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SAFETY NOTICE

SUBJECT:

Mode Awareness and Energy State Management Aspects of Flight Deck Automation

GENERAL: Safety Notices (SNs) are issued by the Civil Aviation Authority – Macao, China to convey advisory information to Macao aviation entities to enhance safety. SNs contain safety-related recommendations, guidance and/or industrial best practices to specific subjects which may or may not have been addressed by established requirements and regulations.

RELATED REGULATIONS: AC/OPS/002 – Operations Manual Requirements

APPLICABILITY: This SN applies to all Macao AOC holders.

CANCELLATION: This SN is the first SN issued on this subject.

REFERENCES: The following material was referred to for the development of this SN:

- Cooperative Development of Operational Safety & Continuing Airworthiness Program – South East Asia (COSCAP-SEA) Advisory Circular CSEA 020
- Commercial Aviation Safety Team (CAST) report for Safety Enhancement 30: Human Factors and Automation

1. Introduction

1.1 As cited in AC/OPS/002 – Operations Manual Requirements, "Instructions on the use of autopilots and auto throttles in instrument meteorological conditions (IMC)" is one of the subjects required to be included in the operator's operations manual. This Safety Notice is issued to provide further guidance and/or industrial best practices towards this subject to enhance safety.

2. Background

2.1 Automation has contributed substantially to the improvement in air operator safety around the world. It increases the timeliness and precision of routine procedures, and greatly reduces the opportunity to introduce risks and threatening flight regimes.

2.2 Nevertheless, in complex and highly automated aircraft, automation has its limits. More critically, flight crews can lose situational awareness of the automation mode under which the aircraft is operating or may not understand the interaction between a mode of automation and a particular phase of flight or pilot input. These and other examples of mode confusion often lead to mismanaging the energy state of the aircraft or to the aircraft deviating from the intended flight path for other reasons.

2.3 The Loss of Control (LOC) Joint Safety Analysis Team (JIMDAT), chartered by the Commercial Aviation Safety Team (CAST), identified these issues as factors or problems in several major accidents in the United States and around the world. Subsequently, a Joint Safety Implementation Team recommended in Safety Enhancement (SE) 30 that CAST charter a JIMDAT sub-team to address mode confusion in cooperation with a working group chartered earlier by the Performance-Based Aviation Rulemaking Committee (PARC), which was in the midst of a more broadly based study of issues related to automation.

2.4 In late 2005, CAST chartered the Safety Enhancement (SE)-30 Data Review Team to undertake this task. CAST directed the team to restrict its work to the issues of mode confusion and mode awareness, and to work closely with PARC, which continued to address a more comprehensive range of automation issues. The SE-30 Data Review Team was charged with producing a prototype automation policy, or an "exemplar," for air operators.

2.3 The objective of the policy exemplar is to help minimize the frequency with which pilots experience mode confusion and undesirable energy states. This, in turn, requires that crews understand the functions of the various modes of automation. The policy exemplar presented in this SN is based on a set of common industry practices that are known to be effective, against which operators may compare this to their existing policies and identify any appropriate changes in their policies. In addition, the exemplar includes practical guidance that air operators could include in their policies in order to help pilots respond effectively to particular types of automation anomalies. The suggested guidance is intended only as examples of effective responses to selected circumstances, and it does not necessarily identify the only proper response.

Note: The terminology used in this document and in the examples reflects terminology for Airbus and Boeing aircraft. Air operators may need to amend the terminology to apply this document to their own fleet mixes, the need for consistent language within a single air operator, or other unique characteristics.

3. Root Causes

3.1 The SE-30 Data Review Team reviewed automation policies from 16 air operators to identify common concepts in order to build a set of industry practices that could establish a baseline for an industry-wide automation policy. To identify which of these policies might be effective and to identify any voids that might exist in common practices, the team reviewed hundreds of reports from the Aviation Safety Reporting System (ASRS) and from other public data sources, including the Federal Aviation Administration's Accident and Incident Data System (AIDS), and the National Transportation Safety Board's Accident and Incident Database. The final dataset included 480 incident and accident reports during Part 121 operations by US air operators, of which 50 cases were studied in detail.

