MODE MANAGEMENT MADE SIMPLE

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Mode management is the processes involved in understanding the character and consequences of autoflight modes, planning and selecting engagement, disengagement and transitions between modes, and anticipating automatic mode transitions made by the autoflight system itself.

Mode management is a problem. The fact that flight crews are sometimes surprised by autoflight system behaviors is well documented in Wiener's study of the 757 flightdeck. When flight crews ask "What's it doing now?" and wonder how to make the plane do certain things, there is a problem. Problems with mode management are also easy to see in ASRS reports. Palmer, et al. on altitude deviations document several cases in which flight crew uncertainty about the behavior of glass cockpit automation led to altitude busts.

Many Boeing customers who come to Boeing for training, ask that their crews NOT be taught the VNAV functions of the FMCS. They make all of their altitude changes in Flight Level Change (FLCH) mode. United Airlines does not teach VNAV operation in its training center[1]. In both cases, the reason given is that VNAV is too complex to teach. In both cases, it is expected that the competence required to use this aspect of the system will be acquired "on the line" as a consequence of learning (and teaching) in actual operations. Another major carrier (Southwest) has placed metal covers over the VNAV mode select switch on the 737-300 mode control panel to prevent crews from using that mode.

Jean Pinet, president of Airbus Industrie subsidiary Aeroformation describing new A-320 training program called Aircrew Integrated Management (AIM), recently said,

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[1] I believe that the manufacturers have a special responsibility to provide the very best training possible. The operators look to the manufacturer as the source of training concepts as well as hardware. An America West training captain complained that America West does not provide conceptual training in the use of the FMCS because none is available from Boeing.

"We took a prudent approach when we saw the proliferation of flight modes and configurations on the A320 and other modern aircraft....We did not want to teach all of the combinations; we kept a 'classic' approach where the training emphasis was on those configurations that seem the best adapted to each of the flight procedures." (From. Lenorovitz, Jeffrey. "Airbus stresses cockpit management, coordination in transition training" Aviation Week and Space Technology, Vol. 136, No. 6. Feb. 10,1992. pp. 29-30)

The authors of the AIM program should probably be congratulated for their operations-centered approach to training. Still, the proliferation of modes is perceived as a problem, and the solution is to teach only a subset of the full system capabilities. Presumably this is because the entire system is thought to be too complex for the instructional designers to describe, too complex for the instructors to teach, too complex for the pilots to learn, or all of the above.

These decisions are symptoms of serious problems with the new generation of highly automated aircraft. Granted that vertical navigation involves the constant interaction of thrust, flight path and speed, there is no need for it to be this difficult. The engineers have created a system of great utility, but the interface to it is conceptually so difficult that operators have given up trying to train their crews to operate and trust instead to the pilots, as a community, to discover and transmit ways of using it in flight[2].

The difficulties that pilots have with mode management are understandable given the nature of the current system. (This goes for all major airframe manufacturers. The differences between Boeing and Douglas mode controls is insignificant. Airbus has a different philosophy, but it may actually be more challenging to the pilot than the American systems because even more is hidden from the pilot in the airbus airplanes.)

AUTOFLIGHT MODES

An autoflight mode is a means of specifying a target for airplane speed, path or thrust. It has been said that the flight management computer system (FMCS) has replaced the autopilot in the current generation of flightdecks (Robert Dorsett, sci.aviation). I believe this is a misconception. The autopilot remains as an alternative to the human pilot as a way of manipulating the control surfaces of the airplane. What has changed is the

[2] Just what it is that pilots are inventing to deal with automated flight modes that are not taught in schools is a very interesting topic that deserves systematic study.

way of specifying and computing the targets that autopilot may be asked to achieve. The FMCS provides new classes of abstractly specified targets for the Autopilot flight director system (AFDS) which can then be achieved either by the pilot acting on the controls to track flight director cues or by the autopilot servos acting on the controls.

The introduction of automation is not often driven primarily by cognitive considerations, but it inevitably has powerful effects on cognition. Automation on the flightdeck is changing both the cognitive tasks that are faced by individual crew members and changing the cognitive properties of the flightdeck itself as a cognitive system.

Although cockpit automation has touched all aspects of flightdeck operations, it has probably had more impact on flight path management than on any other aspect. Through the years there has been a continual process of upgrading and adding new devices and new functions in support of aircraft flight path control. The innovations have come in waves as technologies have matured and made new sorts of operations possible. Unfortunately, the consequence of this process has been the accumulation of a set of poorly integrated devices and functions for flight path management.

Flightdeck Automation

Consider a brief history of flightdeck automation beginning with the Boeing 727.

The 727 flightdeck[3] is a "round-dial" or "steam-gauge" system. The instrumentation is based on electromechanical gauges. Flight path is controlled primarily through the flight controls: control column, rudder pedals, thrust levers, flap handle, trim switches, spoiler lever, landing gear handle, etc. There is a rudimentary autopilot which is capable of holding an already established altitude, maintaining a heading, tracking a VOR radial, and holding an attitude. There is an altitude alerting system, which provides warnings on approaching or deviating from a selected altitude, but it is not connected to the autopilot system and the airplane is not capable of capturing an altitude. Horizontal situation (heading and positional relation to a specified VOR radial or localizer course) are displayed on a Horizontal situation indicator. DME (distance measuring equipment) provides information about distance from station. Considerable cognitive processing is required to construct and maintain situation awareness in this sort of flightdeck. The

[3] I use the 727 as a representative of a class of airplanes. The 737 models prior to the -300, and the older DC-9 models are comparable.

representations that are provided by the instrumentation must be coordinated with other representations in the form of air navigation charts.

