The Role of Moded Input Devices in Modern Airliner Accidents

Lance Sherry, Robert Mauro, and Oleksandra Donnelly

***Abstract*— The automation in the flighdeck of a modern airliner has grown in functionality over the last several decades, improving safety, and operational efficiency. As the sophistication of the automation has increased, some traditional input devices in the flightdeck, such as throttle levers, yokes, and switches, have unobtrusively changed the way they work. Instead of operating the same way at all times, the behavior of these input devices have become context-sensitive (i.e., "moded"). In many cases, the change in context is subtle and is not salient to the flight crew, leading the flight crew to use the input device expecting one behavior but experiencing another. This paper documents the role these "moded" input devices have played in airline accidents in inhibiting or slowing the flight crew intervention in the sequence of events leading up to the accident event. The implications of these results on flightdeck design, certification, and flight crew training are discussed.**

***Index Terms*—accidents, aviation, human-computer-interaction, system complexity**

I. Introduction

THE automation in the flightdeck of a modern airliner has grown in functionality over the last several decade, improving safety, and operational efficiency. Flightdeck automation started with the augmentation of the input control devices to combat non-linear, unstable aerodynamics (e.g., Sperry Gyroscope). Since then the automation has been incrementally layered providing: (i) propulsion system control to overcome non-linearities in the thrust response of engines, (ii) attitude control to reduce pilot fatigue in maintaining a desired aircraft trajectory in the presence of natural aerodynamic oscillations and atmospheric changes (e.g., turbulence), and (iii) planning and optimization to minimize fuel burn and improve flightdeck efficiency in increasingly complex airspace.

As the sophistication of the automation has increased, the behavior of traditional input devices in the flightdeck, such as throttle levers, yokes/side-sticks, and knobs/buttons, have been quietly changing as well. Instead of operating the same way at all times, the behavior of these input devices have become context sensitive resulting in "moded" behavior of the input devices. For example, the Takeoff and Go Around Switch (TOGA Switch) can be disabled temporarily according to logic based on aircraft trajectory and location, or speed protection for pitch commands can be temporarily disabled.

Although the addition of these automation functions increase safety margins and/or improve efficiency, the "moded" input devices add complexity in the cognitive decision-making of the flight crew and may have a negative effect in flight crew response to events in time-sensitive, safety critical scenarios.

This paper describes a cross-cutting analysis of modern airliner accidents using an accident scenario event model [1]. The analysis identified a common theme: moded flightdeck input-devices prevented the flight crew from a timely intervention either in the events triggering the accident sequence, or in the intervention following the start of the accident scenario.

Three classes of "moded" input device behavior were identified: (1) input-device *disabled* (e.g., Takeoff and Go Around switch), (2) input-device *alternate behavior* (e.g., speed protection no longer available during side-stick manual pitch control), or (3) input device commands are *over-ridden* (e.g. throttle lever or rudder pedals).

None of these devices were introduced to the flightdeck with moded behavior. The moded behavior was added as the complexity of avionics functions in the flightdeck automation was increased. As a consequence, in the current design of modern airliner flightdecks, *none* of these input devices have *any* visual indication on the device that they are moded. Further, there is no visual, tactile, or aural indication that the input device is disabled, operating under alternate behavior, or being over-ridden. An example of a visual indication would be a green LED indicating that the switch was active (i.e. not disabled). In some cases, the visual indication is available on the Primary Flight Display (PFD), Engine Synoptic Display (ESD), or Flight Mode Annunciator (FMA). These visual indications require the flight crew to intentionally seek the information out and then interpret the visual cue based on memorized rules of label, color, or presence/absence of display.

The phenomenon of "moded" input devices is a well known issue in Human-Computer Interaction (HCI). Schneiderman's design rules [2] require consistency (rule #1) and informative feedback (rule #3). Krug [3] recommends that designs "do not

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make the user have to think" by providing state "information in the world, so that the operator does not have to apply memorized rules [4]. These general guidelines can also be found in regulatory requirements for design of avionics such as AC 20-175: Controls for Flight Deck Systems, AC 25.1302-1: Installed Systems and Equipment for Use by the Flight crew. For example, 25.1302(b)) identifies a requirement for "distinguishable and predictable controls" such that "the function of a control must be readily apparent" and that "the consequences are predictable and obvious to each flight crewmember." Although AC 25.1302 – 1 does not explicitly refer to input devices it does state that "service experience has found the behavior of some equipment, especially from automated systems, can be complex or *dependent upon logical states or mode transitions that are not well understood or expected by the flightcrew*. Such design characteristics can confuse the flightcrew and have been determined to contribute to incidents and accidents."

The results of the analysis in this paper identify an opportunity to enhance the design and certification of airliner flightdecks with explicit annunciation and/or training for *input devices* that have moded behaviors. Examples of annunciation include backlit switches, buttons, knobs/wheels, indicator lights on stick, levers or indications in a normal visual field-of-view. Further, a design waiver or commitment for explicit remediation through training should be required as part of the engineering design review and as part of the certification process.

