

Loss of Control Due to Flight Crew Loss of Airplane State Awareness: Analysis and Safety Enhancements

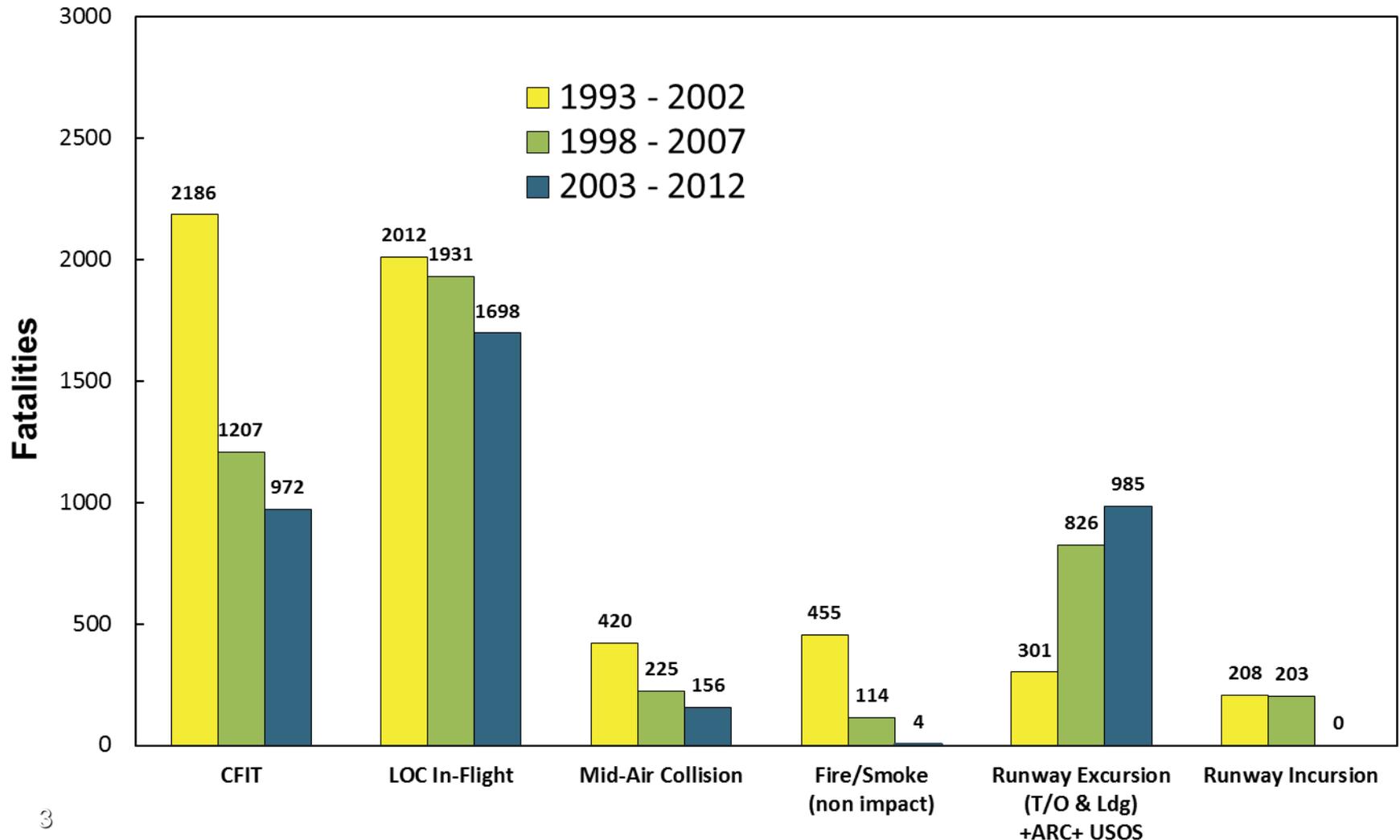
Presented at RASG-AFI LOC-I symposium, Nairobi 22 June 2015
by
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Accident Categories