The DC-10[4] represents another step in flightdeck automation. It is still a "round-dial" flightdeck, but it contains several new features. The autopilot is much more capable. It can not only hold an altitude or track a VOR radial, it can capture a specified altitude and capture a radial or a localizer. The autopilot is capable of controlling pitch to produce a specified target vertical speed. There is also an autothrottle system which is capable of controlling engine thrust in two modes: a thrust reference mode in which a particular thrust parameter (e.g., N1) is tracked, and a speed mode in which thrust is varied to track an airspeed target. The control of the autopilot and the autothrottle are brought together on an autopilot panel mounted in the glareshield. The airspeed, altitude, heading and vertical speed targets to be provided to the autoflight systems are entered on this panel. Modes of operation are armed for engagement or selected by button presses and switch throws on this panel. The selected, armed or engaged modes of flight control are annunciated on a Flight Mode Annunciator panel. Some of the longer-range models of the DC-10 were also equipped (retro-fitted?) with RNAV (inertial navigation) systems that are capable of flying off-airway tracks to distant navigation fixes specified by latitude and longitude.

The MD-80 added to this a "performance box" which can be used to fly more fuel efficient climbs, cruises and descents. This Performance Management System (PMS) is a precursor of the current VNAV functions of the FMS. The computations of the performance system can be coupled to the Flight Director and to the autopilot if desired. Inputs to the performance system are made with a small limited keyboard (digits 0-9 plus characters N, E, S, W, and /) and PMS data entry and computed data are displayed in a 4 line 24 character per line display. The MD-80 also has coupled autopilot approach and autoland capability to Category III minimums.

The Boeing 767/757[5] marked another jump in flightdeck automation. In this airplane, the performance box expanded to become the Flight Management Computer system. This coupled a comprehensive navigation data base with autotuning of navigation radios and automatic position updating. A two-dimensional color lateral navigation

[4] Early versions of the Boeing 747 and the McDonnell Douglas DC-9 have comparable flightdeck designs.
[5] The Boeing 737-300, and the McDonnell Douglas MD 88 have comparable flight deck designs.

display replaced the HSI[6]. CRT displays driven by symbol generators provide great display plasticity. The inertial reference systems support navigation displays that show motion in either track up or heading up modes. They also permit computation and display of ground speed and true wind - items that were simply not possible to compute in earlier technologies.

The plasticity of navigation displays permits the superimposition of other kinds of information onto the depiction of the aircraft track. Nearby airports, navigation aids, and weather radar returns can all be superimposed on the depiction of lateral flight path. Information about the vertical aspect of flight path can be added in the form of data blocks attached to waypoint icons. LNAV provides facilities for flying complete complex lateral paths that consist of a succession of geographic waypoints. Off airway navigation, complete approach procedures, and autolandings are also supported. Complex vertical profiles can be specified and flown in VNAV modes. The 757/767 also introduced additional autothrottle modes. Altitude callouts were added as part of the newest GPWS systems.

All of these new facilities increased the capabilities of the aircraft autoflight systems, but also created new systems for the crew to monitor and supervise.

The present state of the art in flightdeck design is represented by the Airbus A320 (Airbus Industrie, 1991a&b), the McDonnell Douglas MD-11 and the Boeing 747400. These airplanes have full EFIS[7]. Full EFIS means that the airspeed, altitude and vertical speed instruments are also CRT presentations. This permits soft bugs for altitude and airspeed as well as for heading, decision height and minimum descent altitudes. As an acknowledgement of the importance and difficulty of keeping track of autoflight modes, the Flight Mode Annunciators (FMA) have been improved, and consolidated.

There is no doubt that these innovations have transformed the activities of flight crews, changed the cognitive requirements of flight, and changed the properties of the flight deck as a cognitive system. It is easy to focus on the shortcomings of the automation, but we believe any evaluation of this technology must take full account of the increased functionality and ease of operation provided by these systems. In some

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[6] An HSI type display can still be presented by the symbol generators that drive the computer displays. There are operational reasons for preferring this old-style display to the map display in some circumstances.

[7] All except the standby instruments are now on glass. The Boeing 777 may have even the standby instruments on glass.

cases the automation makes possible things that could simply not be done without it; autoland in zero/zero conditions being perhaps the most striking example. In other cases, crew workload is dramatically reduced; flying a DME arc approach procedure is an example.

Modern flight decks present many alternatives for linking elements of descriptions of the aircraft flight path to autoflight systems. One pilot boasted to me that there are six ways to climb or descend the 737-300. The Operations manual for the MD-88 lists four ways to climb, but on closer inspection one discovers that there are actually eleven different mode configurations involved in these climb methods.

These alternative methods provide the pilots with functional flexibility, but the space of possible linkages is large and complex. Mode changes occur at pilot command, but also automatically without pilot action under many conditions. Automatic control modes may revert to other modes as a consequence of pilot action, due to changing flight circumstances, and due to equipment or signal failure. It is not always apparent which mode combination will best accomplish the desired goals. Modes of operation carry with them other implications, so that what appears to be a good solution (and may be at the moment) could become an unsatisfactory solution as flight conditions change. For example, the vertical speed mode provides no stall protection in climb. A rate of climb that is perfectly safe at low altitude may lead to a stall at high altitude.

