Unnoticed Dual Inputs on an aircraft with conventional flight controls

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Introduction

In the past, dual input discussions have mainly been associated with the specific features of Airbus flight controls: the sidesticks are not mechanically linked and they can be operated independently. When both sticks are moved simultaneously, the system adds the signals of both sides algebraically. In order to warn the pilots of dual sidestick operations, aural and visual alerts trigger.

More recently, the BEA has been involved in investigations that raise questions about the recurrence and consequences of dual inputs on aircraft equipped with conventional primary flight controls.

This paper puts in perspective the ongoing safety investigation led by the BEA into the serious incident to a Boeing 777 operated by Air France, when the flight crew initiated a go-around and had difficulties in controlling the trajectory during the go-around, due to unnoticed dual inputs.

The investigation demonstrated that the Primary Flight Control System and Automatic Flight Control System operated as expected and intended.

The analysis focused on the perception of each crew member during the approach, the go-around manoeuver and the crew's knowledge of the flight control system's behavior in case of dual inputs.

AF011 Serious Incident

This serious incident occurred on Tuesday, 5 April 2022, to the Boeing 777 registered F-GSQJ, operated by Air France, during final approach to Paris CDG airport. It was a scheduled flight AF011 between New York JFK and Paris CDG with 177 passengers and 15 crew members on board. The captain, in the left seat, was the Pilot Monitoring (PM), the co-pilot, in the right seat, was the Pilot Flying (PF).

On final for runway 26L, with no outside visual references, in manual flight, the PF expressed his surprise with respect to the aeroplane's bank angle. The bank angle was 1° right at that time and the flight path was still within the operator's stabilization criteria. The PM had not noticed nor called out any deviation. The PF then moved the wheel to the left and the aircraft began to turn left. The PM voiced his surprise with respect to the deviation from the flight path while placing his hand on the wheel, without making any input, to feel the actions made by the PF.

The PF initiated a go-around. The aeroplane was turning left with a small bank angle. It is possible that the co-pilot felt unusual resistance in the controls as the PM had his hand on the wheel. Already surprised by the bank angle before initiating the go-around, he may have accentuated his action, causing the aircraft to pitch up too steeply. The captain made inputs on the control column, probably as a reflex action, to reduce this attitude. Both pilots were simultaneously making inputs on the controls. The control columns (pitch) were desynchronized for 12 seconds, due to opposing forces. The captain held the control column in a nose-down position while the co-pilot made several, more pronounced, nose-up inputs. Two brief episodes of control wheels (roll) desynchronization were also observed. During this phase, the task sharing was disrupted and there was considerable confusion, as neither pilot was aware that he was fighting the other's inputs. They did not perceive the antagonistic inputs made on the controls and the desynchronizations of the control channels.

When the captain announced "I HAVE THE CONTROLS" 54 seconds after the go around had been initiated, the forces recorded on the right-hand column became zero and the trajectory stabilized. After regaining control of the trajectory, the crew carried out a new approach and landing on runway 27R without further incident.

The crew informed the controller that there had been a problem on the flight controls and that the airplane had not responded. The sustained input on the controls led to the PTT button being involuntarily pressed. Communications and noises in the cockpit were transmitted on the frequency and later broadcasted. The incident was publicized, highlighting the doubts about the correct functioning of the systems. The investigation received a certain amount of attention and initially focused on the understanding of the operation of the aircraft.

Description of the primary flight control system of the Boeing 777

The Boeing 777 primary flight control system is a fly-by-wire system: it receives inputs from the crew and the autopilot and commands the movement of the control surfaces in roll, pitch and yaw.

The pilot controls are equipped with position transducers, which convert pilot inputs into analog electrical signals. These signals are transmitted to four Actuator Control Electronics (ACE), which transform the signals into digital format and send them to three Primary Flight Computers (PFC).

The PFCs calculate control surface commands based on the control laws and flight envelope protection functions. Digital control surface command signals from the PFCs are transmitted to the ACEs, which transform these command signals into analog format and send them to the actuators of the control surfaces with a control loop.

Pitch control

The crew uses two control columns to command pitch. They are connected by a column breakout mechanism, which enables the pitch to be controlled with one of the columns if the other jams.

