Flight Safety Foundation

ALAR

Approach-and-landing Accident Reduction

Tool Kit

FSF ALAR Briefing Note 1.2 — Automation

Three generations of system automation for airplane flight guidance — autopilot/flight director (AP/FD), autothrottles (A/THR) and flight management system (FMS) — are currently in service:

- The first generation features a partial integration of the AP/FD and A/THR modes, offering *selected AP/FD modes and lateral navigation only*;
- The second generation features complete integration (pairing) of AP/FD and A/THR modes and offers *selected modes as well as lateral navigation and vertical navigation (FMS)*; and,
- The third generation features *full-regime lateral navigation (LNAV) and vertical navigation (VNAV)*.

High levels of automation provide flight crews with more options from which to select for the task to be accomplished.

Statistical Data

The Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force found that inadequate flight crew interaction with automatic flight systems was a causal factor[1] in 20 percent of 76 approach-and-landing accidents and serious incidents worldwide in 1984 through 1997.[2]

The task force said that these accidents and incidents involved crew unawareness of automated system modes or crew unfamiliarity with automated systems.

AP-A/THR Integration

Integrated AP-A/THR automatic flight systems (AFSs) feature pairing of the AP pitch modes (elevator control) and the A/THR modes (throttles/thrust control).

An integrated AP-A/THR flies the aircraft the same way as a human pilot:

- The elevator is used to control pitch attitude, airspeed, vertical speed, altitude, flight path angle or VNAV profile, or to track a glideslope; and,
- The throttle levers are used to maintain a given thrust setting or a given airspeed.

Depending on the task to be accomplished, maintaining a given airspeed is assigned either to the AP or to the A/THR, as shown in Table 1.

Table 1
Autothrottle/Autopilot Integration

Autothrottles	Autopilot
Throttles/thrust	Elevators
Thrust or idle	Airspeed
Airspeed	Vertical speed Vertical navigation Altitude Glideslope

Source: Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force.

Design Objective

The design objective of the AFS is to provide assistance to the crew throughout the flight, by:

- Relieving the pilot flying (PF) from routine tasks, thus allowing time and resources to enhance his/her situational awareness or for problem-solving tasks; and,

- Providing the PF with adequate attitude guidance and flight-path guidance through the FD for hand-flying the aircraft.

The AFS provides guidance along the defined flight path and at the intended airspeed, in accordance with the modes selected by the crew and the targets (e.g., altitude, airspeed, heading, vertical speed, waypoints, etc.) entered by the crew.

The AFS control panel is the main interface between the pilot and the AFS for *short-term guidance* (i.e., for the current flight phase).

The FMS control display unit (CDU) is the main interface between the pilot and the AFS for *long-term guidance* (i.e., for the current flight phase and subsequent flight phases).

On aircraft equipped with an FMS featuring LNAV and VNAV, two types of guidance (modes and associated targets) are available:

- *Selected guidance*:

  – The aircraft is guided along a flight path defined by the modes selected and the targets entered by the crew on the AFS control panel; and,

- *FMS guidance*:

  – The aircraft is guided along the FMS lateral flight path and vertical flight path; the airspeed and altitude targets are optimized by the FMS (adjusted for restrictions of altitude and/or airspeed).

Automated Systems

Understanding any automated system, but particularly the AFS and FMS, requires answering the following questions:

- How is the system designed?

- Why is the system designed this way?

- How does the system interface and communicate with the pilot?

- How is the system operated in normal conditions and abnormal conditions?

Pilot-Automation Interface

To use the full potential of automation and to maintain situational awareness, a thorough understanding of the interface between the pilot and the automation is required to allow the pilot to answer the following questions at any time:

- What did I tell the aircraft to do?

- Is the aircraft doing what I told it to do?

- What did I plan for the aircraft to do next?

(The terms "tell" and "plan" in the above paragraph refer to arming or selecting modes and/or entering targets.)

The functions of the following controls and displays must be understood:

- AFS mode-selection keys, target-entry knobs and display windows;

- FMS CDU keyboard, line-select keys, display pages and messages;

- Flight-mode annunciator (FMA) annunciations; and,

- Primary flight display (PFD) and navigation display (ND) data.

Effective monitoring of these controls and displays promotes and increases pilot awareness of:

- The status of the system (modes armed and selected); and,

- The available guidance (for flight-path control and airspeed control).

Effective monitoring of controls and displays also enables the pilot to predict and to anticipate the entire sequence of flight-mode annunciations throughout successive flight phases (i.e., throughout mode changes).