Even if a pilot knows which mode to select, it is not always clear how to select the desired mode. Some modes will only arm under certain circumstances and may then only engage when other conditions are met. In most cases, the limiting conditions for mode arming and engagement are not represented anywhere in the flightdeck system (except in the mind of the pilots if they remember the criteria).

As serious as not being able to engage a desired mode is the inability to disengage an undesired mode. This is sometimes an even more subtle problem that mode engagement (Sarter & Woods, in prep.) Some methods of engaging one mode may unintentionally lead to the disengagement of other modes (Palmer, et al, in prep).

Even though autoflight modes are annunciated, it is not clear at all times which modes are actually engaged or what the engaged modes imply about aircraft performance. These problems may be due to the following factors: 1) the annunciations are sometimes cryptic, 2) the annunciated modes combine with each other in complex ways; there are modes for thrust, armed captures, roll and pitch guidance, 3) Mode transitions can occur without pilot intervention and sometimes without apparent change in aircraft behavior, 4) the mode annunications are not prominently displayed, 5) pilots often take the state of the MCP or FGCP as a mode indicator (which it is not).

The complexity of the autoflight systems requires the crew to reason in a complex space about not only the situation of the aircraft and its flight configuration, but also about the configuration of the automatic systems. This creates situations in which pilots are unsure what is being done by which "intelligent" agents. Pilots are very careful about making clear which pilot "has the airplane", and usually communicate efficiently about their intentions. In interaction with sophisticated automation, however, it is sometimes not clear to the crew who (or what) has what part of the airplane and what the automated systems' intentions are. Glass cockpit crews occasionally ask aloud, 'Why's it doing that?", "What's it doing, now?", "Is it supposed to do that?" [Wiener, 1989 #306]. When unexpected mode behavior occurs, there is little support in the modern cockpit for determining the cause or communicating about the state of the system.

Most (but, alas, not all) mode selections are made by taking action on the MCP. The language of execution is button presses and switch throws on the MCP. And on the MCP, there is feedback for the flight crew about the actions they have taken. Flow-bars in the switches on the MCP indicate that a selection has been made. For some, but not all, of the switches an illuminated light means that the mode can be disengaged by selecting the switch again. The proper evaluation of the consequences of mode selection actions taken on the MCP cannot be made on the MCP. Instead, evaluation takes place in a different language, the language of flight mode annunciation and in another place, on the FMA panel (Douglas) or on the PED (Boeing).

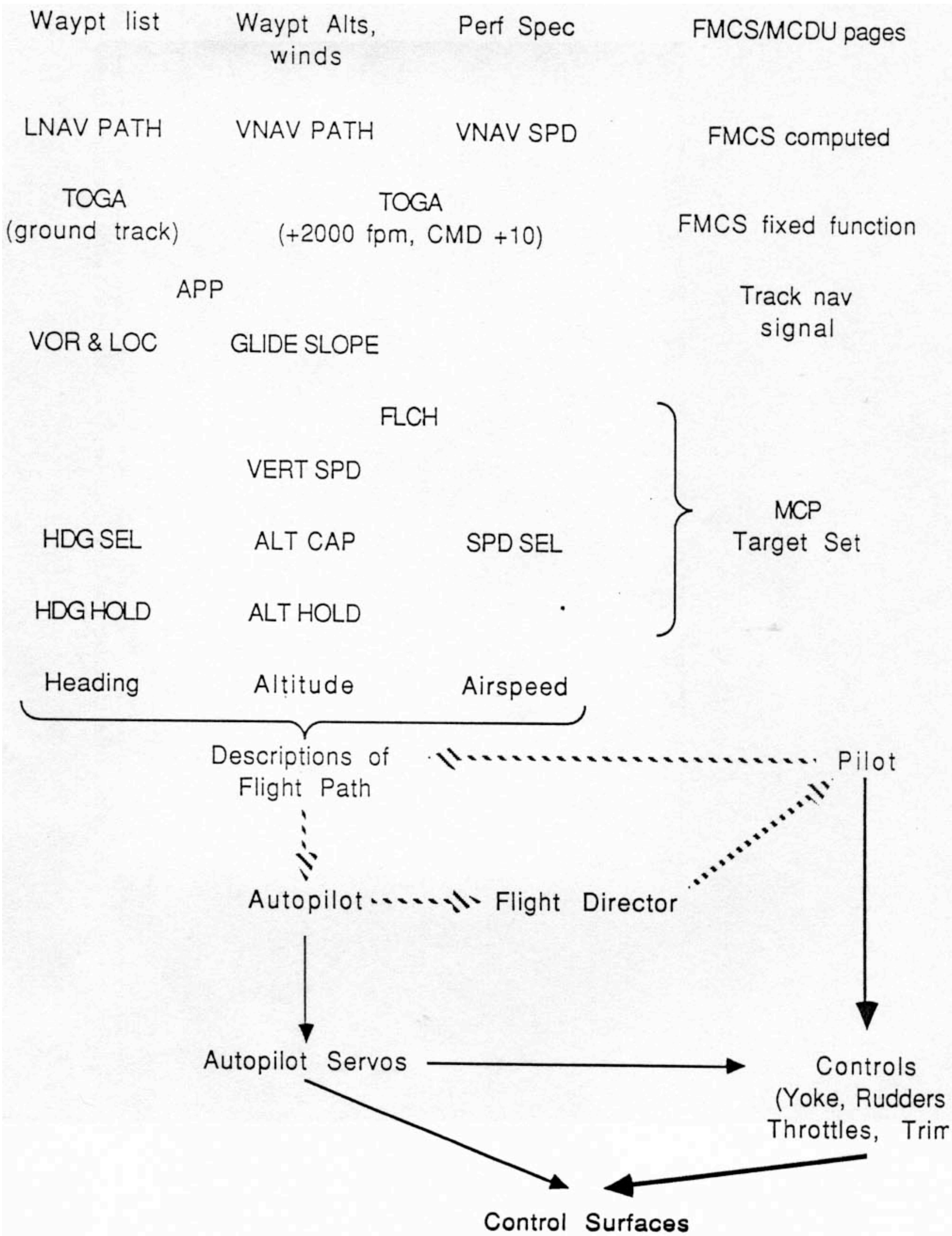
Failure of integration: the flightdeck Tower of Babel