The phenomenon of "moded" input devices is not limited to aviation. The introduction of "lane assist" and "station-keeping cruise control" in automobiles has created moded steering wheels and accelerator pedals. Given the experience of the aviation industry, these subtle changes ought to be evaluated carefully, especially with regards to rare accident scenarios.

This paper is organized as follows: Section 2 provides an overview of automation in the modern airliner flightdeck and the roles of input devices. Section 3 describes a general model for the airline accident sequence, including intervention opportunities used for this analysis. Section 4 provides a summary of airline accidents and the role of moded input device behavior. Section 5 provides a discussion of the results of the study and next steps.

II. OVERVIEW OF FLIGHT GUIDANCE SYSTEMS ON THE MODERN AIRLINER FLIGHTDECK

The flight deck of a modern airliner is a "human-machine system" with responsibility for safely and efficiently managing the mission including, but not limited to, the management of the aircraft trajectory from origin to destination. The desired aircraft trajectory is accomplished by a hierarchy of functions (Fig. 1).

1. Stability Augmentation: real-time, closed-loop stability augmentation and engine control for nearly instantaneous control of control surfaces and engines and mitigation of non-linear, marginally stable control response based on pitch, roll and thrust commands
2. Autopilot and Autothrottle: real-time, closed-loop commands of pitch, thrust, bank to achieve the active targets and control modes selected by the flightcrew or the Vertical/Lateral Navigation functions
3. Vertical and Lateral Navigation: target selection to meet the requirements for the active leg of the flight plan derived from navigation procedures in navigation data-bases and optimization algorithms for speed, fuel burn, and other aircraft performance measures
4. 4-D Flight Planning: generation of a 4-D trajectory based on navigation procedures (e.g., SIDs, airways, STAR, Approach, …), airspace restrictions due to traffic and weather, traffic separation, and other safety, traffic flow management, and business considerations.

The flightcrew are responsible for the overall safe conduct of the flight including the (a) mission flight plan, (b) targets and control modes for each segment of the flight plan and (c) control surface/propulsion commands for each target control mode combination. The flightcrew can use the automation to develop and program, or upload the flight plan (e.g., optimal speeds, navigation data-base), select appropriate targets for each leg of the flight plan, real-time calculation of pitch, roll and thrust to acquire and maintain the targets, and calculate the rudder, aileron, elevator and engine commands.

Input Devices in the Flightdeck

Each of the layers of the functions in the automation "stack" described in Figure 1 have input devices and output displays as summarized in Table 1.

Table 1: Summary of Functions and their Input Devices

Function	*Inputs to Function (Input Devices)*	Function Transform	Outputs from Function	Display
Stability Augmentation	Autopilot & Autothrottle Commands *Yoke/Side-stick Throttle Lever*	real-time, closed-loop stability augmentation and engine control	Elevators, Ailerons, Rudders, and Engine Commands	ESD, ACSD
Autopilot & Autothrottle	VNAV/LNAV *Mode Control Panel TOGA Switch*	real-time, closed-loop commands of pitch, thrust, bank to achieve the active targets and control modes	Pitch, Thrust, Roll Commands	PFD ESD r
Vertical Navigation (VNAV) and Lateral Navigation (LNAV)	Flight Planning	target selection to meet the requirements for the active leg of the flight plan	Altitude, Speed, Course/Heading Targets	PFD
Flight Planning	*Multi-function Control Display Unit (MDCU) pages*	Flight plan based on navigation procedures and optimization of fuel burn etc.	Active Leg of Flight Plan	ND

The Multi-function Control and Display Unit (MCDU) is the primary input device for the Flight Planning (FP) functions (Fig. 2). The MCDU provides the flight-crew with a list of options to select (e.g., Runways, or Departure procedures), and free-form entries with specified formats and/or matches in the data-base (e.g., cruise flight levels, waypoints). Flight crew selections are displayed on the MCDU pages and the

