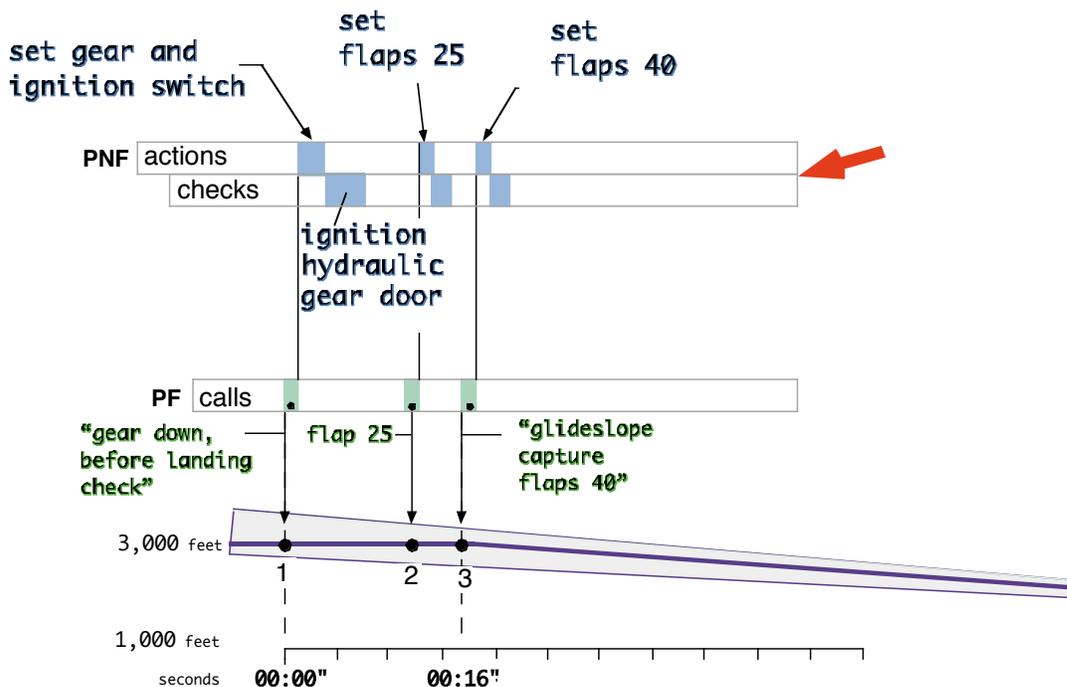
There is a condition here: The doors must be locked before one can arm the spoilers. Question, Why? Because if the doors are hanging out or the gear is not locked in place, one must recycle the gear. Sure. But, if the auto-spoilers are armed, and the gear is recycled, and the air/ground microswitch somehow activated, the auto-spoilers can pop-out 60 degrees in flight! Certainly, not a pleasurable prospect.

You can see this condition as a warning on the expanded checklist in front of you. Right here after the spoiler-arm item. It says:

Warning: do not arm the spoilers until the landing gear indicates down and locked. Do not arm the spoilers if the "auto-spoiler do not use" light or "gear door open" light is illuminated.

We realize that this last check for the PNF is important. The PNF cannot continue the checklist and configure the spoilers until the Gear door open light is OFF. This is, however, a routine sequence used all around the world. Nothing special. A simple pre-condition for arming the spoilers. The next item on the list is slats, flaps, which should be at 40 when the PNF checks this item on the checklist.