The introduction of several waves of automation over the years has made the modern flightdeck a Tower of Babel. Flight path information is expressed in at least ten different identifiable languages: 1. Spoken ATC, 2. Written IFR shorthand, 3. Primary flight control positions, 4. MCP selections, 5. FMA indications, 6. Primary flight display indications, 7. FMCS/CDU character strings, 8. Navigation Displays, 9. Published navigation charts and plates, and 10. The behavior of the aircraft itself. Some pilots have observed that this list is too short, since the FMS/CDU, the navigation displays, and navigation charts may each contain a number of languages themselves. In a typical approach to landing, the crew will interpret, manipulate, and translate expressions in and among all of these languages (except perhaps 2).

In some cases, the multi-voicedness of the flightdeck is useful. The costs of computing some result in a representation that is not well suited to the computation may be greater than the costs of translating the problem into another representation and solving the problem there. For example, weather avoidance planning can be done on the basis of printed descriptions of the locations of weather fronts, but it is so much easier to do the planning on a chart that it may be worth plotting the locations of the fronts on a chart before attempting to formulate a plan for avoiding the weather.

The descriptions of flight path that are supplied to the autoflight systems always ultimately decompose to heading, altitude, airspeed, and implicitly, time. The bottom region of Figure 2 shows the basic control loops of the modern aircraft. These are unlikely to change much in the foreseeable future. The upper region shows, from the bottom up, the layering of increasingly complex specifications of flight path that have been introduced over the years. This corresponds to the discussion above of the history of flightdeck automation. The right hand column of the upper section of figure 2 lists the media in which the constraints to be satisfied are represented at each level.

Given the state of the art in technology, there is no need to have this many representations. What we see now is a consequence of a particular history of innovation. I believe that a considerable reduction in complexity is possible through an integration of these languages into a smaller number of ways to represent and evaluate flight path information. I do not believe that specific functions should be eliminated nor should the ability to revert to simpler descriptions when they are needed be sacrificed. The issue concerns the representational media in which the descriptions are composed and in which the adequacy of the descriptions is evaluated.


Waypt list
Waypt Alts, winds
Perf Spec
FMCS/MCDU pages
LNAV PATH
VNAV PATH
VNAV SPD
FMCS computed
TOGA (ground track)
TOGA (+2000 fpm, CMD +10)
FMCS fixed function
APP
Track nav signal
VOR & LOC
GLIDE SLOPE
FLCH
VERT SPD
MCP Target Set
HDG SEL
ALT CAP
SPD SEL
HDG HOLD
ALT HOLD
Heading
Altitude
Airspeed
Descriptions of Flight Path
Pilot
Autopilot
Flight Director
Autopilot Servos
Controls (Yoke, Rudders Throttles, Trim
Control Surfaces

Descriptions of flight path can be linked to the flight controls either by way of the autopilot servos, or via the flight director and pilot inputs to the controls. The modes concerning lateral navigation of the airplane are called roll modes because they achieve their goals primarily through the control of the roll attitudes of the airplane. The modes concerning the vertical navigation of the airplane are called pitch modes because they achieve their goals primarily through control of the pitch attitudes of the airplane. The modes concerning the thrust of the engines are called autothrottle modes because they primarily act through the autothrottle system to control engine thrust.

In the 747-400, there are 7 roll modes, 9 pitch modes, and 5 autothrottle modes. Logically 315 mode combinations are possible! Fortunately only about 60 of these logical possibilities actually occur. That is still a large space of modes to think about. Is there any way to simplify the conception of the space of modes and the problems of mode management?

Roll Modes

The role modes for the 747-400 are given the following names: HDG SEL (heading select), HDG HOLD (heading hold), LNAV (lateral navigation), TOGA (takeoff and go-around), LOC (localizer), ROLLOUT, .and ATT (attitude). The conception of roll modes can be simplified considerably by noting that each mode is no more than a method for computing the directional target for the airplane. While there are seven roll modes, the modes fall into two major classes: modes in which the target is the heading of the airplane, and modes in which the target is the ground track of the airplane. The heading based roll modes are HDG SEL and HDG HOLD. HDG SEL turns to the airplane to a selected heading and keeps it on that heading. HDG HOLD rolls the airplane's wings level and holds the heading that was achieved when the wings came level.

Further distinctions among modes are made on the basis of the sources of track information. In LNAV mode, a ground track is computed by the flight management computer system, based on inputs to the MCDU. This ground track may be used to do the equivalent of VOR radial tracking, although it is the ground track defined by the radial, rather than the VOR signal that is being tracked. LOC and ROLLOUT modes track the localizer signal of an instrument landing system approach facility. TOGA uses on-board inertial navigation system to determine the ground track of the airplane at the onset of TOGA guided flight and uses that ground track as the target.

Ground track can thus be defined by geographic coordinates (LNAV), by signals from ground based navigation aids (LOC and ROLLOUT), or by a momentary sensation of the inertial reference system (TOGA).

