

#### Federal Aviation Administration

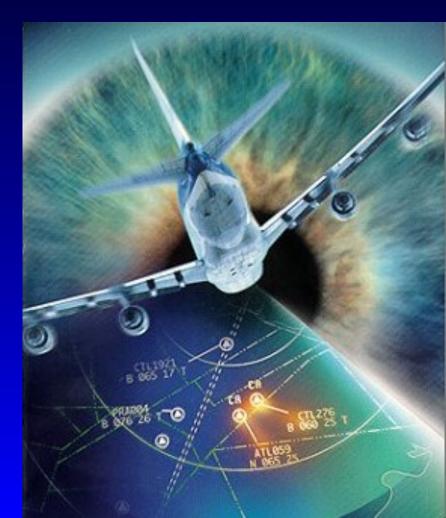
## Human Factors & Safety Issues of Cockpit Automation

Congreso Internacional de Medicina Aeroespacial

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President, International Academy of Aviation & Space Medicine

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## HUMAN FACTORS (ICAO Definition)

"Human Factors is about people; it is about people in their working and living environments, and it is about their relationship with equipment, procedures and the environment"

"Just as important, it is about their relationship with other people. Its twin objectives can be seen as safety and efficiency"

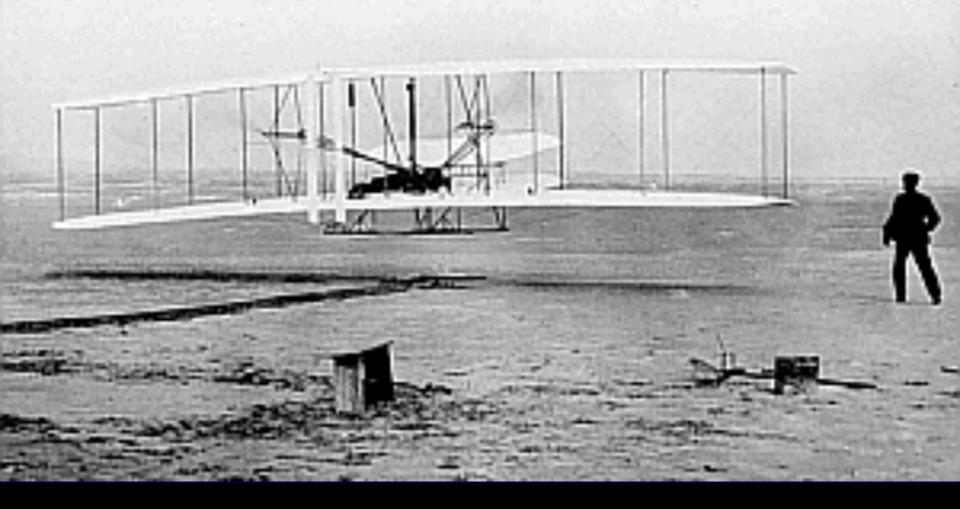
## Why Human Factors are Important?

The majority of all aviation accidents are due to human factors (not necessarily pilot error)

Most aviation accidents and incidents due to human factors are preventable

ICAO has recommended that all pilots receive training in human factors

#### Following their first flight on Dec/17/1903 the Wright Brothers Introduced the Automatic Stabilizer in 1908



## Automation

Automation refers to the techniques, methods, or systems used to operate or control a productive process by means of autonomous mechanical and/or electronic devices

## **Basic Considerations:**

The human being is flexible/adaptable to varying conditions, but has limitations performing repetitive tasks were consistent and reliable results are required

The machine is very consistent and reliable performing repetitive tasks, but is not very flexible/adaptable to new and unexpected conditions



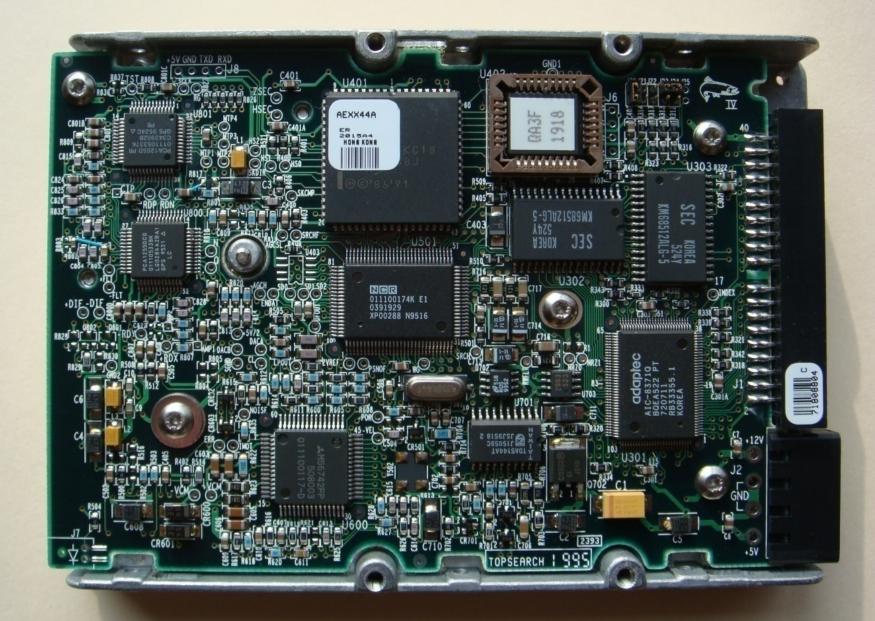
#### Factors that have promoted th development cockpit automation ave have have have have have t have at have hat have coclastatationtation cockdate alatomention