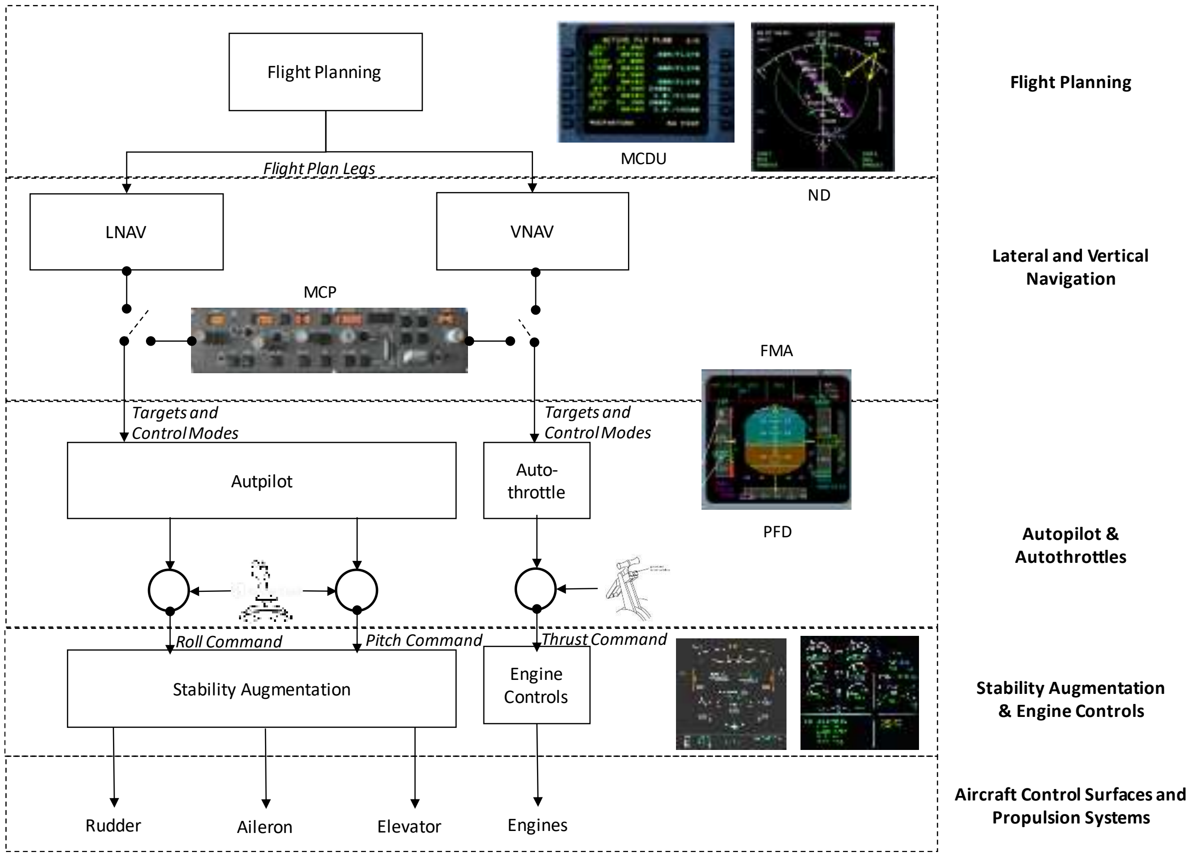


Fig. 1: Stack architecture of the modern airliner flight deck automation functions

Navigation Display.

The LNAV and VNAV functions selects targets and select the control model for the active leg of the flight plan. The flight crew have the option to intervene and manually set the targets using knobs and wheels and/or select the control mode using buttons on the Mode Control Panel (MCP) (Figure 2). The targets are displayed in the airspeed, altitude, heading, and vertical speed tapes on the Primary Flight Display (PFD) and the ND. The control modes are displayed on the Flight Mode Annunciator (FMA) on the PFD. Modes can also be selected by buttons/switches located on other input devices (e.g., yoke/stick and throttle lever).

The Autopilot and Autothrottle calculate the pitch, bank, and thrust commands to meet the targets and control modes for the active leg. The Stick/Rudder Pedals and Throttle Lever provides the means for the flight-crew to intervene and directly issue pitch, thrust, and bank control commands (Figure 2). The commands are displayed on the PFD and the Engine Synoptic (ES display.

The input devices can be used for commanding the trajectory of the aircraft. The input device are *critical* for the intervention by the flight crew during the accident sequence.

III. Method for Accident Scenario Analysis

A cross-cutting analysis of modern airliner accidents identified a common sequence of categories of events in the accident chain [1].

(1) the aircraft is operating close to the limits or migrating towards the limits of the safe operating regime, when

2) a triggering event occurs such as sensor discrepancy and/or pilot commands, leading to

(3) a change in automation mode, configuration or target, resulting in

(4) an inappropriate pitch, bank, and/or thrust command, resulting in

(5) elevator, aileron, rudder and/or engine commands for a trajectory into unsafe operating regime

(6) aircraft enters unsafe operating regime (terrain, traffic, aerodynamics, runway lengths, …)

The categories of events are summarized in Fig. 3.

Each category of events has opportunities for intervention by the flight crew. The flight crew can intervene in the mode or target by intervention through the MCP. For example, the flight crew can over-ride a VNAV late descent to a crossing restriction by changing the rate-of-descent by setting a vertical speed target and selecting the vertical speed mode. Alternatively, the flight crew can intervene by manually setting pitch, roll, and/or thrust. The event categories and intervention opportunities are illustrated in Figure 3.