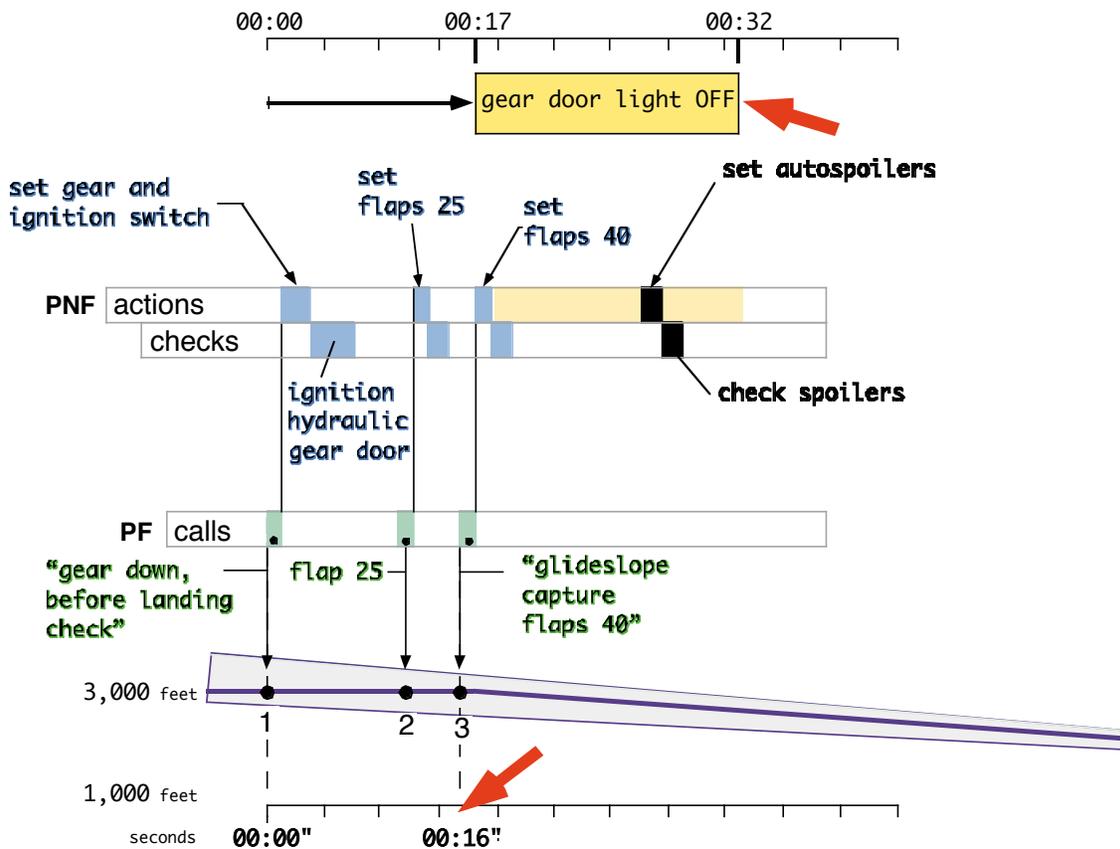
Now let's superimpose the PNF actions on top of the ILS profile diagram. I painted the PNF actions in blue.



Here is the PNF's sequence of actions: Before Landing Check, ignition...gear... 25, 40. Looks like a simple, straightforward, innocent checklist. Seemingly harmless. It is not! Actually, it's a checklist sequence that induces error – guaranteed.

And here is why...It takes more than 17 seconds for the doors to open, and then close. This is from the point at which the PNF puts the gear lever down, to when the light goes OFF. Depending on the aircraft and hydraulic system, that light will come OFF at least by 17 seconds and up to 32 seconds for a higher speed and an older hydraulic system. This is a statistical fact based on more than a hundred and fifty measurements!

Now let's superimpose this timing information on the profile. The PF actions, the PNF actions, and the gear door light timing are at the top. We already know it takes 16 seconds to fly from the gear down point to the flaps 40 point. But it takes much, much longer, from 17 to 32 seconds until the gear door light goes OFF. It will always happen in the yellow region, which as you can easily see will always take place *after* flaps 40.



You see, the PNF is stuck waiting for the door light to complete the gear check, but in the meantime, he is asked to set flaps 25 and flaps 40. The gear check can only be completed after flaps 40. A fact of life. But Flaps 40, as you all know, is a checklist item. So what does the PNF respond after placing the flap lever to 40? “Flaps 40 set,” picks up the checklist, and continues on...