The one remaining roll mode, ATT (attitude) is an infrequently used reversion mode. It engages only when a flight director is turned on in flight after a period in which neither flight director and none of the autopilots have been engaged and the bank angle exceeds 5°. Its main function is to provide a flight director guidance mode that keeps doing what ever the airplane was doing before the flight director was turned on.

Pitch Modes

The pitch modes are: TO/GA (takeoff and go-around), ALT (altitude), V/S (vertical speed), VNAV PTH (path), VNAV SPD (speed), VNAV ALT (altitude), G/S (glide slope), FLARE, and FLCH SPD (flight level change, speed).

These pitch modes can be distinguished from each other on the basis of the sort of target that pitch is manipulated to control. Pitch modes either track speed target or a path target.

Autothrottle Modes

The autothrottle modes are: THR-REF, THR, HOLD, IDLE, and SPD.

These come in two flavors: speed modes and thrust modes.

MODE INTERACTIONS

Fortunately, the Roll modes are essentially independent of the Pitch and Autothrottle modes. (Exceptions: the toga and rollout roll modes only occur with certain pitch and autothrottle modes.) Unfortunately, this independence is conceptually masked by the fact that the flight mode annunciator formats of both Boeing and Douglas aircraft display roll mode between the pitch and autothrottle mode displays. (This is probably an attempt to maintain consistency with the layout of the primary flight displays in which the ADI and the HI (primary roll instruments) lie between the ASI (thrust instrument in level flight) and the Altimeter (a pitch instrument in level flight)).

Treating roll modes independently and knowing that there are few interactions between roll modes and other modes simplifies the mode management problem considerably.

There are, however, significant interactions between pitch and autothrottle modes, and it is here that most of the conceptual problems seem to arise. Segregating the modes into classes and showing a simple set of relations among the classes may help to simplify the conceptual space.

The rule is that whenever the pitch mode is controlling to a speed target, the autothrottle mode will be controlling to a thrust target. Whenever the pitch mode target[8]. Figure 3 shows the interactions between the pitch modes and autothrottle modes.

What every pilot knows

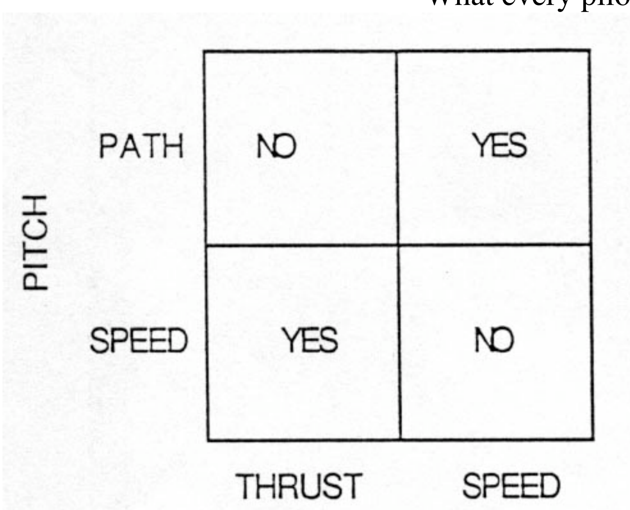


Figure 3. The general rule of interaction between pitch and autothrottle modes.

This should make sense to all instrument rated pilots, since it reflects the changes in the primacy of instruments in standard maneuvers. That is, in a normal climb, thrust is set, and speed is controlled by pitch. If the airspeed is too high, raise the nose; if the

[8] One exception exists. On an autoland, the pitch mode FLARE engages at about 50' AGL and the autothrottle mode IDLE engages at about 25' AGL. For that last 25' of descent, speed bleeds off and neither pitch nor thrust controls to a speed target.

airspeed is low, lower the nose. When approaching cruise altitude, the nose is pushed down and the airplane accelerates to cruise speed. Pitch is now controlling flight path and thrust is controlling speed, which will increase if thrust is not reduced. A similar transition occurs at top of descent where thrust is typically brought to flight idle (or other descent value), and speed is controlled by pitch.

Note that speed should always by controlled by one mode or the other.[9] This regularity considerably reduces the complexity of the space of mode combinations.

Figure 4 shows the space of possible combinations of pitch and autothrottle modes. In this table, the distinctions among modes are made on the basis of the mode type (pitch or autothrottle), the controlled parameter (speed or path for pitch modes, speed or thrust for autothrottle modes), and the source of the target (Mode Control Panel, Flight Management Computer, or Ground Signal).

[9] There is a hidden danger here. It is possible to fly a visual approach in the 747-400 with the autopilot, flight directors, and autothrottles off. If a go around is required, pushing the go-around buttons will provide go around thrust. The upward pitching moment caused by the below -wing mounting of the engines can feel like the TOGA pitch mode acting through the autopilot, even though the autopilot and pitch modes have not engaged. In this case, the autothrottle mode controls thrust, but only pilot action with the control column can control speed. It is possible for a distracted pilot in such a situation to inadvertently approach a stall condition.

