Aircraft Controllability and Primary Flight Displays

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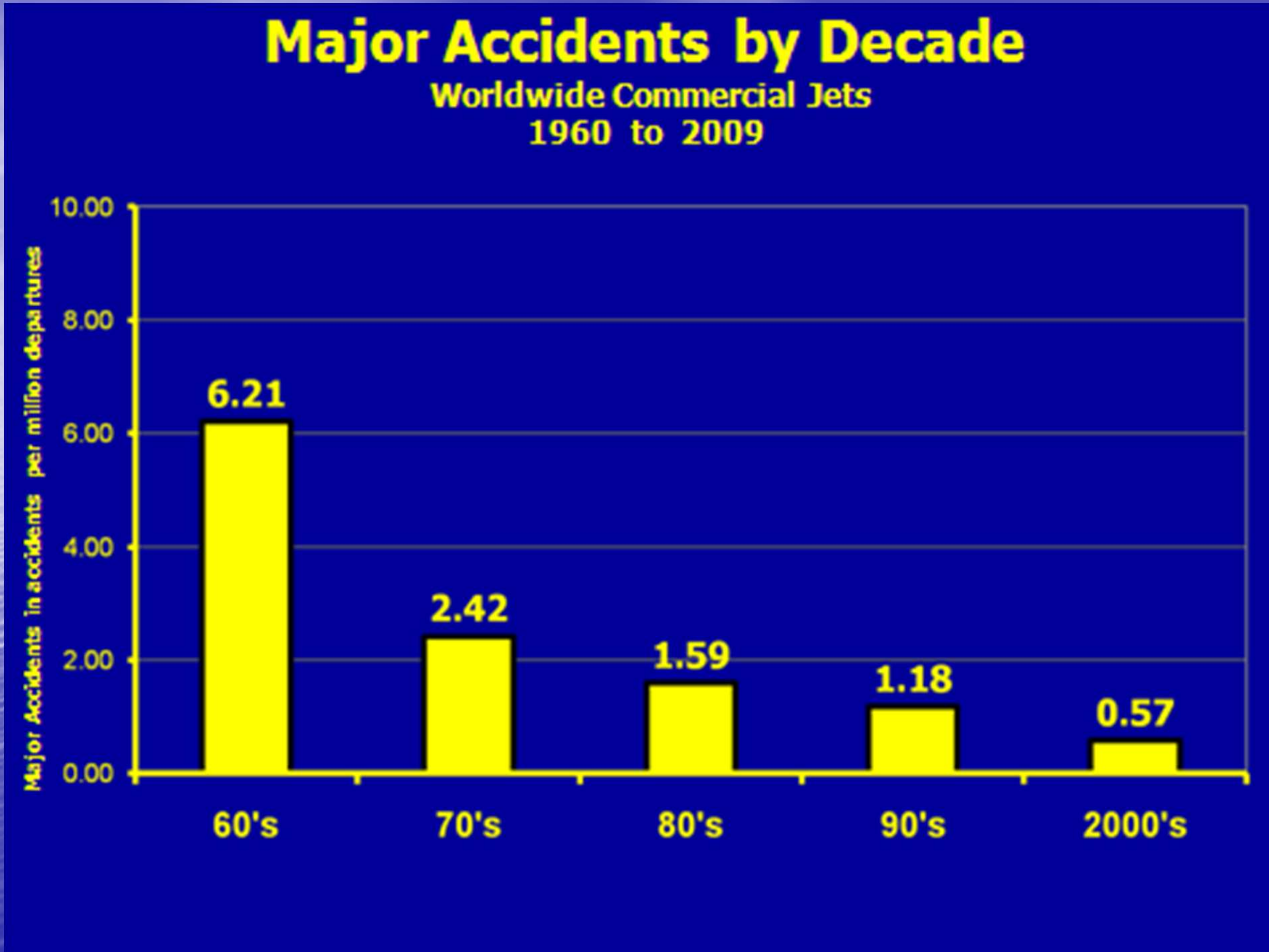
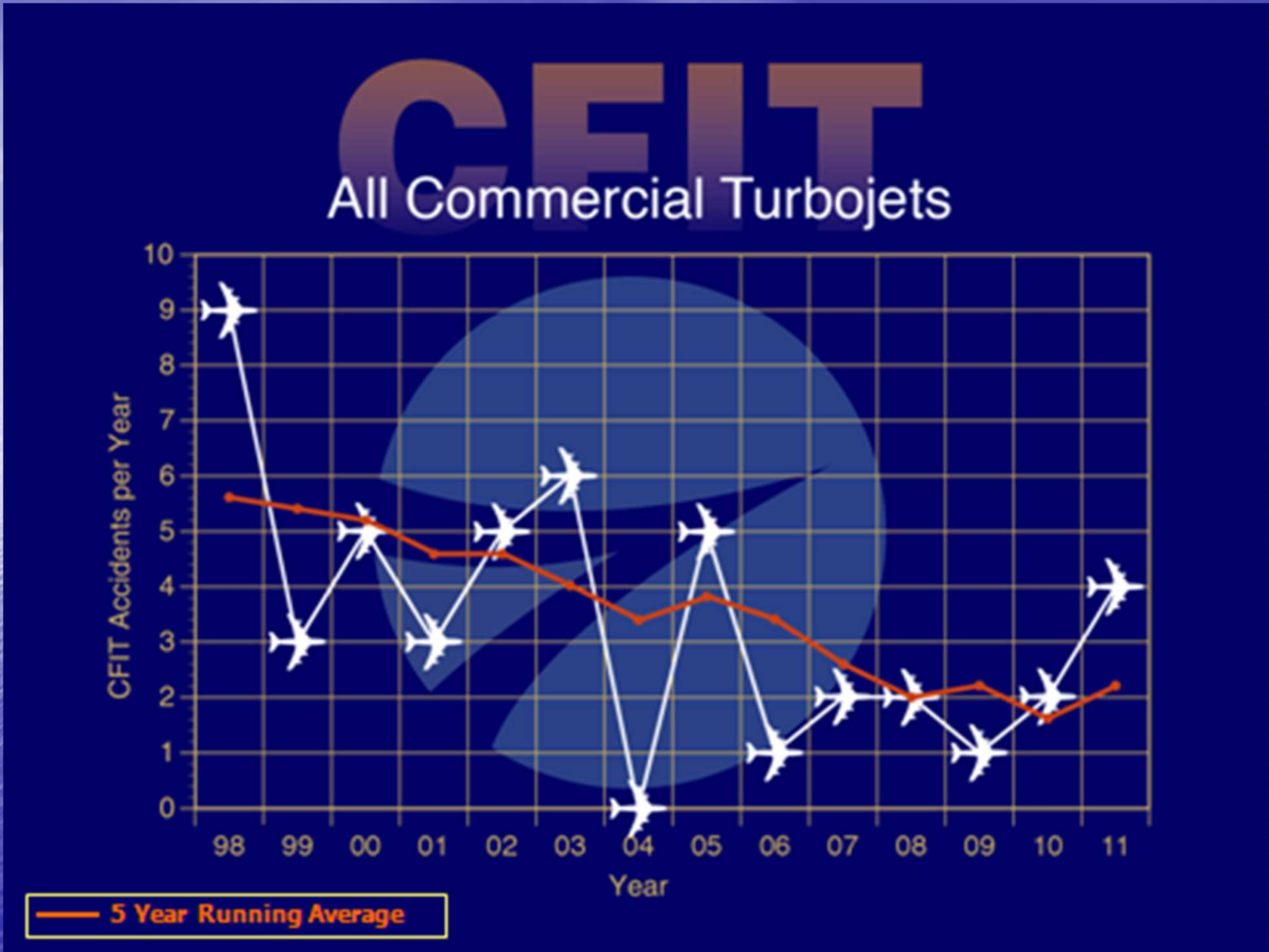
Subject outline:

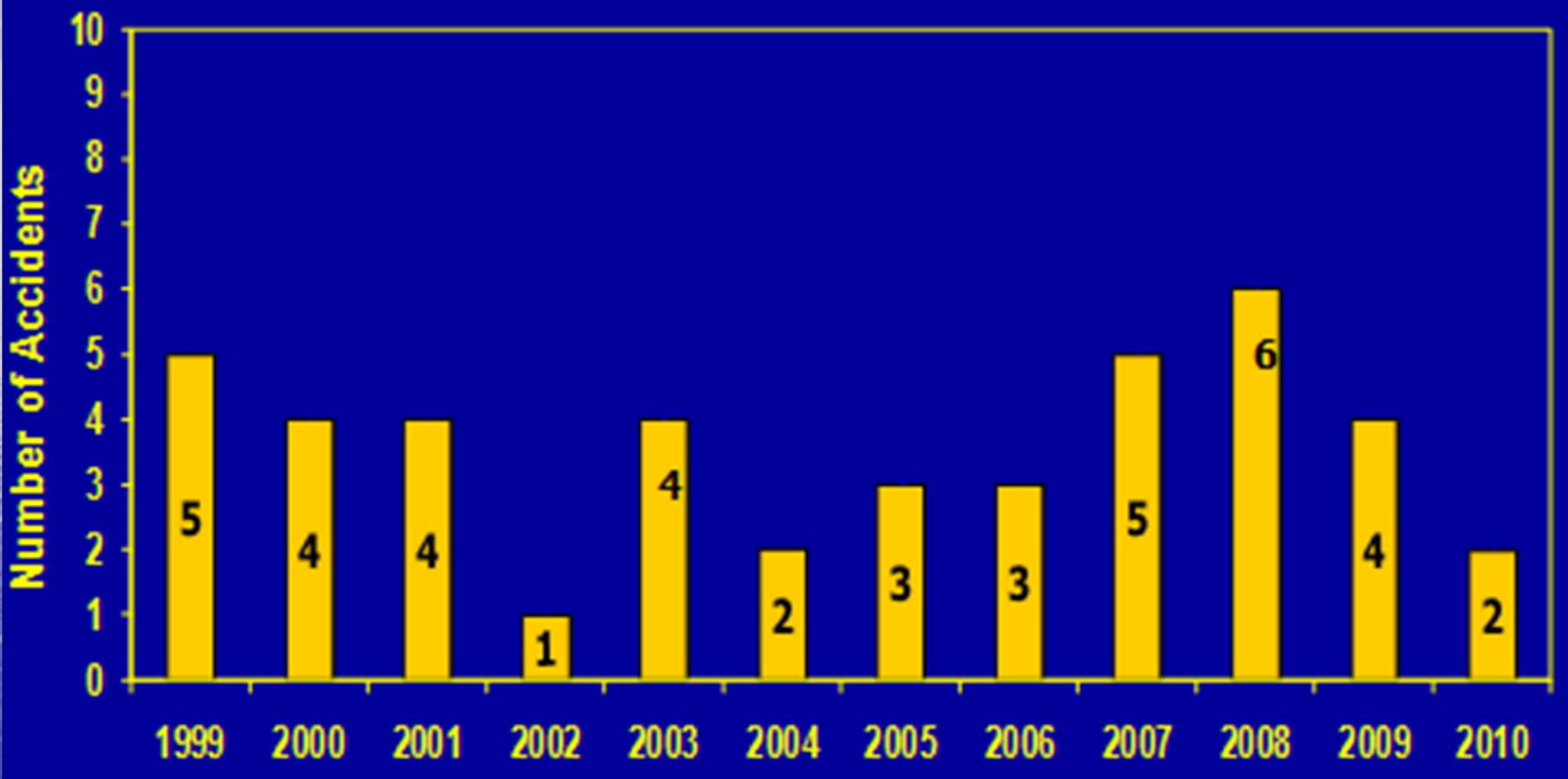
- Review of Aircraft Accidents
- Some Typical LOC-I Accidents
- Accident Investigations
- Coffin Corner
- Aerodynamic Stall and AOA indicators
- Developments in Flight Displays
- Aircraft Controllability
- Developments in Pilot Education and Training
- Cockpit Displays – Test and Evaluation
- Research on Primary Flight Displays and inclusion of AOA Indicator
- Conclusions

Review of Aircraft Accidents


Major Accidents by Decade
Worldwide Commercial Jets
1960 to 2009
Major Accidents in accidents per million departures
10.00
8.00
6.00
4.00
2.00
0.00
6.21
2.42
1.59
1.18
0.57
60's
70's
80's
90's
2000's


CFIT
All Commercial Turbojets
CFIT Accidents per Year
0
1
2
3
4
5
6
7
8
9
10
98
99
00
01
02
03
04
05
06
07
08
09
10
11
Year
5 Year Running Average

Loss of Control Major Accidents
Commercial Jets
1999 through 2010



Source: Ascend, Boeing

Some typical LOC-I Accidents

Stall during high altitude cruise:

- West Carribean MD-82. Venezuela 2005 – high altitude stall («coffin corner») – climbed rapidly from 31,000 ft to 33,000 ft to avoid TS – altitude could not be sustained – on autopilot which gradually lifted the nose to hold altitude until AP disengaged and A/C entered a stall.