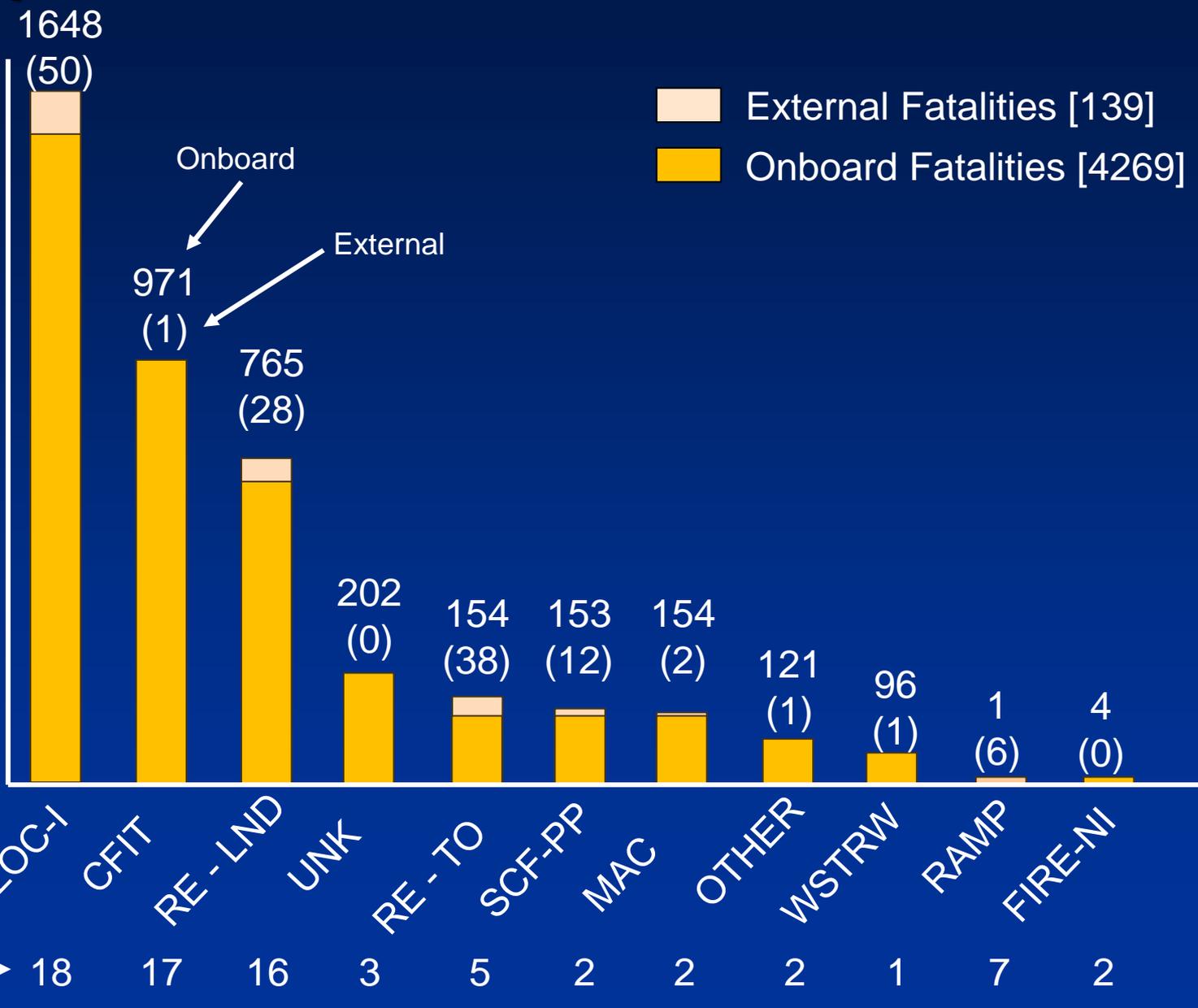
Change over time

Comparison of Fatalities 1993-2002, 1998-2007 and 2003-2012
Fatal Accidents – Worldwide Commercial Jet Fleet



