# Digital is Different:

## Observations on the transition from analog to advanced cockpits

Noelle Brunelle, MSHFS
Presented to EAA Chapter 170
April 2024

# A little about me….

- Learned to fly at SMX
  - First flight: Nov 87;  First Solo Feb 88
  - Private Pilot Sept 88; Instrument June 91
- USAF
  - ATC, Airfield Management, Command Post
  - Keesler MS, Nellis NV, Osan ROK
    - Osan Aero Club Safety Officer
- Embry-Riddle Aeronautical University
  - BS Management of Technical Operations
  - MS Human Factors and Systems
    - Internship: CAMI Cabin Safety Group
- Sikorsky Aircraft Corporation
  - Crew Stations Integration: Digital Cockpit in Blackhawk, CMWS integration, Egress Test
  - Aviation & Product Safety
    - Product Safety:  Mature Models Team Lead  (600+  H-53 and S-61 aircraft)
    - Development Safety:  CH-53K  Rotor and Drive Systems Hazard Analysis, Cockpit Warning System
    - Proactive Data Analysis:  Developed methods to detect emerging safety issues using field data

Photo courtesy of Coastal Valley Aviation https://cvamx.com/about/

# Potential Topics

- Development Safety
    - Hazard Analysis Methods, application in homebuilt environment
- Aviation Safety Culture
    - Safety Management Systems
    - FAA ODA Expert Panel Review of Boeing operations
- Human Factors During Investigations
    - HFACS Analysis in ISS EVA Suit Water Intrusion mishap report
- Egress Tests and Survivability
    - Egress test prep, lessons from adverse events
- Human-Automation Collaboration
    - How information presentation impacts decisions

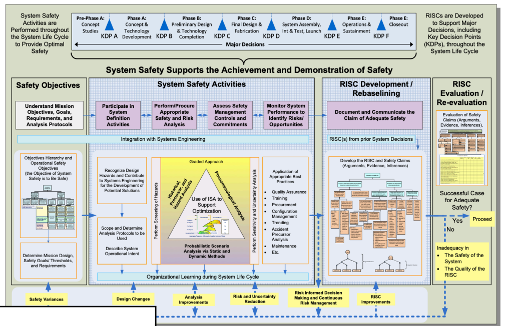



Figure 2-3. The System Safety Framework

**Section 103 Organization Designation Authorizations (ODA) for Transport Airplanes Expert Panel Review Report**

Final Report

Aircraft Certification, Safety, and Accountability Act of 2020 (Pub. L. 116-260, Div. V), Section 103

National Aeronautics and Space Administration

**International Space Station (ISS) EVA Suit Water Intrusion**

**High Visibility Close Call**

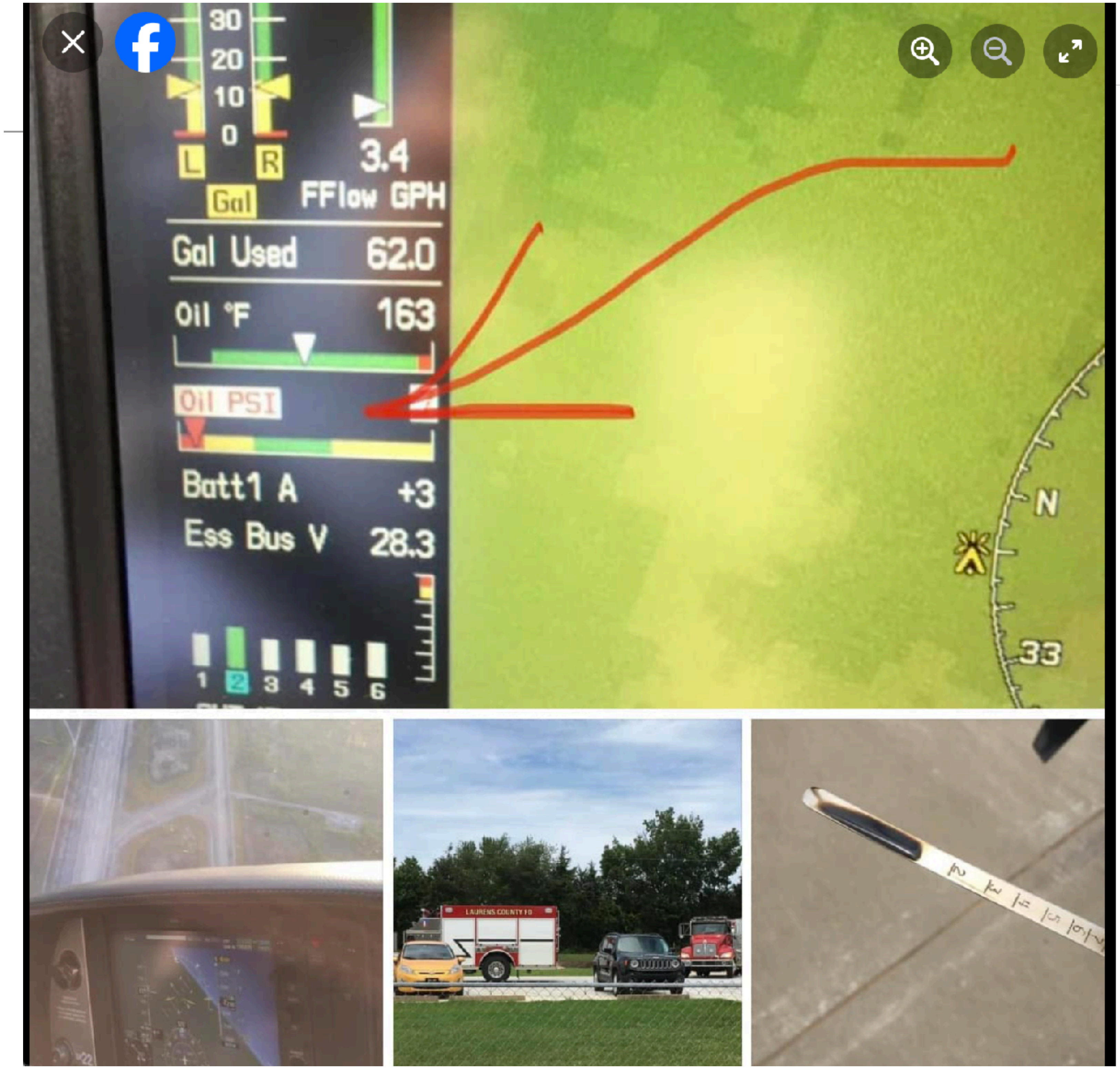
**IRIS Case Number: S–2013–199–00005**

**Date of Mishap: July 16, 2013**

**Date of Report: December 20th, 2013**

REDACTED FOR PUBLIC RELEASE


https://archive.vanityfair.com/article/2009/1/the-devil-at-37000-feet




**Gold Standard Aviation**
Yesterday at 7:35 AM ·

The day oil pressure dropped to zero somewhere in the middle of nowhere.