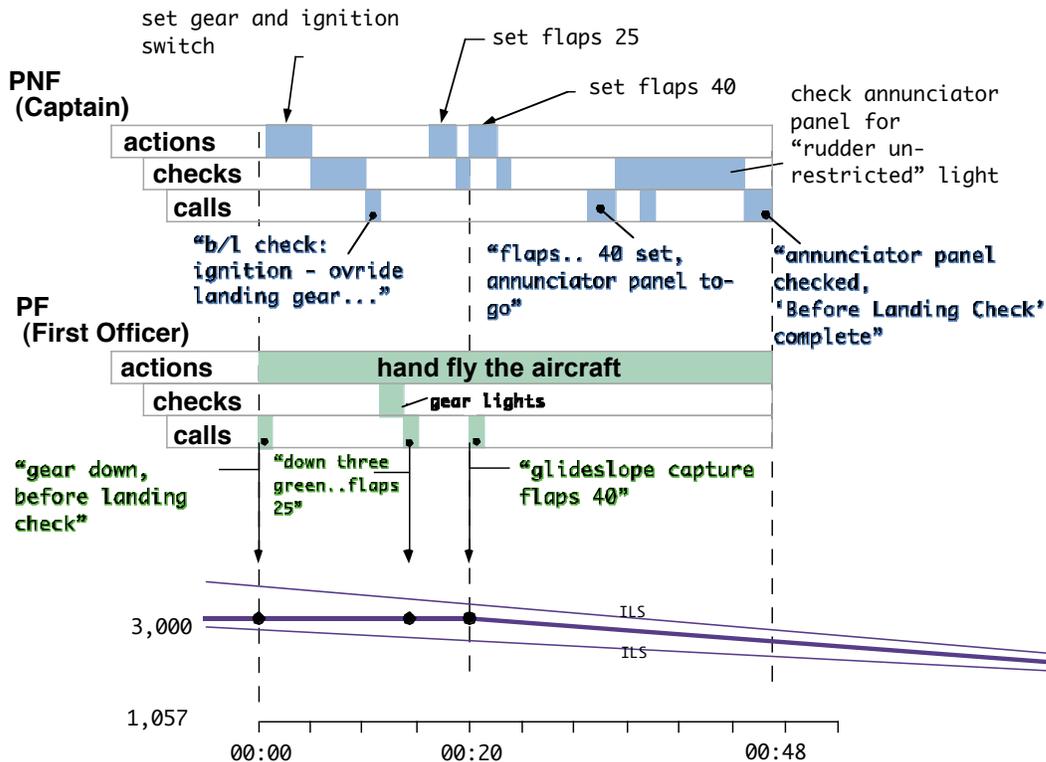
Notice what happened here: We did not set, we did not challenge, and we not did verify the spoiler's position. *We skipped it completely.* The sequence of “gear-then-spoilers” gets switched with the sequence of “gear-then-flaps.” The spoilers are out of the picture, and the pilot is lulled into not setting and not checking the spoilers.

It's not because of any pilot attention problem, but because of simple timing. It takes 16 seconds until we do flaps 40 and much, much longer until the light goes OFF. Flaps 40 is done before spoilers, and if you continue with the checklist you forget the spoilers. It's simple math, and it happens over and over to everyone—to experienced pilots, captains, check airmen, and during IOE. But everyone thinks its because they were not focused enough.

Let's go back to the actual incident I described to you earlier. I placed the CVR transcript information on top of the profile. We start at 00:00, when the First Officer called “gear down, before-landing check.” The captain put the gear down and switched ignition. He then started the before-landing check: “ignition override, landing gear...”

The First officer checked the glideslope, noticed the aircraft was one dot below the glideslope, and responded “down three green and flaps 25.” Fifteen seconds after gear down, just as we calculated for speed of 180 knots, the First Officer said, “glideslope capture, flaps 40.”