  - Contributing cause factors: Let A/S drop to stall speed - improper stall recovery - A/C held with aft stick in deep stall with engine climb power until crashing – pilots confused.

Stall during high altitude cruise:

- Air France A330. South Atlantic 2009 - high altitude stall after loss of IAS (coffin corner) – A/C held with aft stick in a controllable deep stall with engine climb power until it crashed in the sea.

  - Contributing cause factors: Lost A/S – not controlling attitude – allowed the A/C to stall – improper stall recovery – A/C held in deep stall and climb power – pilots confused.

Stall during Approach:

- Colgan Air DHC-8-Q400. Buffalo USA 2009 – stall during approach – went trough stick shaker and pusher.
  Contributing cause factors: Improper stall recovery - overrode the pusher (by pulling) and entered a fatal spin to the right – pilots confused.

- Turkish Airlines B737-800. Amsterdam 2009 – stall during final approach on autopilot with one rad alt malfunction – stick shaker at 460 feet.
  Contributing cause factors: Improper stall recovery – too late recovery actions – pilots confused.

- Asiana Airlines B777-200ER. San Fransico 2013 – stall during final approach. Still under NTSB investigation.

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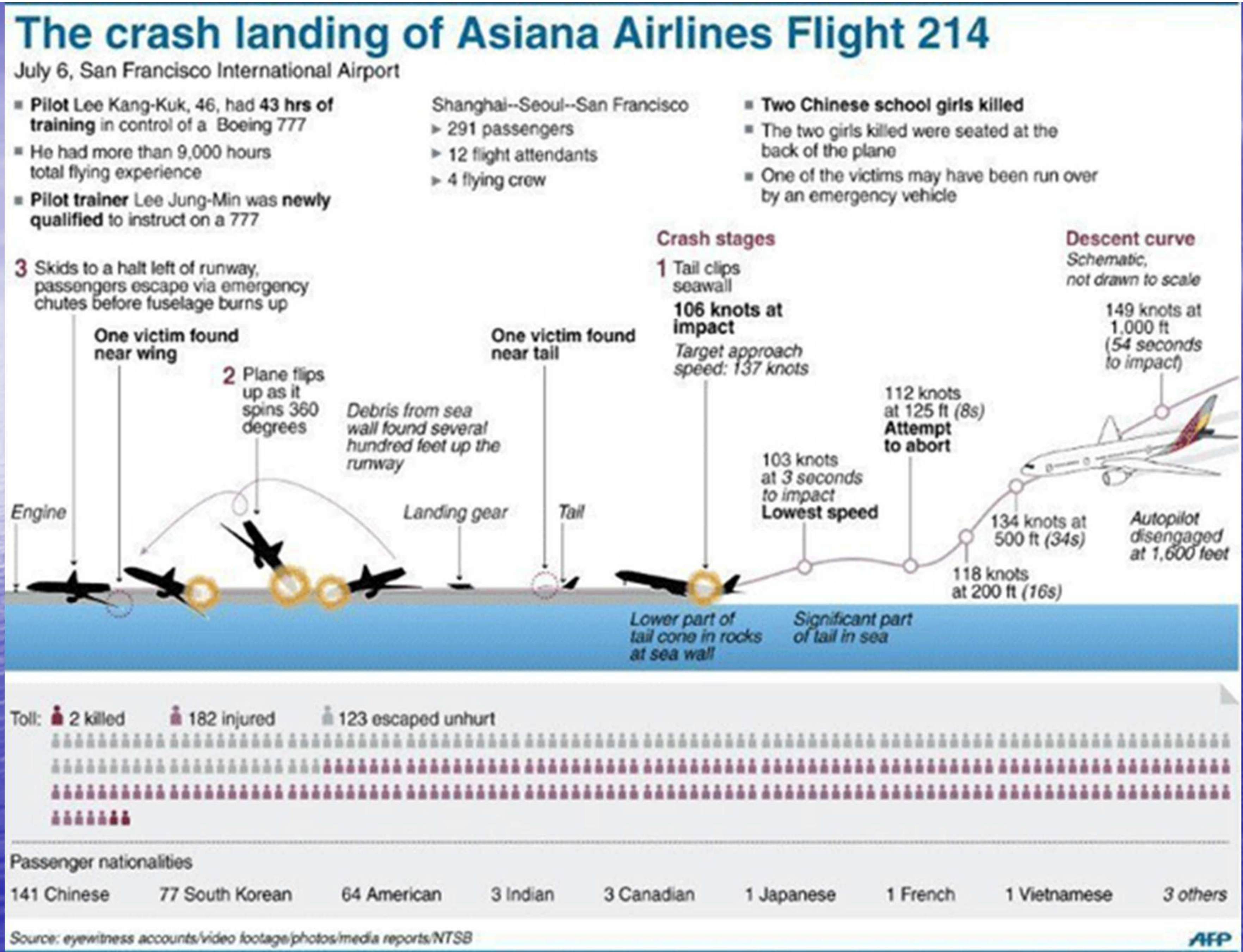
Stall during Approach:

- Asiana Airlines B777-200ER. San Fransico 2013 – stall during final LOC/DME approach. Still under NTSB investigation.

- CHC AS 332L2. Sumburgh, Shetland 2013 – Loss of airspeed during final LOC/DME instrument approach - Vortex Ring State. Still under AAIB investigation.


The crash landing of Asiana Airlines Flight 214
July 6, San Francisco International Airport
Pilot Lee Kang-Kuk, 46, had 43 hrs of training in control of a Boeing 777
He had more than 9,000 hours total flying experience
Pilot trainer Lee Jung-Min was newly qualified to instruct on a 777
Shanghai--Seoul--San Francisco
291 passengers
12 flight attendants
4 flying crew
Two Chinese school girls killed
The two girls killed were seated at the back of the plane
One of the victims may have been run over by an emergency vehicle
Crash stages
1 Tail clips seawall
106 knots at impact
Target approach speed: 137 knots
Descent curve
Schematic, not drawn to scale
149 knots at 1,000 ft (54 seconds to impact)
112 knots at 125 ft (8s)
Attempt to abort
103 knots at 3 seconds to impact
Lowest speed
134 knots at 500 ft (34s)
118 knots at 200 ft (16s)
Autopilot disengaged at 1,600 feet
3 Skids to a halt left of runway, passengers escape via emergency chutes before fuselage burns up
One victim found near wing
2 Plane flips up as it spins 360 degrees
Debris from sea wall found several hundred feet up the runway
One victim found near tail
Engine
Landing gear
Tail
Lower part of tail cone in rocks at sea wall
Significant part of tail in sea
Toll: 2 killed
182 injured
123 escaped unhurt
Passenger nationalities
141 Chinese
77 South Korean
64 American
3 Indian
3 Canadian
1 Japanese
1 French
1 Vietnamese
3 others
Source: eyewitness accounts/video footage/photos/media reports/NTSB
AFP

Accident Investigations

Accident Investigations:

Historically, most LOC accidents are labeled «Pilot/Human Error»

- Professor Dr. James Reason, 1997:

«The Organizational model views human error more as a consequence than as a cause. Errors are the symptoms that reveal the presence of latent conditions in the system at large»

- Professor Dr. Sidney Dekker 2006, offers two views on HE, :

The Old View: *«Human error is a cause of trouble» (bad Apple Theory)*

The New View: *«Human error is a symptom of trouble deeper inside a system»*

- Dr. Simon Bennett, 2012:

"Malfunctions are to be expected in aircraft, by virtue of their interactive complexity, tight coupling, and risk-and-error-prone operating environment. In the risk-laden world of aviation the pilot is the last line of defense".

Accident Investigations:

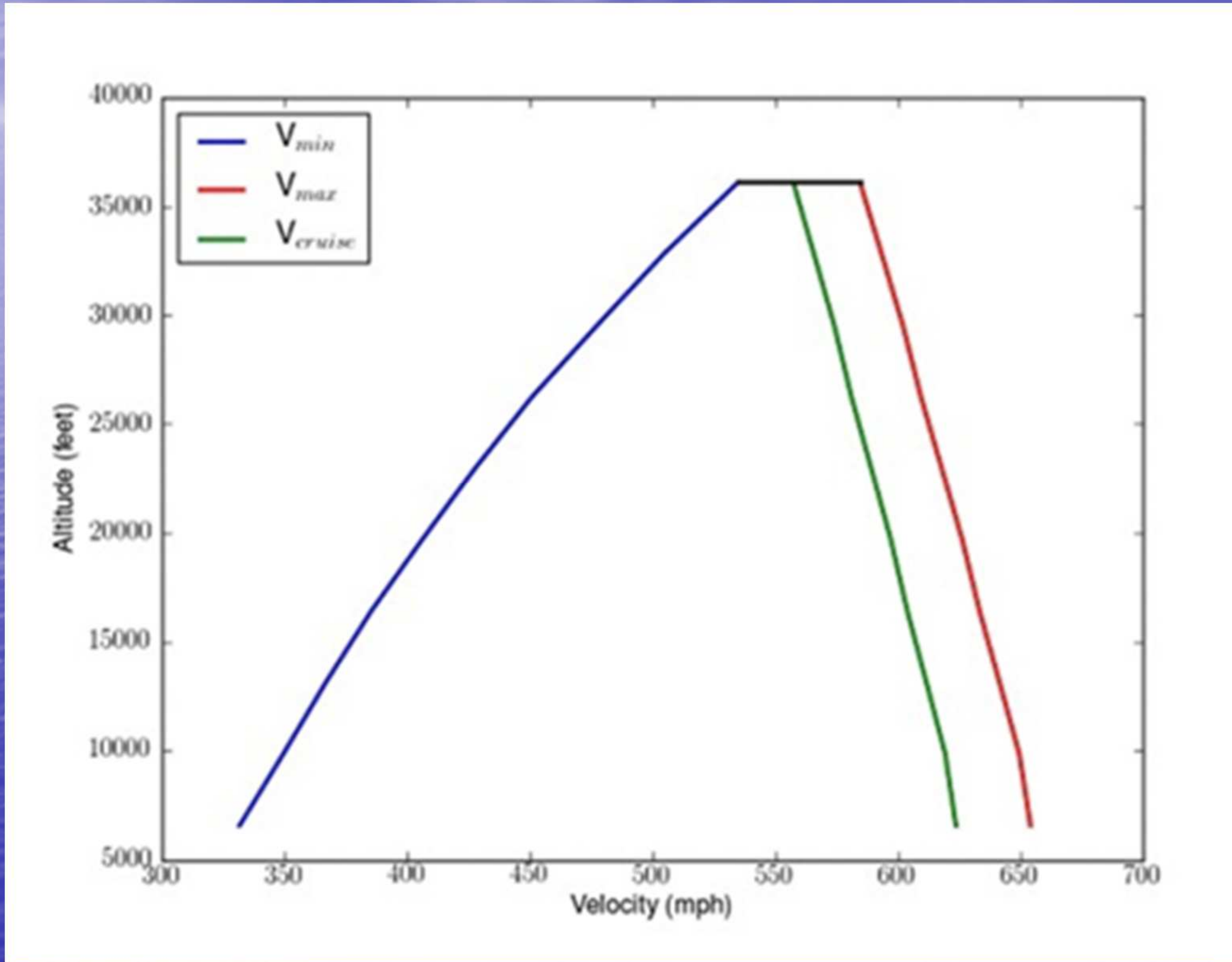
- Historically, most LOC accidents are labeled «Pilot/Human Error».

- In modern accident investigation theory Human Error is not considered a cause of accident, but a symptom of systemic weakness.

- LOC accidents are considered «Organizational Accidents» and have several underlying cause factors.