Operating Philosophy

FMS or selected guidance can be used in succession or in combination (e.g., FMS lateral guidance together with selected vertical guidance) as best suited for the flight phase and prevailing conditions.

Operation of the AFS must be monitored at all times by:

- Cross-checking the status of AP/FD and A/THR modes (armed and selected) on the FMA;

- Observing the result of any target entry (on the AFS control panel) on the related data as displayed on the PFD or ND; and,

- Supervising the resulting AP/FD guidance and A/THR operation on the PFD and ND (e.g., attitude, airspeed and airspeed trend, altitude, vertical speed, heading, etc.).

The PF always retains the authority and the capability to use the most appropriate guidance and level of automation for the task. This includes:

- Reverting from FMS guidance to selected guidance (more direct level of automation);

- Selecting a more appropriate lateral mode or vertical mode; or,

- Reverting to hand-flying (with or without FD, with or without A/THR) for direct control of the aircraft trajectory and thrust.

If doubt exists about the aircraft's flight path or airspeed control, no attempt should be made to reprogram the automated systems. Selected guidance or hand-flying with raw data[3] 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 engagement status. If engaged, the AP must be disconnected using the AP-disconnect switch to revert to hand-flying with FD guidance or with reference to raw data.

When hand-flying, the FD commands should be followed; otherwise, the FD command bars should be cleared from the PFD.

If the A/THR does not function as desired, the A/THR must be disconnected using the A/THR-disconnect switch to revert to manual thrust control.

AP systems and A/THR systems must not be overridden manually (except under conditions set forth in the aircraft operating manual [AOM] or quick reference handbook [QRH]).

Factors and Errors

The following factors and errors can cause an incorrect flight path, which — if not recognized — can lead to an approach-and-landing accident, including one involving controlled flight into terrain:

- Inadvertent arming of a mode or selection of an incorrect mode;

- Failure to verify the armed mode or selected mode by reference to the FMA;

- Entering an incorrect target (e.g., altitude, airspeed, heading) on the AFS control panel and failure to confirm the entered target on the PFD and/or ND;

- Changing the AFS control panel altitude target to any altitude below the final approach intercept altitude during approach;

- Inserting an incorrect waypoint;

- Arming the LNAV mode with an incorrect active waypoint (i.e., with an incorrect "TO" waypoint);

- Preoccupation with FMS programming during a critical flight phase, with consequent loss of situational awareness;

- Inadequate understanding of mode changes (e.g., mode confusion, automation surprises);

- Inadequate task-sharing and/or inadequate crew resource management (CRM), preventing the PF from monitoring the flight path and airspeed (e.g., both pilots being engaged in the management of automation or in the troubleshooting of an unanticipated or abnormal condition); and,

- Engaging the AP or disengaging the AP when the aircraft is in an out-of-trim condition.

Recommendations

Proper use of automated systems reduces workload and increases the time and resources available to the flight crew for responding to any unanticipated change or abnormal/emergency condition.

During normal line operations, the AP and A/THR should be engaged throughout the flight, including the descent and the approach, especially in marginal weather or when operating into an unfamiliar airport.

Using the AFS also enables the flight crew to give more attention to air traffic control (ATC) communications and to other aircraft, particularly in congested terminal areas.

The AFS/FMS also is a valuable aid during a go-around or missed approach.

When the applicable missed approach procedure is included in the FMS flight plan and the FMS navigation accuracy has been confirmed, the LNAV mode reduces workload during this critical flight phase.

Safe-and-efficient use of the AFS and FMS is based on the following three-step method:

- Anticipate:

  – Understand system operation and the result(s) of any action, be aware of modes being armed or selected, and seek concurrence of other flight crewmember(s);

- Execute:
  - Perform the action on the AFS control panel or on the FMS CDU; and,
- Confirm:
  - Cross-check armed modes, selected modes and target entries on the FMA, PFD/ND and FMS CDU.