The captain picked up the checklist and came on shortly after with “flaps extended 40 set, annunciator panel to-go.” He was already preparing for the next checklist item—the annunciator panel. He was long beyond the gear check and spoiler arming. He closed the checklist at 55:44 with “annunciator panel checked, before landing check complete.”



Now notice that the captain did try to do it right. He called landing gear, but never responded with the standard “Pressure quantity check.” Why?

He never got to it, or to the Gear Door Light check. The First Officer immediately sent him to flaps 25, 40, and down the path of deviation. You see—it’s all in the timing. And this indeed is the problem with this checklist. I think we are all, in one way or another, locked in this mindset—on looking at the surface, at the facade, and missing the real complexity of pilot error.

ALTITUDE CAPTURE

In the checklist example that I just presented to you, we were confused about the real reason for missing the spoiler items. We called it, initially, a pilot error, only to find out—when looking beyond, when bringing in other factors and timing—that it was actually something else.

Now I would like to show you another system—a little bit more complicated—a modern automated flight control system that includes an autopilot and an FMS. Again, you will see that what seemingly shines like pilot inattention and complacency, looks very, very different when we look deeper.

I’ll tell you a story that happened during a flight from Burbank (California) to Phoenix. Actually, you know what? I’ll let the pilot tell it to you in his own words....

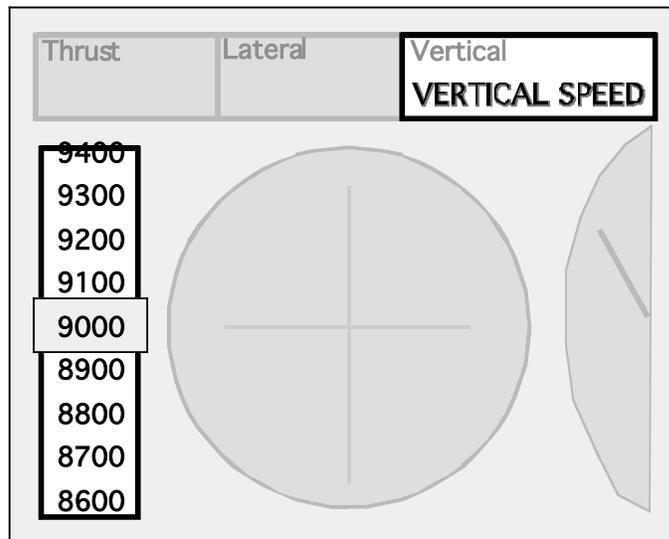
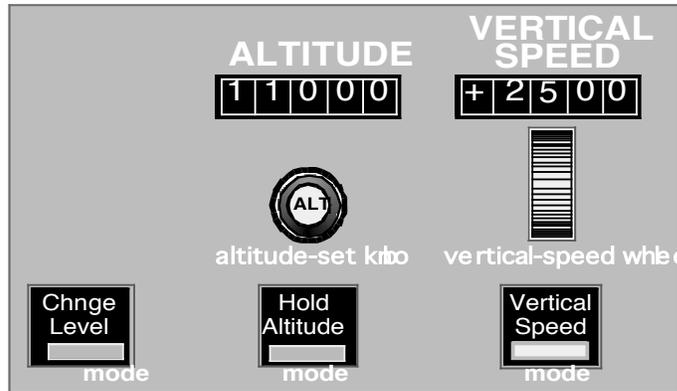
“On climb, we were assigned 16,000 feet by Departure Control. As we were climbing through 15,000 feet, the autopilot went into Capture mode and appeared to be working properly. We were given a heading and a radial to intercept at about the same time. Inadvertently, I touched the altitude set knob. Set it quickly back to 16,000. No problem.

After setting the heading and radial, I noticed that we were still climbing and approaching 17,000 feet. Obviously, the automatic level-off function of the autopilot had failed. I started a quick descent back to 16,000 feet.... At Phoenix, we had maintenance fix the autopilot and it checked out OK for our next flight....”

I’ll present to you an analysis of this autopilot behavior. But the focus here is not about this specific autopilot, although a very popular one, but about pilot error and automation in general.