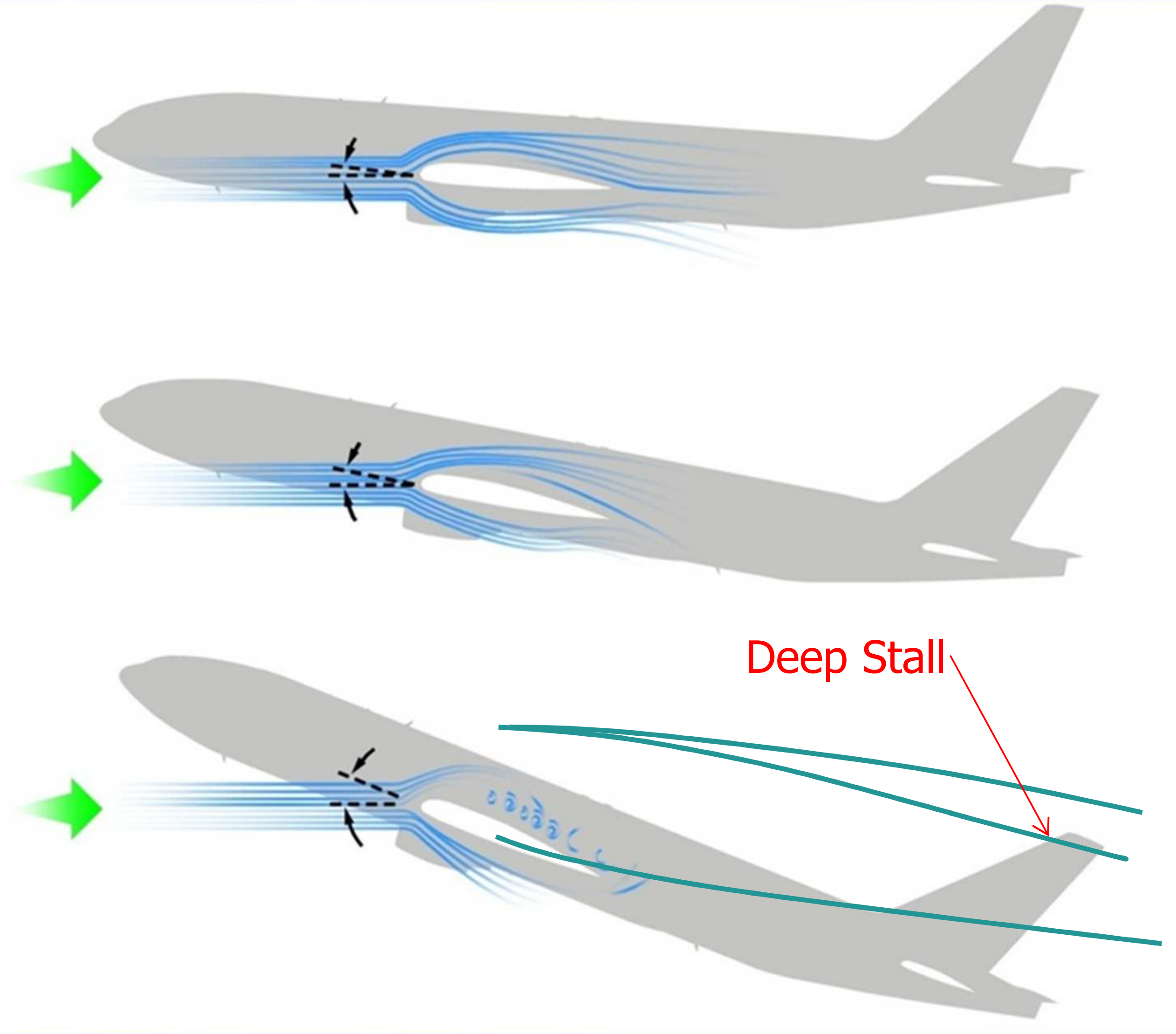
Coffin Corner

Coffin Corner



Aerodynamic Stall
and
AOA indicators

Aerodynamic Stall



Stall can occur when performing a variety maneuvers

The wing does not know about airplane attitude or airspeed

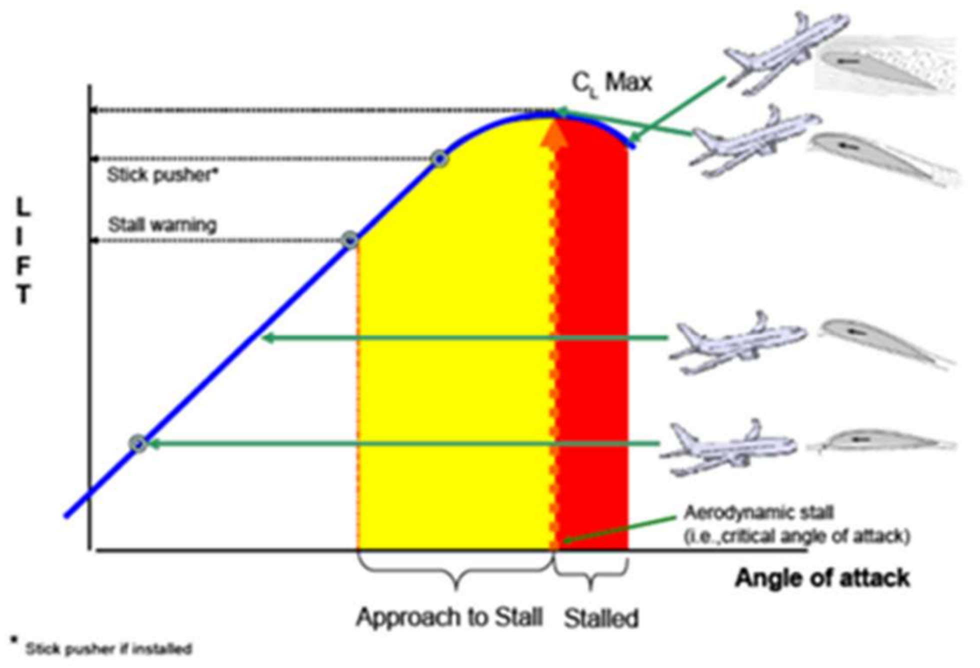
The deciding factor is the critical/stall angle of attack

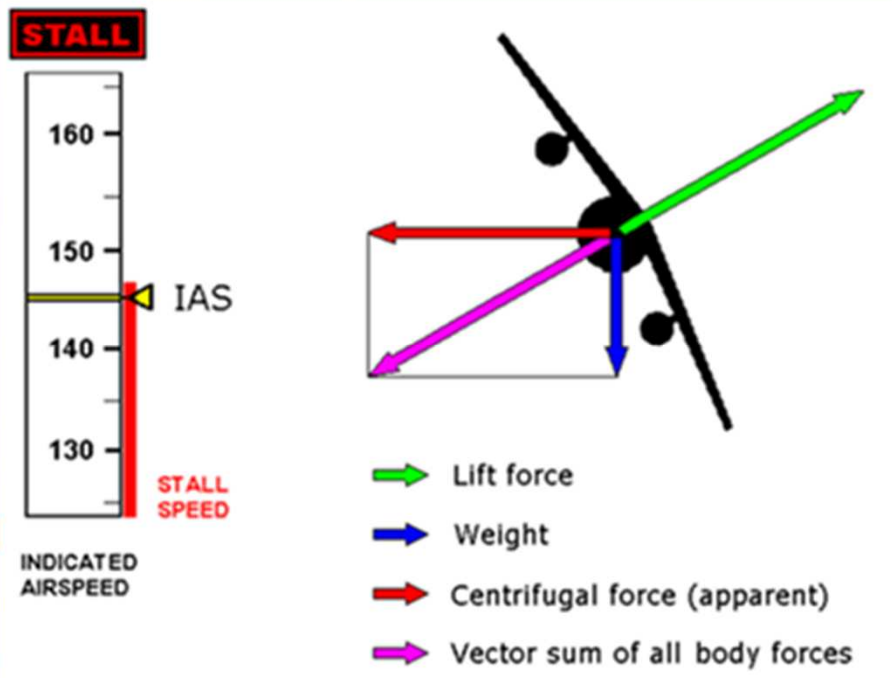
The wing stops flying when the stall angle of attack is exceeded

Result = Stall (and possible LOC)

Required = Angle of Attack Indicator

Aerodynamic Stall





Stall recovery:

JAR 25 CS: « As soon as the aeroplane is stalled, recover by normal recovery technique.»

What is normal recovery technique?

UK CAA: "Simultaneous pitch down and full power"

FAA: "Unstall, smoothly increase power to increase airspeed and minimize loss of altitude"

NTPS: "Unstall, let airspeed increase to at least 1.2Vs before increasing power, recover"

(or, "unstall, delay power for 2 sec and increase power in 2 sec, recover").

Boeing:

"Emphasis during recovery should be to immediately reduce angle of attack and return the aircraft to a safe flying condition".

"Reducing angle of attack as the first and most important response in the recovery".

Airbus:

"Apply nose down pitch control to reduce AOA".

"Tests show that while applying full thrust at stall warning while maintaining altitude can contribute to reaching full stall conditions" (Ref. AF447).

"Civilian pilots, and even turboprop military pilots, are not familiar with high Mach buffet".

"Stall recovery training is possible in FFS."

Some aircraft are equipped with artificial stall warning (shaker) and artificial stall break/nose drop (pusher).

In US NAVY AOA has been in use since the early jet days.

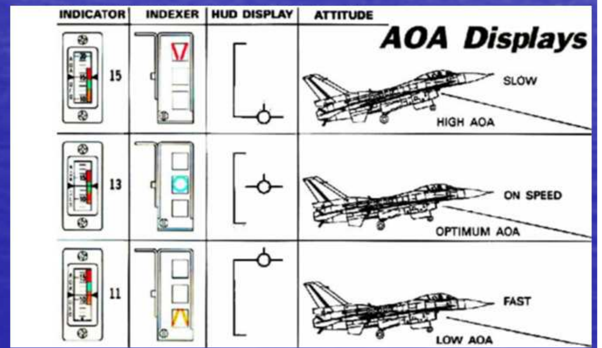
Ex A-4

A-7

etc

In USAF AOA was introduced in some «difficult» A/C types during 1950-ies, ex. F-104.

Later A/C has AOA, ex. F-16.

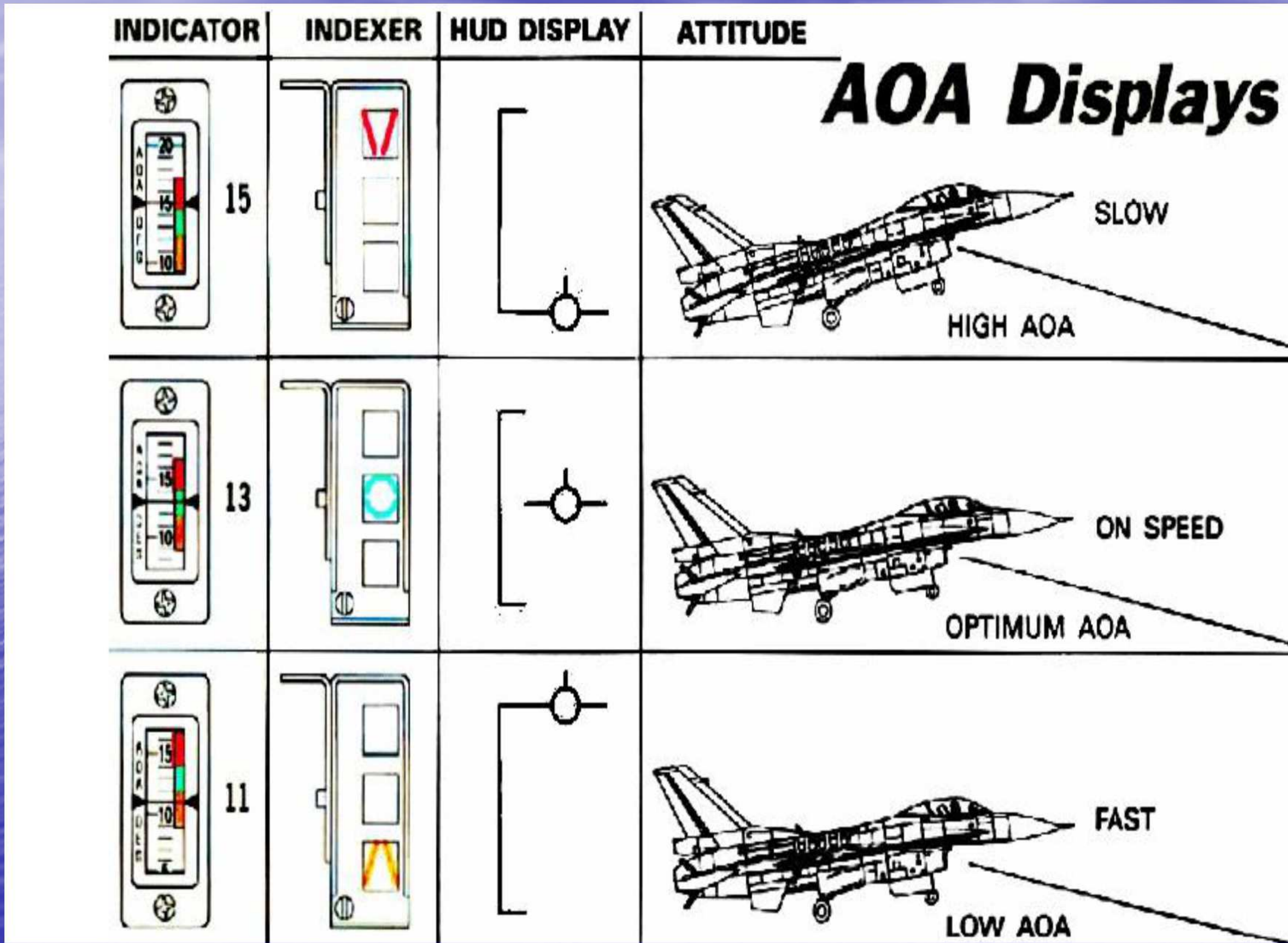


During stall training with «pusher» A/C, activation of «pusher» is the artificial «stall» which must trigger recovery action.