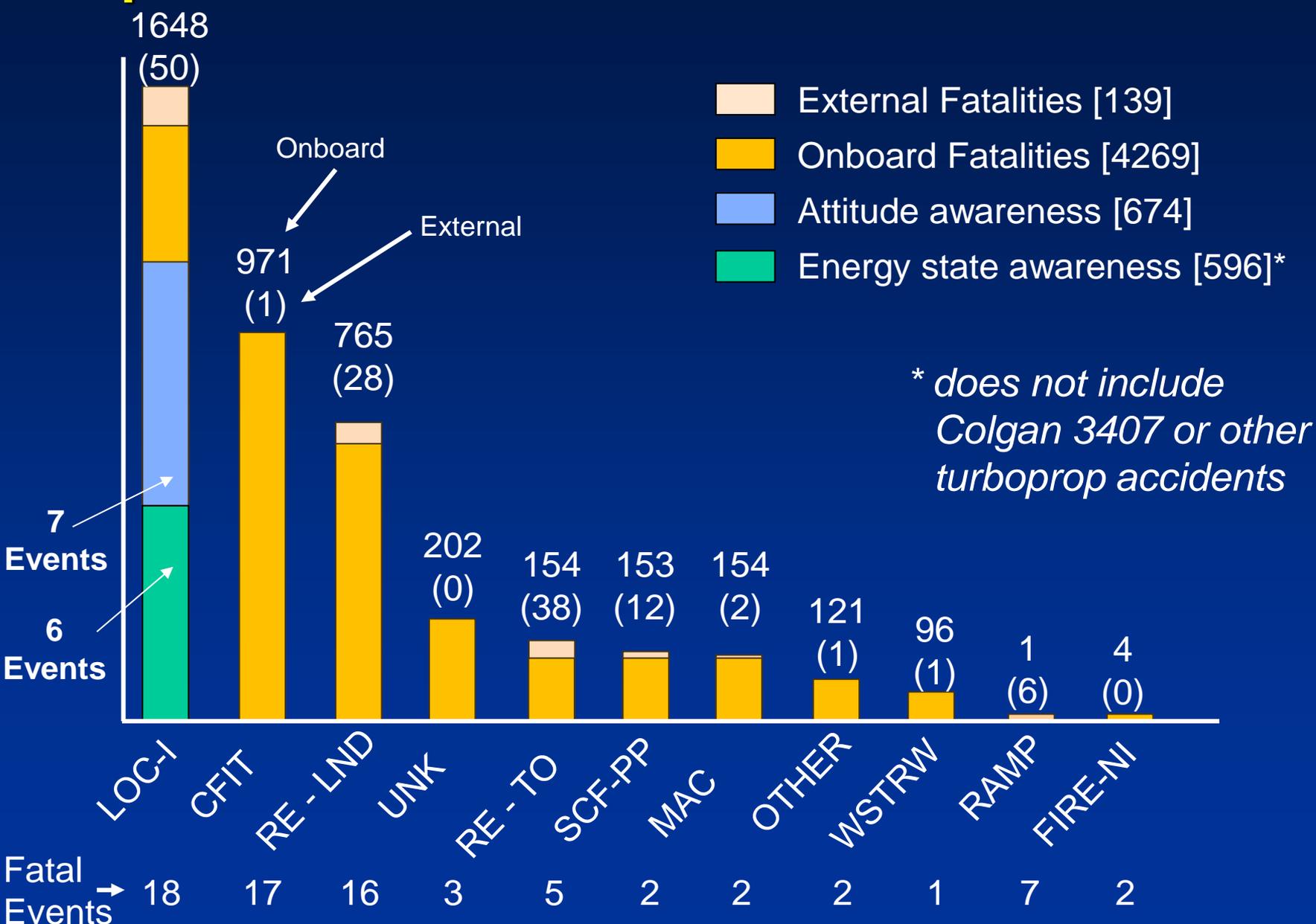
Worldwide Fatal Jet Accidents 2003-2012

Airplane State Awareness Contribution

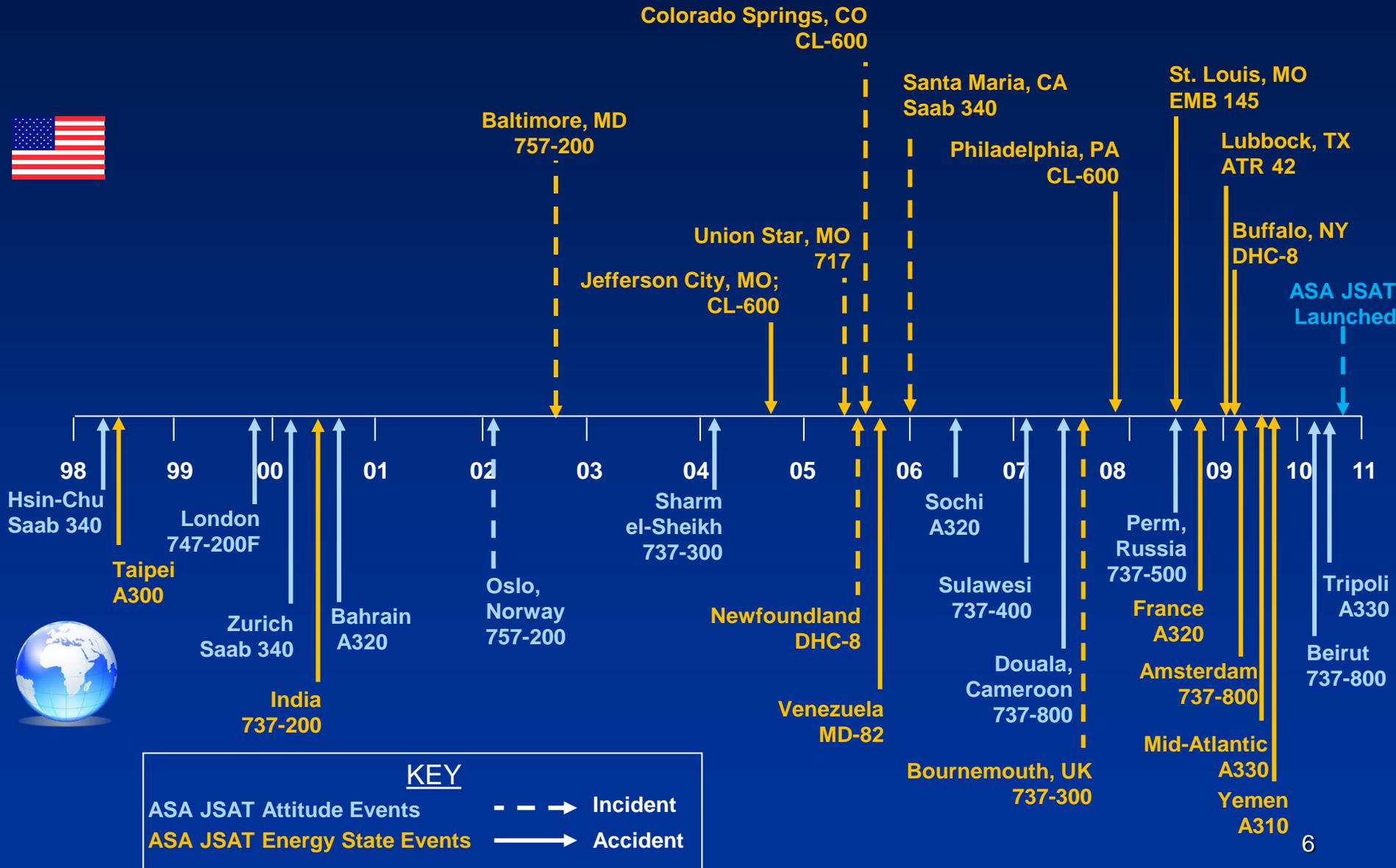


Worldwide Fatal Jet Accidents 2003-2012

Airplane State Awareness Contribution