3.2 The team found that a fundamental problem applied to almost all cases in the dataset: the flight crew did not comprehend what the automation was doing, or did not know how to manipulate the automation to eliminate the error. In such cases, when the crew changed automation levels they often made the problem worse. This problem applied to all automation modes and it applied regardless of whether the crew induced the event or the event was precipitated by a problem with the automation system. In all 50 cases, pilots were unable return the aircraft to the desired flight path in a timely manner.

3.3 This was due to two root causes:

- Inadequate training and system knowledge; and
- Unexpected incompatibility of the automation system with the flight regime confronting pilots in their normal duties.

For example, the crew may have made a manual input to the flight controls that would have been appropriate with the autopilot disengaged. However, if the auto thrust system in fact was still engaged and was in a mode that did not support the flight control input, the resulting flight path or energy state was often undesirable.

3.3 Yet, among the 16 air operator automation policies, the most common concept as stated by one operator simply directed crews to “use the level of automation that will best support the desired operation of the aircraft.” This concept is fine if the crew understands what the automation is doing at the time of the problem onset, and is then able to determine if the current or another automation level will better suit the operation. However, nearly all incident reports shared one common factor: regardless of whether an error was pilot-induced or was a function of the automation system, pilots did not understand what the automation was doing, or did not know how to use the automation to eliminate the error. Consequently, the team’s recommendations emphasize specific elements that should be incorporated into automation policies and then should be systematically reinforced.

3.4 The team identified a core philosophy that should permeate any air operator’s policy on automation. While recognizing that automation has brought major improvements to safety, the team strongly recommends that air operator should promulgate and systematically reinforce a philosophy of “fly the airplane.”If pilots recognize that they do not understand the nature of an anomaly and do not precisely understand the solution, pilots should not continue in an unstable or unpredictable flight path or energy state while attempting to correct an anomaly. Instead, crews should revert to a more direct level of automation until the aircraft resumes the desired flight path and/or airspeed. This may ultimately require the crew to turn off all automation systems and flying the aircraft manually. When the aircraft once again is flying the desired flight path and/or airspeed, the crew can begin to reengage the automation, as appropriate. Below is a recommended statement to be included in operators’ automation policies and which should be systematically reinforced.

At any time, if the aircraft does not follow the desired vertical flight path, lateral flight path or airspeed, do not hesitate to revert to a more direct level of automation.

For example, revert from flight management system (FMS) guidance to non-FMS guidance, or when operating in a non-FMS guidance but with A/THR or A/T engaged, disengage and set thrust manually.

3.5 In addition to this recommended philosophical foundation, the team developed a broad set of elements that should be incorporated in operators' automation policies. The policy recommendations are organized according to seven broad topics that automation policies should address:

- Philosophy
- Levels of Automation
- Situational Awareness
- Communication
- Verification
- Monitoring
- Command-and-Control

4. Recommended Automation Policy Exemplar

4.1 Philosophy and Approach to the Use of Automation

An automation policy should begin with a description of the organization's philosophy and approach to the use of automation.

4.1.1 Fly the airplane

First and foremost, though automation has brought major improvements to safety, air operators should promulgate and systematically reinforce the philosophy of "fly the airplane." If pilots recognize that they are uncertain about the autoflight modes or energy state, they should not allow the airplane to continue in an unstable or unpredictable flight path or energy state while attempting to correct the situation. Instead, pilots should revert to a better understood level or combination of automation until the aircraft resumes the desired flight path and/or airspeed. This may ultimately require that pilots turn off all automation systems and fly the aircraft manually. When the aircraft again is flying the desired flight path and/or airspeed, pilots can begin to reengage the automation as appropriate.