cockpit automation

New digital technology is highly reliable and requires minimum maintenance

New types of multi-function electronic displays that offer great flexibility to present information in various formats

Less physical space is required in the cockpit to install digital instruments



Computers allow a more efficient control of power plants

More precise navigation and control of the aircraft

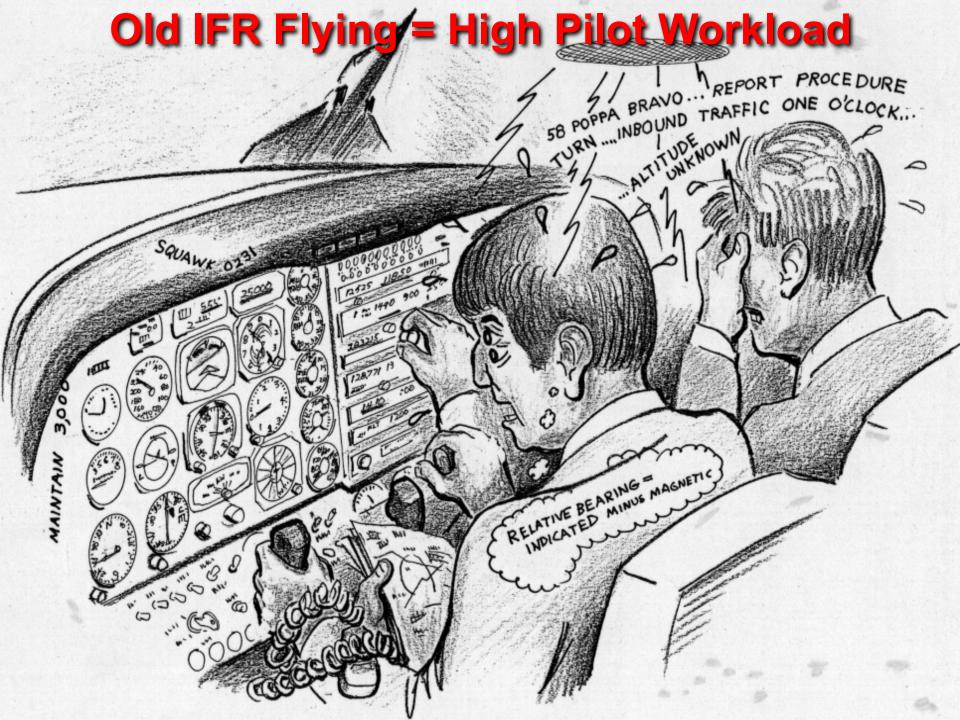
Release flight crews from performing monotonous repetitive tasks

#### Decrease workload in the cockpit

Goal to eliminate pilot error as a cause of incidents and accidents

Improve the human-machine interface

Enable certification of commercial aircraft with pilot and co-pilot only (no flight engineer/navigator)



#### OLD AUTOMATED SYSTEMS (Analog Technology)

#### Gyroscopes

#### Auto Pilot

Alarm Systems (advisory & emergency)

## Sperry Autopilot 1922

#### Wiley Post: 7 Days around World July 15-22, 1933 Sperry Autopilot





## ECONOMIC AND SAFE AIRCRAFT OPERATIONS

### NEW AUTOMATED SYSTEMS (Digital Technology)

Fly-By-Wire Auto-throttle Flight Director Flight and Navigation Control Systems TCAS Automatic Landing Advisory and Emergency Information Anti-lock Braking Systems

## First fly-by-wire System



Mexico Los Voladores de Papantla www.baxtion.com







# **Glass Cockpit**

This term is used to describe highly automated cockpits using <u>several</u> <u>computer-driven multi-function electronic</u> <u>displays</u> that allow the presentation of <u>different types of information</u>, in different formats, but on the same screen

