Glass Cockpits in General Aviation Aircraft. Consequences for training and simulators

Fred Abbink
Content

- Development of Air transport cockpits, avionics, automation and safety
  - Pre World War 2
  - Post World War 2

- Automated Air Transport Glass Cockpit problem area’s

- Development of General Aviation cockpits

- Analysis of General Aviation Glass Cockpit accidents

- Conclusions and Recommendations
1924: Fokker FVII
1929: Jimmy Doolittle - Blind Flying
1933: Wiley Post - First Solo Around The World
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Global Standardisation and introduction of the new technology

Civil Air Transport development:

- ICAO
- IATA
- FAA
- ATC, radar, radio navigation, and landing systems
- Transatlantic air transport
- Jet airliners
- Wide-body FBW jet airliners
- Environmental restrictions
1970: Boeing 747
Computers and Electronic Displays
Moore’s Law
1982: Airbus A310
Reduced Flight Crew Complement
1945-1982: Flight Deck Crew From 5 to 2

- **Lockheed Constellation: 5**
  - 2 pilots
  - Radio operator
  - Navigator
  - Flight Mechanic

- **Boeing 707: 4**
  - 2 pilots
  - Navigator
  - Flight Mechanic

- **Boeing 747: 3**
  - 2 pilots
  - Flight Mechanic

- **A310: 2**
  - 2 pilots

- Dad, why are there always 2 pilots?
- One has to prevent the other from doing stupid things.
- Which one is doing the stupid things?
Flight Simulator Development
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Flight Control System Overview

- Crew interface
  - Flight control panel
  - Primary flight displays
  - Crew selections
  - Crew indications

- Flight guidance system
  - Mode logic
  - Flight control laws

- Flight management system
  - Measured state
  - Aircraft state sensor data

- Flight director guidance cues
  - On/off
  - Roll guidance
  - Pitch guidance

- Autopilot
  - Engage/disengage
  - Actuator commands

- Control surfaces

Source: NASA Langley RC
Current airliners have Flight Control Systems with about 25 thrust-, lateral- and vertical modes.

Sometimes flight crews wonder: “What is it doing now?” and “What will it do next?”

The flight crew believe that they are in a Flight Guidance System mode, different than the one they are actually in and consequently make inappropriate requests or responses to the automation.

The flight crew do not fully understand the behaviour of the automation in certain modes, i.e., when the flight crew has a poor “Mental Model” of the automation. Sometimes this is simply called losing track of the automation.
1996: FAA Modern Flight Deck Systems
Human Factors Study

- Initiated by 2 accidents and 1 incident caused by difficulties in flight crews interacting with increasing flight deck automation:
  - 1994 China Airlines Airbus A300-600 at Nagoya, Japan
  - 1995 American Airlines Boeing 757 near Cali, Colombia
  - 1995 American Airlines Douglas MD-80 near Bradley Intl Airport Connecticut, USA

- 24 Accidents were analysed

- The Human Factors Study Team identified many vulnerabilities in:
  - Flight Crew Management of Automation
  - Situation Awareness
“I do not believe that ATC controllers understand the operation of computer driven aircraft...”

“Controllers need to understand the increase in workload that is placed on a 2-man crew using an FMC when giving restrictions and holding instructions...We are plagued with late clearances, frequent changes...”

“Simple changes to [ATC] procedures would help cut out workload so we could keep our heads out of the cockpit and still use the computer...”

- Quotes from the ASRS database
The Human Factors Team provided many recommendations:

- Measurements of and Incentives for Safety (3)
- Management of Automation (5)
- Flight crew Situation Awareness (9)
- Communication and Coordination (10)
- Processes for Design, Regulatory and Training Activities (3)
- Criteria, Regulatory Standards and Tools for Design and Certification (4)
- Knowledge and Skills of Designers, Pilots, Operators, Regulators and Researchers (13)
- Cultural and Language Differences (4)
Boeing Fatal Accident Statistics 2000-2009

[Bar chart showing fatalities distribution by category.]