While in level flight at 10000′ my instrument student and I were blindsided by an aural BING in the cockpit. Our eyes were immediately directed to an OIL PRESS caution annunciation on the Cirrus SR22's PFD display. Anyone who pilots an airplane will tell you this could mean big trouble.

A quick cross-check of the oil temperature indication showed a normal reading so it was our job to decide if this was... **See more**

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**Ben Anderson**
So you can land a Cirrus with out pulling the parachute. 👍
1d Like Reply 196

Write a comment...

https://www.facebook.com/photo?fbid=1163363408048086&set=a.725388498512248

# Flight Plan

- A little about me
- Evolution of Automation
- Impacts of Advanced Automation
- Warning Systems
- Application to GA / EAA Environment
- Q & A

# Evolution of Automation

- In the beginning….

- Displays
  - Anemometers (Airspeed)
  - Barometric altimeters
  - Magnetic Compass
  - Cork + flag for fuel indications

- Flight Controls
  - Cables and Pushrods

- Navigation
  - Lighted Beacons

Airmail beacon atop Sherman Hill between Cheyenne and Laramie, Wyoming in the mid 1920s.

https://postalmuseum.si.edu/exhibition/fad-to-fundamental-airmail-in-america-airmail-creates-an-industry/innovations

Stix, G (1991) Along for the ride, Scientific American, July, p. 95-106

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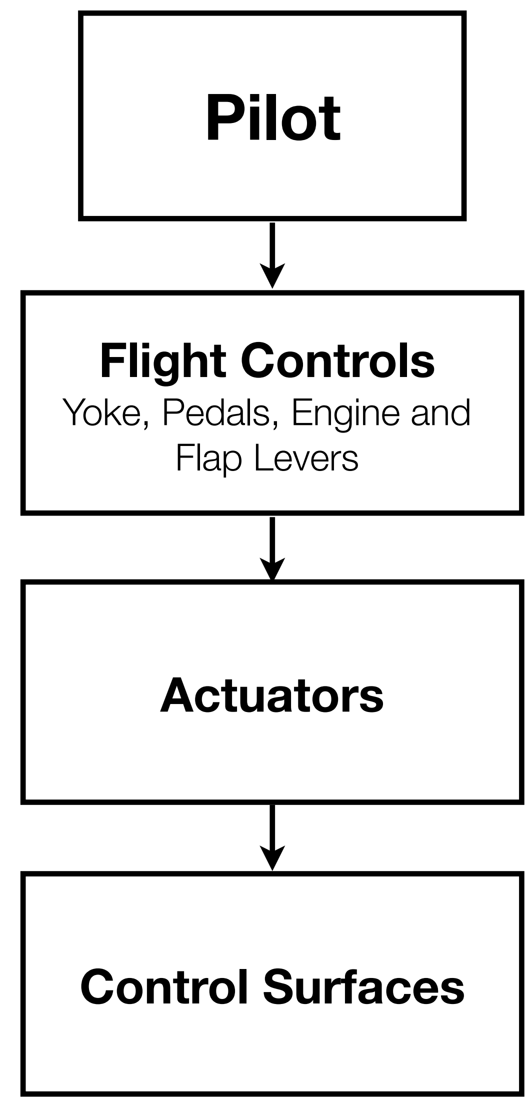