More accurate flying by AOA. We may control A/C by using AOA.

Indicated Airspeed (actually EAS) is just an aerodynamic reference associated with airloads.

F-16A AOA



INDICATOR
INDEXER
HUD DISPLAY
ATTITUDE
AOA Displays
15
SLOW
HIGH AOA
13
ON SPEED
OPTIMUM AOA
11
FAST
LOW AOA

A-10C AOA


Trim Nose Up Some More
170(ish) KIAS
AoA Indicator
UHF
HEADING SET
HARS
STR PT
NOSE DOWN
Trim Hat

BOEING AOA

SPD
LOC
V/S
4572M
15000
175
IPAE/162°
DME 00.0
240
220
NO
V
S
P
D
FD
5.6
800
1600
30
30

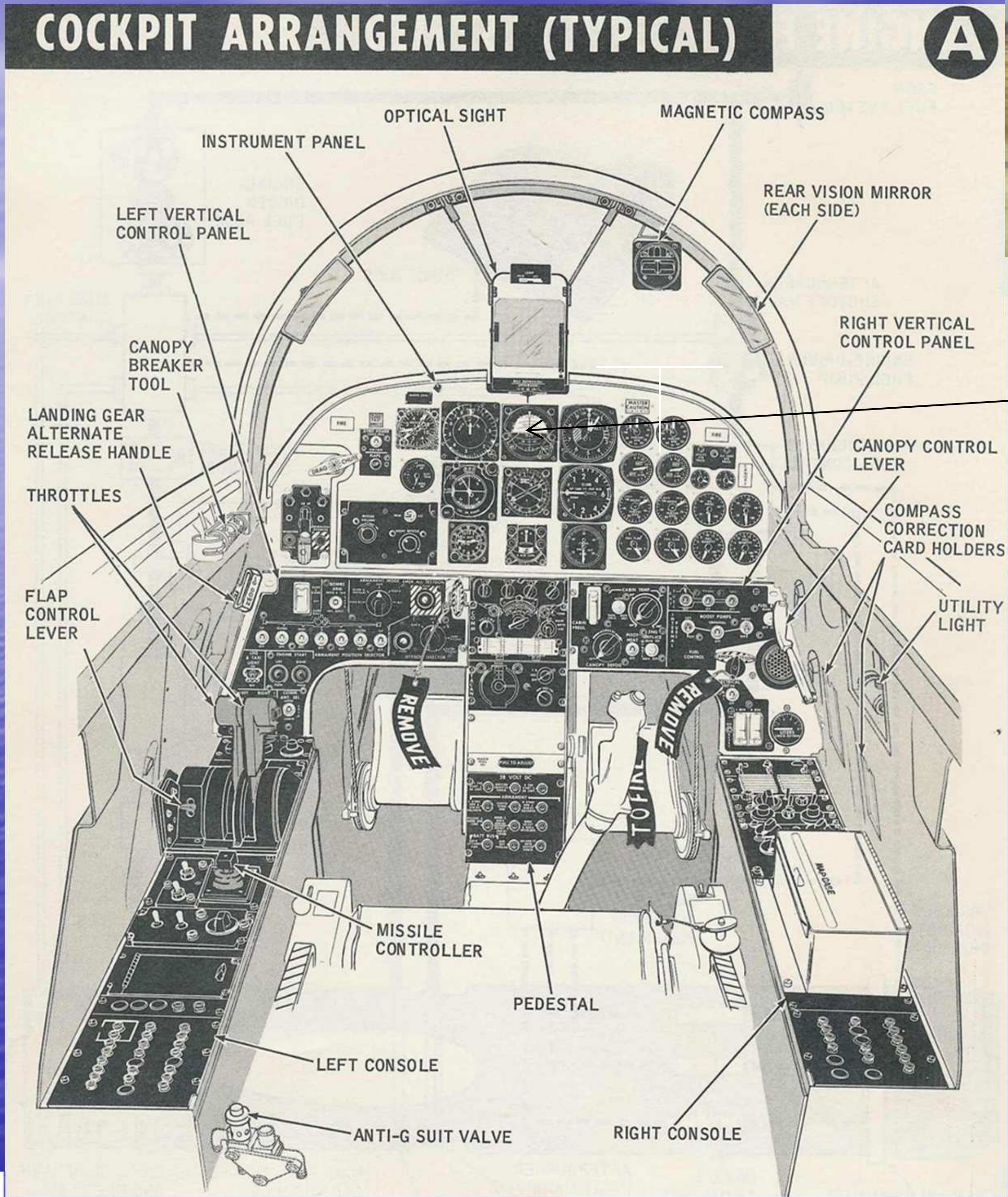
TYPICAL AOA INDICATORS

Developments in Flight Displays

TYPICAL FLIGHT DISPLAYS - 1950's

CF-104 - 1960's

F-5A – 1960's



Basic T

C-47 1940's – 50's – 60's

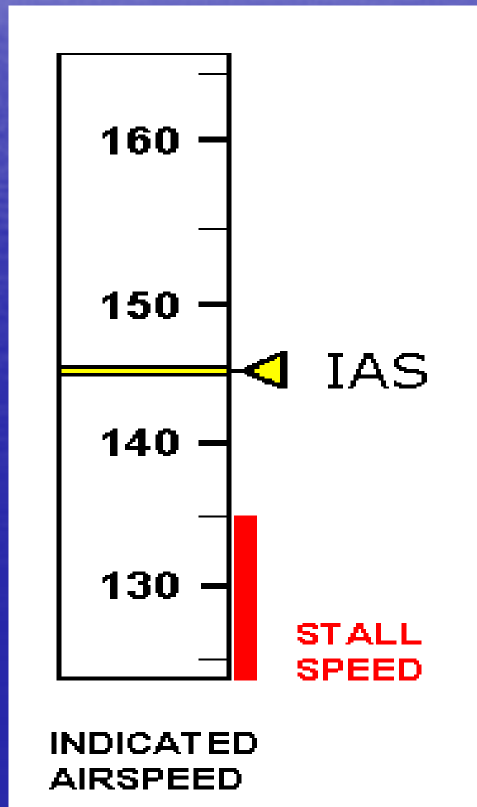
COMMERCIAL AILINER 1970's

Basic T

GLASS COCKPIT – VERTICAL TAPE – 1980's

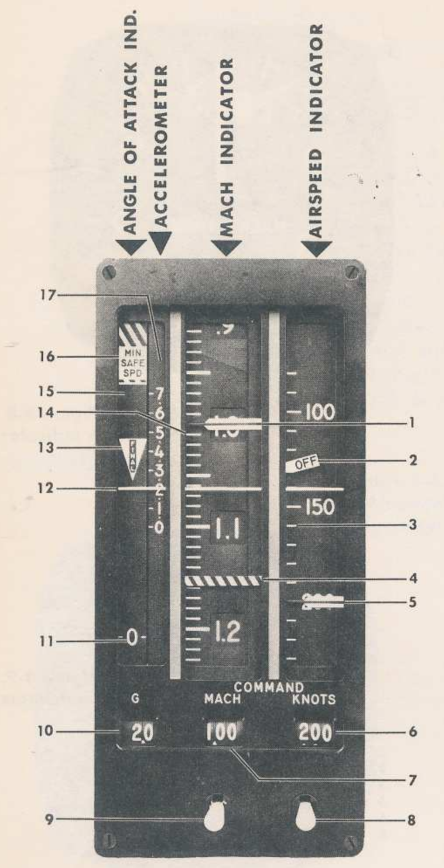
ROUND DIAL AND POINTER – PRE 1980's

VERTICAL TAPE – POST 1980's



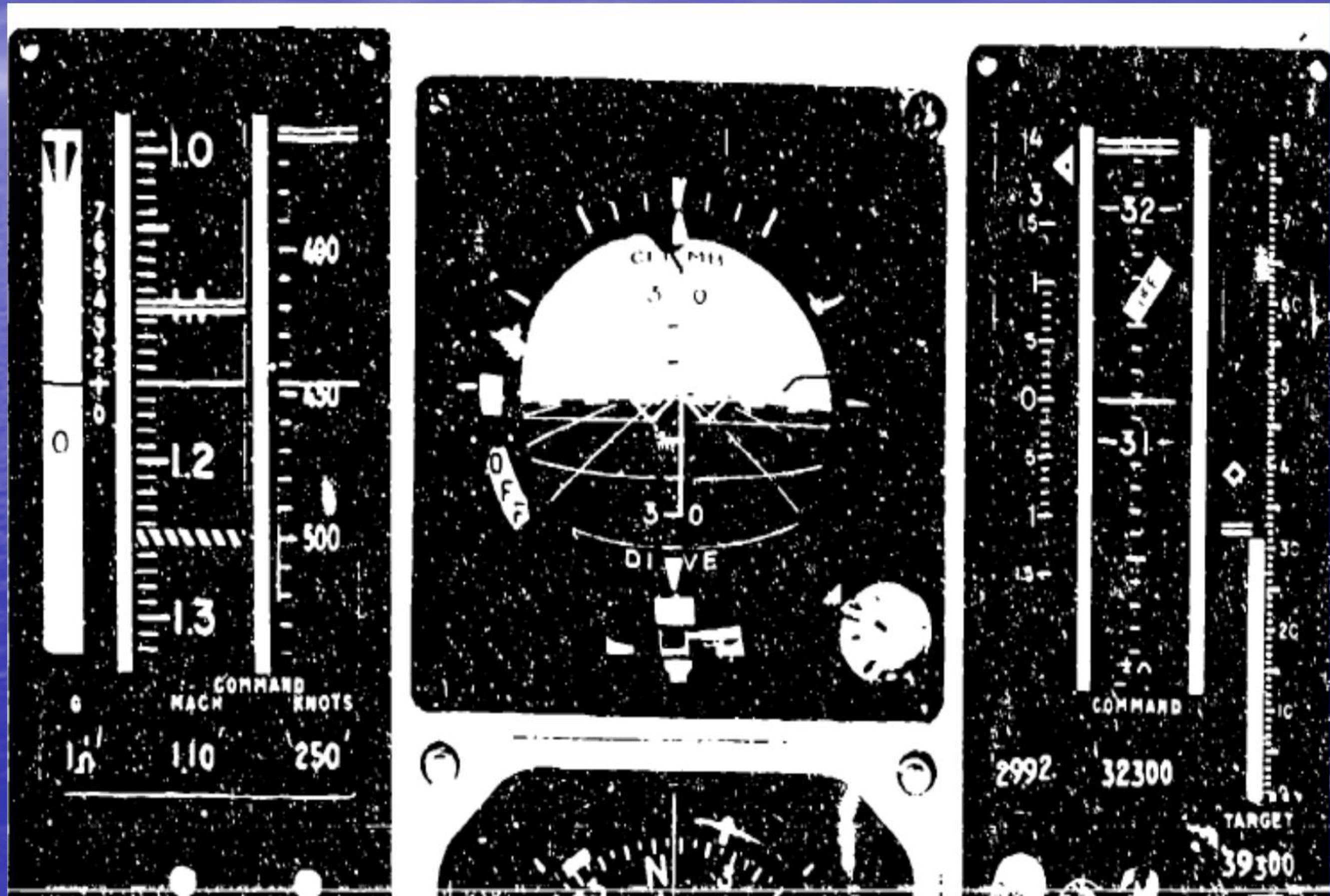
USAF AIRSPEED MACH INDICATOR – 1960's

AFM 51-37



1. Command Mach Marker
2. Airspeed Warning Flag
3. Airspeed Scale
4. Maximum Allowable Mach Marker
5. Command Airspeed Marker
6. Command Airspeed Readout Window
7. Command Mach-Readout Window
8. Command Airspeed Slewing Switch
9. Command Mach Slewing Switch
10. Acceleration Readout Window
11. Zero Angle of Attack Symbol
12. Fixed Index Lines
13. Final Approach Symbol
14. Mach Scale
15. Angle of Attack Scale
16. Minimum Safe Speed Symbol
17. Acceleration Scale