- External fatalities [Total 244]
- Onboard fatalities [Total 5001]

No accidents were noted in the following principal categories:
- ADRM: Aerodrome
- AMAN: Abrupt Maneuver
- ATM: Air Traffic Management/Communications, Navigation, Surveillance
- BIRD: Bird
- CABIN: Cabin Safety Events
- EVAC: Evacuation
- F-POST: Fire/Smoke (Post-Impact)
- GCOL: Ground Collision
- ICE: Icing
- LALT: Low Altitude Operations
- LOC-G: Loss of Control – Ground
- RI-A: Runway Incursion – Animal
- SEC: Security Related
- TURB: Turbulence Encounter

For a complete description go to: http://www.intaviationstandards.org/
Advisory Circular

Subject: APPROVAL OF FLIGHT GUIDANCE SYSTEMS
Date: 7/17/06
AC No: 25.1329-1B
initiated by: ANM-110

1. PURPOSE. This advisory circular (AC) describes an acceptable means for showing compliance with certain requirements of Title 14, Code of Federal Regulations (CFR) 25.1329, Flight guidance systems. While Part 25 contains the airworthiness standards applicable to transport category airplanes, the guidance in this AC pertains to the functions of autopilots, flight directors (FD), and automatic thrust control as well as any interactions with stability augmentation and trim functions.

2. CANCELLATION. Advisory Circular 25.1329-1A, dated July 8, 1968, is canceled.

3. APPLICABILITY.
   a. The guidance provided in this document is directed to airplane manufacturers, modifiers, and operators of certain transport category airplanes.
   b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The Federal Aviation Administration (FAA) will consider other methods of demonstrating compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. On the other hand, if we become aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation or design changes as a basis for finding compliance.
   c. This material does not change, create any additional, authorize changes in, or permit deviations from, regulatory requirements.

● First amendment since 1964
● Special attention to operationally relevant mode changes:
   ● Annunciation of sustained speed protection should be clear and distinct to ensure flight crew awareness
   ● The transition from an armed mode to an engaged mode should provide an additional attention – getting feature as boxing and flashing on an electronic display
● Aural alerts may be warranted:
   ● When airplane nears the limits of the AP design limits in pitch, roll or amount of trim
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General Aviation Cockpit Development

1937: Piper Cup  
1957: Cessna 172  
2000: Cirrus SR22
FITS is joint government-stakeholder initiative to improve pilot learning to safely, competently and efficiently operate technically advanced piston or light jet aircraft in the modern National Airspace System.

Implement training to reduce Human Error and to accelerate acquisition of higher level judgement and decision making skills.

Scenario-based training to effectively integrate:
- Risk Management
- Aeronautical Decision Making
- Situational Awareness
- Single Pilot Resource Management
2005: AOPA Technically Advanced Aircraft (TAA)
Safety and Training

Contents

- Introduction and overview
- Safety implications
- Accident reviews
- Training for the glass age
- TAA hardware and software
- Report conclusions

An AOPA Air Safety Foundation Special Report

NLR - Dedicated to innovation in aerospace
The penalties for poor judgement, misinterpretation, misprogramming, or clumsy flight-control handling remain the same as they always have.

Learning to fly the TAA will change the flight-training world, and it should pay noticeable dividends to all segments of the industry.

Until more TAA are introduced in the fleet, it will be difficult to directly measure the safety benefit.

TAA offer increased safety with added situational awareness. But for pilots to avail themselves of these improvements, the key ingredient will remain a balance between training tied to experience and ever improving, smarter technology.
2004: Airplane Flying Handbook
2008: Handbook of Aeronautical Knowledge
Contents

- Introduction
- Navigation
- Automated Flight Control
- Information
2009: FAA Part 23 - Small Airplane Certification Process Study. (Recommendations for GA for the next 20 years)

Contents

- Structure and Process of Part 23
- Design Certification
- Continued Airworthiness
- Data Management
- Pilot Interface
Avionics and aircraft systems in part 23 airplanes are offering more features and integration of these features.

Not all airplane and avionics designers have used good human factors practices. General Aviation needs airplanes that are intuitive to operate, requiring as little training as possible.

Most part 23 airplanes operate under part 91 and do not require airplane specific training or equipment specific training.

As new integrated systems continue to add features, the pilot usability gets harder.

In some cases equipment designed for 2 person crew, part 25 airplanes is installed on single-pilot part 23 airplanes.