All modern autopilots use three basic modes for climbing or descending and capturing an altitude. Each one gives a different performance depending on what parameters the pilots care about—constant thrust, speed, or vertical speed setting. Let’s look at how each mode responds to pilot actions.

Modes and parameters are set in the mode control panel (MCP), guidance control panel (GCP), or guidance control unit (GCU). Different names, depending on the manufacturer, but same basic functionality.



The action that we will consider here is setting the altitude window to a value that is behind the aircraft, just as it happened in the story. We are climbing to 16,000 feet, we are now at 15,500, and we touch the altitude knob and set the altitude to 15,000. 15,500 is behind the current altitude of the aircraft.

Let's take another situation. Say we are at 3,000 feet descending to 2,000. At 2,600, we set the altitude in the window to 3,000. Why? Maybe because we want to set the missed approach altitude. Or we got a new clearance. Or we engaged approach mode and want the get altitude out of the way. There are many reasons.

We are in a "change level" mode, something like "flight level change" in a Boeing aircraft or "open descend" in an Airbus, and we are descending to 2,000 feet. The aircraft is expected to transition to level flight at 2,000 feet. Now, at 2,600 feet, we set the autopilot to 3,000. What will happen? The right diagram shows that the autopilot will honor the new setting. The aircraft will immediately pitch up and fly to 3,000 feet.

Now climbing to 3,000 feet and if we set the altitude back to 2,000 feet, the aircraft will do a popup and start diving back to 2,000. We call it a dog-on-a-leash behavior. You say up, you say down and it follows. Your leash is the altitude knob.

Change Level Mode

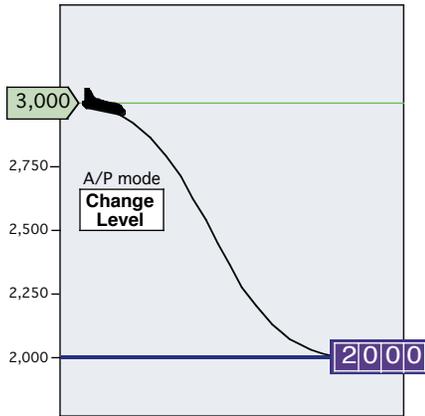


Figure 1

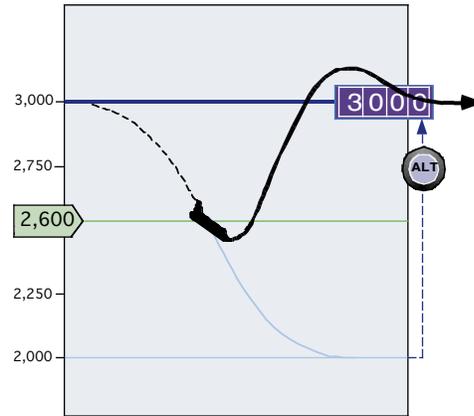


Figure 2

Let's explore another mode—vertical speed. Again, we are descending to 2,000 feet. At 2,600 feet set the altitude window to 3,000 feet. The right figure shows that the aircraft will continue the descent past 2000 feet, and all the way toward the ground.