The following recommendations support the implementation of the three-step method:

- Before engaging the AP, ensure that:
  - The modes selected for FD guidance (as shown by the FMA) are the correct modes for the intended flight phase; and,
  - The FD command bars do not show large flight-path-correction commands (if large corrections are commanded, hand-fly the aircraft to center the FD command bars [engaging the AP while large flight-path corrections are required may result in overshooting the intended target]);
- Before taking any action on the AFS control panel, check that the knob or push-button is the correct one for the desired function;
- After each action on the AFS control panel, verify the result of the action by reference to the FMA (for mode arming or mode selection) and to other PFD/ND data (for entered targets) or by reference to the flight path and airspeed;
- Monitor the FMA and call all mode changes in accordance with standard operating procedures (SOPs);
- When changing the altitude entered on the AFS control panel, cross-check the selected-altitude readout on the PFD:
  - During descent, check whether the entered altitude is below the minimum en route altitude (MEA) or minimum safe altitude (MSA) — if the entered altitude is below the MEA or MSA, obtain altitude confirmation from ATC; and,
  - During final approach, set the go-around altitude on the AFS control panel altitude window (the minimum descent altitude/height [MDA(H)] or decision altitude/height [DA(H)] should *not* be set in the window);
- Prepare the FMS for arrival before beginning the descent;
- An expected alternative arrival routing and/or runway can be prepared on the second flight plan;
- If a routing change occurs (e.g., "DIR TO" [direct to a waypoint]), cross-check the new "TO" waypoint before selecting the "DIR TO" mode (making sure that the intended "DIR TO" waypoint is not already behind the aircraft):
  - Caution is essential during descent in mountainous areas; and,
  - If necessary, the selected heading mode and raw data can be used while verifying the new route;
- Before arming the LNAV mode, ensure that the correct active waypoint (i.e., the "TO" waypoint) is displayed on the FMS CDU and ND (as applicable);
- If the displayed "TO" waypoint is not correct, the desired "TO" waypoint can be restored by either:
  - Deleting an intermediate waypoint; or,
  - Performing a "DIR TO" the desired waypoint; and then,
  - Monitoring the interception of the lateral flight path;
- If a late routing change or runway change occurs, reversion to selected modes and raw data is recommended;
- Reprogramming the FMS during a critical flight phase (e.g., in terminal area, on approach or go-around) is not recommended, except to activate the second flight plan, if needed. Primary tasks are, in order of priority:
  - Lateral flight path control and vertical flight path control;
  - Altitude awareness and traffic awareness; and,
  - ATC communications;
- No attempt should be made to analyze or to correct an anomaly by reprogramming the AFS or the FMS until the desired flight path and airspeed are restored;
- If cleared to leave a holding pattern on a radar vector, the holding exit prompt should be pressed (or the holding pattern otherwise deleted) to allow the correct sequencing of the FMS flight plan;
- On a radar vector, when intercepting the final approach course in a selected mode (e.g., heading, localizer capture, etc. [not LNAV]), the flight crew should ensure that the FMS flight plan is sequencing normally by checking that the "TO" waypoint (on the FMS CDU and the ND, as applicable) is correct, so that the LNAV mode can be re-selected for a go-around;
- If the FMS flight plan does not sequence correctly, the correct sequencing can be restored by either:
  - Deleting an intermediate waypoint; or,

– Performing a "DIR TO" a waypoint ahead in the approach;

– Otherwise, the LNAV mode should not be used for the remainder of the approach or for a go-around; and,

- Any time the aircraft does not follow the desired flight path and/or airspeed, do not hesitate to revert to a lower (more direct) level of automation. For example:

  – Revert from FMS to selected modes;

  – Disengage the AP and follow FD guidance;

  – Disengage the FD, select the flight path vector (FPV [as available]) and fly raw data or fly visually (if in visual meteorological conditions); and/or,

  – Disengage the A/THR and control the thrust manually.

Summary

For optimum use of automation, the following should be emphasized:

- Understanding of AP/FD and A/THR modes integration (pairing);

- Understanding of all mode-change sequences;

- Understanding of the pilot-system interface:

  – Pilot-to-system communication (mode selection and target entries); and,

  – System-to-pilot feedback (modes and target cross-check);

- Awareness of available guidance (AP/FD and A/THR status, modes armed or engaged, active targets); and,

- Alertness and willingness to revert to a lower level of automation or to hand-flying/manual thrust control, if required.

The following FSF ALAR Briefing Notes provide information to supplement this discussion:

- *1.1 — Operating Philosophy*;

- *1.3 — Golden Rules*; and,

- *1.4 — Standard Calls*.♦

References

1. The Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force defines *causal factor* as "an event or item judged to be directly instrumental in the causal chain of events leading to the accident [or incident]." Each accident and incident in the study sample involved several causal factors.

2. Flight Safety Foundation. "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-landing and Controlled-flight-into-terrain Accidents." *Flight Safety Digest* Volume 17 (November–December 1998) and Volume 18 (January–February 1999): 1–121. The facts presented by the FSF ALAR Task Force were based on analyses of 287 fatal approach-and-landing accidents (ALAs) that occurred in 1980 through 1996 involving turbine aircraft weighing more than 12,500 pounds/5,700 kilograms, detailed studies of 76 ALAs and serious incidents in 1984 through 1997 and audits of about 3,300 flights.