Stix, G (1991) Along for the ride, Scientific American, July, p. 95-106

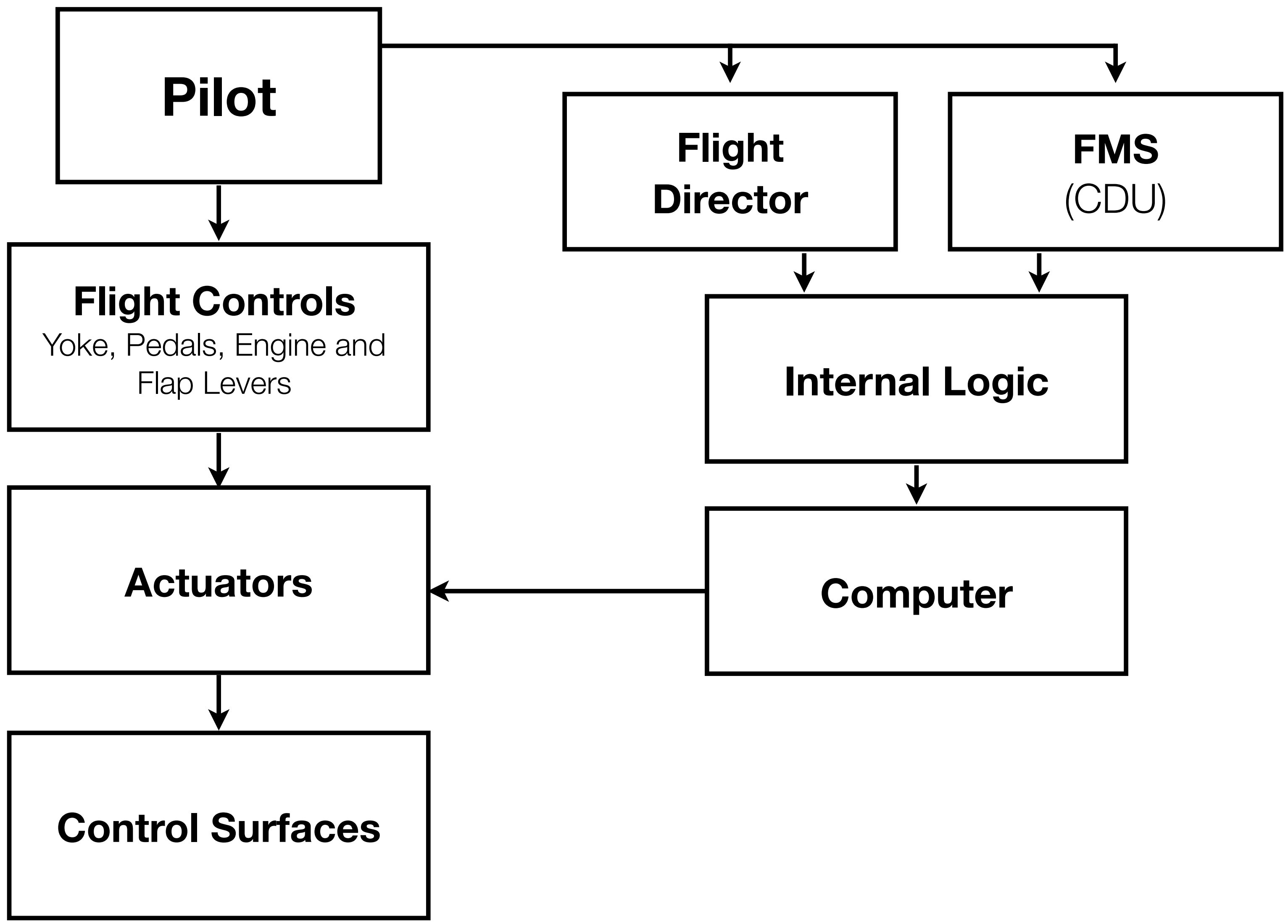
# Evolution of Automation

- Along the way:
- Displays
  - Pitot airspeed indicators
  - Radio Altimeters, weather radar
  - Mechanical flight director, digital system status displays
- Flight Controls
  - Aerodynamic tabs
  - Automatic pilots (altitude, then speed and direction)
  - ‘Fly-by-oil’ hydraulic systems, automatic landing systems
- Navigation
  - Radio Beacons
  - Omnidirectional beacons, instrument landing systems
  - Internal Navigation Systems

SR-71 Blackbird Cockpit

Stix, G (1991) Along for the ride, Scientific American, July, p. 95-106

# Evolution of Automation



# Evolution of Automation

- Systems have evolved into high authority, high autonomy devices (A320, B747-400, A380, B777, etc.)
- High Autonomy:
  - Automation can accomplish tasks without
    - Direct pilot commands
    - Immediately preceding pilot commands
    - Pilot consent
  - Internal logic responds to:
    - Target values
    - Preprogrammed instructions
    - Protection Limits
    - Other sensor inputs

Sarter, NB & Woods, DD (1997) Team play with a powerful independent agent: Operational experiences and automation surprises on the Airbus A-320, *Human Factors*, 39(4), 553-569

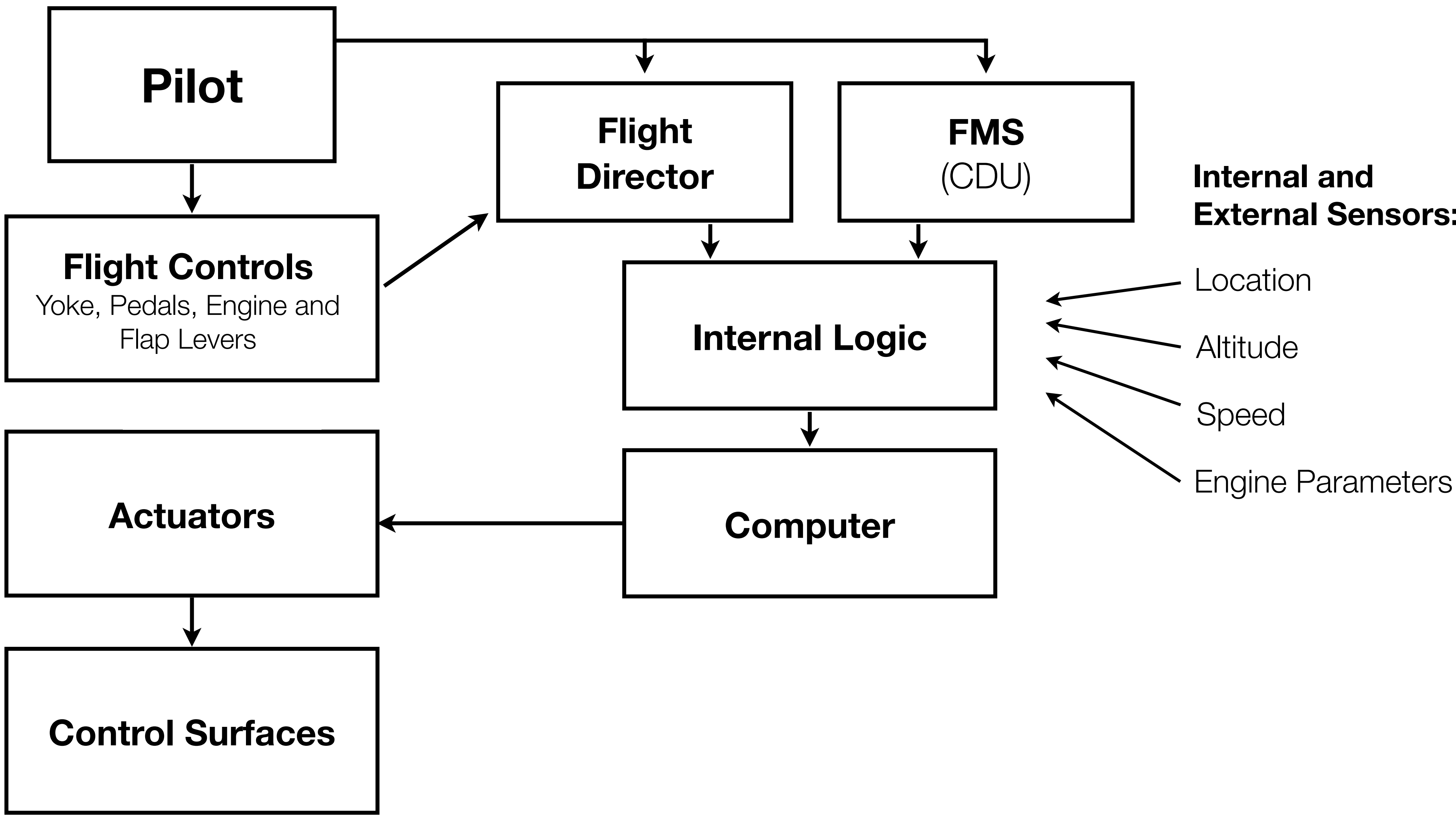
# Evolution of Automation

- High Authority
  - Includes envelope protections
  - Automation can detect, prevent, or recover from predefined unsafe conditions
  - Automation has the power to limit, alter, or override pilot inputs

https://www.youtube.com/watch?v=-kHa3WNerjU

Sarter, NB & Woods, DD (1997) Team play with a powerful independent agent: Operational experiences and automation surprises on the Airbus A-320, *Human Factors*, 39(4), 553-569

# Evolution of Automation



Experiences with cockpit automation?