Vertical Speed Mode

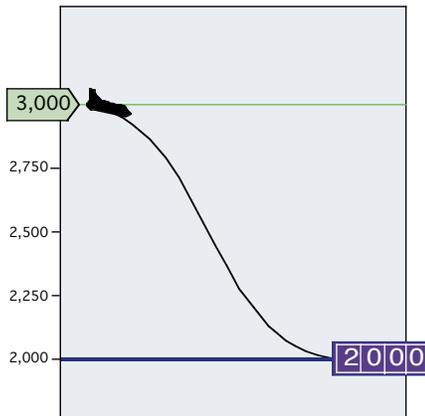


Figure 1

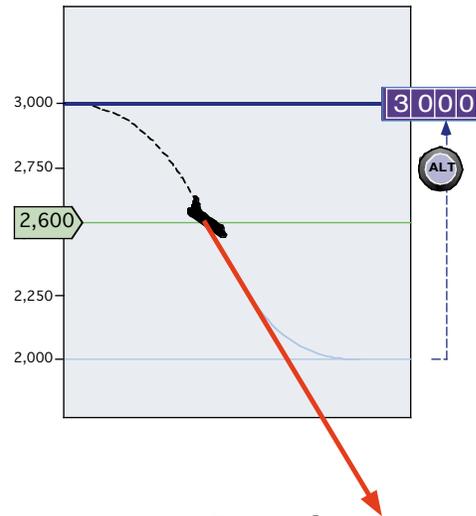


Figure 2

This is called “kill the capture,” and “kill it” it does! Now you say to yourself, this can be quite dangerous. Not watching for a second and the aircraft descends toward the ground.

Imagine this scenario: “Hey Tom, what was that frequency again? I did not hear the controller clearly.” “Can you check the approach plate? Oh, and also set the missed approach altitude, please.” “No problem, let me help you find it.” Now you have two heads looking down and the aircraft is descending past 2,000 feet, unconstrained. Sounds far-fetched? Actually not. It happened on an approach to Detroit.

Between descend and level off, there is a transition phase. It’s called Capture and it is a mode by itself. In Capture mode, setting the altitude behind the aircraft will yield yet another response, which I will get to shortly.

First observation: Three different modes and three different responses to the same pilot action. Confusing? It sure is. Moreover, all these different responses are not explicitly described in the manual, and most flight crews who fly these aircraft don’t even know about them, unless they got bitten themselves.

But, I want to take you even one step deeper. To a darker world in which humans and automation mingle, and confusion arises. Lets look at the level off and then the capture maneuver. When leveling off, the autopilot *automatically* transitions to Capture mode. and does a gentle maneuver to bring the aircraft back to level flight. The altitude, or the altitude range, when this takes place, varies. Sometimes this occurs several hundred feet, or even 100 feet prior to the assigned altitude (in a high-altitude cruise climb) and sometimes capture occurs several thousand feet prior (during initial climb on a powerful set of engines). The main idea is that the capture-range varies – it is not a fixed value. It’s a factor of the current altitude, acceleration, and climb rate.

Level off Maneuver

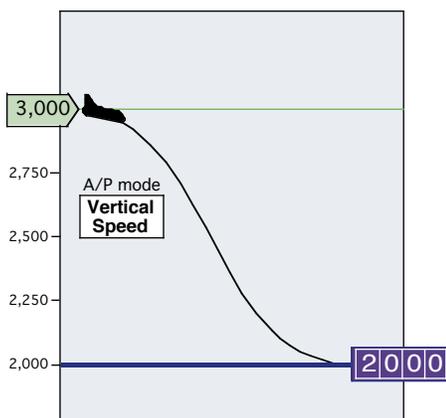


Figure 1

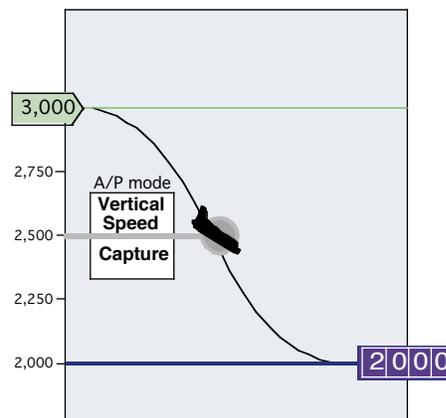


Figure 2

When we are in Capture mode things become much more messy. Say we are descending to 2000 feet. At 2,500 feet the autopilot transitions, automatically, to Capture and starts the level off maneuver. Now we are at 2,200 feet and we set the altitude to a value behind the aircraft. Here is what happens:

If we set the altitude to a value behind the point of capture, say 3000 feet, the aircraft will kill the 2,000 foot capture altitude and continue straight down. Aha, you say, just like vertical speed. Correct. But there is a catch. If we set the altitude to 2,400 feet (which is below the capture point of 2,500 feet), the aircraft will drop down, pop up, and capture 2,400 feet!