## Cockpit Automation in Commercial Aviation





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## Cockpit Automation in General Aviation

# Advanced General Aviation Transport Experiments (AGATE)

Joint Sponsored Research Agreement NASA/FAA/Industry/Universities

#### **AGATE Work Packages**

- Flight Systems
- Propulsion Sensors & Controls
- Integrated Design & Manufacturing
- Ice Protection Systems
- Training Systems
- Airspace Systems Infrastructure
- Ground Systems Infrastructure

#### **NASA AGATE Vision From Early 1990's**



## How Could GA Safety Be Improved?

Eliminate the Cause and Mitigate the Effects of an Accident

- Reduce Pilot Workload / Human Error
- Improve Terrain Avoidance Capability
- Improve Low Speed (Stall) Handling
- Improve Weather Information to Pilot
- Improve Crashworthiness

- Enhanced single pilot performance
- Integrated aircraft automation
- Autopilot with auto-throttle
- Autoland
- Open architecture
- Intelligent auto-flight systems
- Envelope protection and automation

SATS-Cockpit Concept NASA Langley Research Center

2/3/2000

Image # EL-2000-00008

What Automation Technology is Available in Today's GA Cockpits?

# "Technically-Advanced" Aircraft (TAA)

The pilot interfaces with one or more computers in order to fly, navigate, or communicate.

Aircraft with a minimum of an IFR-certified GPS navigation system with a moving map display, and an integrated autopilot.

Some TAAs have a <u>multi-function display that shows</u> weather, traffic and terrain graphics.

### **Technically Advanced Aircraft?**



# Examples of Technically Advanced Aircraft



# Avidyne Cockpit



## **Chelton Cockpit**



# Garmin Cockpit

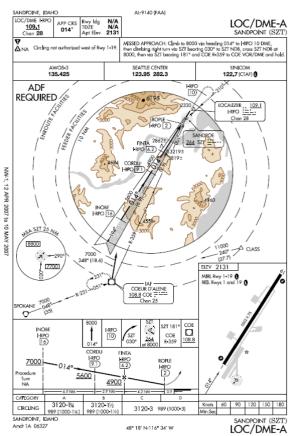




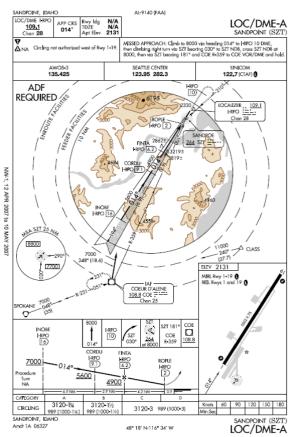
#### **Terrain and towers**

#### Terrain, weather, roads, cities





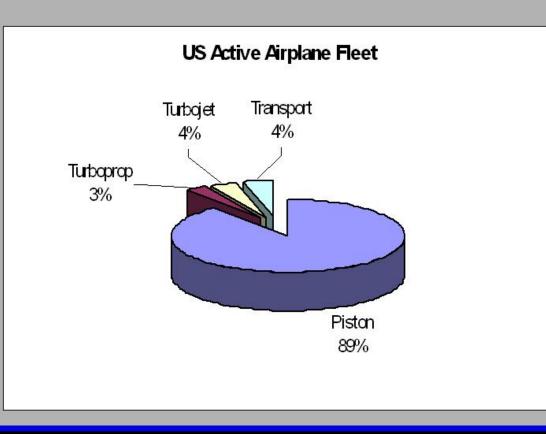






## Technology Integration Issue Updating the Small Airplane Fleet for Safety

- > 210,000 Airplanes in US - 89% Piston
- Average age >35yrs
- Few New Airplane Designs
- Retrofit issues to make them safer



### Cirrus Sr20 "Blue Button" Recovery



# Cirrus GFC 700 "Level" Button Introduced in May 2008





However, Cockpit Automation in GA has not Achieved the Desired Safety Goals

# 2010 NTSB REPORT

Glass cockpit technology has not significantly improved safety of small light aircraft.

During the <u>2002-08</u> period conventionally equipped aircraft suffered 141 accidents (16% fatal), while glass-equipped aircraft suffered 125 accidents (28% fatal).

The NTSB made 5 recommendations related to equipment specific training and one related to testing requirements.