# Benefits of Automation

- Increased capacity to:
  - Collect data
  - Transmit data
  - Tranform data

- Enables:
  - Increased precision
  - Added system complexity
  - Offload of tasks
  - Reduced cockpit staffing

Sarter, NB & Woods, DD (1997) Team play with a powerful independent agent: Operational experiences and automation surprises on the Airbus A-320, *Human Factors*, 39(4), 553-569

# Automation related accidents

- Airbus Industrie 296Q  Mulhouse France, 1988
  - Take-off power applied while aircraft was in approach mode, automation engage alpha protections to prevent stall
- Air Inter 5148  Strasbourg France, 1992
  - Crew entered 3,300 feet as vertical descent rate rather than descent altitude
- American Airlines 965  Cali Columbia, 1995
  - Incorrect waypoint entry caused aircraft to execute turn into terrain
- Gol 1907 vs Legacy 600XL  Amazon Rainforest Brazil, 2006
  - Disconnected transponder led to lack of ATC and Legacy crew awareness, loss of TCAS functionality and alerts
- Air France 447 Atlantic Ocean, 2009
  - Iced pitot tubes caused automation to switch from ‘normal law’ to ‘alternate law 2’
  - Automation began to automatically adjust angle of attack
  - When safety limits reached automation returned manual control to pilots
- US Airways 1549  New York City, 2009
  - Geese encountered on departure, both engines failed, aircraft ditched in Hudson River
  - Captain Sullenberger attributes successful outcome to A320 automation

# Research Overview

- Nadine Sarter and David Woods (Ohio State University)
  - Expanded work of Earl Weiner (NASA)
- Explored pilot experiences with advanced automation
  - Surveys
  - Observation (airline training)
  - Simulated flight segments
  - Initially Boeing 737-300 /400
  - Later Airbus 320, Boeing 747-400

# Reference List


Sarter N. B., & Woods D. D. (1992) Pilot Interaction With Cockpit Automation: Operational Experiences With the Flight Management System, *International Journal of Aviation Psychology*, 2(4), 303-321

Sarter N. B., & Woods D. D. (1994) Pilot interaction with cockpit automation: II. An experimental study of pilots' model and awareness of the flight management and guidance system, *International Journal of Aviation Psychology*, 4, 1-28

Sarter, N.B. & Woods, D.D. (1995) How in the world did we ever get into that mode? Mode error and awareness in supervisory control, *Human Factors*, 37(1), 5-19

Sarter, N.B. & Woods, D.D. (1997) Team Play with a Powerful and Independent Agent: Operational Experiences and Automation Surprises on the Airbus A-320, *Human Factors*, 39 (4), 553-569

Sarter, N. B. & Woods, D. D. (2000) Team Play with a Powerful and Independent Agent: A Full-Mission Simulation Study, *Human Factors*, 42(3), 390-402

Nikolic, M. I. & Sarter, N. B. (2007) Flight Deck Disturbance Management: A Simulator Study of Diagnosis and Recovery from Breakdowns in Pilot-Automation Coordination, *Human Factors*, 49(4) 553-563

# New Events: Automation Surprises

- Automation surprises occur when automation
  - Takes an unexpected action
  - Fails to take an expected action
  - Carries out an expected action in an unexpected manner
- Automation surprises can result from
  - Missing, incomplete, or delayed feedback
  - Failure of a flight management/guidance computer
  - Inputs by one pilot are not visible or recognized by other pilots
  - Ineffective monitoring strategies
- During automation surprises pilots
  - Hesitate to take manual control of the aircraft
  - Troubleshoot he system rather than take manual control

# Research Overview

- Research indicated:
  - Pilots perform well during routine tasks
  - Pilots are challenged during:
    - Unusual events
    - Non-nominal events
    - Unexpected events

- Pilots exhibited ‘gaps’ in mental models of automation
  - Routine tasks presented in an unusual manner
    - Hold present position vs hold at fix
  - Demonstrated ‘inert knowledge’
    - Can recite facts about the system
    - Unable to apply same facts successfully during ‘flight’

# Research Overview

- Revealed changes in flight tasks
  - New **knowledge** requirements
  - New **memory** demands
  - New **attention** demands
  - New **cognitive** demands
  - New **communication** tasks
- Offered strategies for managing these changes

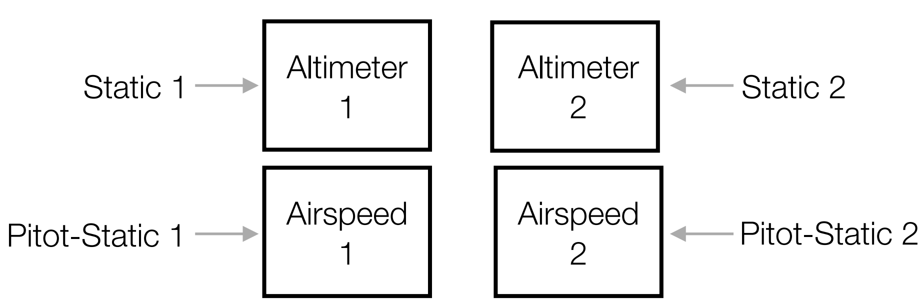
# New **Knowledge** Requirements: Hardware

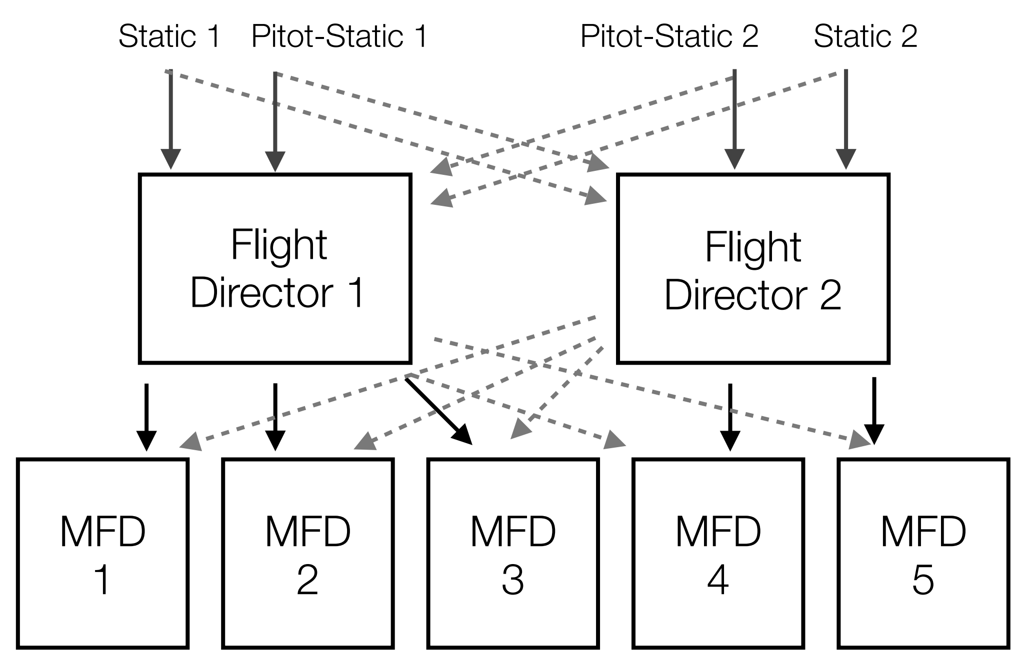
Aeronca C-2-N

S-61 Cockpit

S-92A Cockpit


Vans RV-6



# **Knowledge** Requirements: Information Location

- How do I track aircraft status?
- Normal Operations
  - Primary flight indications
  - Heading / navigation indications
  - Engine / system parameters
  - Display page heirarchies
  - Automation mode and status
  - Responses to commands (status cues)
    - Which info to expect when
- Unusual events
  - Warnings
  - Cautions
  - Advisories
  - Status indications
  - Are alerts listed by severity or chronology?
  - What happens when I acknowledge an alert?