Capture Mode

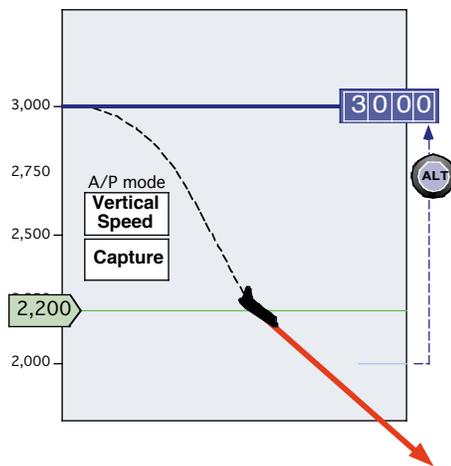


Figure 1

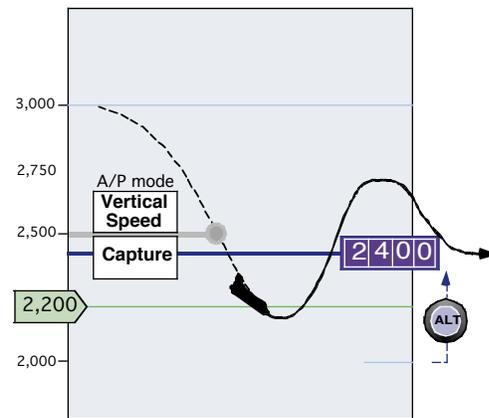


Figure 2

Wait a minute, what is going on here, you ask—two different responses? True: if you set the altitude to a value above the capture start point, you get a bust. If you set it below the capture start point you get a radical maneuver, but a capture alright.

Do pilots know about this? No. Its not in the manual, not mentioned in training or IOE, and practically unknown. But the real problem is that even if the pilots knew about it, they still could not help it. Ahem, you say—what do you mean?

Here is the logic: The only way to know how the aircraft will respond, is to keep a record of the altitude at which the autopilot transitioned to capture. Behind this value the capture is one thing, and below it is another. But the pilot has no record of this value. The transition to Capture happens automatically and there is no way to retrieve the altitude value associated with it. As a consequence, the pilot cannot discern whether the aircraft will kill the capture or do a pop-up maneuver and capture the altitude. Even the “old salts” can’t do this one.

Actually, even if we were to build a robot to do this task, this robot will fail on it. You see, it's simply impossible. Now we are not talking about some minor event, but uncertainty about how the aircraft will behave in a basic flying maneuver, one that is often performed very close to the ground. This is a very critical maneuver.

There are two kinds of pilot reaction to such problems; that is, after they become confused: Some blame it on themselves for being inattentive and out of the loop. They even have a name for it: automation complacency. Others, as we seen earlier, blame it on an autopilot, write it up the log as a malfunction, and demand that a mechanic check out the autopilot.

But the real problem is, of course, none of the above: it's not about being inattentive, and the autopilot always checks OK. The real problem is somewhere else. But from the outside, it sure looks like another one of those pilot-error things.

CONCLUSIONS

I told you, today, three stories. Stories about interactions. A story about a captain-copilot interaction that at first glance seemed quite problematic. But when you understand the hidden context, everything falls into place. Then there was the spoiler problem. A bona-fide pilot error. Actually, it was a timing and sequencing problem, and it will happen to anyone who uses this checklist. And finally there was the autopilot behavior.

The message that I would like to end with is about looking beyond the facade. About using existing Human Factors and Computer Science methods, tools, and techniques to achieve this. But it's also about a mindset. A mindset that must change if we want to achieve a higher level of safety.

I think it is the role of this professional community, as well as other similar ones, to demand a more scrupulous perspective to pilot error, especially when we move into a more technologically challenging era. It involves going beyond the facade, and taking into account complicated human and technological factors. It is our responsibility, and it is not a simple one.

Thank you.