Description of the pitch force feedback system

The two elevator feel units (one for each control column) consist of a mechanical assembly of springs, cams and rollers, linkages and actuators which perform three functions:

- To bring the control columns back to neutral when no force is applied by the crew;

- To create a resistive force gradient correlated to the angle of deflection of the columns[1];

- To create a resistive force gradient correlated to the aircraft speed[2] via elevator feel actuators.

In addition, the flexibility of the compliance springs simulates the feel of a mechanical system for the crew.

Description of the column breakout / jam override mechanism

The column breakout mechanism consists of a mechanical assembly of two torque tubes, each linked to a control column. The left torque tube is linked to a roller which runs on a cam, itself linked to the right torque tube. Two springs, connected to the left torque tube and the roller, retain the roller in the cam recess. In this position, the two torque tubes are rigidly connected and the control columns are therefore synchronized. Each spring is designed to extend when subjected to a force in excess of a threshold. Desynchronization of the right and left control columns occurs if opposing forces on the right and left, due to a blockage in the control column mechanism or opposing forces applied by the two pilots, exceed the threshold of approx. 50 lb. The spring mechanism ensures the control columns synchronize again as soon as the opposing forces fall below the mechanism's override threshold.

The PFCs use the arithmetic mean of the column positions to calculate the positions of the pitch control surfaces, even when the control columns are desynchronized.

By design, simultaneous, opposing actions of the pilots on the control columns do not trigger any visual or audible indications in the cockpit, other than the visible opposing control column movements and heavier than normal control column forces.

Roll control

The crew uses two control wheels to command roll. They are connected by a control wheel jam breakout mechanism, which enables the roll to be controlled with one of the control wheels if the other jams.

A wheel force transducer is used in the flight control logic for bank angle protection (BAP) by determining whether the crew is applying force to the control wheels.

Description of the roll force feedback system

The feel and centering mechanism consists of a mechanical assembly of springs, cam and roller, linkages and an actuator which performs three functions:

- To bring the control wheels back to neutral when no force is applied by the crew;

- To move the neutral position of the control wheels via the aileron trim actuator according to the setting commanded by the crew[3];

- To create a resistive force gradient correlated to the angle of rotation of the control wheels[4].

Description of the wheel breakout / jam override mechanism

The wheel jam breakout mechanism is different from the column breakout mechanism.

The wheel jam breakout mechanism consists of a mechanical assembly of two force limiters connecting the left and right wheel cable drums. In normal operation, these rods behave rigidly and allow synchronized movement of the control wheels. Each spring-loaded connecting rod is designed to compress or extend when subjected to a force exceeding a threshold of approximately 25 lb. The control wheels become desynchronized if opposing forces on the left and right, due to a blockage in the control channel or to opposing forces applied by the two pilots, exceed the threshold of approx. 50 lb. The control wheels synchronize again as soon as the opposing forces fall below the mechanism's release threshold.

The PFCs use the arithmetic mean of the control wheel positions to calculate the positions of the roll control surfaces, even when the control wheels are desynchronized.

By design, simultaneous and opposing actions of the pilots on the control wheels do not trigger any visual or audible indications in the cockpit, other than the visible opposing movements of the control wheels and heavier than normal control wheel forces.

Pilots' knowledge of the systems

At the time of the serious incident, the description of the jam override mechanisms in the Boeing 777 Flight Crew Operations Manual (FCOM) explained the case of control jamming as follows: "*The columns and wheels are connected through jam override mechanisms. If a jam occurs in a column or wheel, the pilots can maintain control by applying force to the other column or wheel to overcome the jam*." It did not indicate that these mechanisms will be activated in the case of antagonistic inputs without jamming. It did not indicate that the mechanism will synchronise again as soon as the forces fall below the release threshold, which is a feature different from other aircraft equipped with conventional flight control systems and a jam override breakout device.

It should be noted that this behaviour can be approximated in a training simulator provided the simulator control loaders are modelled to represent the mechanical hardware found on the Boeing 777

At Air France, flight control desynchronization is covered during type rating theoretical training, when the flight controls are described, and during the first full flight simulator session. This system is not specifically reviewed during recurrent training.

Therefore, all pilots may not fully understand the implications of these mechanisms and/or be aware of the consequences of dual inputs.