3. The FSF ALAR Task Force defines *raw data* as "data received directly (not via the flight director or flight management computer) from basic navigation aids (e.g., ADF, VOR, DME, barometric altimeter)."

Related Reading from FSF Publications

Flight Safety Foundation (FSF) Editorial Staff. "Crew Fails to Compute Crosswind Component, Boeing 757 Nosewheel Collapses on Landing." *Accident Prevention* Volume 57 (March 2000).

Wiener, Earl L.; Chute, Rebecca D.; Moses, John H. "Transition to Glass: Pilot Training for High-technology Transport Aircraft." *Flight Safety Digest* Volume 18 (June–August 1999).

Australia Department of Transport and Regional Development, Bureau of Air Safety Investigation. "Advanced-technology Aircraft Safety Survey Report." *Flight Safety Digest* Volume 18 (June–August 1999).

Sumwalt, Robert L., III. "Enhancing Flight-crew Monitoring Skills Can Increase Flight Safety." *Flight Safety Digest* Volume 18 (March 1999).

FSF Editorial Staff. "Preparing for Last-minute Runway Change, Boeing 757 Flight Crew Loses Situational Awareness, Resulting in Collision with Terrain." *Accident Prevention* Volume 54 (July–August 1997).

FSF Editorial Staff. "Stall and Improper Recovery During ILS Approach Result in Commuter Airplane's Uncontrolled

Collision with Terrain." *Accident Prevention* Volume 52 (January 1995).

Lawton, Russell. "Airframe Icing and Captain's Improper Use of Autoflight System Result in Stall and Loss of Control of Commuter Airplane." *Accident Prevention* Volume 51 (November 1994).

Roscoe, Alan H. "Workload in the Glass Cockpit." *Flight Safety Digest* Volume 11 (April 1992).

King, Jack L. "Coping with High-tech Cockpit Complacency." *Accident Prevention* Volume 49 (January 1992).

FSF. "Head-up Guidance System Technology (HGST) — A Powerful Tool for Accident Prevention." *Flight Safety Digest* Volume 10 (September 1991).

Orlady, Harry W. "Advanced Cockpit Technology in the Real World." *Accident Prevention* Volume 48 (July 1991).

Foushee, H. Clayton. "Preparing for the Unexpected: A Psychologist's Case for Improved Training." *Flight Safety Digest* Volume 9 (March 1990).

Regulatory Resources

International Civil Aviation Organization (ICAO). *International Standards and Recommended Practices, Annex 6 to the Convention of International Civil Aviation, Operation of Aircraft*. Part I, *International Commercial Air Transport – Aeroplanes*. Appendix 2, "Contents of an Operations Manual," 5.14. Seventh edition – July 1998, incorporating Amendments 1–25.

ICAO. *Human Factors Training Manual*. First edition – 1998, incorporating Circular 234.

ICAO. Circular 234, *Human Factors Digest No. 5*, "Operational Implications of Automation in Advanced Technology Flight Decks." 1992.

Notice

The Flight Safety Foundation (FSF) Approach-and-landing Accident Reduction (ALAR) Task Force has produced this briefing note to help prevent ALAs, including those involving controlled flight into terrain. The briefing note is based on the task force's data-driven conclusions and recommendations, as well as data from the U.S. Commercial Aviation Safety Team (CAST) Joint Safety Analysis Team (JSAT) and the European Joint Aviation Authorities Safety Strategy Initiative (JSSI).

The briefing note has been prepared primarily for operators and pilots of turbine-powered airplanes with underwing-mounted engines (but can be adapted for fuselage-mounted turbine engines, turboprop-powered aircraft and piston-powered aircraft) and with the following:

- Glass flight deck (i.e., an electronic flight instrument system with a primary flight display and a navigation display);
- Integrated autopilot, flight director and autothrottle systems;
- Flight management system;
- Automatic ground spoilers;
- Autobrakes;
- Thrust reversers;
- Manufacturers'/operators' standard operating procedures; and,
- Two-person flight crew.

This briefing note is one of 34 briefing notes that comprise a fundamental part of the FSF *ALAR Tool Kit,* which includes a variety of other safety products that have been developed to help prevent ALAs.

This information is not intended to supersede operators' or manufacturers' policies, practices or requirements, and is not intended to supersede government regulations.

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