Note: This type of statement in the automation policy would help the pilot to know how to correctly interact with automation to reduce workload and increase safety and efficiency.

4.1.2 Adopt "CAMI" or "VVM" procedure

Include references to and descriptions of generalized procedures, such as the CAMI or VVM, that have been developed by various air operators as effective means for pilots to validate the arming/engagement of autoflight system (AFS) and to monitor functions/mode changes.

- **CAMI** procedure for the pilot flying:
  Confirm airborne (or ground) inputs to the FMS with the other pilot.
  Activate inputs.
  Monitor mode annunciations to ensure the autoflight system performs as desired.
  Intervene if necessary.

  or

- **VVM** policy for both flight crew members:
  Verbalize.
  Verify.
  Monitor.

General approaches like these are easy to train and review on the line and have been shown to help flight crews in their overall approach to the use of automation.

4.1.3 <u>Other topics</u>

Operators also should consider including other statements on automation philosophy to provide operational guidance to pilots.

- Appreciate specified capability, limitations, and failure susceptibility of the automation.
- Be wary of autoflight states when crew coordination, communication, and monitoring of automation is more important.
- Resist situations when automation can increase pilot workload or degrade performance.
- Avoid over-reliance on automation to the detriment of manual flying skills.

4.2 Choice of Systems or "Levels" of Automation

Automation policy should include information to guide pilots on making choices about how to combine and use automated systems. Some airlines have defined "levels of automation" to help with this. However, a definition alone is not adequate for this topic. Below is a list of recommended topics that could add substance to a definition and that could provide practical guidance for pilots.

4.2.1 <u>Use the appropriate automation for the task</u>

On highly automated and integrated aircraft, several combinations, or levels, of automaton may be available to perform a given task in either FMS modes and guidance or non-FMS modes and guidance.

- The most appropriate level of automation depends on the task to be performed, the phase of flight and the amount of time available to manage a task. A short-term or tactical task, such as responding to an ATC direction to go briefly to a different altitude or heading, should be accomplished in the flight control unit (FCU)/mode control panel (MCP); this allows the crew to maintain head-up flight. A long-term or strategic task that changes most or all of the remaining flight should be accomplished in the flight management system (FMS) control and display unit (CDU), which requires more head-down time by one pilot.

- The most appropriate level also may depend on the level with which the pilot feels most comfortable for the task or for the prevailing conditions, depending on his/her knowledge and experience operating the aircraft and systems. Reverting to hand-flying and manual thrust control actually may be most appropriate, depending on conditions.

- The pilot flying (PF) should retain the authority and capability to select the most appropriate level of automation and guidance for the task. Making this selection includes adopting a more direct level of automation by reverting from FMS guidance to selected guidance (that is, selected modes and targets through the use of either the FCU or MCP); selecting a more appropriate lateral or vertical mode; or reverting to hand-flying (with or without flight director (FD) guidance, with or without auto thrust (A/THR) or auto throttle (A/T)), for direct control of aircraft vertical trajectory, lateral trajectory, thrust and airspeed.

4.2.2 *<u>Ensure that pilots possess required skills and knowledge</u>*

Some airlines have also included statements in their automation policies about the requirement for pilots to be skilled in and knowledgeable about the use of certain combinations of automated systems or all possible combinations of systems.

Understanding and interacting with any autoflight system ideally requires answering the following fundamental questions:

- How is the system designed?
- Why is the system designed that way?
- How does the system interact and communicate with the pilot?
- How does the pilot operate the system in normal and abnormal situations?

Ensure that pilots fully understand the following aspects in the use of automation:

- Integration of autopilot (AP)/flight director (FD) and auto thrust (A/THR) or auto throttle (A/T) modes (that is, pairing of modes), if applicable;
- Mode transition and reversion sequences; and
- Pilot-system interaction for
  - pilot-to-system communication (that is, for target selections and modes engagement) and
  - system-to-pilot feedback (that is, for cross-checking the status of modes and accuracy).