ASA Events 1998-2010

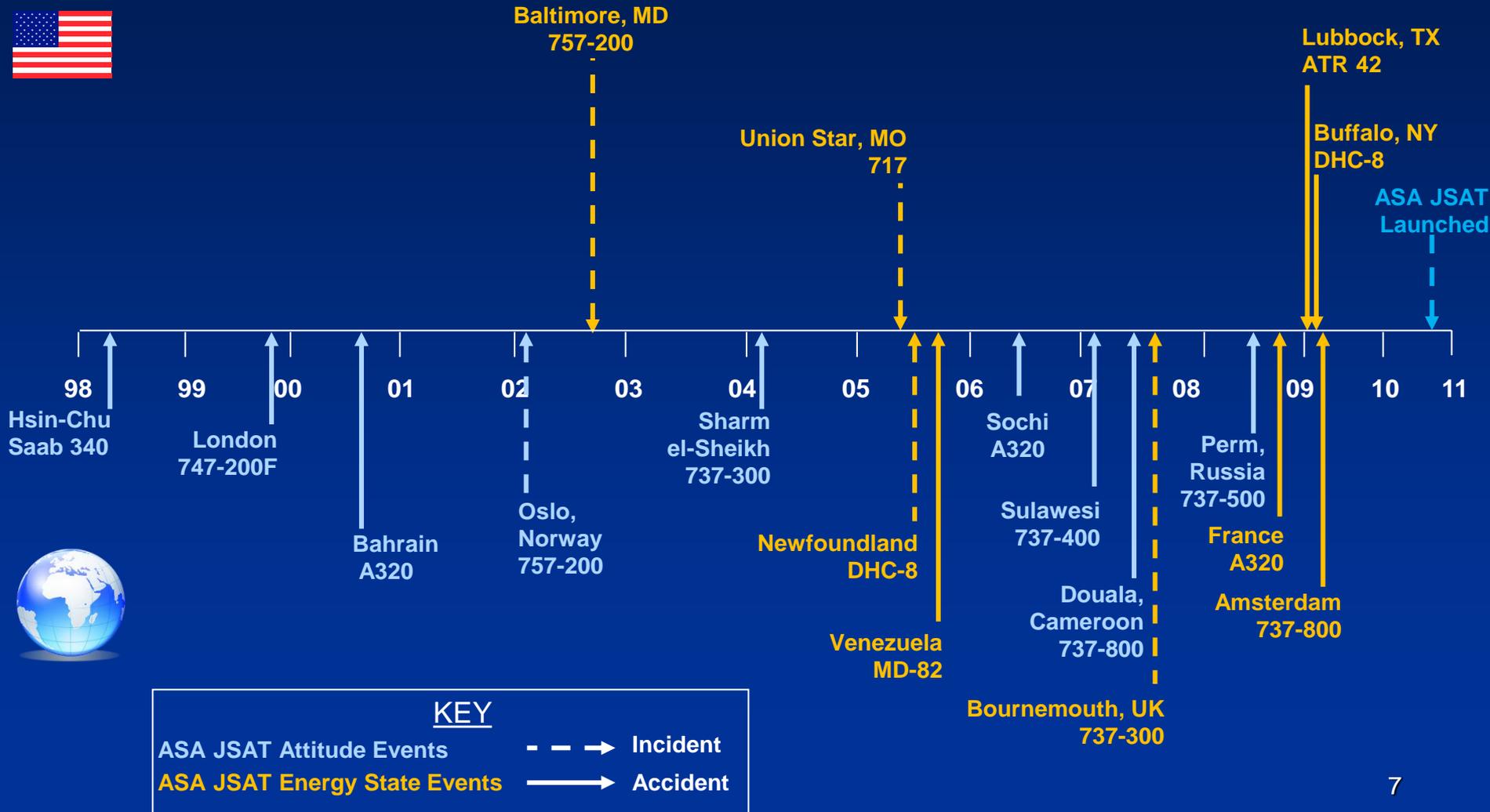


KEY

ASA JSAT Attitude Events - - - -> Incident

ASA JSAT Energy State Events ———> Accident

ASA Analysis Set



KEY

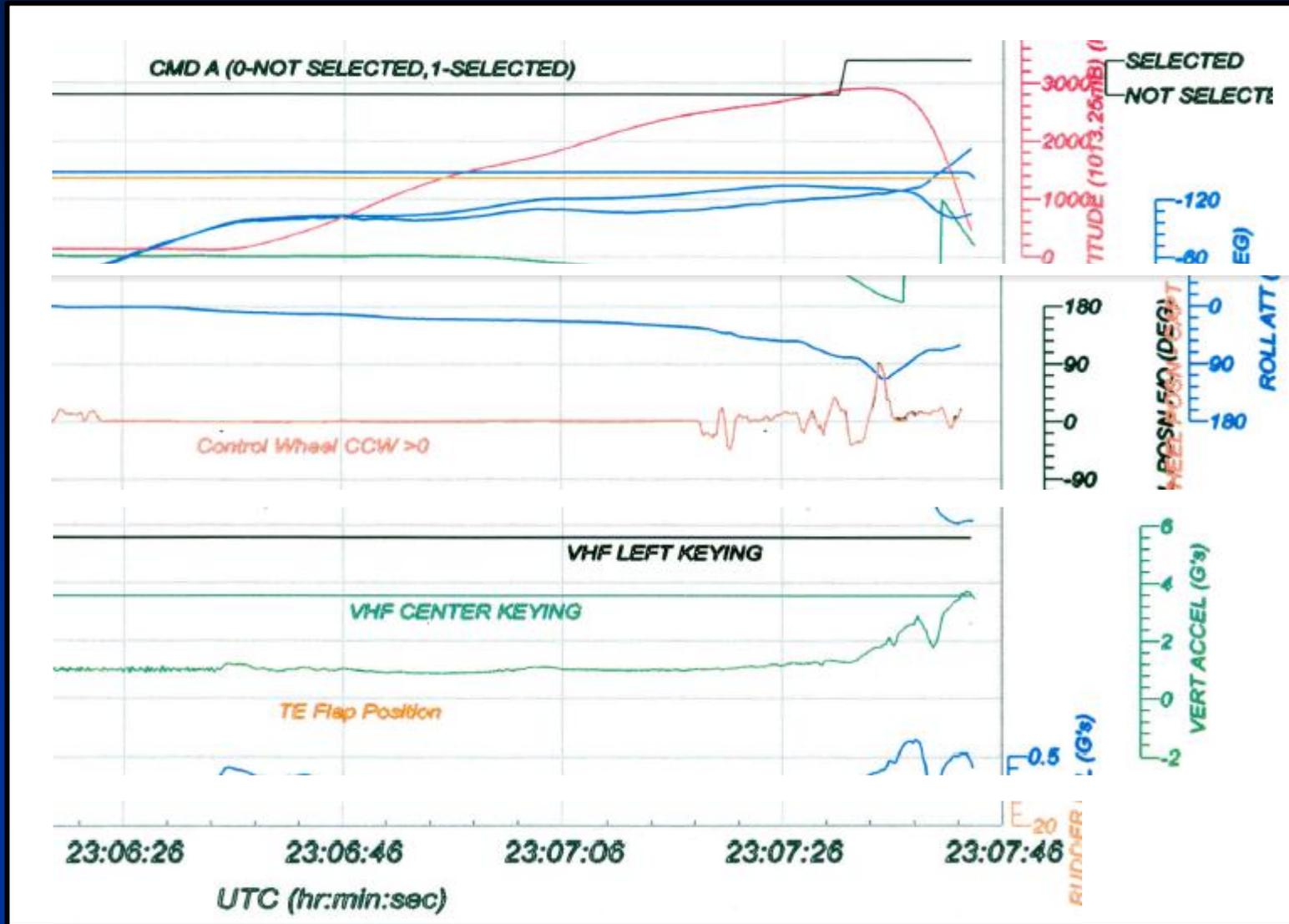
ASA JSAT Attitude Events - - - -> Incident