- Needed info may be several layers down (nested)
  - Pilots often learn by exploration / trial & error

# New **Knowledge** Requirements: Commands

- How are automation commands executed?
  - Where to input / execute the command
  - Sequences and syntax
  - Methods to execute the same command may vary by where command is inputted
  - Which commands are not allowed  (or when/where)

- System responses to commands
  - How do inputs propagate through the system?
  - Current and future behaviors once a command is inputted
  - Indications / feedback throughout the automation response
  - Which values are used during which maneuvers / commanded actions?
  - Are system responses immediate or delayed?
  - Are effects short term or long term?

- How do I track the status of a command?
  - Location of status cues?
  - Which indications should I expect when?

# **Knowledge** Requirements: Automation Modes

- Different automation modes and levels
  - Manual
  - Managed Lateral, Vertical navigation
  - Full Automation (Takeoff, Level Off, Approach, Go-Around, etc.)
- Which modes are used when?
  - Which is appropriate for given conditions?
  - What conditions must be met to use a mode?
  - Does display screen (PFD, EICAS, NAV) affect how command inputs are interpreted?
  - How are mode violations or restrictions indicated?
- How to switch smoothly between modes
  - Transition between automation modes (LNav to VNav, Approach to Go-Around)
  - Transition between full automation and manual control
- Inadvertent mode activations
  - When they happen (new target value, protection limits reached)
  - What they look like
  - How they are indicated to the pilot

# **Knowledge** Requirements: System Behaviors

- Some mode transitions occur without direct pilot input
(Example: Climb transitions to Level-Off)
  - When do these occur?
  - How are these indicated?
  - What are their effects?
- Effects of partial system or subsystem failures on automation functionality
  - Indications
  - Consequences
  - Which systems are still active?  How do I tell?
  - Effects of failure(s) on flight control modes?
- System limitations
  - Especially limits that cause automation to disengage

# **Memory** Demands: Complex Mental Models

- System knowledge is assembled in to a mental model
  - Mental models include:
    - System and subsystem structures and functions
    - Display page heirarchies (nested information / functions)
    - Cue map - where to look for actual / inputted target values
    - System logic and limitations
    - Expectations of system behavior (current and future)
    - Strategies for utilizing automation
- Relevant knowledge is activated when initiating and responding to events
  - Guide actions during problem solving
- Mental models may be incomplete due to:
  - Infrequently used commands
  - Interactions between / consequences of different automation levels or modes
  - Different task strategies for different flight contexts
- Accurate mental models are needed to effectively manage automation

# New **Attention** Demands

- Regardless of automation, pilots must monitor
  - Control tasks
  - Guidance tasks
  - Navigation tasks
  - Monitor system status
  - Monitor environmental conditions

- Automation adds new attention tasks
  - Automation status - What mode is it in?
  - Automation behavior - What is it doing?
  - Intentions - What will it do next?

Casner, SM (1994) Understanding the determinants of problem-solving behavior in a complex environment, *Human Factors*, 36(4), 580-596
Weiner, EL (1993) Crew coordination and training in the advanced technology cockpit, in EL Weiner, BG Kanki & RL Helmreich, *Crew Resource Management,* (pp.199-230), San Diego CA, Academic Press

# New **Cognitive** Demands

- Attention allocation
  - Which cues to monitor
  - When to monitor
  - How long to monitor
  - Detected cues must be recognized and integrated into an organized model
  - Signals may be distributed throughout the cockpit

- Mode awareness
  - Awareness and anticipation fo current and future automation states and behaviors
  - Maintained by recognizing and interpreting cues and integrating signals
  - Used to predict when mode transitions might or will occur

- Mode awareness impacted by
  - Accuracy and/or completes of mental models
  - Quality of system feedback
  - Attention allocation
  - Workload (during busy phases of flight, automation status and behaviors my change frequently and quickly)
  - Simultaneous use by multiple operators

# New **Communication** Demands

- Advanced automation allows use by multiple crew members
  - Commands/values may be selected by either crew member
  - Crew members may utilize different use and monitoring strategies
  - Inputs by one crew member may not be clearly indicated to others
- To operate effectively, crew members must use common mental models (shared cognition)
- Communication/coordination between crew members regarding automation inputs and actions is essential

# Automation Research: Findings

- Advanced automation has changed the role of pilot
  - Hand-flying replaced with indirect control
  - System manipulator to system monitor
  - Pilots intervene:
    - During system start up
    - When changes are necessary
    - When unusual situations occur
  - Effective operations require collaboration between pilots and automation

Sarter, NB & Woods, DD (1997) Team play with a powerful independent agent: Operational experiences and automation surprises on the Airbus A-320, *Human Factors*, 39(4), 553-569

# Automation Research: Findings

- Pilots in traditional cockpits utilize standard instrument scan (check-reading)
  - Allocates attention efficiently
  - Allows quick assessment of aircraft state
  - Relevant flight parameters are checked on a regular basis
  - ‘Heads-down’ time is borrowed from external scan