4.2.3 *<u>AP-A/THR integration</u>*

Integrated AP-A/THR or AP-A/T systems pair AP pitch modes (elevator control) with the A/THR or A/T modes (thrust levers/throttle levers). Integrated AP-A/THR or AP-A/T systems operate in the same way as a pilot who hand-flies with manual thrust.

- Elevator is used to control pitch attitude, airspeed, vertical speed, altitude, flight-path-angle, and vertical navigation profile or to capture and track a glideslope beam.
- Thrust levers or throttle levers are used to maintain a given thrust or a given airspeed.

Throughout the flight, the pilot's objective is to fly either:

- Performance segments at constant thrust or at idle, as on takeoff, climb or descent; or
- Trajectory segments at constant speed (as in cruise or on approach).

Depending on the task to be accomplished, airspeed is maintained either by the AP (elevators) or the A/THR (thrust levers) or A/T (throttles levers), as shown in Table 1 below.

Table 1 – AP-A/THR & A/T Mode Integration

	A/THR or A/T	***A/P***
	Thrust levers / Throttle levers	Elevators
Aircraft Performance is controlled by:	Thrust or idle	Speed
Aircraft Trajectory is controlled by:	Speed	V/S vertical profile Altitude glideslope

4.2.4 <u>*Automation design objectives*</u>

The autoflight system provides guidance to capture and maintain the selected targets and the defined flight path, in accordance with the modes engaged and the targets set by the flight crew on either the flight control unit (FCU)/mode control panel (MCP) or on the flight management system (FMS) control and display unit (CDU).

The FCU/MCP constitutes the main interface between the pilot and the autoflight system for short-term guidance (i.e., for immediate guidance such as radar vectors).

The FMS CDU constitutes the main interface between the pilot and the autoflight system for long-term guidance (i.e., for the current and subsequent flight phases).

Two types of guidance (modes and associated targets) are available on aircraft equipped with either a flight management guidance system (FMGS) or flight management computer (FMC), featuring both lateral and vertical navigation:

- Selected guidance:
  The aircraft is guided to acquire and maintain the targets set by the crew, using the modes engaged or armed by the crew (i.e., using either the FCU or MCP target setting knobs and mode arming/engagement pushbuttons)

- FMS guidance:
  The aircraft is guided along a pilot-defined FMS lateral navigation (LNAV) and a vertical navigation (VNAV) flight plan, speed profile, altitude targets/constraints

4.2.5 *Engaging automation*

Before engaging the AP, ensure that:

- Modes engaged (check flight modes annunciator (FMA) annunciations) for FD guidance are the correct modes for the intended flight phase and task;
- Select the appropriate mode(s), as required and confirm;
- FD command bars do not display any large displacements; if large displacements are commanded, continue to hand fly until FD bars are centered prior to engaging the AP.

Engaging the AP while large commands are required to achieve the intended flight path may result in the AP overshooting the intended vertical target or lateral target, and/or surprise the pilot due to the resulting large pitch / roll changes and thrust variations.

4.2.6 *Other topics related to the choice of automation levels*

Include other statements to help pilots choose the appropriate level of automation.

- Use optimum automation combination or “level” for comfortable workload, high situation awareness, and improved operations capability (passenger comfort, schedule and economy).
- Do not try to solve automation problems with conditioned responses from the same level of automation.
- Prioritize correctly (e.g. avoid programming during critical flight phases).

4.3 Situational Awareness

Policies should include statements about the importance of maintaining situation awareness and, particularly, mode and energy awareness.

4.3.1 *Mode and energy awareness*

Situational awareness requires that pilots know the available guidance at all times. The FCU/MCP and the FMS CDU are the primary interfaces for pilots to set targets and arm or engage modes. Any action on the FCU/MCP or on the FMS keyboard and line-select keys should be confirmed by crosschecking the corresponding annunciation or data on the primary flight display (PFD) and/or navigational display (ND) (and on the FMS CDU). At all times, the pilot flying (PF) and pilot not flying (PNF) should be aware of the status of the guidance modes being armed or engaged and of any mode changes throughout mode transitions and reversions.