Other Advanced Technologies

### Visual Augmentation Systems (Synthetic Vision)

#### Universal

Chelton





### Honeywell







#### Visual Augmentation Systems (Night Flying)





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Human Factors in Cockpit Automation



Federal Aviation Administration



Fusion of the SVS PFD with infrared enhanced vision is another innovation from the Rockwell Collins team. In this view, the pilot can see his 3D pathway in the sky, obstacles in the SVS database and IR EVS imagery—the actual terrain in front of the aircraft—in real time. Rockwell Collins

#### **Digital Personal Assistants**



The "Pilots Personal Assistant," essentially a portable computer that stores checklists, charts and approach plates, manuals and logbooks, is an Epic system option. It can in-terface with aircraft avionics or be removed for flight planning.

Law Rel. Charge Co.

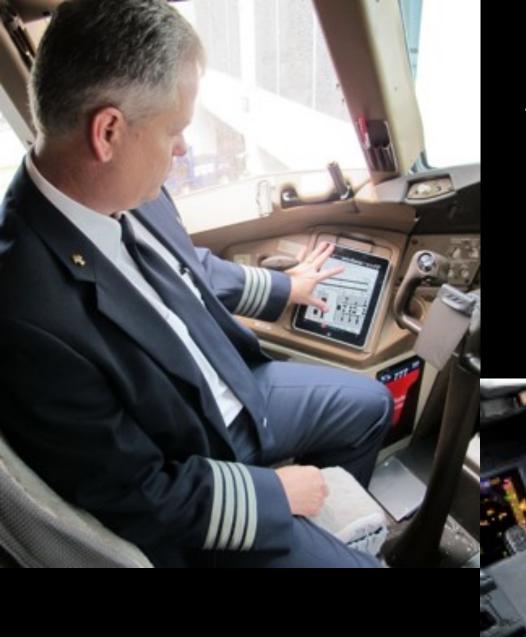
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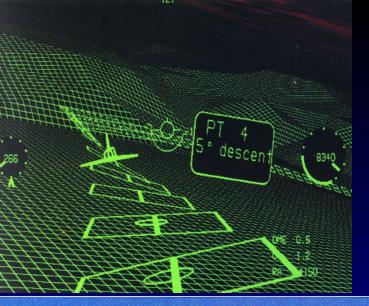
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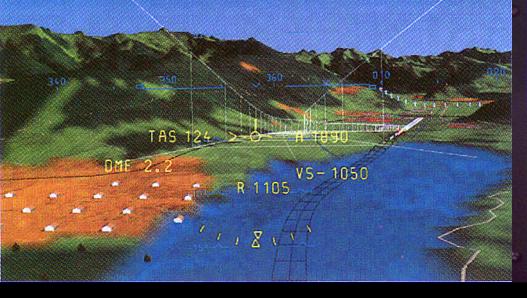


I Pads are being used in the cockpit (except for navigation purposes, during takeoff and landing)