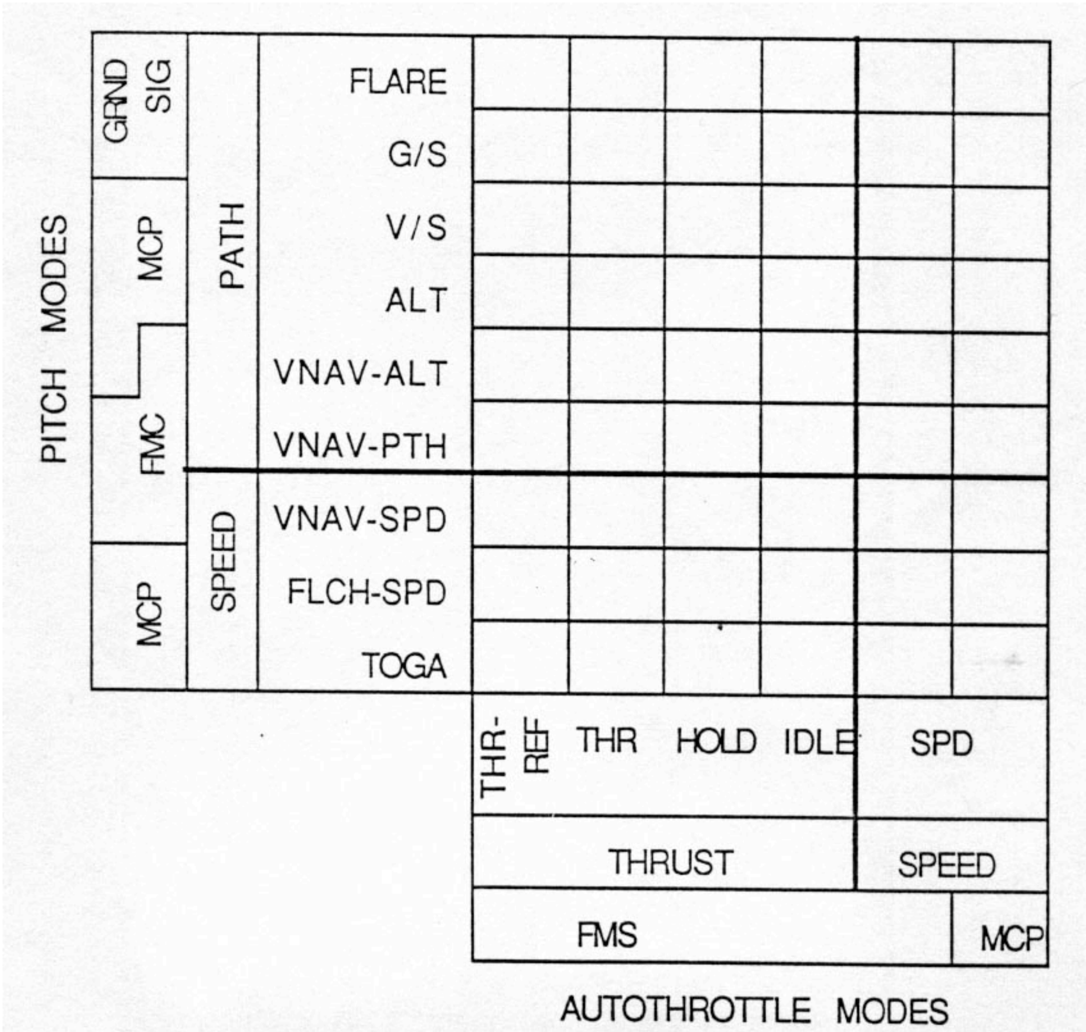


Figure 4. The logically possible mode combinations.

Figure 5 shows the space of actually occurring mode combinations. The crosshatched area indicates combinations that do not occur.