4.3.2 *Monitor the use and operation of the automated systems*

- Check and announce the status of the FMA, such as the status of AP/FD modes and A/THR or A/T mode;
- Observe and announce the result of any target setting or change (on the FCU/MCP) on the related PFD and/or ND scales; and
- Supervise the AP/FD guidance and A/THR or A/T operation on the PFD and ND (pitch attitude and bank angle, speed and speed trend, altitude, vertical speed, heading, or track).

4.3.3 Other topics on situation awareness

- Remain alert for signs of deteriorating flying skills, excessive workload, stress, or fatigue (avert complacency).
- Ensure at least one crewmember monitors the actual flight path.
- Consider "hand flying" in manual mode for immediate change of flight path.
- Brief the plan for using automation before takeoff and rebrief in flight as the situation dictates.

4.4 Communication and Coordination

Topics related to communication and coordination to consider in developing the automation policy are statements to help flight crews:

- Announce automatic or manual changes to autoflight status (or update other pilot at first opportunity);
- Brief and compare programmed flight path with charted procedure / active routing;
- Coordinate (verbalize) before executing any inputs which alter aircraft flight profile;
- Make callout 1,000 feet before clearance altitude and verbally acknowledge;
- Utilize the "point and acknowledge" procedure with any ATC clearance;
- Brief special automation duties and responsibilities; and
- Actively listen for traffic, communication and clearances.

4.5 Verification

Include statements about verifying and cross-checking automation selections and anticipating subsequent aircraft performance in an automation policy.

4.5.1 Know your modes and targets

At a high level, the goal of verification can be generalized as "know your modes and targets." The AP control panel and FMS control display unit/keyboard are the prime interactions for pilots to communicate with aircraft systems (to arm modes or engage modes, and to set targets). The PFD, particularly the FMA section and target symbols on the speed scale and altitude scale, and ND are the primary interactions for the aircraft to communicate with pilots. These interfaces confirm that aircraft systems have correctly accepted the pilot's mode selections and target entries.

Any action on the autopilot control panel or on FMS keyboard/line-select keys should be confirmed by cross-checking the corresponding annunciation or data on the PFD and/or the ND. The PF and PNF should be aware of the following:

- Modes armed or engaged;
- Guidance targets set;
- Aircraft response in terms of attitude, speed and trajectory; and
- Mode transitions or reversions.

When flight crews perform an action on the FCU/MCP or FMS CDU to give a command, the pilot expects a particular aircraft reaction and, therefore, must have in mind the following questions:

- Which mode did I engage and which target did I set for the aircraft to fly now?
- Is the aircraft following intended vertical and lateral flight path and targets?
- Which mode did I arm and which target did I preset for the aircraft to fly next?

To answer such questions, pilots must understand the certain controls and displays:

- FCU/MCP mode selection keys, target-setting knobs and display windows;
- FMS CDU keyboard, line-select keys, display pages and messages;
- FMA on the PFD; and
- PFD and ND displays and scales (that is, for cross-checking guidance targets).

4.5.2 *<u>Specific topics related to verification</u>*

Include statements to help pilots verify and cross-check inputs and aircraft responses.

- Cross-check raw data and computed data, as appropriate.
- Vertify (both pilots) entered waypoints and confirm FMS data against printed charts.
- Maintain effective cross-check of system performance with desired flight path.
- Verify programming that alters route, track, or altitude, and cross-check proper mode annunciation.
- Cross-check (verify) results of selections, settings and changes.
- If a transition is selected or built, verify between pilots that it matches clearance and that it produces desired track.

4.6 System and Crew Monitoring

Monitoring automation is simply carefully observing flight deck displays and indications to ensure the aircraft response matches your mode selections and guidance target entries, and the aircraft attitude, speed and trajectory match expectations.