ASA JSAT Energy State Events ———> Accident

Example of Overbank from ASA Event Set

Kenya Airways 507 - Douala, Cameroon

Boeing 737-800 - May 5, 2007 - 114 fatalities

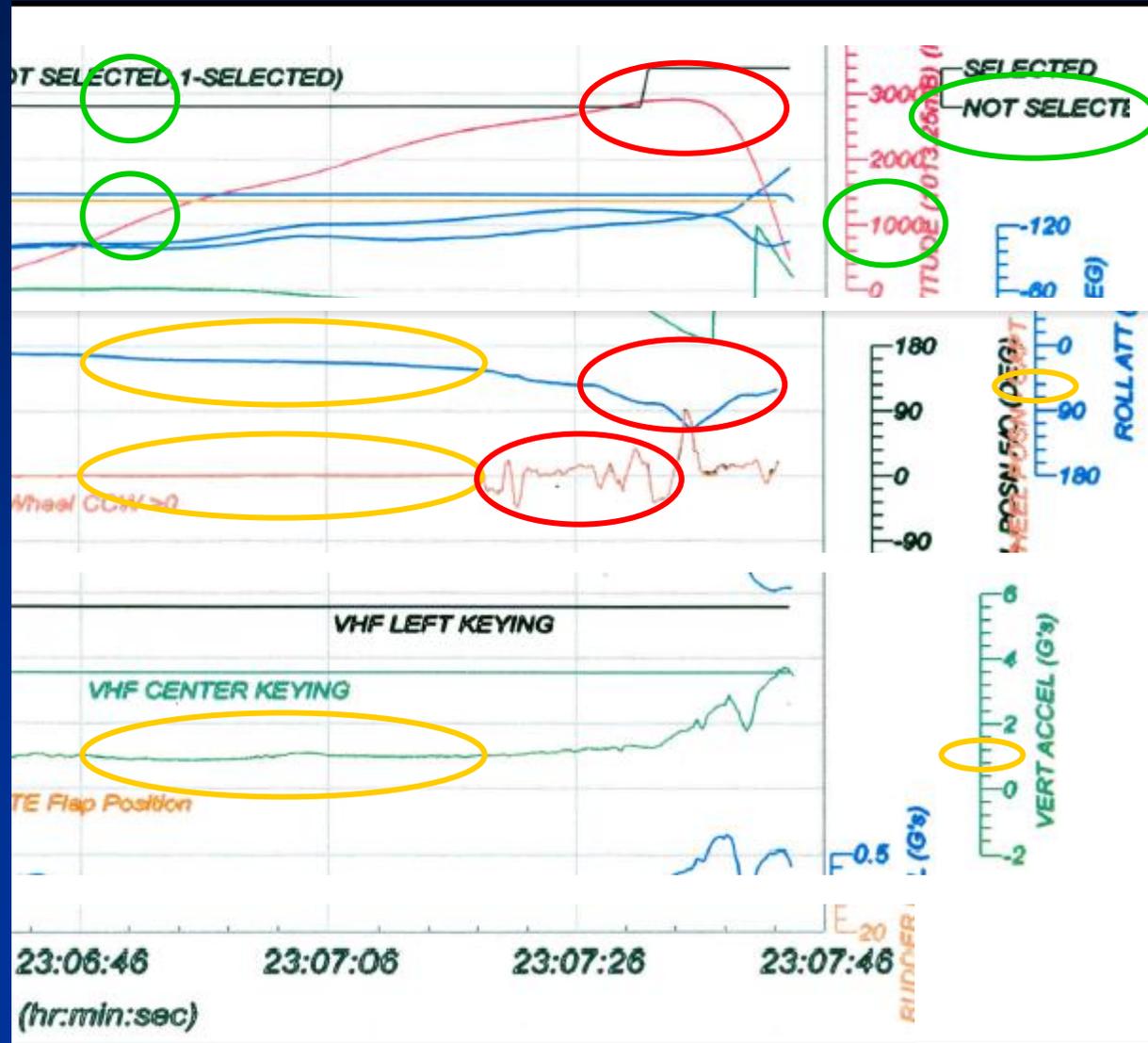


Example of Overbank from ASA Event Set

Kenya Airways 507 - Douala, Cameroon

Boeing 737-800 - May 5, 2007 - 114 fatalities

- During initial climb at 1000 ft AGL with autopilot disconnected
- Bank angle increases from 20° to 35° over roughly thirty seconds at normal g
- No initial input from the PF (from CVR, crew likely believes autopilot engaged): loss of attitude awareness
- At 35° bank, PF control wheel: right, left, right (mostly right) over 20 sec
- Bank angle increases past 90° and vertical speed goes from positive to negative



Accident: Kenya Airways 737-800 near Douala, Cameroon on 4 May 2007

Event Type: Loss of Attitude Awareness

Injuries/Fatalities: 114 fatalities: 108 passengers / 6 crew; no survivors; airplane destroyed

Flight: Kenya Airways 507

Registration: 5Y-KYA

Local Time: 12:07 am

Phase of Flight: Climb to Cruise

Narrative

- Capt is PF; 8682 ttl hrs; type: 824 (Capt on 737-700/800);
- ① - FO has 831 ttl hrs; type: 170; FO hadn't had CRM training yet
- Flight crew training did not provide: UAR, SD
- ② - Local weather: thunderstorms and moderate rain; 800 m visibility, scattered 300 ft, broken 1000 ft
- Initially canceled start-up due to heavy rain; prior to take-off they are focused on identifying a departure corridor away from weather
- On take-off the airplane has a tendency to bank right (not trimmed) and the Capt uses small left wheel inputs to maintain wings level
- At about 1000 ft, a period of 55 seconds commences where there are no control inputs; airplane begins slowly rolling right
- ③ - Attention at this time is on navigating through the weather
- ④ - 13 seconds after the last control input, Capt: "OK, command"; but the autopilot is not engaged (and there is no response from the FO); they are at 1600 ft and bank right of 11°
- They are attempting to use the heading bug to maneuver around the weather for 40 more seconds, but the heading bug has no effect since autopilot is not engaged.
- ⑤ - As bank angle nears 35°, the Capt exclaims and then EGPWS: "bank angle, bank angle"
- ⑥ - Capt makes wheel inputs to right, then left, then right with inputs to right dominating; airplane rolls to 45° right
- ⑦ - They engage the autopilot but due to force on wheel, transitions into CWS-R
- Capt makes inputs to right and left, and pulls back on wheel; bank angle eventually reaches 115° to the right, but is recovered to 70° right
- The FO states, "right captain, left, left, left, correction left."
- ⑧ - Capt and FO are both on controls; Capt rolling right; FO rolling left