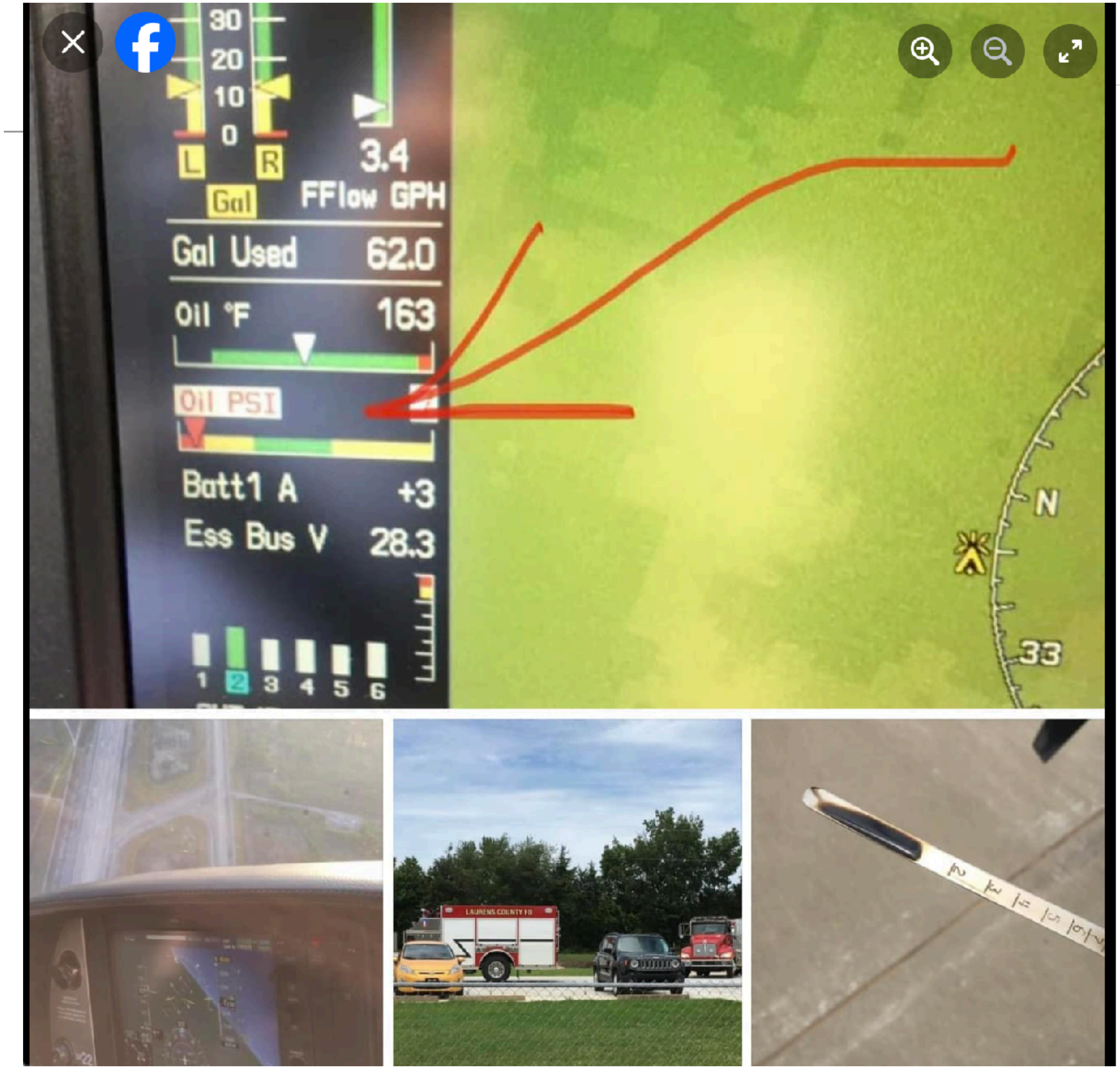
- Advanced automation has changed scanning behavior
  - Scope and depth of scan has increased
  - Scan has widened to include Multiple MFDs, Flight Director, FMS/CDU, Console displays
  - Pilots must read text (rather than scan dials) to acquire data

- Basic instrument scan (check-reading) has been replaced with expectation-driven monitoring (context-specific reflective questions)

Helberg, JR & Wickens, CD (2003) Effects of data link modality and display redundancy on pilot performance: An attentional perspective, *International Journal of Aviation Psychology,* 13(3), p.189-210

# Automation Research: Findings

- Pilots report scanning to verify expected changes and system behaviors
  - Requires an accurate mental model of the **system**
    - Important cues may be missed if the model is inaccurate
  - Requires an accurate mental model of the **system**
    - Pilots must decide which displays/indications to monitor
    - False or incomplete expectations may lead to monitoring ‘wrong’ cues
    - Parameters that are not expected to change may be ignored
- Pilots report using a smaller, quicker, one-instrument (PFD) scan
  - Increases the potential to miss important information
  - Increases the potential for attention errors
    - inattention blindness
    - Change blindness
- Unmatched expectations may result in delayed detection and recovery

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Most relevant

**Ben Anderson**
So you can land a Cirrus with out pulling the parachute. 👍
196
1d Like Reply

Write a comment...

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# Warning Systems

- Diagnostic automation provides system status information
  - Includes warnings, cautions, advisories

- Diagnostic systems are imperfect
  - Sensors must be $10^{-5}$ reliable while critical systems designed to $10^{-7}$ reliability
    - Alarms can be triggered by actual event or sensor failure
  - Two error types:  false alarm (false positive) and miss (false negative)
  - The more reliable the hardware (engines, gearbox) the higher the false alarm rate
    - Pilots with ‘better’ hardware get ‘worse’ warnings
  - False alarms are especially problematic during high workload intervals
    - Limited time to assess signal reliability
  - Operators are surprisingly attuned to warning reliability

Dixon, SR, Wickens, CD & McCarley, JS (2007) On the independence of compliance and reliance: Are automation false alarms worse than misses? Human Factors, 49(4), pp.564-572
Meyer, J & Bitan, Y (2002) Why better operators receive worse warnings, *Human Factors*, 44(3)

# Alert Reliability Effects on Compliance

- Operator Responses:
  - Compliance: Correct response to signal
  - Reliance: Correct response to silence
  - Responses affected by background noise, interruptions, workload
- 'Cry Wolf' effect
  - False alarm becomes nuisance alarm
  - Nuisance alarms provoke operators to disable or ignore alerts
  - Observed in cockpit, ATC, medical environments, smoke alarms
    - ATC controllers good at detecting concerns before alarms sound
    - Automation complacency
- Both false alarms and misses have costs
  - Diversions are expensive
  - Late or incorrect responses can be lethal

Dixon, SR, Wickens, CD & McCarley, JS (2007) On the independence of compliance and reliance: Are automation false alarms worse than misses? Human Factors, 49(4), pp.564-572
Ruskin KJ, Corvin C, Rice S, Richards G, Winter SR & Ruskin AC (2021) Alarms, alerts and warnings in air traffic control: An analysis of reports from the Aviation Safety Reporting System, *Transportation Research Interdisciplinary Perspectives*, 12 (2021) 100502

# Colleague Research: Rail Crossing Warnings

- 2021: More than 1,600 collisions between vehicles and freight and commuter trains
- Dissertation: Simulator study of driver behavior at dynamic rail crossings
- Four system states:
  - Proper activation (hit)
  - False Activation (false alarm)
  - Failure to activate (miss, false negative)
  - Proper inactivation
- Drivers' expectation of train arrival related to proceed decisions
  - Increased system reliability and trust increased compliance
  - Increased false alarm rate reduced trust and led to increased gate violations