- During the capture phase, observe the progressive centering of FD bars and the progressive centering of deviation symbols (during localizer and glideslope capture). This enhances supervision of automation during capture phases and cross-check with raw data, as applicable, to enable early detection of a false capture or capture of an incorrect beam.
- If the aircraft does not follow the desired flight path or airspeed, do not hesitate to revert to a more direct level of automation, as recommended by the airplane manufacturer or as required by the operator’s standard operating procedures.
- In the event of an uncommanded AP disconnection, engage the second AP immediately to reduce pilot workload.

The effective monitoring of these controls and displays promotes increased pilot awareness of the modes being engaged or armed and the available guidance (flight path and speed control). Active monitoring of controls and displays also enables the pilot to anticipate the sequence of flight modes annunciations throughout successive mode transitions or mode reversions. Operators should also consider the following types of statements to help provide operational guidance to pilots.

- Scan indications to ensure aircraft performs "as expected";
- Monitor Status (indications and mode annunciations);
- Monitor ALT capture mode to ensure commands for smooth level-off at assigned altitude are followed when using ALT capture mode of A/P-F/D, or VNAV;
- Maintain One "head up" at all times at low altitude;
- Avoid distraction from duties;
- Do not let automation interfere with outside vigilance;
- Maintain continuous lookout during ground movement and VMC flight;
- PF and PNF monitor each other's actions; and
- Do not use any system displaying an inoperative flag or some other failure indication.

4.7 Workload and System Use

Consider including statements on workload and system use to provide some operational guidance to pilots, such as the following:

- Ensure PF has responsibility for flight path; remain prepared to assume manual control (abnormal conditions).
- Intervene if the flight status is not "as desired"; revert to lower automation level; disengage any autoflight system not operating "as expected".
- Encourage manual flying for maintaining proficiency when flight conditions permit.
- Clearly establish who controls Aircraft under what Conditions.
- Allow for switch of PF and PNF duties providing that control is properly maintained.
- PF and PNF monitor each other's actions.
- Designate one pilot to control (abnormal conditions).

4.8 Summary

The SE-30 Data Review Team has indentified seven broad topics that should be addressed in automation policies. Only a specific air operator knows what is best for its own circumstances, but the seven topics provide a basic exemplar, based on current practices that are known to be effective and on incident analysis by an expert panel.

For the optimum use of automation, operators should promote the following, in which the central point remains "fly the airplane".

- Understanding the integration of AP/FD and A/THR-A/T modes (pairing of modes).
- Understanding all mode transition and reversion sequences.
- Understanding pilot-system interfaces for:
  - pilot-to-system communication (for mode engagement and target selections)
  - system-to-pilot feedback (i.e., for mode and target cross-check)
- Awareness of available guidance (AP/FD and A/THR or A/T status and which modes are armed or engaged, active targets).
- Alertness to adapt the level of automation to the task and/or circumstances, or to revert to hand flying or manual thrust/throttle control, if required.
- Adherence to the aircraft specific design and operating philosophy and the air operator's standard operating procedures.
- If double exists regarding the aircraft flight path or speed control, do not attempt to reprogram the automated systems.
- Selected guidance or hand flying together with the use of navaids raw data should be used until time and conditions permit reprogramming the AP/FD or FMS.
- If the aircraft does not follow the intended flight path, check the AP and A/THR or A/T engagement status:
  - If engaged, disconnect the AP and/or A/THR or A/T using the associated disconnect push button(s), to revert to hand flying (with FD guidance or with reference to raw data) and/or to manual thrust control.
  - In hand flying, the FD commands should be followed. Otherwise, the FD bars should be cleared from display, AP and A/THR or A/T.

5. Recommended Actions

5.1 Air operators are encouraged to note the information and to review their policies, procedures and training on the way to reflect the safety issues contained in this Safety Notice.

- End -