UnRec Rec **Spatial Disorientation**

④
⑤

Lack of External Visual References

②

Flight Crew Impairment

Training

①

Airplane Maintenance

Safety Culture

Invalid Source Data

Dec Mak **Distraction**

③

Systems Knowledge

CRM

④
⑧

Automation Confusion / Awareness

④
⑦

Ineffective Alerting

⑤

Inappropriate Control Actions

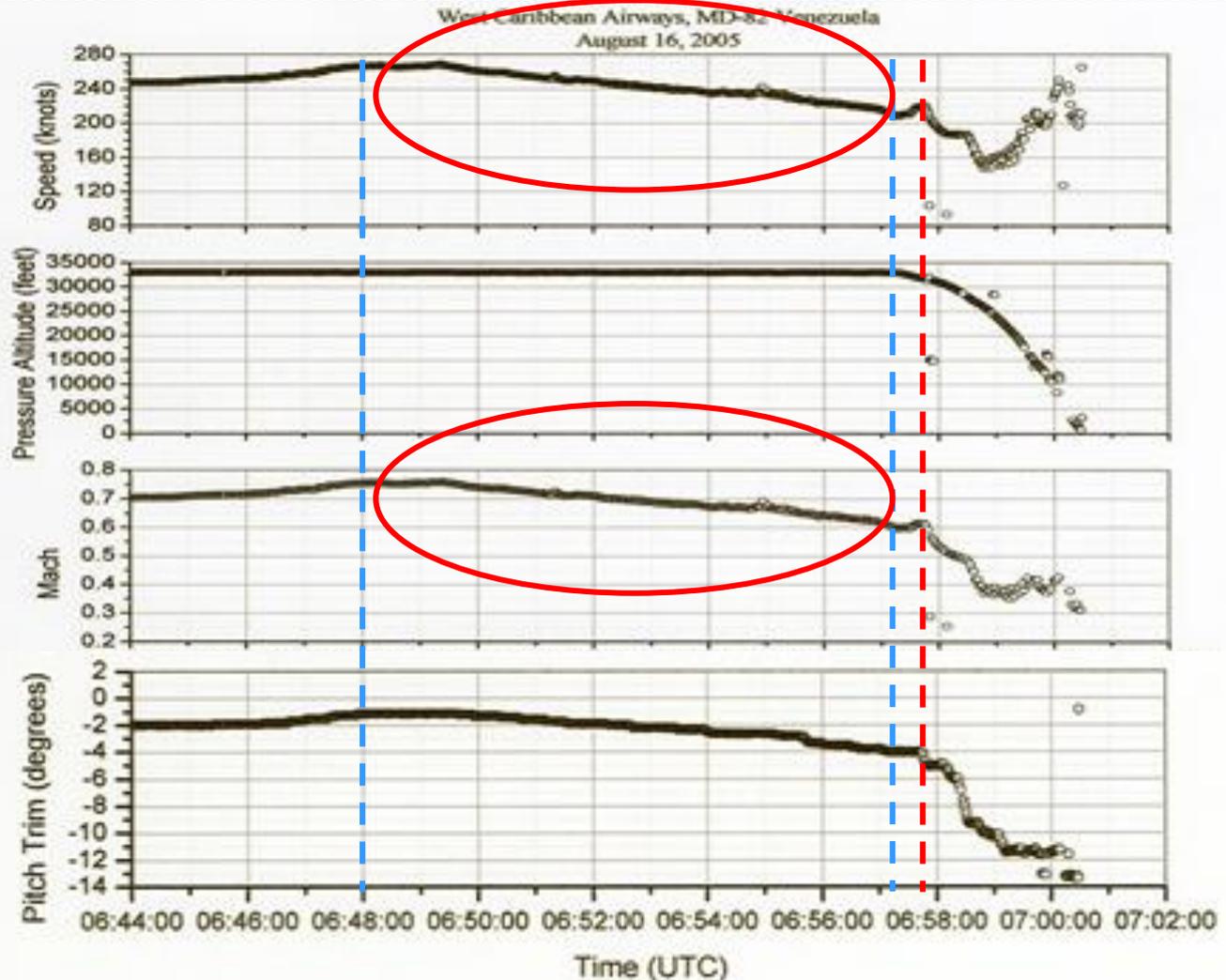
⑥

Example of Speed Decay/Stall from ASA Event Set

West Caribbean Airways 701 – Venezuela

Boeing MD-82 - August 15, 2005 - 160 fatalities

- Engine anti-ice turned off to climb to FL330
- Engine anti-ice re-engaged; EPR reduced
- A/P in altitude hold
- Airspeed and Mach decay over next 10 minutes
- Autopilot disconnected
- Stall warning – pilot responds with full aft column and NU trim



Accident: West Caribbean MD-82 over Venezuela on 16-AUG-2005

Appr to Full Low Energy / Stall 7 10

Event Type: Loss of Energy Awareness

Injuries/Fatalities: 160 (152 PAX + 8 crew)

Flight: WCA 701

Local Time: ~2:00 am local time

Registration: HK-4374X

Phase of Flight: Cruise

Lack of External Visual References 4

Flight Crew Impairment 4

Training

Airplane Maintenance

Safety Culture 1 3

Invalid Source Data

Chan Atten Distraction 12

Systems Knowledge 2 5 11

CRM 10

Automation Confusion / Awareness 5 6 9

Ineffective Alerting 7

Inappropriate Control Actions 8

Narrative

- ① - Significant safety oversight issues at operator for previous 6 months
 - CAPT experienced but low time in type; FO had low time but more in type
 - Takeoff at or near max allowable weight (performance limited)
- ② - Flight plan called for cruise at FL350; airplane not capable of achieving altitude with anti-ice
- ③ - Significant weather along the planned route; not noted on the flight plan
- ④ - Night, IMC. Middle of the night for crew's Circadian rhythm.
 - Initial cruise at FL310 encountered weather cells, routed around by ATC
 - Crew requested climb to FL330 but could not reach altitude in level change mode
- ⑤ - Crew turned off anti-ice; switched to VS; aircraft climbed at max power, losing airspeed
- ⑥ - At FL330, crew restored anti-ice, re-engaged A/P in ALT HOLD, commenced other activities
- ⑦ - Aircraft could not maintain altitude at selected airspeed; Mach began to decrease
 - As Mach decreased to 0.65, airplane also began to lose altitude
 - Crew asked ATC for lower altitude and began to descend as Mach decreased below 0.60M
 - Just below FL320 stick shaker activated
- ⑧ - CAPT disengaged autopilot and pulled the column aft, then began to trim nose up
- ⑨ - Autothrottles remained engaged, throttles to idle (reasons unclear, possibly from surge)
- ⑩ - Aircraft entered full stall. FO recognized stall but did not intervene. CAPT did not respond to FO
- ⑪ - Crew mistook idle thrust as indication of engine flameout, contact ATC to declare emergency and request lower altitude
- ⑫ - CAPT continued to hold column aft as crew continued to call for lower altitudes and diagnose perceived engine trouble
 - Crew apparently believed the reduced airspeed was the result of dual engine flameout. The CAPT never attempted to reduce angle of attack.
 - Descent reached 12,000 fpm just before the airplane impacted the ground.

ASA Significant Themes

Summary of
Significant Themes
Across All Events

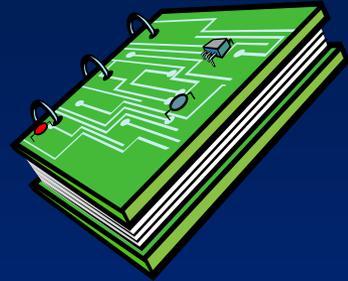
	<i>Lack of External Visual References</i>	<i>Flight Crew Impairment</i>	<i>Training</i>	<i>Airplane Maintenance</i>	<i>Safety Culture</i>	<i>Invalid Source Data</i>	<i>Distraction</i>	<i>Systems Knowledge</i>	<i>Crew Resource Management</i>	<i>Automation Confusion / Awareness</i>	<i>Ineffective Alerting</i>	<i>Inappropriate Control Actions</i>	<i>Total</i>
Formosa Airlines Saab 340	x	x			x		x	x	x		x		7
Korean Air 747-200F	x			x		x	x		x		x		6
Flash Airlines 737-300	x		x		x		x		x	x	x	x	8
Adam Air 737-400	x		x	x			x	x	x	x	x	x	9
Kenya Airways 737-800	x		x				x		x	x	x	x	7
Aeroflot-Nord 737-500	x	x	x	x	x		x	x	x	x	x	x	11
Gulf Air A320	x		x				x		x		x	x	6
Icelandair 757-200 (Oslo)	x						x		x	x	x	x	6
Armavia A320	x	x			x		x		x	x	x	x	8
Icelandair 757-200 (Baltimore)	x				x	x	x	x	x	x	x	x	9
Midwest Express 717	x				x	x	x		x		x	x	7
Colgan Air DHC-8-Q400	x	x	x		x		x	x	x	x	x	x	10
Provincial Airlines DHC-8	x		x				x			x	x	x	6
Thomsonfly 737-800	x		x	x	x		x			x	x		7
West Caribbean MD-82	x	x			x		x	x	x	x	x	x	9
XL Airways A320		x	x	x	x	x	x	x	x	x	x		10
Turkish Airlines 737-800	x			x	x	x	x		x	x	x		8
Empire Air ATR-42	x	x			x		x		x	x	x		7
Overall	17	7	9	6	12	5	18	7	16	14	18	12	133