In all the accident scenarios, the flight crew were required to monitor the performance of the automation at each stage of the accident scenario for rare inappropriate: (1) triggering events, (2) effects on the automation modes, targets, and configuration, (3) commands and/or for (4) inappropriate flight

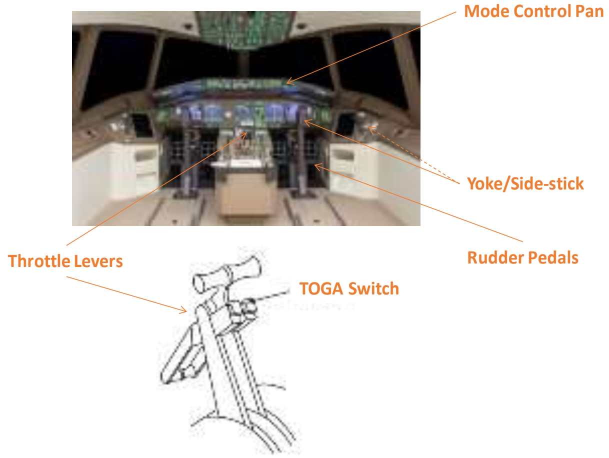


Fig. 2: Example of Input Control Devices: Mode Control Panel, Yoke, Rudder Pedals, Throttle Lever and Takeoff/Go Around Switch

path trajectories. The flight crew were expected to intervene in the rare circumstances if any of these did not match their expectations given the current operational situation.

IV. ANALYSIS OF THE ROLE OF MODED INPUT DEVICES IN THE ACCIDENT SEQUENCE

Over 44 modern airliner accidents and incidents were analyzed using the common accident scenario analysis described above [1]. In the course of this analysis, the presence of a moded input device at one or more stages in the accident sequence was identified (Tables 2, 3, 4). The moded input devices were involved triggering the accident scenario, or inhibited timely intervention by the flight crew during the accident scenario.

There were three classes of "moded" behavior:

(1) Input-device *disabled* (e.g. Takeoff and Go Around switch, or Mode Control Panel Vertical Speed wheel disabled)
(2) Input-device *alternate behavior* (e.g. yoke/side-stick pitch command no longer providing speed protection), or
(3) Input-device *over-ridden* (e.g. rudder pedals over-ridden by autopilot commands).

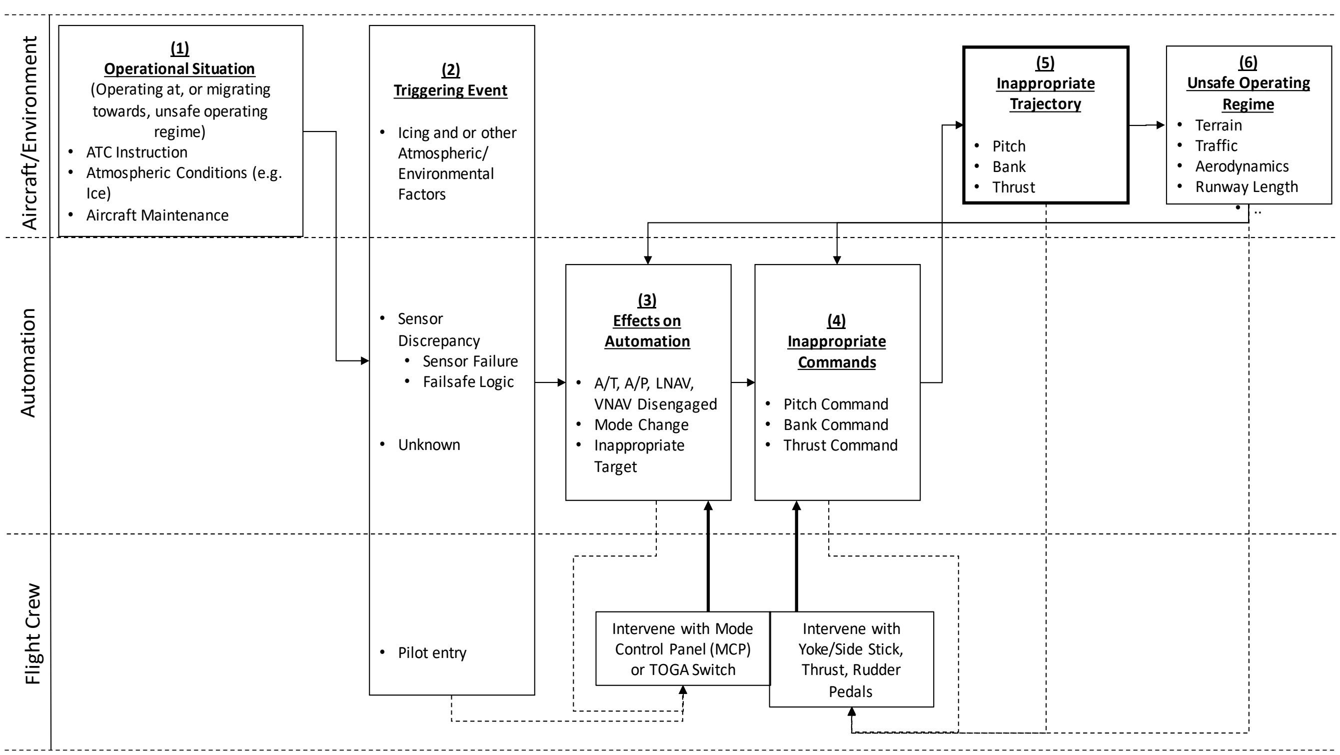
A. *Input Devices Disabled*

In several accident/incident scenarios, a disabled input device triggered the accident scenario or was disabled when the flight crew attempted to intervene during a time-sensitive maneuver. The disabled input device was either a switch/button or knob/wheel on the MCP, or the Throttle Lever (Table 2).