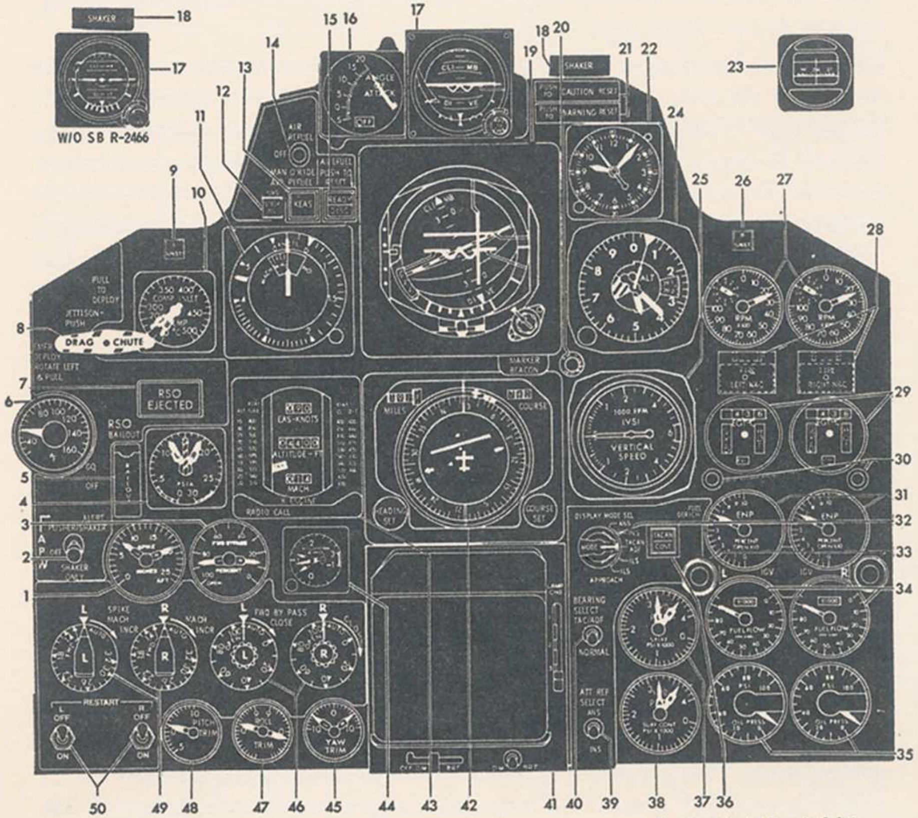
Figure 3-10.
Airspeed-Mach Indicator (AMI)



USAF SR-71A INSTRUMENT PANEL – 1960's – 70's – 80's

SR-71A-1

CENTER INSTRUMENT PANEL – Forward Cockpit



1 Spike Position Indicator
2 Pusher/ Shaker Switch
3 Forward Bypass Position Indicator
4 Compressor Inlet Pressure Gage
5 RSO Bailout Switch
6 Temperature Indicator
7 RSO Ejected Indicator Light
8 Drag Chute Handle
9 Left Inlet Unstart Light
10 Compressor Inlet Temperature Gage
11 Airspeed - Mach Meter
12 Nosewheel Steering Engaged Light
13 KEAS Warning Light
14 Air Refuel Switch
15 Air Refuel Ready - Disc Pushbutton and Light
16 Angle of Attack Indicator
17 Standby Attitude Indicator
18 Shaker Indicator Light
19 Attitude Director Indicator
20 MarkerBeacon Light
21 Master Caution and Warning Lights
22 Elapsed Time Clock
23 Standby Compass (In Canopy)
24 Altimeter
25 Inertial - lead Vertical Speed Ind.
26 Right Inlet Unstart Light
27 Tachometers
28 Fire Warning Lights
29 Exhaust Gas Temperature Inds.
30 Fuel Derich Lights
31 Exhaust Nozzle Position Indicators
32 Display Mode Select Switch
33 IGV Lights
34 Fuel Flow Indicators
35 Oil Pressure Indicators
36 Tacan Control Transfer Switch
37 L and R Hydraulic Systems Pressure Gage
38 A and B Hydraulic Systems Pressure Gage
39 Attitude Reference Select Switch
40 Bearing Select Switch
41 Nav Map Display
42 Horizontal Situation Indicator
43 Triple Display Indicator
44 Accelerometer
45 Yaw Trim Indicator
46 Forward Bypass Switches
47 Roll Trim Indicator
48 Pitch Trim Indicator
49 Spike Switches
50 Inlet Restart Switches

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FUTURE PFD's – CIRRUS PERSPECTIVE – 2013 + ?

AIRBUS PFD's – 1980's – 2010's + 30 YEARS?

BOEING PFD's 2010's + 30 YEARS?

CYBERJET SJ 30 PFD's - 2013

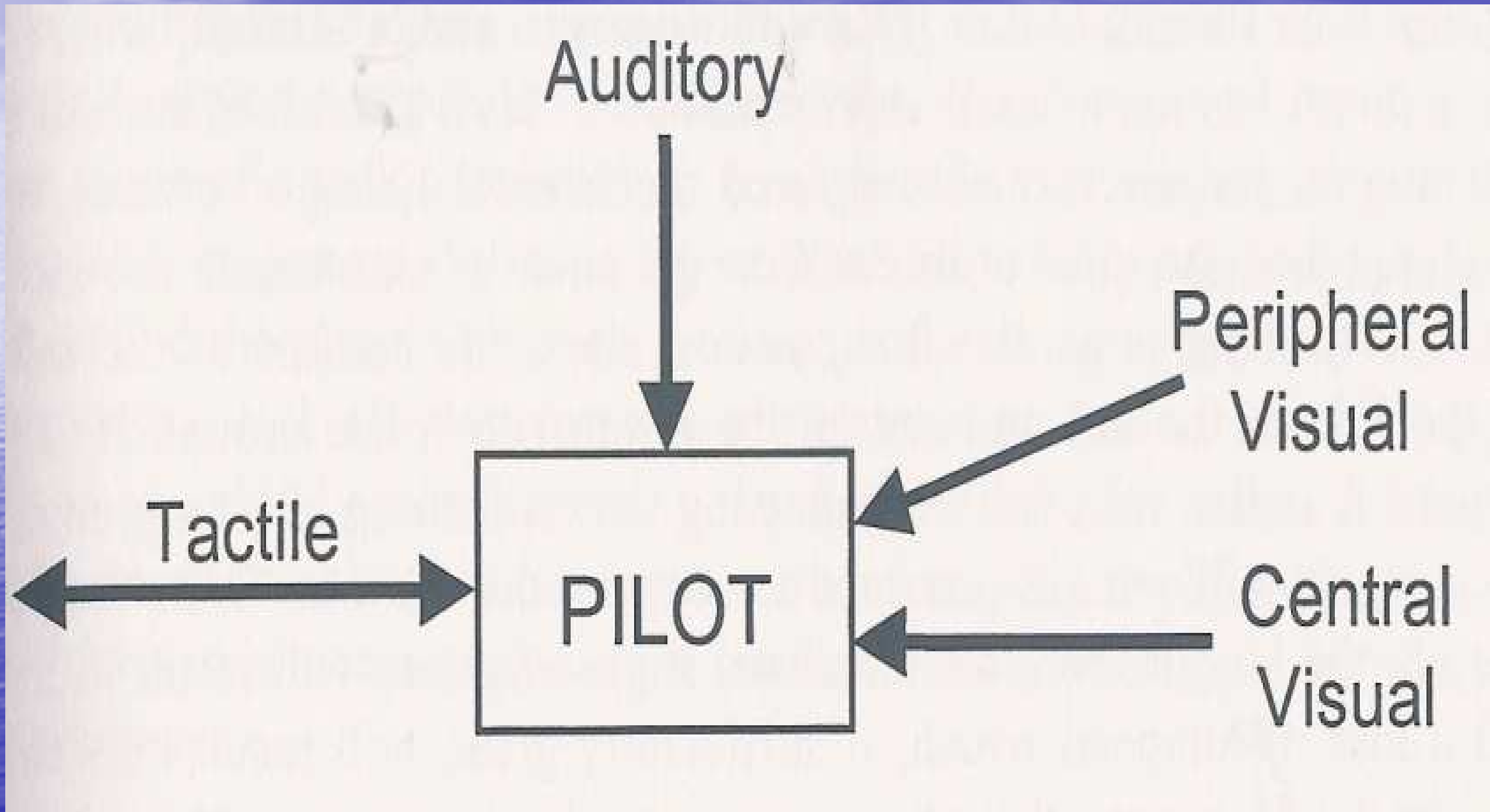
AGUSTA WESTLAND AW 101

EUROCOPTER EC 225

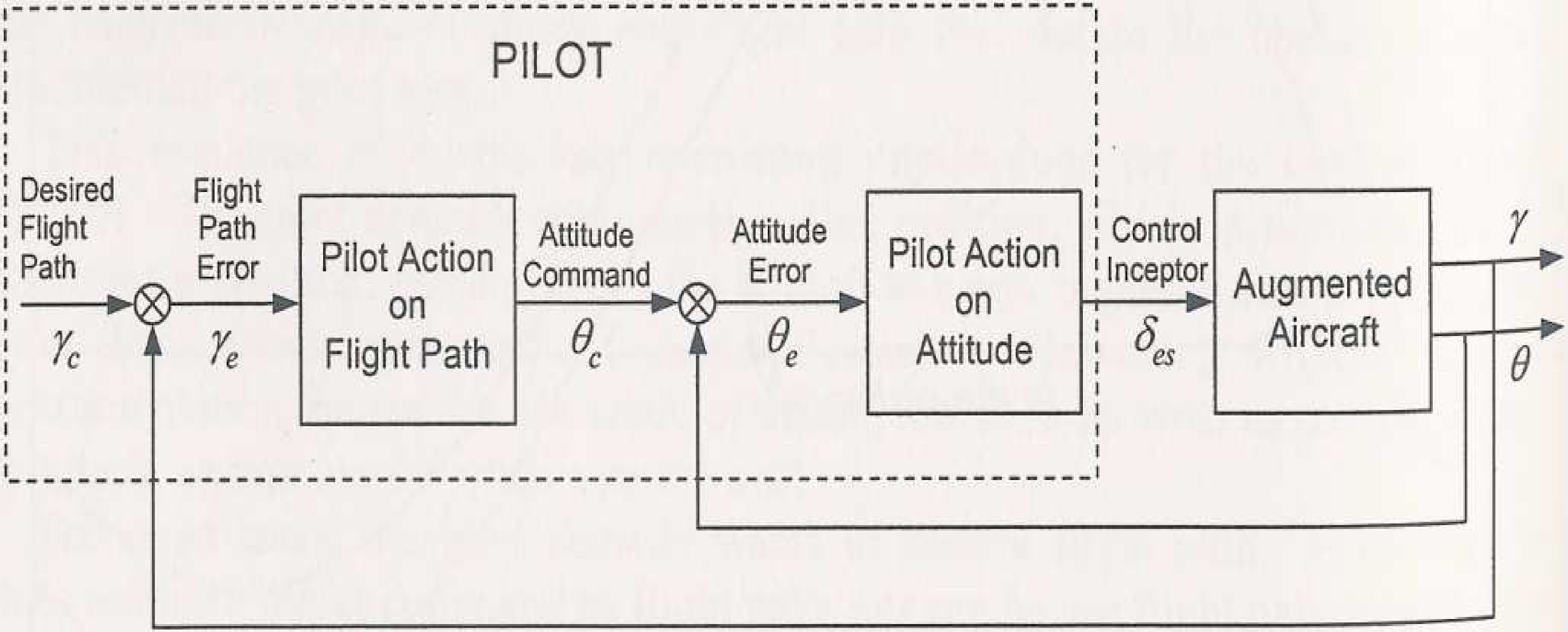
SIKORSKY S-92A – 2005 - ?