ASA Proposed Safety Enhancements

Recommended Safety Enhancements

Air Carrier Actions

- **Low Airspeed Alerting**
 - Incorporate existing service bulletins to install low airspeed aural alerting in the U.S. fleet
- **SOP Effectiveness and Adherence**
 - Review and update SOPs to align with latest CAST, manufacturer, and ATO recommendations
 - Assess and revise SOPs based on feedback from data monitoring programs
- **Non-Standard Flight Operations**
 - Improve safety of non-revenue, non-standard flight operations
- **Training Verification and Validation**
 - Ensure flight crew training is verified by the operator



Recommended Safety Enhancements

Flight Crew Training

- **Enhanced Upset Recovery Training, Including Approach-to-Stall**
 - New approach-to-stall recovery procedures
 - Upset prevention & recovery, including unreliable airspeed
- **Scenario-Based Training for Go-Arounds**
 - Go-arounds for other than decision height
 - Complicating factors (trim, light weight, entry into clouds)



- **Enhanced Crew Resource Management**
 - Focus on pilot monitoring duties
- **Training for Non-Normal Situations**
 - Focus flying the airplane first



Recommended Safety Enhancements

Airplane Design

- Latest type designs from the four major airframe manufacturers include the following design features that mitigate ASA:

- Low airspeed alerting / protection
- Removal of invalid airspeed data from displays
- Automatic pitot heat activation
- Multi-sensory alerting of invalid air and inertial system data
- Fault tolerant data source design
- Connection of checklists to faults or malfunctions
- Angle-of-attack / stall protection
- Low speed protection or inhibiting of nose-up pitch trim

New Airplanes

- Low airspeed alerting
- Remove invalid airspeed from display
- Automatic pitot heat activation
- Multisensory alerting of invalid data
- Improved source data fault tolerant designs
- Connect conditions to checklist
- AOA protection
- Low speed nose-up trim protection/inhibit

Recommended Safety Enhancements

Airplane Design

New Airplanes

- Low airspeed alerting
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Recommended Safety Enhancements Airplane Design

- Additional features for new designs to further mitigate ASA issues:

Thrust asymmetry compensation

Alert asymmetric thrust

Energy state symbology on PFD +
Virtual day-VMC equivalent displays

Multisensory roll alert w/guidance

Bank / pitch attitude protection

New Airplanes

Low airspeed alerting

Remove invalid airspeed from display

Automatic pitot heat activation

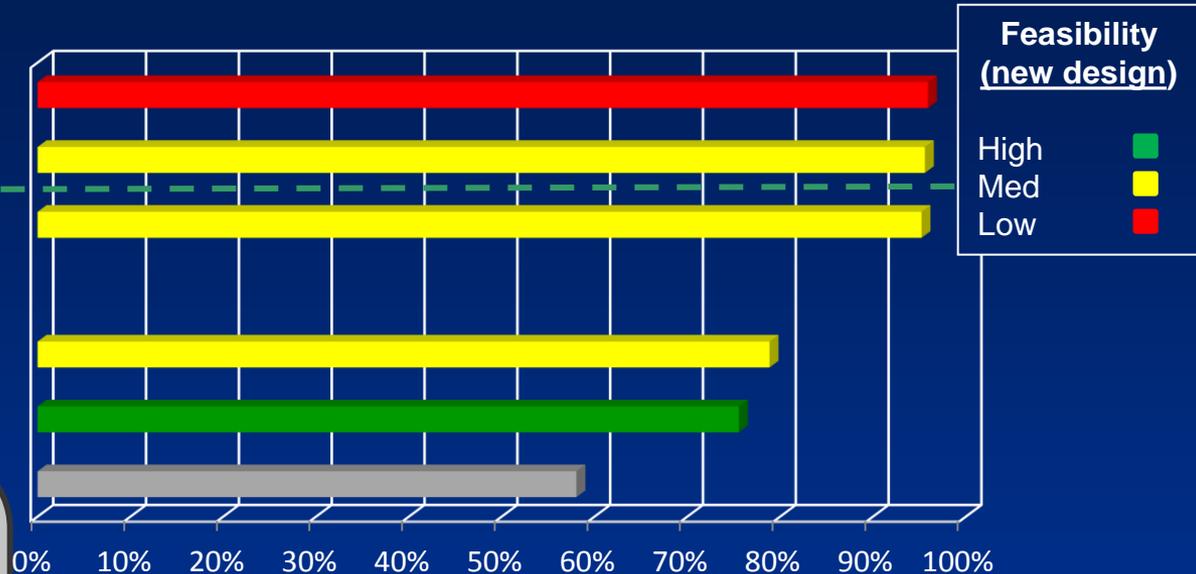
Multisensory alerting of invalid data

Improved source data fault tolerant designs

Connect conditions to checklist

AOA protection

Low speed nose-up trim protection/inhibit



Recommended Safety Enhancements

Airplane Design

- For new designs:
 - Continue incorporating features currently delivered on latest type designs, plus:
 - Bank angle protection on new fly-by-wire airplanes
 - Advanced bank angle alerting with recovery guidance
 - Virtual day-VMC displays with energy path guidance



At 35° bank...



BANK ANGLE



At 45° bank...