1) *TOGA Switch on Throttle Lever Disabled*

Singapore airlines flight SQ-237 experienced a runway excursion landing on Runway 08L at Munich airport [5].

Operational Situation: SQ-237 was on the final approach segment for landing. The meteorological conditions at the airport were Category I, but at the discretion of the Captain, SQ-237 was flying with a Category III Instrument Landing System (i.e., Autoland). The airline standard operating procedures permit the use of a Category III landing under Category I conditions, but warn the flight crew of the need to monitor for a Localizer signal disruption and be prepared to perform a Go Around.



Fig, 3: Common sequence of categories of events in the accident chain (Sherry, Mauro, 2017)

Table 2: Examples of Disabled Input Devices

Input Device	Moded Behavior	Example Accident	Moded Input Device Role in Accident Scenario
(1) Switches (e.g. TOGA Switch), Buttons (e.g. MCP Control Mode buttons)	Disabled under specific circumstances	SQ237 Runway Excursion at Munich Airport	Prevented flight crew timely intervention
(2) Knobs/Wheels (e.g. MCP Altitude setting)	Disabled under specific circumstances	MD-11 Excessive Pitch Oscillations	Triggered accident scenario
(3) Levers (e.g. Throttle Lever)	Disabled under specific circumstances	OZ241 Controlled Flight into Aerodynamic Stall	Triggered accident scenario

Triggering Event: The arriving aircraft was lined-up with the runway center-line with the Cat III Autoland engaged. At 50 ft AGL, there was a Localizer signal disruption caused by a departing aircraft on the same runway. The Localizer monitoring on the ground and in the aircraft did not detect the Localizer signal disruption.

Effect on Automation/Inappropriate Command: In response to the Localizer signal, the Autoland commanded the aircraft to bank 3.5 degrees to the left.

Flight crew Intervention: The attempt by the flight crew to intervene was inhibited by a disabled switch. The flight crew had an estimated 10 – 16 seconds to recognize and respond to the slight banking left during the flare and before touchdown. The Pilot Flying (PF) decided to initiate a Go Around. The PF selected the TOGA Switch. This switch, however, by design, is disabled when the wheels touch down. The absence of response to the selection of the switch momentarily confused the flight crew.

2) MCP Vertical Speed Wheel Disabled

A China Airlines MD-11 was conducting a descent from the Cruise Flight level. During level-off at an intermediate crossing restriction, the aircraft experienced large magnitude pitch oscillations [6].

Operational Situation: The First-Officer initiated the descent to a crossing restriction at 20,000' via the MCP.

Triggering Event: With approximately 1200' left in the descent, the Captain became concerned the aircraft would not level off at the required altitude. The Captain had previously flown the MD-10 with a slower "exponential/variable-g" altitude capture and was not familiar with the faster MD-11 "circular path/constant-g" altitude capture.

The Captain instructed the First-Officer to slow the descent rate. The First-Officer adjusted the MCP Vertical Speed Wheel (which automatically selected the Vertical Speed control mode).

Effect on Automation/Inappropriate Command: This proved ineffective. Unbeknownst to the flight crew, when the aircraft is within the 0.05g altitude capture region to the level altitude, the Vertical Speed Wheel is inactive. The altitude capture region is not displayed in the flightdeck [7].

Intervention: The Captain took manual control of the airplane, pulled back on the yoke, and then disengaged the Autopilot. Due to the design of the stability augmentation system, the commands on the yoke prior to Autopilot disengagement had built up large magnitude pitch up which was commanded when the Autopilot was disengaged. This resulted in large aircraft trajectory oscillations as the flight crew over corrected whole attempting to dampen the oscillations.

3) Throttle Lever Disabled

OZ 214 provides an example of a Throttle Lever that can become disabled [8]. In this rare circumstance, the throttle is "dormant" and does not actively adjust thrust to control airspeed.

Operational Situation: On an extended final approach in VFR conditions conducted without an ILS signal (due to ILS equipment maintenance).

Triggering Event: An unusual sequence of flight crew actions on the MCP intended to increase the rate of descent while the aircraft was below the pre-set the Go Around Altitude.

Effect on Automation: These pilot entries inadvertently resulted in the Autothrottle transition to a "dormant throttles" mode. This mode is designed to allow the flight crew to set the thrust manually to achieve a desired rate-of-descent for operations. This mode is strictly designed for use at high altitudes while descending from the cruise flight level to perhaps 10,000'. This mode is **not** intended for use on the final approach segment.

Inappropriate Command: The throttles did not advance to hold the reference landing speed (as would be expected).