#### Pathway In The Sky Displays

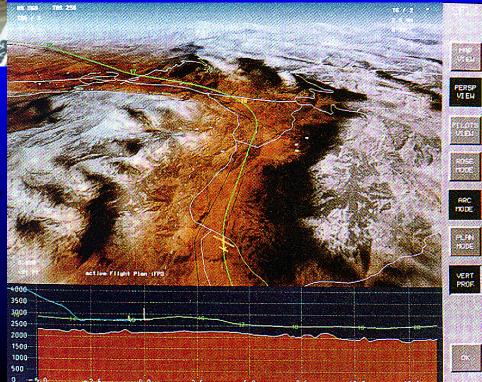








### Enhanced Ground Proximity Warning System



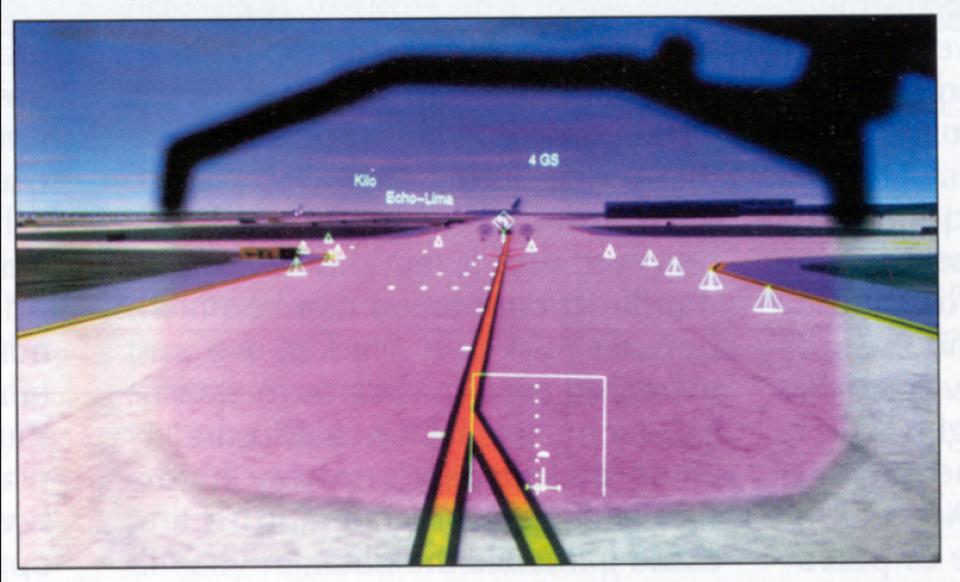


#### **Head-Up Displays**

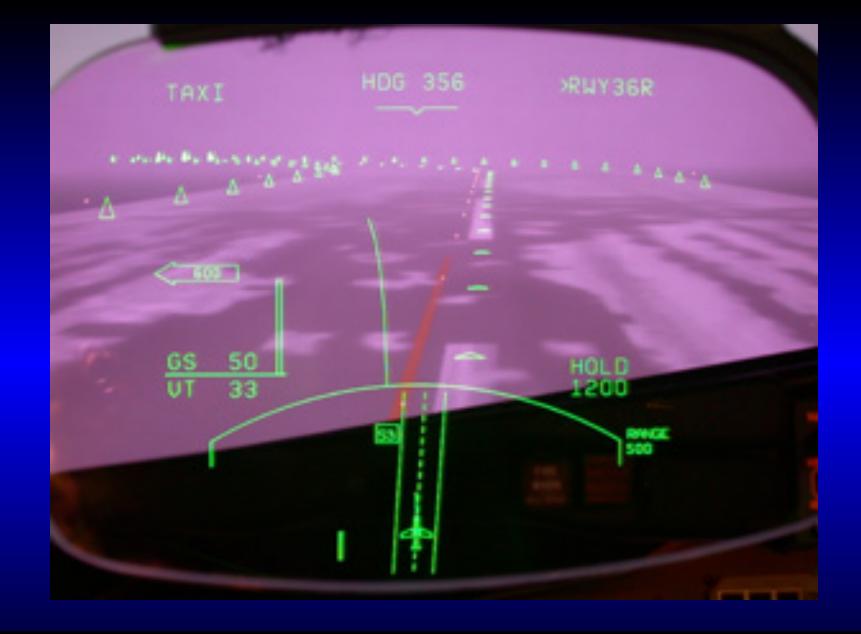


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NASA's runway incursion prevention system (RIPS) combines GPS, datalink and ADS-B with a HUD interface. Virtual cones delineate taxi routes while position and speed data are provided in text form.

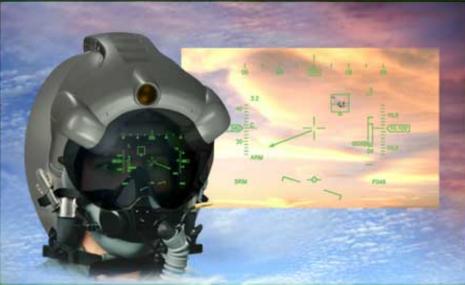














### Head-Mounted Displays for Civil Aviation





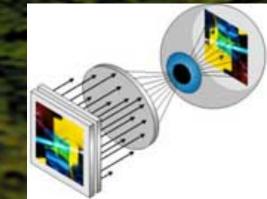
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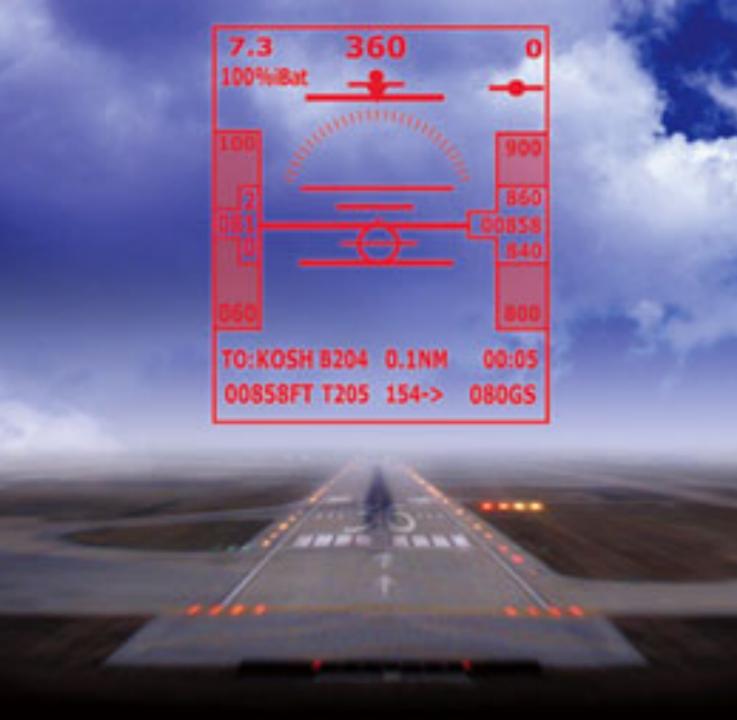
FLEXIBLE VIDEO SCREEN prototype from Universal Display Corporation gives new meaning to the words "motion picture."