Installing part 25 equipment could result in a high workload for single-pilot operations.
5.1: Human performance is a dominant factor in General Aviation accidents. Improve the minimum crew determination requirements to provide clear discriminators for pilot workload

5.2: Incorporate better human-performance based designs in new airplanes or new avionics to make airplane operation more error tolerant

5.3: There should be an obvious cue for the pilot anytime the pilot pushes a button or switch and expects a resulting operation to occur. If the system does not respond in a timely matter, the aircraft should display an appropriate alert or warning
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Since 2002 new GA aircraft are equipped with Glass Cockpits with new displays integrating:
- Aircraft Control and Autopilot
- Communication and Navigation
- Aircraft Systems Monitoring

Light single-engine aircraft equipped with glass cockpits showed:
- Lower total accident rates
- Higher fatal accident rates

FAA has updated the training handbooks and test standards

Current Airman knowledge written tests do not assess pilot’s knowledge of glass cockpit displays

FAA has no specific training requirements for glass cockpit pilots
Traditional Cockpit Instrumentation
Conventional Air Speed Indicator

- Diaphragm
- Long lever
- Sector
- Pitot connection
- Pitot tube
- Ram air
- Static air line
- Handstaff pinion
Airspeed Failure Modes
Central Air Data Computer (CADC)

**Inputs**
- Static Pressure
- Pitot Pressure (dynamic)
- Total Air Temp (TAT)

**Outputs**
- Vertical speed indicator
- Flight data recorder
- ATC transponder
- Cabin pressure control
- Autopilot altitude hold
- Autopilot altitude rate
- Flight data recorder
- Autopilot gain control
- Autothrottle
- Autopilot airspeed hold
- Autopilot Mach hold
- Autothrottle
- Autopilot gain control
- True airspeed
- True air temp (OAT)
Air Data Computer Failure Modes
NTSB Comments with respect to the FAA

- Developed FAA-Industry Training Standards (FITS) in response to new advanced aircraft
- Included generic glass cockpit avionic information in manuals and handbooks
- Did not include specific training or testing requirements
- Has not yet updated knowledge tests
Main recommendations of the NTSB Study

- Revise airman knowledge tests regarding electronic flight and navigation displays, including malfunctions.

- Include in AFM and Pilot’s operational handbook abnormal equipment operation or malfunction, including Pitot-static, magnetic sensor and AHRS failures.

- Incorporate training elements regarding Electronic Primary Flight Displays in training material, knowledge requirements and into initial and recurring flight proficiency requirements.

- Develop guidance for equipment-specific electronic avionics display simulators and procedural trainers.
AC 61-126: PC-Based Aviation Training Devices

FAA Approved PC-based Aviation Training Devices

- AC 61-126 Provides procedures for Qualification and Approval of PC-based Aviation Training Devices
- Approved PC-based ATDs can provide up to 10 hours reduction in training flight hours

Advisory Circular

Subject: QUALIFICATION AND APPROVAL OF PERSONAL COMPUTER-BASED AVIATION TRAINING DEVICES

Date: 8/12/97
AC No: 61-126
Initiated By: AFS-840
Change:

1. PURPOSE. This Advisory Circular (AC) provides information and guidelines to potential training device manufacturers and aviation training companies concerning a means, acceptable to the Administrator, by which personal computer-based aviation training devices (PCATD) may be qualified and approved for flight training toward satisfying the instrument rating training under the provisions of Title 14 of the Code of Federal Regulations (14 CFR) parts 61 and 141. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent parts of 14 CFR. Mandatory terms used in this AC, such as “shall” and “must” are used only in the sense of ensuring availability of this method of compliance. PCATDs are distinct from flight training devices (FTD) qualified under AC 120-45, Airplane Flight Training Device Qualification, and flight simulators qualified under AC 120-40, Airplane Simulator Qualification. It also provides acceptable criteria under which the airplane or FTD flight-hour training time required for an instrument rating may be reduced by using PCATDs that have been determined to meet acceptable FAA standards. This AC details only one means of determining the acceptability of such devices for use in instrument training curriculums.

2. RELATED 14 CFR SECTIONS. Sections of the regulations related to the information in this AC are in parts 61 and 141.

3. DEFINITIONS.

a. PCATD. A device which:
   (1) Meets or exceeds the criteria shown in Appendix A.
   (2) Functionally provides a training platform for at least the procedural aspects of flight relating to an instrument training curriculum.
   (3) Has been qualified by the FAA.

b. Qualification Guide. Design criteria to assist in the evaluation and qualification process for PCATDs. A Qualification Guide is included in Appendix A.
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Conclusions and Recommendations

- The development of electronics and digital computers transformed the Air Transport Flight Deck enormously.

- The introduction of integrated electronic Flight-, Navigation- and Systems displays and integrated autoflight systems changed the role of the airline pilot.

- Scenario-based training was introduced to cope with the changed role.

- The new generation of general aviation aircraft is becoming equipped with glass cockpits and integrated autoflight systems.

- Lessons from the airline experience with glass cockpits should be re-used in designing the scenario-based training of GA pilots and adequate PC-based training devices.