Inappropriate Trajectory: The aircraft decelerated through the minimum safe operating speed all the way to the stall speed.

Intervention: The flight crew did not recognize the "dormant" mode status of the throttles.

B. Input Devices with Alternate Behavior – Moded

Input devices such as the Throttle Lever and Yoke/Side-stick can, in rare circumstances, exhibit alternate behaviors from the same user interaction depending on the circumstances. In these cases, the flight crew expected normal behavior from the input device but experienced an alternate behavior (Table 3). In these cases, the alternate behavior occurs only in rare circumstances that a line-pilot may not see in revenue service except for training scenarios in a simulator.

1) AF447 Aerodynamic Stall

AF 447 provides an example of side-stick that can exhibit moded behavior [9]. In this rare circumstance, the side-stick does not provide speed protection when pilots are manually controlling aircraft pitch.

Table 3: Examples of Input Devices with Alternate Behaviors

Input Device	Moded Behavior	Example Accident	Moded Input Device Role in Accident Scenario
(1) Levers (e.g., Throttle Lever)	Alternate behavior for same input	TK1951 Controlled Flight into Aerodynamic Stall	Triggered accident scenario
			Prevented flight crew timely intervention
(2) Stick (e.g., yoke)	Alternate behavior for same input	AF 447 Controlled Flight into Aerodynamic Stall	Triggered accident scenario and Prevented flight crew timely intervention
		XL Germany Controlled Flight into Aerodynamic Stall	Prevented flight crew timely intervention
		QZ 8501 Controlled Flight into Aerodynamic Stall	Prevented flight crew timely intervention

<u>Operational Situation</u>*:* During high altitude cruise at FL370 at night in a massive thunderstorm over the Pacific Ocean. Atmospheric conditions with Ice Super Satuation that can freeze pitot tubes. Also, aircraft operating in "coffin corner" with small range between maximum and minimum safe operating speeds.

*<u>Triggering Event</u>: T*he pitot tubes on the AF 447 Airbus A330 froze resulting in discrepant airspeed readings.

<u>Effect on Automation</u>: As a result of a cascade of automation cross-checks, the automation disconnected and handed control to the flight crew for manual control of the aircraft trajectory. Critically, the automation also transitioned from a stability augmentation mode known as "Normal" to a stability augmentation mode known as "Alternate." The alternate stability augmentation mode is intended to be more responsive to flight crew inputs and therefore does ***not*** offer the automatic speed protection that is available in the "Normal" mode.

<u>Intervention</u>: Without visibility of the horizon, the flight crew were obliged to rely on the instruments, which in the case of airspeed, exhibited large magnitude changes in a short time period and three different readings on each of the three displays. The pilot flying, it is understood from the voice recording, attempted to climb to fly over the storm. The pilot used the side-stick, probably under the assumption that speed protection was active and that the automation would *not* command a trajectory that would stall the aircraft. The speed protection was not available in the Alternate stability augmentation mode, and the aircraft ultimately stalled.

There are several other accidents in which moded side-stick that no longer provided speed protection was a factor including: XL-Germany aerodynamic stall [10], and AirAsia 8501 aerodynamic stall [11].

2) TK 1951 Aerodynamic Stall

TK 1951 provides an example of a Throttle Lever with alternate behavior. In this rare circumstance, the throttle is set to a mode that does not actively adjust thrust to control airspeed. Further, the throttle lever does not maintain the thrust setting made by the pilot.

TK1951 experienced an aerodynamic stall and crashed while on final approach in marginal VFR conditions to runway 18R at Schiphol airport [12].

<u>Triggering Events</u>: The aircraft had been vectored for a late localizer intercept resulting in a "high" and "fast" descent to capture the glideslope. During the descent to recapture the glideslope a discrepancy in Radar Altimeters manifested.

<u>Effect on Automation</u>: The discrepant Radar Altimeters caused the Autothrottle to transition to a "land" mode even though the aircraft was still airborne. In the "land" mode, the Autothrottle sets the thrust to an idle setting (and the Throttle Levers retard to the Idle Stop).

<u>Inappropriate Command</u>: During the intercept of the glideslope from above and the deceleration on the glideslope to the landing reference speed, the thrust setting (Idle) was compatible with a decelerating descent, so the automation behavior was consistent the required maneuver. However, as the aircraft decelerated through the minimum safe operating speed, the Autothrottle (in a "land" mode) did not advance the throttles as it would normally, and allowed the aircraft to decelerate to the stall speed.

<u>Intervention</u>: With the aircraft airspeed below the minimum safe operating speed and approaching onset of stall, the flight crew attempted to intervene to arrest the deceleration by advancing the throttles. Once the flight crew removed back pressure from the throttles, the throttles automatically retarded to the Idle Stop, consistent with the design for the throttles in a "land" mode.