Aircraft Controllability

Pilot Information Cueing Channels



The Series Pilot Model



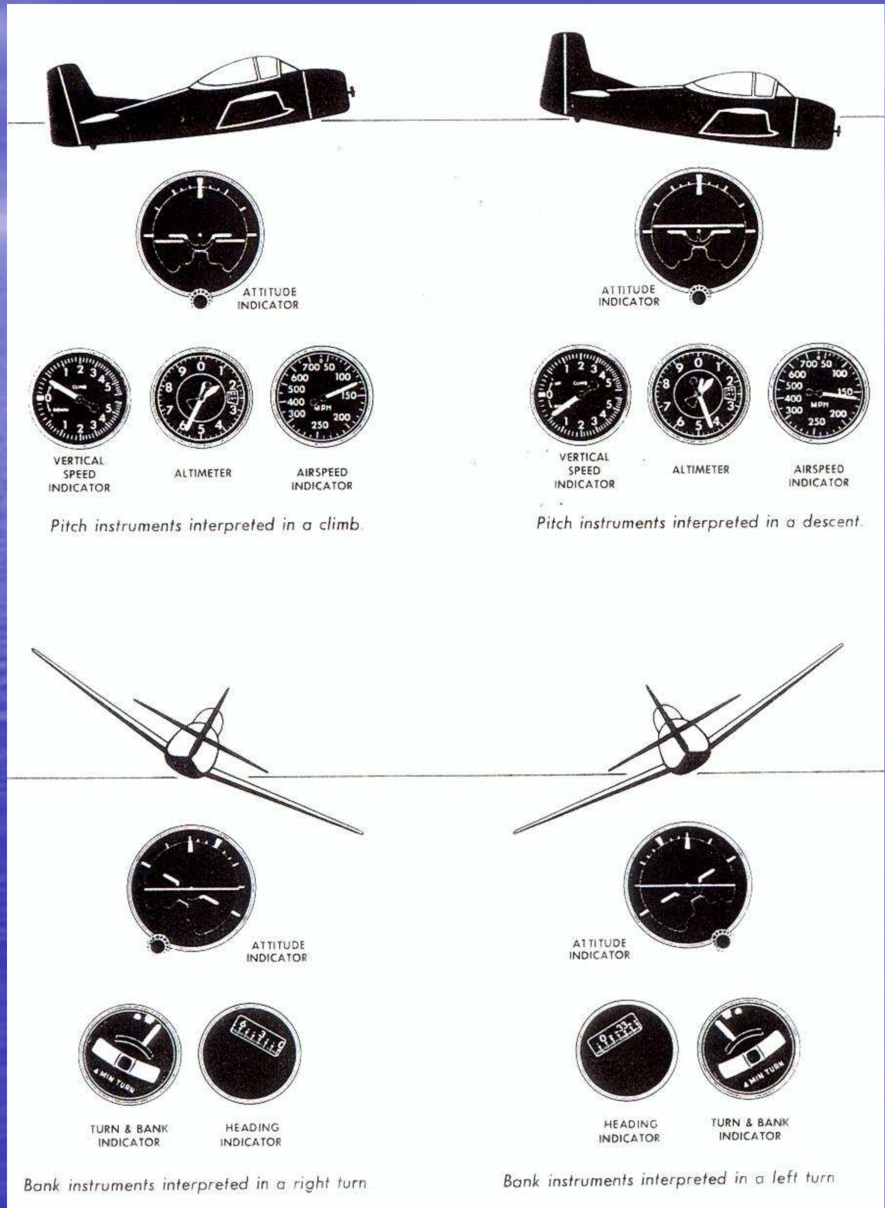
Basic Pilot Knowledge ?

$$R/C = (T - D)V/W$$

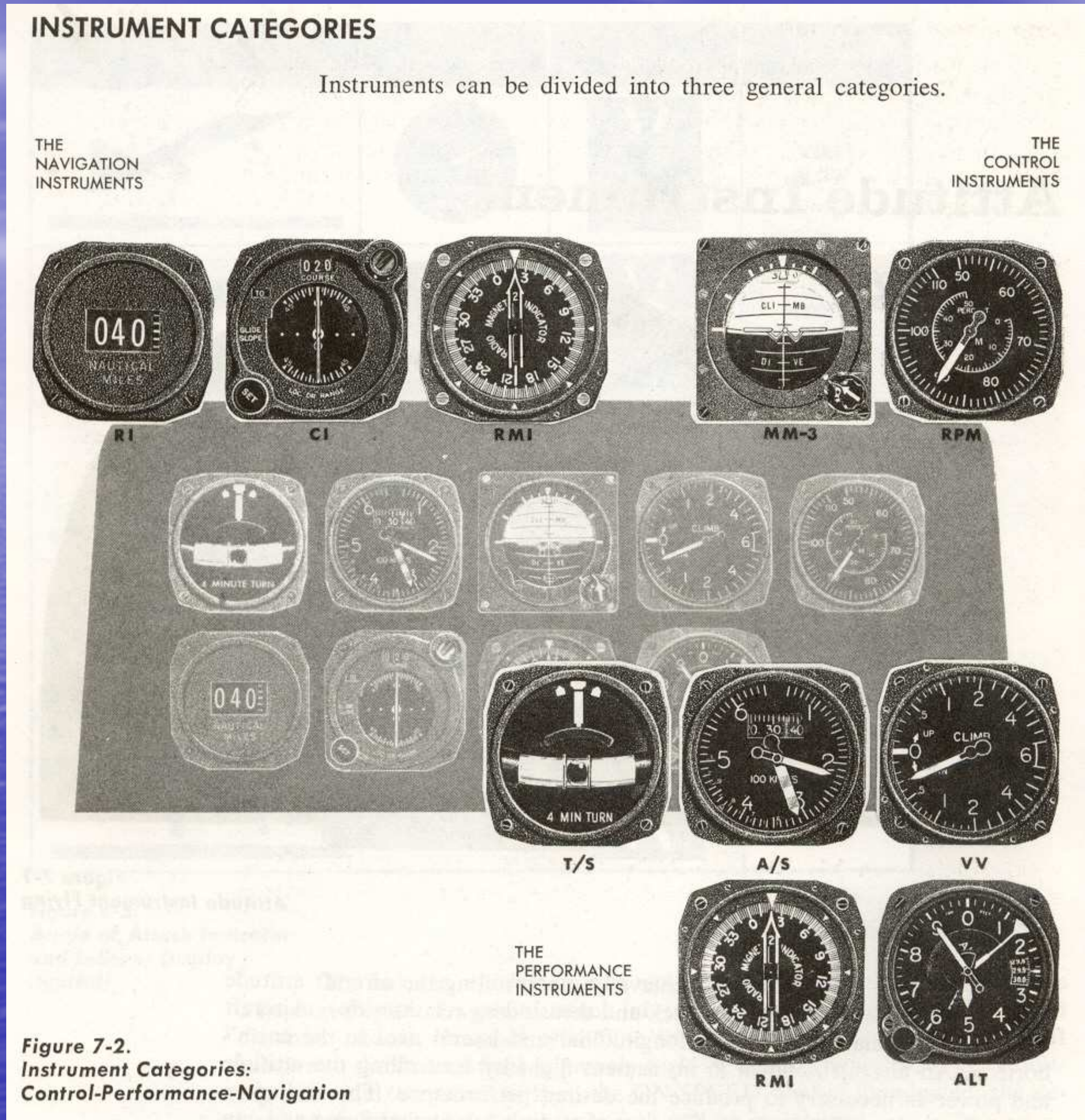
$$R/D = (D - T)V/W$$

Developments in Pilot Education and Training

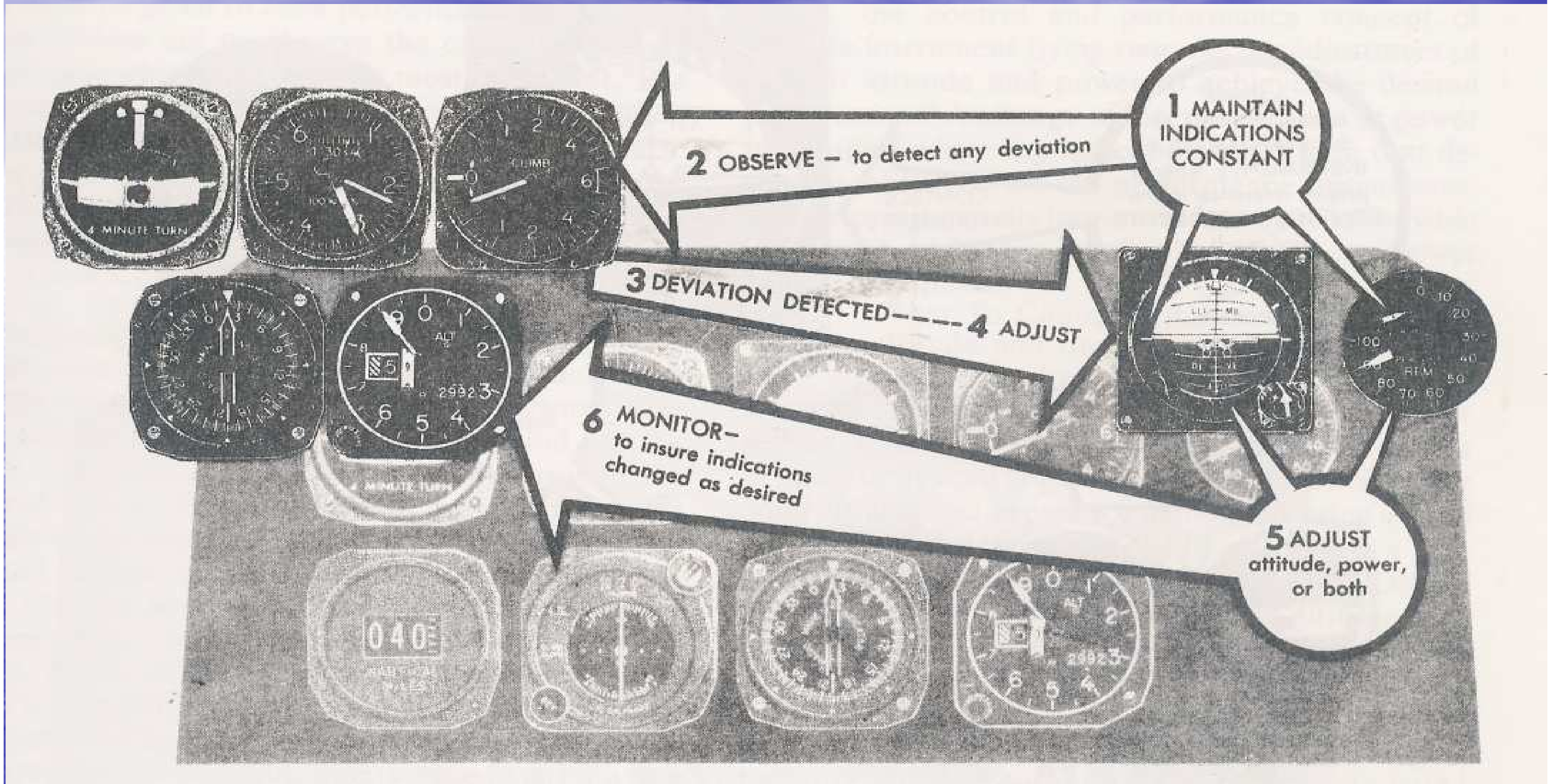
Attitude Instrument Flying – 1940's - ?



Instrument Categories – 1950's - ?