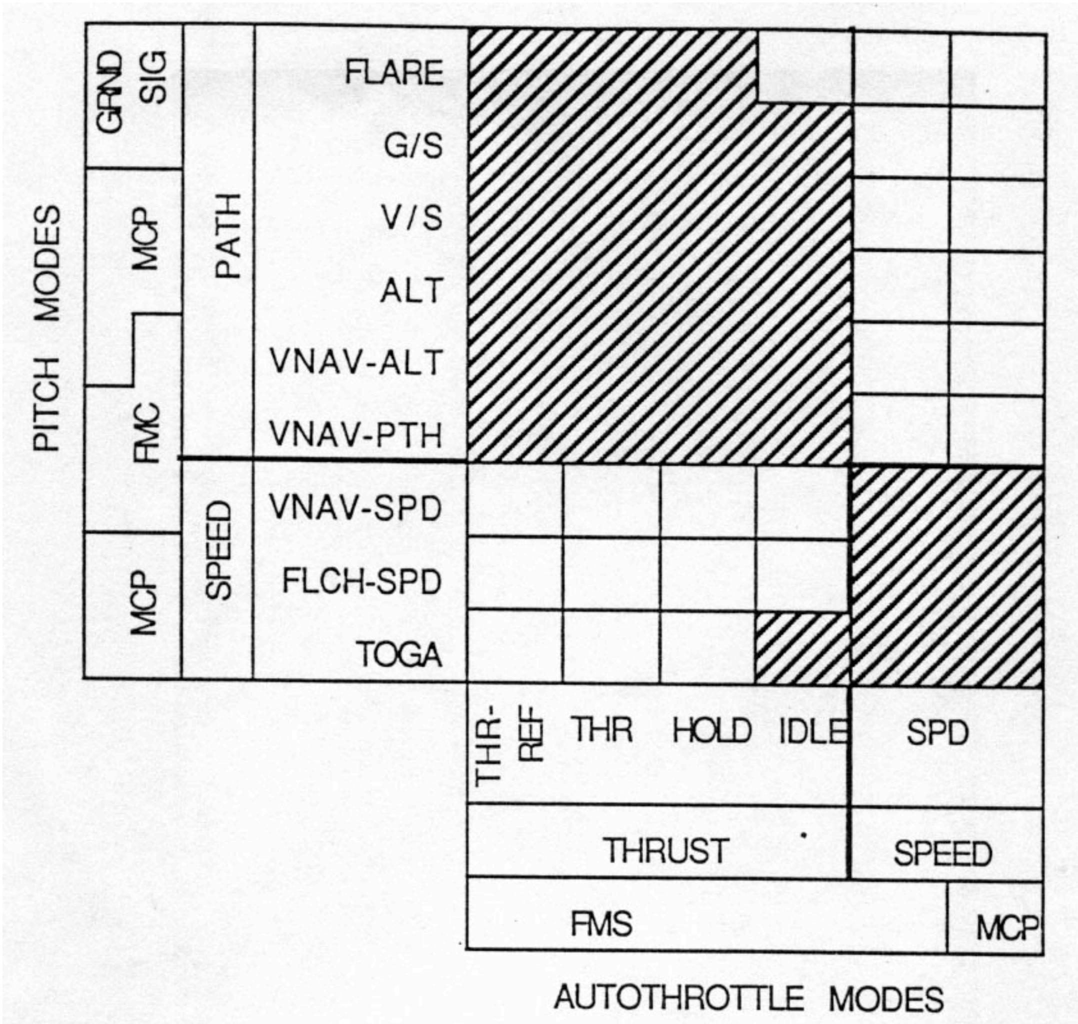


Figure 5

In training a lot of emphasis is placed on monitoring and calling out mode transitions whether they are crew selected or automatic. The purpose of making mode transition callouts must be to bring the conceptual implications of the current mode to the attention of the pilots. These conceptual implications concern what is being controlled and how. This is precisely what the figures above attempt to capture. Unfortunately, these relationships do not appear explicitly anywhere in the ~ ;~; - training materials. One reason that crews in training have so much trouble learning to attend to and call out mode transitions is that such callouts are only perceived as useful to the extent they bring to mind operational implications. When crew members are unclear on the meanings of the modes, they have little motivation to note mode transitions.

Implications and applications

Training:

Line pilots are normally quite enthusiastic about the quality of the training they receive. However, they do sometimes observe that a good deal remains to be learned on the line. In school they are often taught one way to solve each of ~e most frequently encountered tasks of automation management (see the airbus quote above). They are usually not taught how that one way compares to other possible ways, or just why any of those ways of proceeding work the ways they do. Some training pilots flying Boeing airplanes complain that Boeing does not supply the material needed to do proper training. Current training is based on rote memory, "if you do this, then this will happen. " There is a perceived lack of conceptual underpinning and operational orientation. Pilots would like to be able to ask, "What problems does this solve? When would I used it? How does it solve the problem I am facing?" (personal communication Capt. David Weeks. America West 737.)

Consider the following examples. In the automatic flight section of the airplane operations manual the description of the speed switch on the mode control panel states that the speed switch is "inactive if in FLCH, VNAV, or TOGA" (07.10.2A). A pilot in training may choose to memorize this bit of information. If he does not, he is at risk of pushing this button while on one of these modes and finding that it does not respond. "What's going on?", he might ask. "Why can't I get speed mode?"

The answer is difficult to see in the current system for two reasons, one having to do with the design of the mode control panel, the other having to do with the training. The answer to the question is that the speed switch engages an autothrottle speed mode. It is clear from the diagrams above that FLCH, VNAV, and TO/GA (pitch modes) are speed controlling modes. Speed is already being controlled by pitch in these modes, so it cannot also be controlled by the autothrottle. But this is hard to see because 1) the layout of the MCP provides only implicit hints that the speed switch controls an autothrottle mode rather than a pitch mode (after all, either sort of mode could control speed) and 2) the training does not make it clear that autothrottle and pitch modes have a mutually exclusive relationships with respect to the control of speed. If these relationships had been made clear, it would be easy for a pilot reading the manual to know immediately why this switch will be inactive when the pitch mode is FLCH, VNAV, or TO/GA. The need to memorize the fact that SPD is inactive in these modes is eliminated. The behavior of the airplane autoflight system becomes meaningful rather than mysterious.

In the description of the L\S/MACH selector, the pilot is told that when the IAS/MACH selector is pushed, the "IAS/MACH window does not blank if SPD, FLCH, or TO/GA mode is active" (07.10.02B). Again, to avoid surprises in flight, the pilot could either memorize these facts, or understand the reasons behind them. But the underlying conceptions are masked by the organization of the presentation of information. In this cas<, no effort has been made to distinguish the autothrottle mode, SPD, from the pitch modes, FLCH and TO/GA. If this had been done, it would be easy to see from the diagrams above that these three modes share in common the properties that they are modes that control the speed parameter on the basis of a speed target that is set on the MCP. The existing instruction and design of the flight deck give absolutely no explicit representations of the dimensions on which these three modes are members of a single conceptual category. If these dimensions were to be represented to the pilots, it would be obvious why the IAS/MACH window does not blank when the selector knob is pushed while these modes are engaged. These are just the modes in which a speed target is already being set on the MCP. A simple conceptual regularity replaces the need to memorize what otherwise seem to be unrelated facts.

Similar problems exist in the relationship between the autothrottle mode engaged with the speed switch and the speed modes engaged by "speed intervention" when the IAS/MACH selector is pushed. The former is an autothrottle mode. The latter is a "hidden" pitch mode. I say hidden because when speed intervention is selected on a descent, all the outward indications are that pitch is controlling path. However, "During descent, when speed intervention is used, the guidance mode essentially changes to speed on elevator...." FCTM, p. 3-7. Path is no longer controlled by the pitch of the airplane. Deviations from path must be controlled with speed brakes or throttle.