C. Input Devices with Alternate Behavior - Over-ridden

Input devices such as the Throttle Lever and Rudder Pedals can, in rare circumstances, exhibit alternate behaviors from the same user interaction depending on the circumstances. In these cases, the flight crew expected normal behavior from the input device but experienced an alternate behavior that is the result of their commands being over-ridden by with the automation or by a co-pilot (Table 4). In these cases, the alternate behavior occurs only in rare circumstances that a line-pilot may not see in revenue service except for training scenarios in a simulator.

Table 4: Examples of Input Devices Over-ridden

Input Device	Moded Behavior	Example Accident	Moded Input Device Role in Accident Scenario
(1) Levers (e.g., Throttle Lever)	Pilot input over-ridden	AF 447 Controlled Flight into Aerodynamic Stall	Prevented flight crew timely intervention
		TK 1951 Controlled Flight into Aerodynamic Stall	Prevented flight crew timely intervention
(2) Pedals (e.g., Rudder Pedals)	Pilot input over-ridden	SQ237 Ruy Excursion at Munich Airport	Prevented flight crew timely intervention

1) AF 447 Aerodynamic Stall Continued

In the AF 447 accident event sequence describe above, the flight crew were required to fly the aircraft with manual inputs and were provided with discrepant airspeed indications. As the accident sequence progressed, both Pilot Flying (PF) and Pilot Monitoring (PM) were simultaneously making contradictory side stick commands (one up, the other down). The system summed the commands, resulting in a compromise command that neither pilot intended.

2) SQ-237 Runway Excursion Continued

In the SQ 237 accident sequence described above, the aircraft touched down with a slight left bank due to a disruption in the Localizer signal. The flight-crew attempted to perform an automated go around by selecting the TOGA switch. However, as the wheels had touched-down, the TOGA switch was disabled. The pilots now had to intervene in the landing roll-out.

The pilots attempted to steer the aircraft trajectory once it had landed back onto the runway using the rudder pedals. The autopilot, however, was still engaged and generated rudder commands to follow the (disrupted) localizer signal sending the aircraft left of the runway. The autopilot commands over-rode the rudder pedal inputs made by the pilots.

Eventually, when the combined flight crew rudder pedal inputs exceeded a force threshold (e.g., 48 lbs), the autopilot disengaged automatically. The commands to the rudder were now excessive from the pedal inputs and the aircraft over corrected, crossed the runway, and came to rest to the right of the runway.

There are several other accidents in which the manual pilot input device commands were over-ridden by the automaton China Airlines B1816 (Aircraft Accident Investigation, Ministry of Transport, 1996).

V. DISCUSSION

Moded input devices played roles in each of the accidents and incidents described. In some cases, the moded input device triggered the accident scenario. In other cases, the moded input device inhibited timely response by the flight crew to intervene in the accident. In both cases, the flight crew used an input device that behaved differently than expected.

The types of "moding" are classified into *disabled* and *alternative behavior (moded and over-ride).* The moded behavior are rare events and may only occur a handful of times in a professional pilots career. According to the accident reports, the flight crew experienced cognitive dissonance when the input device behaved differently than expected.

In both the disabled and alternative behavior cases, in the modern airliner flight deck, there is no indication of the change in status on the device itself. The absence of indication of the moded status is the result of “feature creep” that occurred when new features were added to the avionics.

In the cases where the alternative behavior is annunciated on the FMA, there are several issues. First, the *indication* may not be noticed. If it is noticed, then the pilot must retrieve from memory all of the changes that are associated with that cryptic message. Once retrieved, the pilot would need to search through those remembered items to identify any that might apply to the particular operation in progress. In many cases, there will be no immediate effect. Rather, the change will become relevant at a future point when the aircraft state has changed, and the associated items are no longer in working memory. So, even a well-trained pilot who noticed the mode change may not remember that an important change has happened. Indeed, the recall can be inhibited ("lateral inhibition") by the initial judgment that the change did not have an important effect.

A. Human Factors Design Challenge

The design of salient feedback on the mode device presents some design challenges. An example of salient feedback would be an LED light indicating disabled or alternate behavior. First, the input devices are not in the normal field-of-view of the pilot, so putting an LED on the input device would not provide the required feedback. Second, for an LED with green for normal and red for disabled or not normal, what is considered a green or red operation? Third, the LED would violate the “quiet, dark flightdeck” design philosophy that is the basis for all flight deck designs. This design principle prescribes that objects only light up when a pilot action is required.

To overcome these limitations, one option is to provide salient feedback on the input device status in the pilot’s direct field-of-view (FOV) such as a synoptic display. One example is an extension to a previously proposed synoptic display used for automation function (e.g., AP, AT, VNAV, LNAV) configuration annunciation [14]. This display would identify the disabled status of the input devices (Figure 4-a), the alternative behavior – moded (Figure 4-b), and the alternative behavior – over-ride (Figure 4-c). The indications of moded behavior, shown in orange, are notional and will need to be designed further before implementation and testing.

VI. CONCLUSIONS

The analysis of the accidents identified moded input devices as contributing factors to triggering the accident chain as well as inhibiting timely intervention by the flightcrew once the accident chain had begun.