Tests performed at the Boeing systems integration lab (which fully reproduces the real aircraft control column and wheel linkage and breakout systems) enabled investigators to experience pilot control conditions such as oppositional control inputs, flight control sweeps, jammed controls, and autopilot override. Participants gained a more thorough understanding of the Boeing 777 pilot control design and documented observations regarding control forces. It was concluded that the pilots' references and handling skills are greatly disrupted when the controls are desynchronised. The control column and wheel forces are modified when both pilots make inputs on the desynchronised controls and reduce awareness of relative control surface response.

Boeing has updated its documentation to more explicitly advise flight crews on positive transfer of aircraft control, applying breakout force in the same direction when a perceived jam is present, and to explain the jam override breakout behaviour in the system description.

Air France intends to provide its pilots with a more detailed description of the jam override mechanisms and the consequences of the desynchronization of the commands on the flight. Air France also intends to update its documentation to clarify the transfer of aircraft control and to reinforce dual input awareness.

Dual input

The normal separation of roles between the PF and the PM should result in only one pilot, the PF, making inputs on the primary flight controls at one time, except when a control has jammed.

Standard operating procedures (SOPs) and training are developed to avoid dual input. However, dual input is not explicitly mentioned in Boeing's or Air France's Boeing 777 documentation, nor is it covered in training. This may be explained by the fact that as the primary flight control systems are linked, the pilots have both tactile and visual indications of inputs from the other pilot. Dual input may be considered marginal on this aircraft because it is commonly assumed that any dual input would be quickly detected. Consequently, this type of event is scarcely screened by Boeing 777 operators in their flight data monitoring program. The BEA's experience is that dual inputs have been regularly observed and reported to the BEA on other aircraft types.

Air France FDM over the last five years shows a dual input rate of 0.4 per 1,000 flights on Boeing 777s. This rate is similar to the one reported on the Air France Airbus fleet, on which aircraft a dual input warning system exists. It is also similar to the rate mentioned in the ATSB Safety Report related to in-flight upset, inadvertent pitch disconnect, and continued operation with serious damage involving ATR72 aircraft[5].

In an article in its Safety First magazine[6], Airbus identified three types of dual inputs:

- Spurious inputs: typically due to inadvertent movement of the stick by the PM, such as from an accidental contact with the control. These only marginally affect the aircraft's behavior due to these inputs only being limited in time and small.
- Comfort inputs: typically due to short interventions by the PM when they have decided they want to improve the aircraft's attitude or trajectory. They are generally made during the approach, acquisition of the glideslope or localiser, or flare. This type of inputs has minor effects, however as the PF is not aware of these interventions, they may attempt to counteract the inputs by the PM.
- Instinctive inputs: typically due to a reflex action by the PM. This may occur as a result of an unexpected event. Such instinctive interventions are more significant in terms of control deflection and may last longer, especially if the PF is not aware of the PM action.

Conclusion

On all types of aircraft, flight crew may inadvertently introduce flight control inputs which may result in a deviation from the actual or intended immediate flight path. Inappropriate flight control inputs, depending on the circumstance and their magnitude, may result in undesirable safety consequences.

A good knowledge of the systems and the consequences of dual inputs play a key role in flight crew performance, by improving their cognitive capacity to recognise the situation and react appropriately.

The BEA believes that dual inputs are not screened enough by operators in their flight data monitoring program. Flight crew are probably unaware that dual inputs are common on all types of aircraft and may not realise the safety consequences of this behaviour.

The crew should always clearly understand which pilot has control of the aircraft, at all times. Standardized procedures for transferring aircraft control that emphasize clear communication and a positive handover of the responsibility for the PF duties are essential.

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[1] At low speed, the force felt at the column varies from 2.9 kg at start of travel to 19.6 kg at maximum column travel.

[2] At maximum travel, column force varies from 19.6 kg at low speed to 45.4 kg at high speed.

[3] When the autopilot is engaged or the BAP is active, the aileron trim is deactivated.

[4] The force felt at the wheels varies from 2 kg at the onset of bank to a maximum of 6 kg at 65 degrees of wheel travel. Force does not vary with flight speed.

[5] AO-2014-032.

[6] Dual Side Stick Inputs.