In some cases, very useful functions are provided without adequate operational context. For example, consider the use of vertical speed mode in descent. Imagine a crew flying an FMS equipped airplane that pre-dates the 747-400. The crew has constructed the approach and is flying in VNAV-PATH at cruise altitude. Prior to reaching top of descent, ATC clears the airplane to a lower altitude. What are the mode options and what will they do? VNAV-PATH is the current mode, and although it would do the most economical thing, it would not comply with the ATC instruction to start down now. FLCH-SPD would being the descent now, but at idle thrust and a high rate of descent that would lead to excessive uneconomical low altitude flight. The solution in the older airplanes is to use vertical speed mode and being a descent at about 1,200 fpm. This is a descent rate that will keep ATC happy without deviating from the economy path by much. In the 747-400 this contingency is now met with the DES NOW feature available via the VNAV descent page, o r from the MCP when within 50 nm of T/D. This function gives a 1200 fpm descent from the current location to intercept the descent profile. It is exactly what is needed to solve this frequently encountered problem, but existing training does not present it in that operational context.

Providing proper conceptual training should decrease, not increase, training time. Retention is better when that which is learned can be integrated into a coherent conceptual framework. Conceptual training is more difficult to administer than rote training, and it is more difficult to maintain quality control among instructors. Appropriate use of computer based training media may help in this regard.

If the analysis presented above is correct (and there are ways of finding that out), then making the concepts that underlie autoflight operations more explicit may improve the rate and quality of learning. The reasons for automatic mode transitions should become clear, and problem solving concerning which course of action to pursue in order to deal effectively with particular flight circumstances should be clearer. Increased use of automation will save operators money and that gives the product an edge in the marketplace.

The least expensive intervention in the training system would be changes to the airplane operations manual. The current manuals do a poor job of explaining flight modes and the relations among them.

There has recently been concern that flight crews are reluctant to turn off the automatic systems when they should. A number of aviation specialists have argued for "turn it off" training. No doubt this is a real problem, but there is a corresponding problem of turning off the automatics when there is no need to do so. The latter problem may result from poor understanding of the autoflight system's behavior. This is not an argument for training the crews to keep the automation on longer. Rather it is an argument for giving the crews a better understanding of what the automation does and how it does it. The expected consequence is that crews so trained will turn the automation off when it is to their advantage to do so, but will not turn the automation off in circumstances where it could be helpful.

Flightdeck design.

There should be a fit between the way pilots think about (or should think about) what they are doing, and the structures in the flightdeck that represent the things thought about. The current flight deck designs are a residuum of an evolutionary process. Just as airframes and engines are now designed for maintainability, flightdecks should be designed for learnability. Substantial savings in training costs due to reduced training time, and operational savings due to increased appropriate use of automation could be realized in a flight deck that was designed for learnability.

One source of difficulty in performing mode management on the glass flightdeck is that the current lexicon of modes fails to capture any coherent set of conceptual distinctions among modes. It is a product of an evolutionary process of technological change in the flight deck. Each new wave of automation brought with it not only new functions and concepts, but a new lexicon for talking about functions and concepts as well. The result is that there is no coherent conceptual framework for thinking about flight automation, and the conceptual distinctions that are important are not reflected in the organization of the lexicon. For example, the autothrottle "SPD" mode lumps together quite different kinds of control processes. Speed targets set on the MCP, and speed targets set by the FMS behave differently, but the difference is not marked in the lexicon of modes. Both kinds of modes have the same name "SPD". This is indicated in figures 4 and 5 by the - - double column for the autothrottle speed modes.

An integrated approach to flightdeck automation will require the development of 1) a coherent organizing conception for autoflight functions, 2) a lexicon of autoflight events that captures the key distinctions in the conceptual model, and 3) a physical environment of interaction that matches the conceptual arid lexical structures. Put in other words, there ought to be a simple and clear way of thinking about autoflight, and that way of thinking should be reflected in the ways of talking about, acting on, and evaluating autoflight functions. This is not the case in the current generation of flightdecks. It is within current technological means, but the problem has never (to my knowledge) been put in these terms so there are no efforts to produce the sort of system described below.

Given the emergent nature of flightdeck design, technology implementation and operational use, there are opportunities to intervene at any of several stages of development. There is no doubt room to act in the short run to change the training or the procedures for using the systems as they currently exist There are many proposals to work within the constraints of the present system. To study what is problematic [Sarter, 1991#307] and to propose training changes (Corwin, personal communication) that will make the existing system easier to use. In the slightly longer run, there are opportunities to introduce changes in the current system that will solve existing problems. For example, the composition of EICAS messages could be changed to make them less ambiguous. I agree that there is both a need and an opportunity to make these short term improvements and would like to contribute to both of these efforts. However, I also propose something more ambitious: to look into the future and develop design concepts for an integrated flightpath information environment. I believe that such an effort could solve many of the existing problems. Perhaps more importantly, the right design concepts properly implemented may simply eliminate many of the current problems that are consequences of poor usage of existing technology or poor integration among different aspects of flight path control.

The development of such design concepts will require a combination of an understanding of the nature of the flightdeck itself as a cognitive system, a mastery of the principles of interface design, and an awareness of the tasks that airplanes and their crews must perform as they participate in an evolving aviation system ~