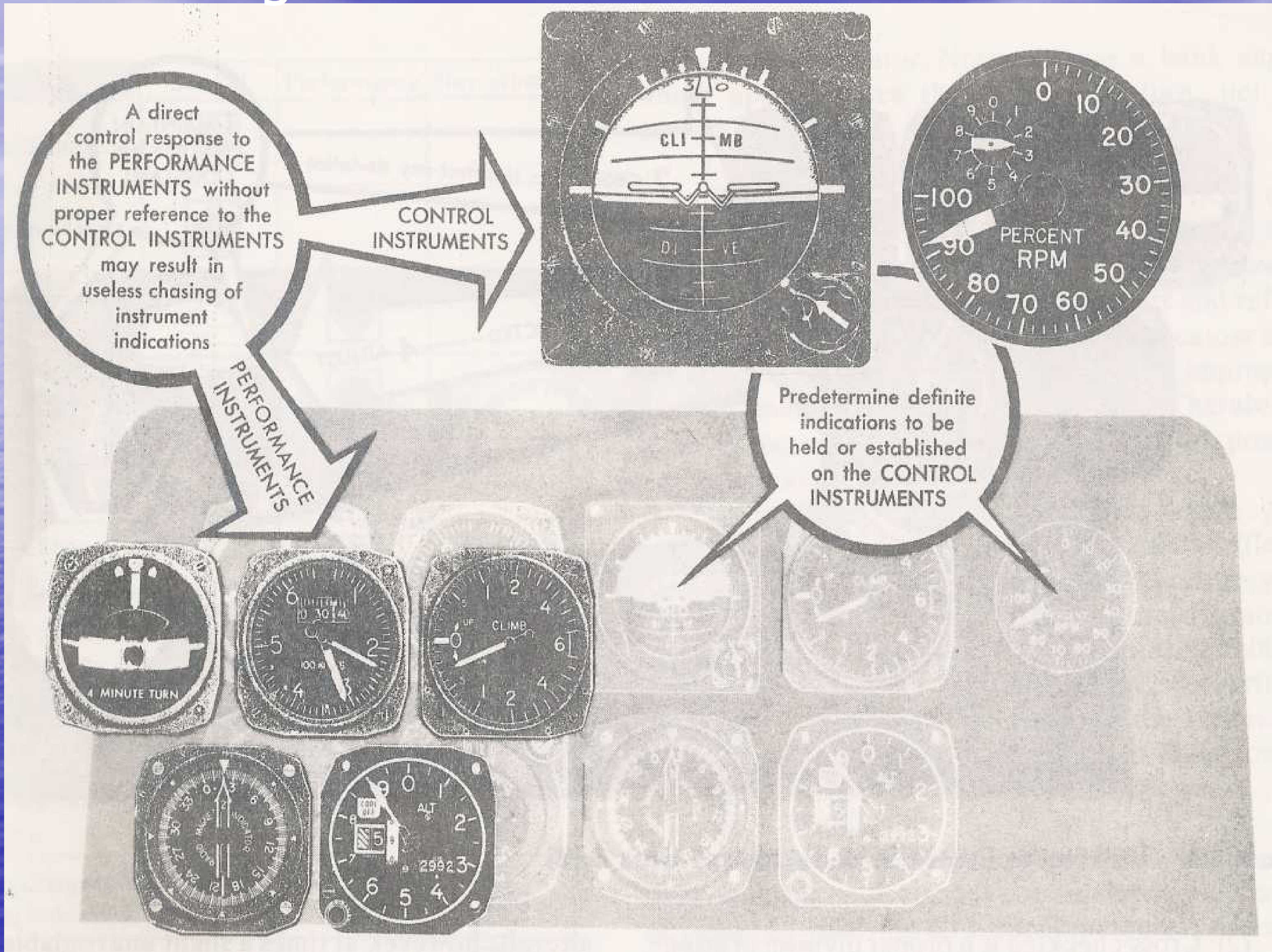
Instrument Cross Check Technique – 1950's - ?



Aircraft Control Fundamentals:

- Pitch controls Airspeed
- Power controls Energy (Accel -R/C-R/D)
- $R/C = (T - D)V/W$
- $R/D = (D - T)V/W$

Factors Influencing Cross Check Technique «Chasing the Performance Instruments»



Recommended Instrument Cross Check Technique?

Universal Avionics PFD – 2010's + ?

Rockwell Collins Proline Fusion – 2013 - ?

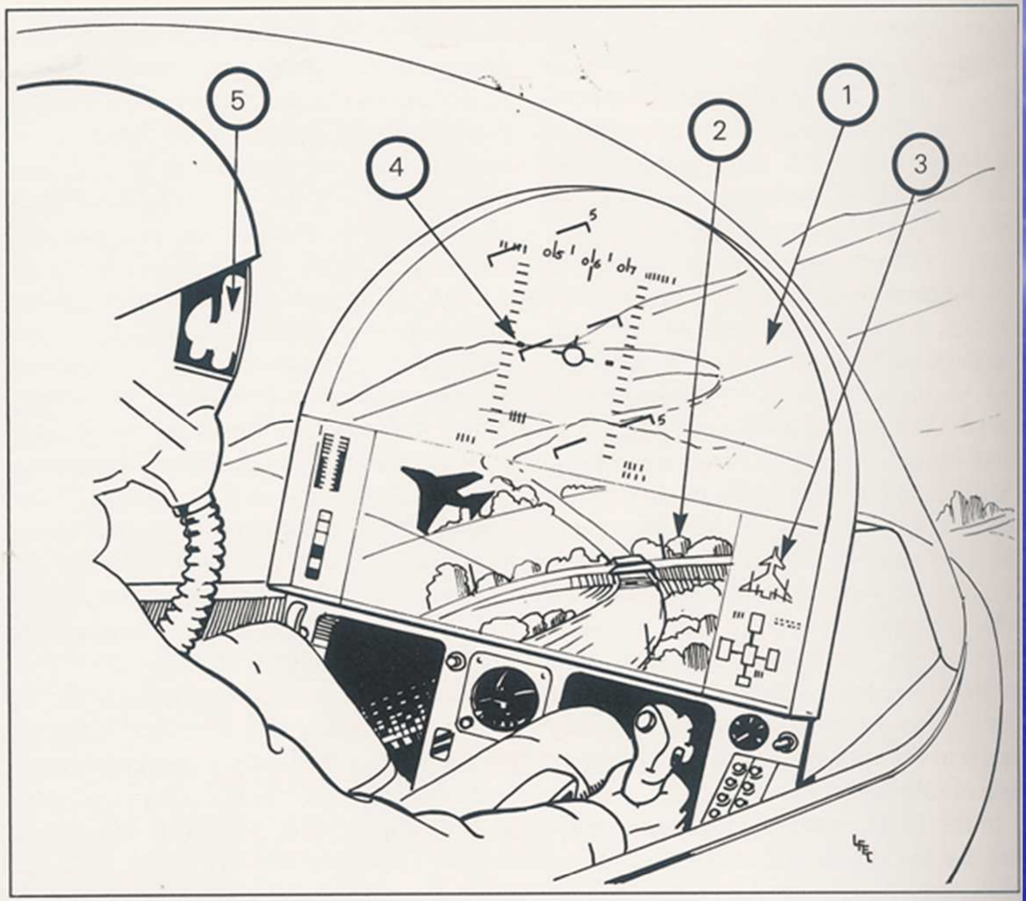
Enhanced Flight Vision System HUD

Pilatus PC-12 PFD

“The Big Picture” (Proposed 1990)

'Big Picture' — one large electronic display screen. The pilot uses touch, voice and helmet pointing to indicate, select, command and initiate modes, functions and actions.

1. *On the upper area of the screen the pilot sees head-up display (HUD) and weapon-aiming symbols and alphanumerics superposed on the view of the real world. At night or in poor visibility low light television or infra red views are used.*
2. *Television or infra red sensors produce a view below the nose of the aircraft.*
3. *The sides of the display are used to present systems information such as fuel, engine, communications and weapon 'stores'.*
4. *HUD symbols and alphanumerics.*
5. *Pilot's visor used for pointing.*



presentation of information so as to appear three-dimensional. Another attribute is the opportunity it affords the pilot of selecting a different 'point of view'. For example the computer-generated view of the world can be seen as if from a position behind the aircraft. As with some video computer games, the pilot can fly his aircraft against the 'background' of sky and ground. The pilot might even take a position to one

to the 1930s such an idea was viewed with some concern by some pilots because the overall technology of aviation within their experience was limited. Today the most recent generation of pilots and those about to take up flying live in a vastly different world: a world in which they have come to accept the abilities and reliability of the computer. Therefore they do not expect to have controls directly connected to the

Cockpit Displays – Test and Evaluation

Cockpit Displays – Test and Evaluation

Ref. 21 - Newman Rickhard L. and Greeley Kevin W.

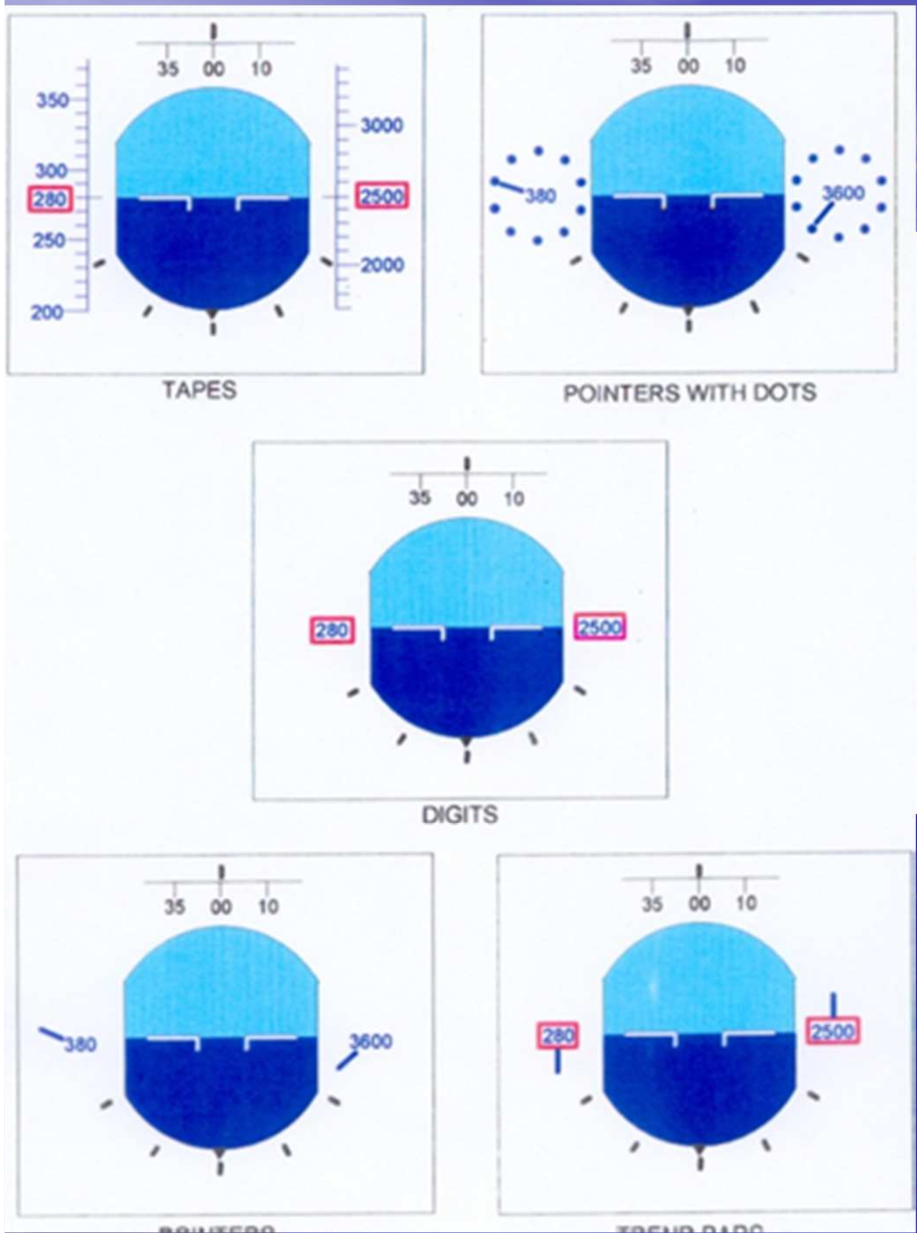
"There have been a number of papers and articles written about operational difficulties with modern display and other cockpit systems. As we see it, the problem has been a series of discontinuities between the **users and the designers**, **between the designers and the testers**, and **between the users and the testers**.