### **Retinal Displays**









Garmin's pocket-sized, portable HUD wirelessly connects to a smartphone running a navigation app, and throws directions and useful information onto the inside of the windshield

## AUTOMATED SYSTEMS OF THE FUTURE

- 3D Holographic Displays
- Artificial Intelligence
- Virtual Reality Systems
- Vision-Controlled Systems
- Voice-Controlled Systems
- Mind-Controlled Systems





## Multi-modal control lab



Researchers at the University of Minnesota are developing a mindcontrolled quadcopter

Using a skullcap fitted with a Brain Computer Interface (BCI), the University's College of Science and Engineering hopes to develop ways for people suffering from paralysis or neurodegenerative diseases to employ thought to control wheelchairs and other devices

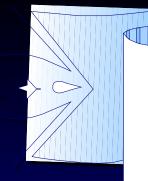
# Brainflight Project



Scientists at the Institute for Flight System Dynamics at Technische Universität München (TUM) and Technische Universität Berlin (TU Berlin) are involved in the EU-funded Brainflight project

An algorithm developed by scientists at TU Berlin deciphers electrical potentials and converts them into control commands

The goal of project BRAINFLIGHT is to investigate what are the best approaches and parameters that allow fast learning to control an aircraft using brain signals, while allowing pilots to multitask



# **Cockpit Automation Design Philosophies**

A) Automate all of those functions that prevent a pilot from exceeding (inadvertently) the safety limits of the aircraft.

<u>THE AUTOMATED SYSTEM HAS FINAL</u> <u>AUTHORITY</u>



#### A320





#### A340

## AIRBUS (A-320, A-330, A-340):

Fly-by-wire aircraft have "hard" speed envelope protection features that prevent pilots from stalling the aircraft and from pulling more than 2 +Gz even in an emergency

Pilots do not have access to the aircraft's full performance envelope



B) Automate only those functions that help the pilot operate an aircraft without interfering with the pilot's choice to fly the aircraft manually. Pilot has access to full performance envelope.

<u>THE PILOT HAS FINAL AUTHORITY</u>



#### **BOEING (B-777):**

The fly-by-wire system lets pilots fly the aircraft through a computer, but it does not have a "hard" speed envelope protection

It requires the pilot to apply more force on the yoke during >35 deg. banks and when pulling the yoke back if the aircraft decelerates below minimum maneuver speed ('soft" speed envelope protection)



C) Combines a "soft" speed envelope protection system with automatic controllers that have a high level of authority controlling other systems

<u>THE AUTOMATED SYSTEM AND THE PILOT</u> SHARE FINAL AUTHORITY





#### McDonnell Douglas (MD-11):

The fly-by-wire system is similar to the B-777 but it also incorporates high authority automatic controllers to manage the fuel, hydraulic, pneumatic, and electrical systems operated independently by two computers

Pilots have access the full performance envelope



#### Always be prepared to deal with risks in disguise!



Increase in pilot's mental workload when flying below 10,000 and in the terminal area

Increase in "head down time" associated with the re-programming of computers in response to ATC directives

Higher risk of human errors associated with the initial and subsequent programming of computers

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#### 

Seu periodo de testes esgotou!

Favor registrar-se para continuar usando este software !



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WHITE MISTING

Complacency, monotony, boredom, and lack of vigilance during the low workload portions of a flight that can lead to inadequate response to unexpected emergencies

Difficulty to identify problems in the operation of automated systems (hardware & software), including false alarms (positive & negative)











Decrease of pilot motivation and satisfaction to fly

Concern about decreased performance in manual piloting skills

Loss of situational awareness

Tendency to use automated systems in response to sudden operational changes during flight, even when there is not enough time to re-program computers Pilot reluctance to take manual control over a malfunctioning automated system due to overconfidence on computerized systems

Sudden and unexpected malfunctions. Automated systems usually do not provide information about progressive changes that lead to a malfunction until the malfunction occurs Problems involving pilot transition between equipment with different types of automated systems

Transition problems between aircraft with glass cockpits and aircraft with minimum automation

Digital displays eliminate small errors but lead to severe errors (am. vs pm.) Current ATC systems are not compatible with the advanced capabilities (climb and descent profiles) of automated aircraft

It is difficult for one crewmember to see what the other is doing because the multifunction displays can show different information at the same time

A transference of authority from the pilot to the first officer can happen as a function of skills with automated systems



# "If you can't convince them, confuse them"

### **President** Harry Truman



#### **Clear Communications are Essential**



# **PILOT CONFUSION**

Pilots operating highly automated systems frequently ask themselves the following questions about such systems:

¿ What is it doing ?