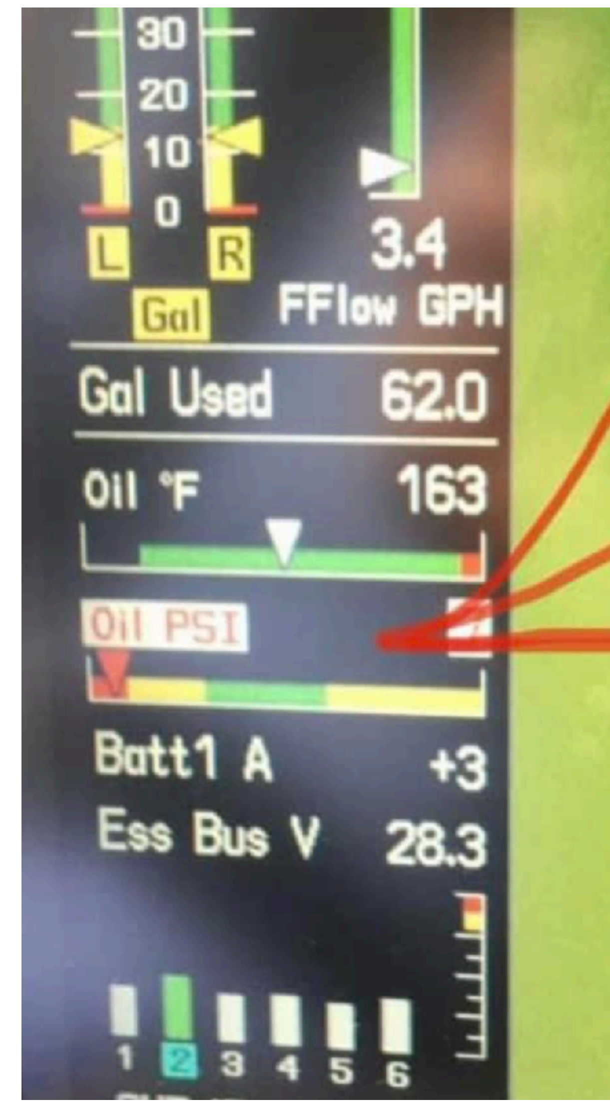
*Always expect a train*, video at https://www.nhtsa.gov/campaign/railroad-crossing

Gil, MC (2005) Driver compliance and noncompliance at actively protected highway-railroad grade crossings, Doctoral Dissertations. AAI3180204. https://digitalcommons.lib.uconn.edu/dissertations/AAI3180204

# Alert Reliability Effects on Compliance

- Researchers explored effects of warning reliability
  - Participants responded to alerts during tracking tasks
  - Three conditions:
    - 100% reliable
    - 60% False alarms
    - 60% Missed alarms
  - Researchers used eye tracker to measure scanning behavior

- Findings:
  - The more reliable the alerts, the more reliable the responses
  - Miss-prone automation
    - Did not affect compliance with alerts (misses are less visible)
    - Participants reduced tracking time to increase scanning parameters for danger
  - False Alarm Prone automation
    - Negatively affected compliance with alerts
    - Response time increased as operators spent significant time double checking parameters related to alerts

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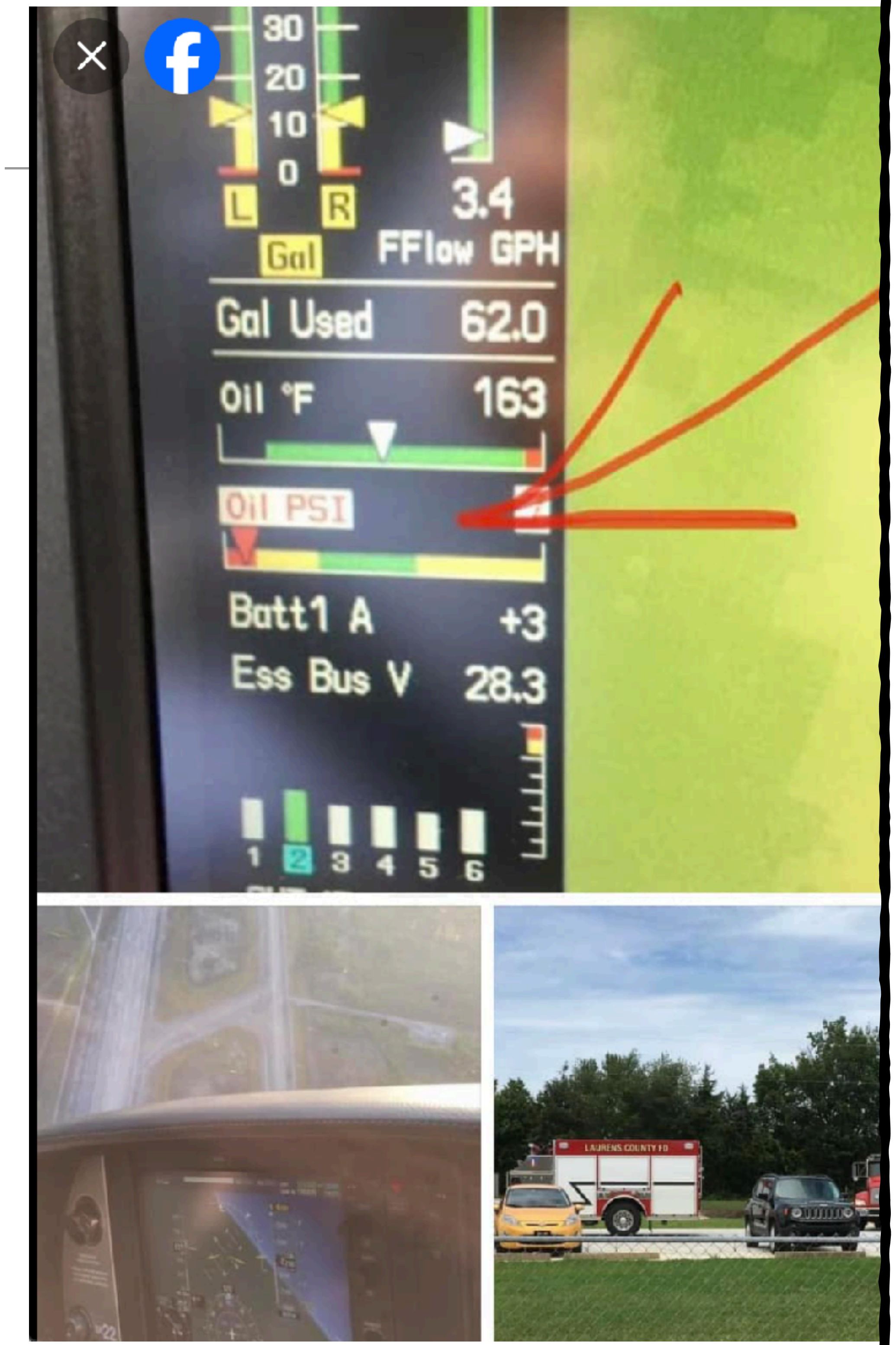


https://www.facebook.com/photo?fbid=1163363408048086&set=a.72

The day oil pressure dropped to zero somewhere in the middle of nowhere.