ROLL RIGHT



- For existing designs: Study feasibility to implement and retrofit

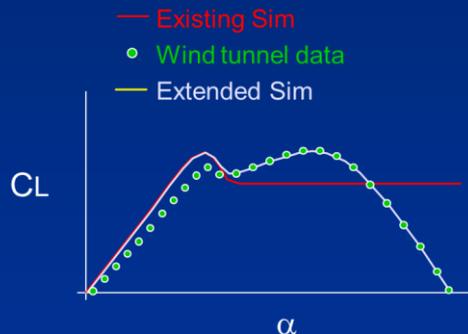
Recommended Safety Enhancements

Coverage of ASA Themes and Events

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Formosa Airlines Saab 340								x					1
Korean Air 747-200F						x	x						2
Flash Airlines 737-300							x			x			2
Adam Air 737-400								x		x			2
Kenya Airways 737-800							x			x			2
Aeroflot-Nord 737-500		x					x	x		x			4
Gulf Air A320			x				x				x		3
Icelandair 757-200 (Oslo)										x	x		2
Armavia A320							x			x	x		3
Icelandair 757-200 (Baltimore)					x			x				x	3
Midwest Express 717					x							x	2
Colgan Air DHC-8-Q400							x	x					2
Provincial Airlines DHC-8							x						1
Thomsonfly 737-800													0
West Caribbean MD-82							x	x			x		3
XL Airways A320								x		x			3
Turkish Airlines 737-800					x					x			2
Empire Air ATR-42							x			x			2
Overall	0	1	1	0	3	1	10	7	0	9	4	2	

Recommended Safety Enhancements Research

- **Flight Deck Systems (SE 207, 208)**
 - Effectiveness of angle-of-attack indicators/displays
 - Low energy state monitoring and alerting
 - Spatial disorientation detection and alerting
 - Improved display of automation states, including autoflight system disconnects and failures
 - Routine and non-routine use of autoflight systems, mode transitions, and autopilot/autothrottle disconnect



- **Simulator Fidelity (SE 209)**
 - Full stall modeling
 - In-flight validation of simulator-based training

- **Human Performance (SE 210, 211)**
 - Database of pilot responses to critical warnings and alerts
 - Training scenarios for attention issues

Recommended Safety Enhancements

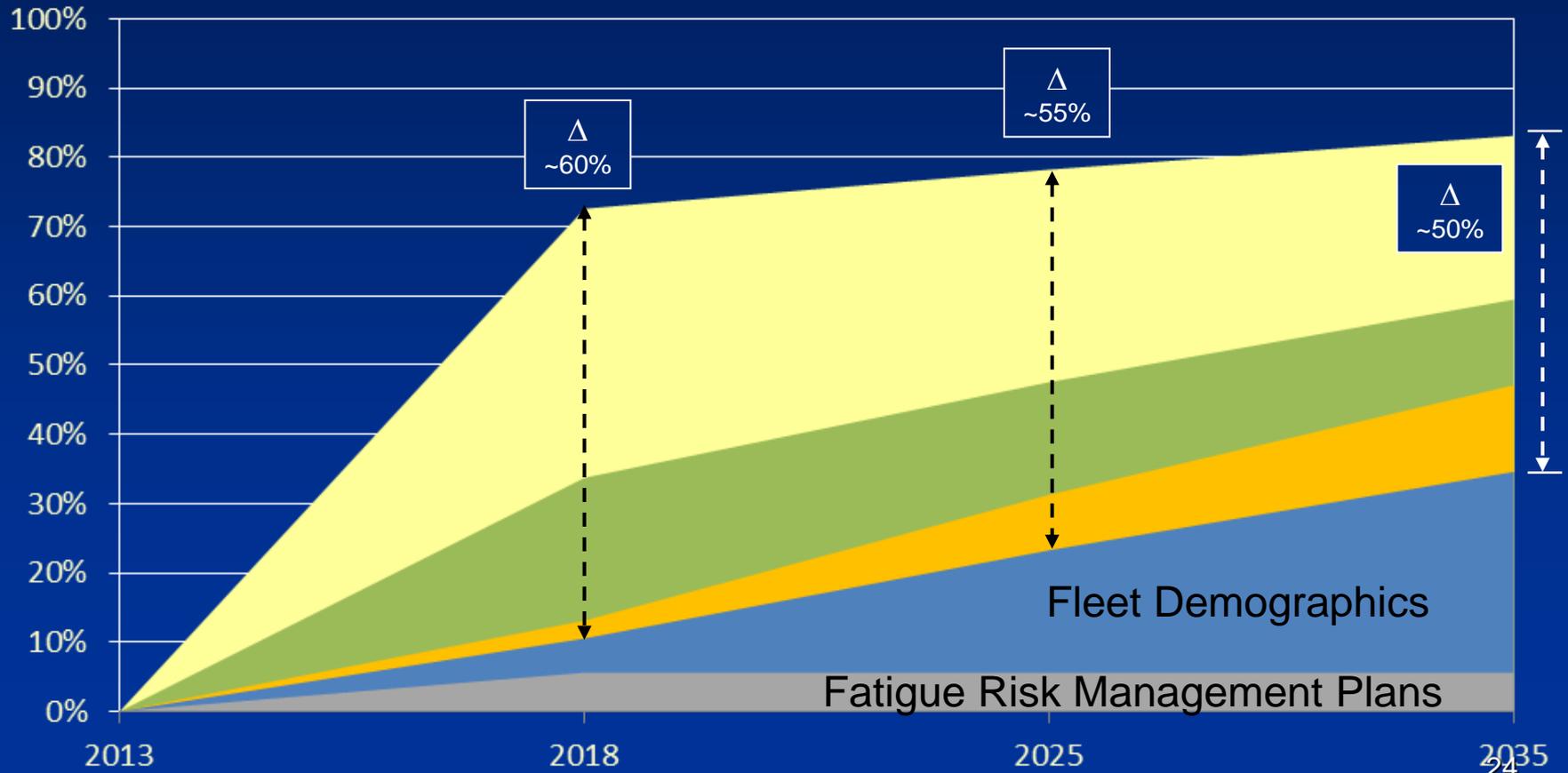
Research Areas Addressed

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Kenya Airways 737-800													0
Aeroflot-Nord 737-500		x											1
Gulf Air A320			x										1
Icelandair 757-200 (Oslo)													0
Armavia A320													0
Icelandair 757-200 (Baltimore)					x								1
Midwest Express 717					x								1
Colgan Air DHC-8-Q400								x					1
Provincial Airlines DHC-8													0
Thomsonfly 737-800													0
West Caribbean MD-82								x		x			2
XL Airways A320													0
Turkish Airlines 737-800					x								1
Empire Air ATR-42													0
Overall	0	1	1	0	3	1	0	2	0	0	1	0	

Recommended Safety Enhancements

Projected Risk Reduction

- Airplane Design ■
- Airline Operations ■
- Flight Crew Training ■



Acknowledgements

Industry partners

- Airbus
- Airlines for America
- Air Line Pilots Association
- Alaska Airlines
- Austin Digital, Inc.
- Boeing
- Bombardier
- Compass Airlines
- Embraer
- Federal Express
- Honeywell
- Mitre
- Pinnacle Airlines
- Polar Air Cargo
- Rockwell-Collins
- Southwest Airlines

Government partners

- FAA
- NASA
- USAF

CAST SEs on SkyBrary:

www.skybrary.aero/index.php/Portal:CAST_SE_Plan

Thank You