¿ Why did it do that ?

¿ What is it going to do next ?

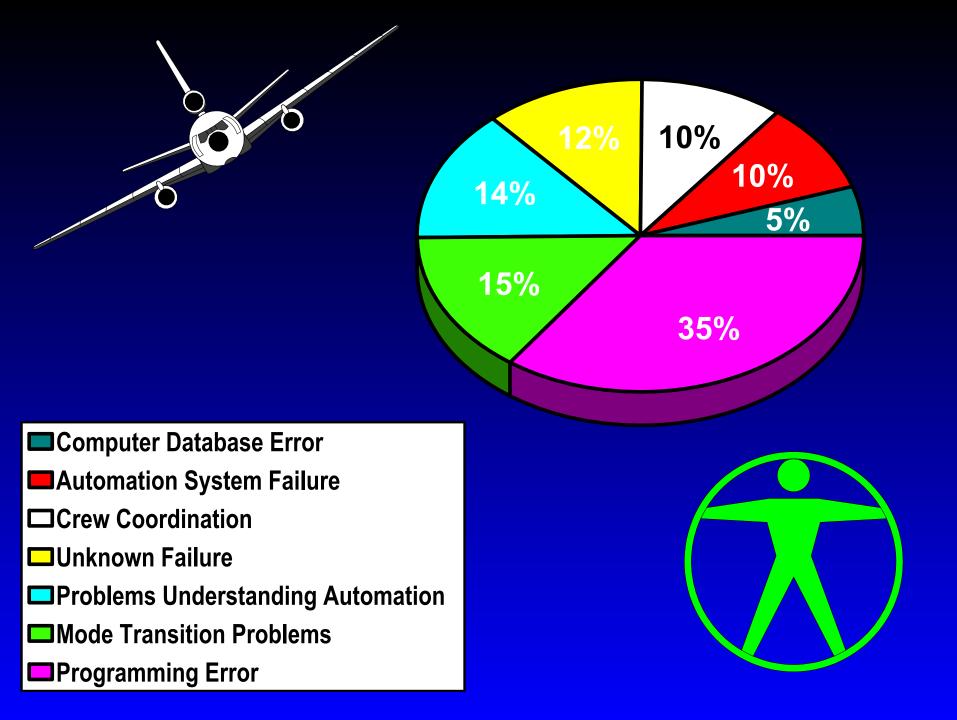
The most frequent cause of confusion among pilots flying aircraft with highly automated systems is commonly known as "mode confusion"

#### EXAMPLE

In an automated flight control system the transition between vertical climb mode, altitude capture, and altitude hold (level-off) occur rapidly and the system responds differently under each mode of operation MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT) - ASRS - (Feb 90-Ene 94)

- Analyzed 184 incidents related to mode confusion
- 74% involved confusion/errors in vertical navigation

26% involved confusion/errors in horizontal navigation

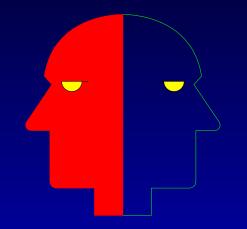




## "If something can go wrong, then it will go wrong"

Murphy's Law

## What is the primary function of a pilot in an automated cockpit?



#### FLY THE AIRCRAFT or CONTROL AND MONITOR AUTOMATED SYSTEMS

In general, the main problem with highly automated cockpits is the lack of a common design philosophy to ensure the development of a harmonious interface between the pilot and the automation

**Earl Wiener** 

The pilot is the most complex, capable, and flexible component of any air transport system, and, as such, is the most adequate to determine the optional use of all available resources in any given situation





Cockpit automation must be used to support and augment, but not to replace the functions performed by a human being during the operation of an aircraft



### **Principles of Human-Centered Automation**



Pilots must have an active role in controlling or managing the systems to which they delegate control of the aircraft

Pilots must be informed on real-time regarding the status and progress of tasks, operations, or systems Pilots must be able to monitor the automated systems because automation can fail