While in level flight at 10000’ my instrument student and I were **blindsided by an aural BING** in the cockpit. **Our eyes were immediately directed to an OIL PRESS caution annunciation** on the Cirrus SR22’s PFD display. Anyone who pilots an airplane will tell you this could mean big trouble.

A quick **cross-check of the oil temperature indication showed a normal reading** so it was our job to **decide if this was just a pressure sensor failure or an actual loss of pressure.** If a rise in oil temperature accompanies a low oil pressure indication you should expect imminent engine failure. This wasn’t the the case though.

Our first thought was to go through the six Aeronautical Decision Making (ADM) steps to make a **decision to continue and monitor the situation or divert and land immediately**. Those six steps are:

1. Recognize a problem exists. DETECT
2. Should we act immediately or can we wait? ESTIMATE
3. Choose to act or wait. CHOOSE
4. Identity what courses of action are available to mitigate the problem. IDENTIFY
5. Implement the best course of action. DO
6. Evaluate the outcome. EVALUATE

**Considering the possibility of an engine failur**e, we decided to not continue the remaining 30nm to our destination and instead **divert to the nearest airport** which was approximately 10nm straight ahead, smack in the middle of nowhere. We would then check the oil level and call the mechanic to get an opinion. My student alerted the Center controller and received an amended instrument clearance “you are cleared direct—descend and maintain 4000 feet”. The controller then asked if we needed assistance to which we replied “not at this time but we prefer to remain at 10000 feet until overhead the airport just in case the engine quits”. Minutes later and **nearing the destination airport, the caution changed to a warning with a constant BING BING BING. We saw zero oil pressure indication and immediately declared an EMERGENCY.** My student pulled power to idle and we began to spiral down to the runway below. We made certain that we stayed directly above the runway all the way down.

As we passed through 3000’ agl, I requested a frequency change to **announce our intentions** on the advisory frequency at this non-towered airport. There was one aircraft holding short and one on downwind to which I announced “traffic at XYZ airport you have a Cirrus directly overhead at 3000 feet spiraling down to the runway with an engine failure. Please do not takeoff, and will the airplane on downwind please extend until we land”. They both replied that they would.

Our last spiral placed us abeam the numbers at around 1500’ agl. My student performed a near perfect short approach and landed next to what appeared to be every fire truck and fireman in this little town. Apparently the **fire department was alerted by ATC** and managed to get there in the eight to ten minutes it took us to spiral down and taxi in.

A quick check of the oil **dip stick (less than one quart remaining) and belly of the Cirrus (covered with oil)** revealed the urgency of the problem. We were pleased with our decision to divert as it turns out **two cylinders needed to be replaced.** ADM worked great that day!

Fly safe friends

# Research Findings

- Pilots can overestimate their system knowledge
  - Inert Knowledge: Can recite facts but not cannot apply during events
  - Knowledge Gaps: Difficult to detect, can lead to overconfidence
- Pilots experienced difficulties when forced out of well-practiced routines
  - Pilots tend to learn/stay proficient in a subset of systems and commands
  - Routine system knowledge often does not apply during challenging operations
  - These situations are infrequent so there are fewer opportunities for exposure and practice

Woods, DD (1993) The price of flexibility in intelligent interfaces, *Knowledge-Based Systems,* 6, p.1-8

# Research Findings: Automation Strategies

- View training as a longer-continuous learning process
  - Build top-down system representations of physical and functional structures
  - Develop deep mental models of the system
  - Develop and practice scenarios utilizing less-used features, difficult or unusual flight contexts
  - **PRACTICE BASIC HANDING SKILLS** - Overreliance on automation can leave pilots vulnerable

- View automation as a task-offload system
  - Determine usage strategies
    - Each level/mode
    - High-tempo periods
    - High-workload periods / events
  - Determine strategies for managing automation surprises
    - Revert to hand flying if you need to

Woods, DD (1993) The price of flexibility in intelligent interfaces, *Knowledge-Based Systems,* 6, p.1-8

# Research Findings: Automation Strategies

- Collaborate with manufacturer / airframer
  - If you have a question - ask!
  - Events to report :
  - When information and/or cues needed to maintain situational awareness are hidden from the operator
  - Instances where automation increases memory demands
  - When automation makes indirect changes without clearly informing users
  - Complex, arbitrary control sequences
  - Multiple unrelated functions assigned to a single control
  - Situations that impair forming accurate models of system functioning
  - Situations that mislead users into thinking inaccurate mental models are accurate
  - Forced serial display / access to interrelated data, esp. during high workload/high tempo tasks
  - Suggestions to attenuate cues and alerts
- Incorporate unusual display events into training scenarios

Woods, DD (1993) The price of flexibility in intelligent interfaces, *Knowledge-Based Systems,* 6, p.1-8

Questions?

# Situational Awareness

- Situational Awareness: An internalized mental model of the correct state of the flight environment

- Five Components:
  - Geographic: Where we are in relation to other elements such as airports, waypoints, other aircraft, etc.
  - Spatial / Temporal: Where we are in relationship to these elements over time
  - System: Knowledge of aircraft structures and the current status of aircraft systems and subsystems
  - Environmental: Status of the flight in reference to terrain, weather, NAS, and regulatory environments
  - Tactical: Where we are in relation to the goals of the flight

- Three Levels
  - One: Perception of elements in the environment
  - Two: Comprehension of the current situation
  - Three: Projection of future status

- Barriers to Effective Situational Awareness
  - Cognitive, social

- Team Situational Awareness
  - Crew members must have shared mental models or crew effectiveness is reduced

Endsley, M (1999) Situational awareness in aviation systems, in Handbook of Aviation Human Factors, Garland DJ, Wise JA & Hopkin VD, Eds., p. 257-276

# Mental Models

- Goal-driven internal representations used to store, recognize, and interpret information to navigate the world around us
  - Also known as cognitive models, schema
- Developed during interactions with the environment
  - Sound: Engine noise, aural alerts, other crewmembers, passengers
  - Smell: Oil, fuel, burning, fresh air
  - Vibration: Stick shaker, change in motor RPM, turbulence
  - Sight: Outside information, cockpit environment
  - Taste: ??
- Larger elements are incorporated first, then details
  - Models are enhanced with repetition
- Generate expectations of how elements in the environment will behave
- Core element of the naturalistic-decision making process