Three types of moded inputs that played a role in all the accidents were identified:

- mode switches and knobs that are disabled in specific situations
- throttle levers, yoke and side-sticks and rudder pedals that exhibit different behaviors depending on the situation
- throttle levers, yoke and side-sticks and rudder pedals that can be over-ridden by the automation or by inputs from another crew member depending on the situation.

Throttle Levers that appeared to be actively controlling thrust to maintain airspeed but were either in a “dormant” mode, a mode that set the thrust to an Idle setting, or did not hold a thrust setting manually set by the pilot were common. Also common, side-stick controllers that offered automatic speed protection, until they did not, in rare but safety critical circumstances.

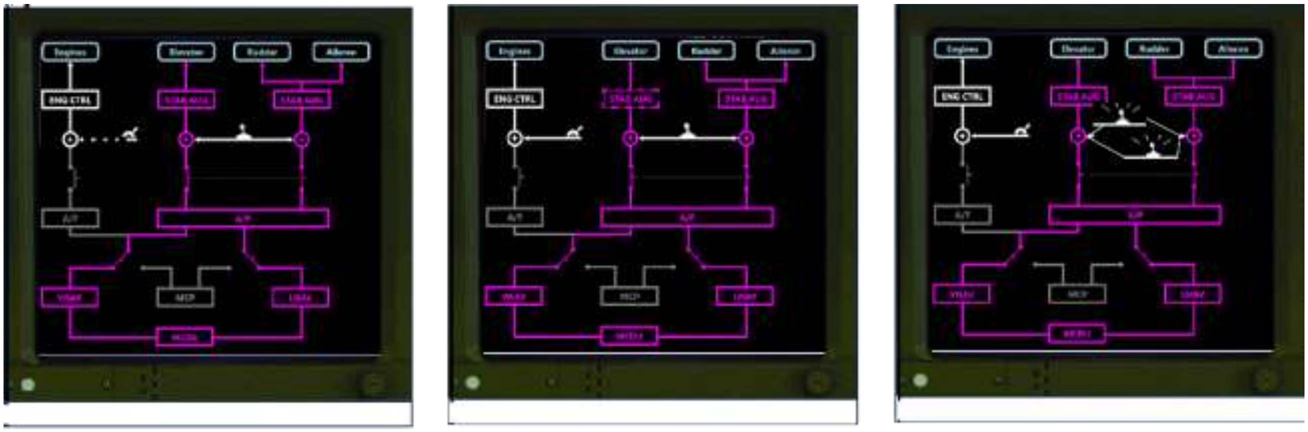


Fig. 4: Proposed synoptic display to annunciate, in the pilots field-of-view, the disabled status of input devices (a), the alternative behavior – moded (b), and the alternative behavior – over-ride (c)

A. *Mitigation*

It is not practical or realistic to ban moded input devices, but we need to be more aware of the issue and more diligent in the design and certification process. It is recommended in the design process, to avoid turning any input device into a moded input device unless it is absolutely necessary. When a moded input device cannot be avoided, the design should consider a salient mode indicator to the operator. During the engineering design review process, any moded device in the design should require a written waiver from the program manager and the regulatory authorities. The waiver should trigger a paper-work chain to make sure it is highlighted in the training materials and in the procedures.

B. *Design Guidelines*

Given the occurrence of these designs in the modern flightdeck, the Design Guidelines and Advisory Circulars could be updated to explicitly identify *moded input devices*. Current regulations refer to the generic "systems." In the event, a moded input device is required it should receive a written waiver by the program manager and options for salient feedback of device status should be considered. This feedback should include:

- Stick/Rudder Pedals and Throttle Lever need indication when automation is still engaged, and manual inputs are over-riding automation control commands.
- Stick/Rudder Pedals and Throttle Lever need indication when automation is still engaged.
- TOGA Switch needs indication when disabled.
- MCP knobs/wheels need indication when disabled

Salient feedback for devices that are not in the pilot's line-of-sight is an issues and may require feedback elsewhere in the flightdeck.

A significant component of the design should consider the Allowable Operational Time Window (AOTW) in which the flight crew recognition must take place before hazardous event occurs [15].

C. *Design Review and Certification*

In the event, a moded input device is required it should receive a written waiver by regulatory authorities and options explicit training of the moded functionality should be provided. Further, the regulatory documentation should explicitly define "moded" input devices and offer guidelines for compliance, including required training.

D. *Moded Input Devices in Automobiles*

The transition to moded-input devices is not limited to aviation. Recent advances in automobile technology have seen the migration of formerly straightforward input devices to moded-input devices. "Lane-assist" technology has made the steering wheel moded, preventing the driver from steering out of lane to avoid debris in the road. Likewise, cruise control with "station-keeping" has created a moded accelerator pedal that in certain conditions prevents acceleration for a lane change. Given the experience of the aviation industry, these subtle changes ought to be evaluated carefully, especially with regards to rare accident scenarios.

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