"The display design must consider **why the pilot needs the data** and what the **pilot is expected to do with the data**. According to Singleton, several questions must be answered during development of a display:

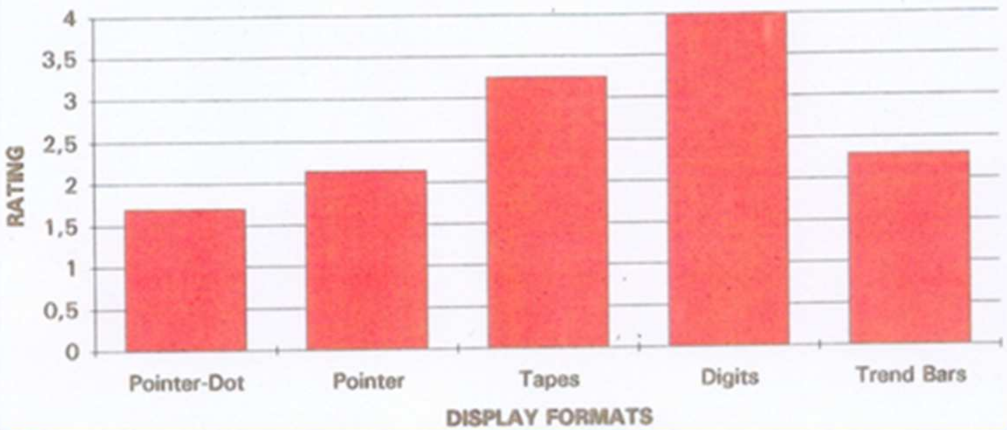
- **Does the pilot's need justify the display**?
- **What data does the pilot need** that has not been provided?
- Can the **average pilot** obtain what is required easily?
- Does the **display conform to the real world**?
- To other cockpit displays?
- With previous pilot habits and skills?
- With required decisions and actions?"

Research on Primary Flight Displays and inclusion of AOA Indicator

Research 1990



Mean subjective ratings for the 5 altitude and airspeed display formats. A rating of "1" was very favorable and "5" was very unfavorable.



Research 2002-2004

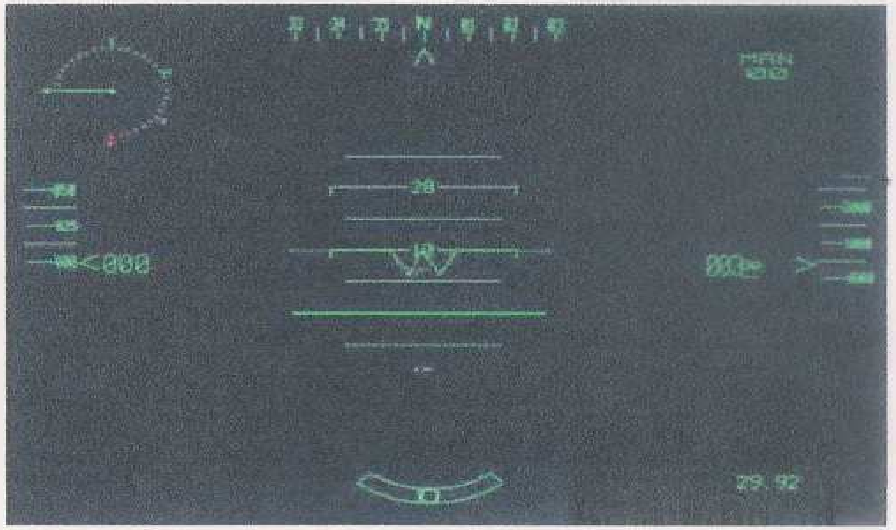


Figure 6 – moving horizon pitch ladder AI[2].

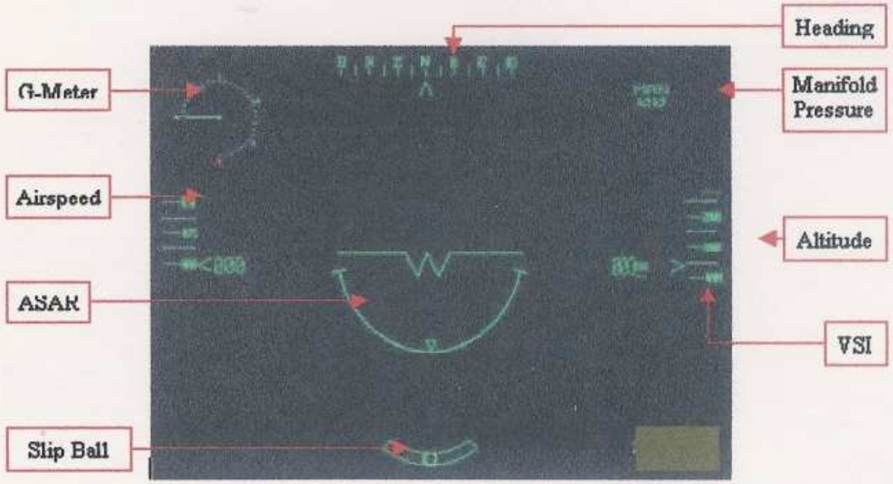


Figure 5 – PFD with ADI in arc-segmented attitude reference (ASAR) display format, as used for UA recovery research in the Harvard[2].

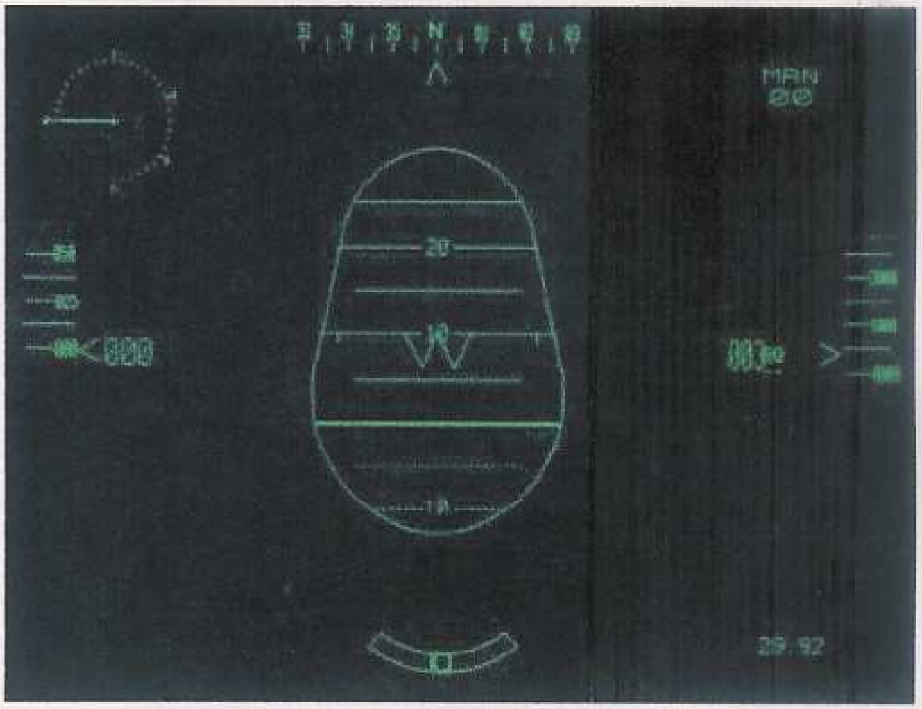


Figure 7 – asymmetric attitude reference AI display[2].

Research results 2002-2004

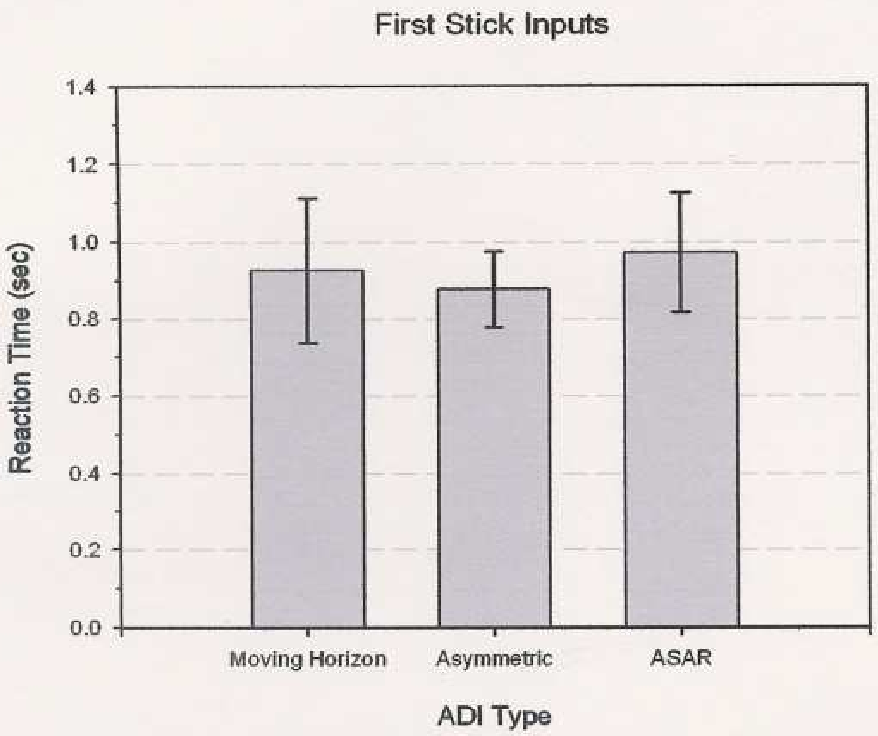


Figure 11 – average reaction time for each of the three ADI displays, summed for all six entry manoeuvres and subject pilots[2].

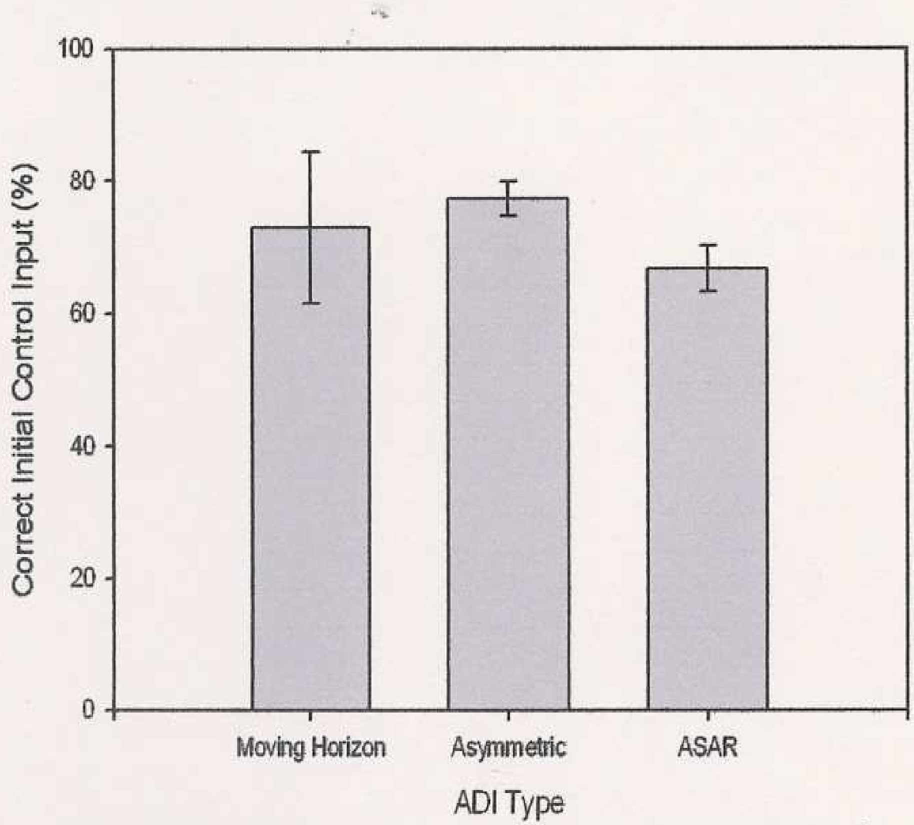


Figure 12 – control reversal errors, for each type of ADI display[2].

Conclusions

- Several recent LOC accidents indicate that the human factor related aspects of primary flight displays, lack of AOA displays, flight control design, and pilot education and training, play a significant role in the pilots handling of an aircraft.

- It is recommended that the industry initiate more human factor based research within these areas.

- The author suggest that SETP should get more involved in human factor focused development, simulator and flight experiment, and flight testing of new types of PFD.

Thank you for your attention

Questions?