Automated systems must be able to monitor pilot performance because humans can fail

Automated systems must be predictable to allow pilots evaluate system performance and quickly detect and recognize malfunctions Through cross-monitoring, pilots and automated systems need to understand what each is trying to do

Automated systems must allow the pilot to take total manual control over a malfunctioning system

Automated systems must maintain the number of false alarms (positive and negative) within acceptable limits Automated systems must allow the pilot to select the desired level of automation

Automated systems must prevent excessive levels of pilot workload

Automated systems must allow the corroboration/confirmation of the information programmed by the pilot

## How to Certify New Technologies?

#### **ISSUES**

- Very hard to develop specific standards too many variables
- Develop performance standards because they are less restrictive for innovation
- Performance standards allow for subjectivity and can be vague
- Applicants would like assurances that what their designs will be certifiable

### How to Certify New Technologies?

#### SOLUTIONS

- Early FAA involvement
- Multi-pilot evaluations bench tests, simulators, and flight test
- Evaluations conducted by flight test human factors specialist – one person
- Try to use the same core group of test pilots for all evaluations

## How to Certify New Technologies?

#### SOLUTIONS

- Getting more involved in system development
- Also more involved in post-certification pilot training
  - FITS voluntary training programs
  - Emphasizing specific areas based on accident studies and historically weak pilot performance

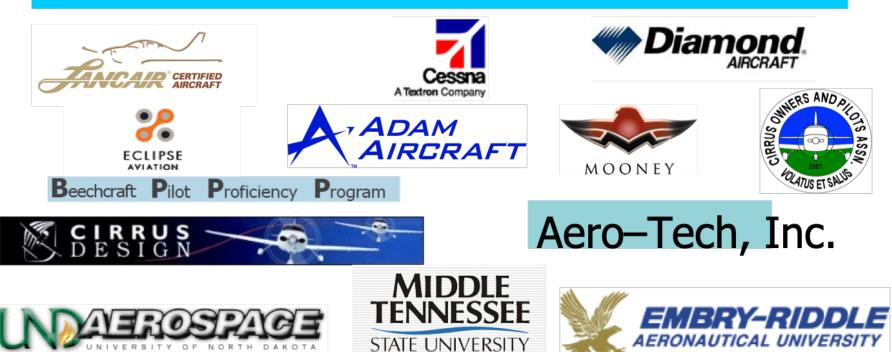
## How to Train Pilots to Fly Technologically-Advanced Aircraft (TAA) ???







## **"FITS"**



FITS was developed by the Embry-Riddle Aeronautical University and the Aerospace Department at the University of North Dakota through the FAA Air Transportation Center of Excellence for General Aviation Research (CGAR) FITS demonstrated that Scenario-Based Training (SBT) was as effective or better than traditional or Maneuvers-Based Training (MBT)

FITS trained pilots are more conservative with IFR decision making



What is the best approach to share final authority between the pilot and the automated systems?

What is the level of job satisfaction and motivation of a pilot who flies a highly automated aircraft?

What is the perceived level of responsibility of a pilot who flies a highly automated aircraft where the automated systems have final authority? What is the best criteria for the selection of pilots who operate highly automated cockpits?

What is the most effective combination of monitoring and control tasks for pilots flying highly automated aircraft?

What are the minimum requirements to maintain pilot proficiency to manually operate a highly automated aircraft?

# Incidents and Accidents Involving Cockpit



#### A Boeing 707 flying at 35,000 ft over Terranova

Autopilot was disconnected accidentally and nobody noticed

Aircraft entered a spin

The crew was able to regain control of the aircraft at 6,000 ft above the Atlantic Ocean

#### Lockheed L-1011



The crew of a Lockheed L-1011 was trying to determine the cause of a landing gear alarm

The autopilot was disconnected accidentally and nobody noticed

The aircraft initiated a slow descent from 2,000 ft and crashed in a swamp





The crew of an Airbus 320 was demonstrating a take off with a simulated engine failure

When the autopilot was activated the system selected an altitude capture mode where there is no AOA limit

The aircraft exceeded an angle of attack of 31 degrees

The aircraft lost speed suddenly, became uncontrollable, and crashed

#### Airbus 320 during touch down

Air/ground logic did not properly activate and caused a delayed use of ground spoilers and reverser

Aircraft overran the runway and two people were killed





Pilot versus autopilot dispute in an Airbus 310 caused aircraft to go out of trim

Followed by 5 pitch cycles peaking at 70-80 deg. nose up and 30 deg. nose down

Airspeed varied from 300 kt to below 30 kt in 4,000 ft cycles

Roll angles exceeded 100 deg. Aircraft was recovered



