Synthetic Vision Commercial Aircraft Flight Deck Display Technologies for Attitude State Awareness, Prevention of Entry Into and Recovery From Unusual Attitudes

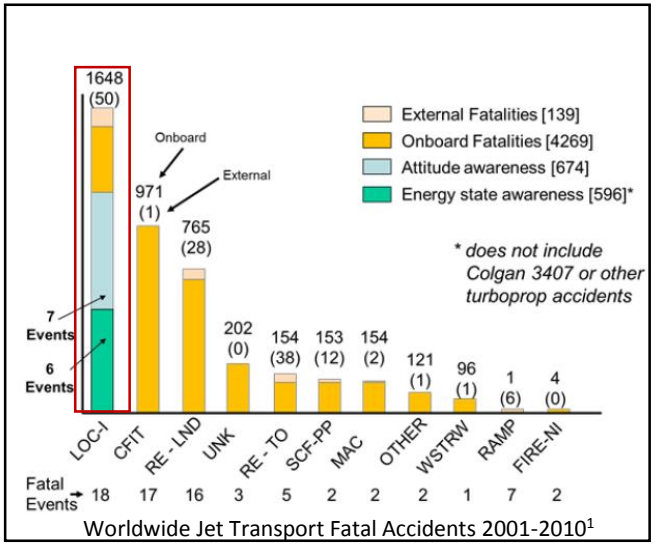
Kyle E. Ellis, Ph.D.
Lawrence J. Prinzel III, Ph.D.
Captain Daniel Kiggins

NASA Langley Research Center
Hampton, Virginia

June 9-12, 2017

Commercial Aviation Safety Team

- Airplane State Awareness (ASA) Joint Safety Analysis Team (JSAT) – chartered August 2010
- Purpose was to analyze a subset of LOC – inflight (LOC-I) accidents and incidents in which the flight crew lost awareness of airplane's state, defined as:
  - Attitude (pitch or bank angle or rate), or
  - Energy (combination of airspeed, altitude, vertical speed, thrust, and airplane configuration)
- Analysis revealed many LOC-I accidents involved loss of attitude (e.g., spatial disorientation) and/or loss-of-energy state awareness (LESA)



Worldwide Jet Transport Fatal Accidents 2001-2010[1]

[1]*Airplane State Awareness Joint Safety Analysis Team Final Report (2014). Washington, D.C.: CAST*

Technologies for Airplane State Awareness

CAST teams (2010-2014)

JSAT

- Analyzed 18 events from ~10 years prior; Identified 12 recurring problem themes; Suggested >270 intervention strategies

JSIT

- Assessed each intervention strategy for effectiveness & feasibility; Recommended
  - **13** safety enhancements (SEs), no research req'd
  - **5 research** safety enhancements (SEs)
  - **1 design** SE where research is critical to implementation

- Published plans to achieve each safety enhancement

Summary of Significant Themes Across All Events

	Lack of External Visual References	Flight Crew Impairment	Training	Airplane Maintenance	Safety Culture	Invalid Source Data	Distraction	Systems Knowledge	Crew Resource Management	Automation Confusion / Awareness	Ineffective Alerting	Inappropriate Control Actions	Total
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 737-300	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	

Virtual Day-VMC Displays (SE-200)

Attitude & Energy State Techs (SE-207)

Systems State Technologies (SE-208)

Simulator Fidelity (SE-209)

Flight Crew Performance (SE-210)

Training for Attention Management (SE-211)

Detailed Implementation Plans

Desired Outputs and Schedule

NASA R&D project plans and deliverables (2014-2019)

CAST The Commercial Aviation Safety Team

Reference Materials

http://www.skybrary.aero/bookshelf/books/2999.pdf
http://www.skybrary.aero/bookshelf/books/3000.pdf

Technical Objectives

- Mitigate the problems and Contributing Factors that lead to flight crew loss of airplane state awareness

- “Develop data, systems, models, training methods and technologies for transition to the aviation community (OEMs, Regulators, Training Orgs, and Operators) which can reduce the flight crew’s loss of airplane state awareness as a causal factor in commercial aviation accidents and incidents.

NASA Safety Enhancement Focus Areas

- 207 – ASA-Research – Attitude and Energy State Awareness
- 208 – ASA-Research – Airplane Systems Awareness
- 209 – ASA-Research – Simulator Fidelity
- 210 – ASA-Research – Flight Crew Performance Data
- 211 – ASA-Research – Training for Attention Management
- 200 – ASA-Design – Virtual Day-VMC Displays

Research Partners

Rockwell Collins

Honeywell

BOEING

American Airlines

SAAB Sensis

OHIO UNIVERSITY

FEDERAL AVIATION ADMINISTRATION

Georgia Tech

GEORGE MASON UNIVERSITY

KBRwyle

THE UNIVERSITY OF IOWA

NAVAL MEDICAL RESEARCH UNIT DAYTON

ARCHITECTURE TECHNOLOGY CORPORATION

DECISIONRESEARCH

New Research Partner?

Avianca

Rockwell Collins

Honeywell

BOEING

American Airlines

SAAB Sensis

OHIO UNIVERSITY

Georgia Tech

GEORGE MASON UNIVERSITY

KBRwyle

THE UNIVERSITY OF IOWA

ARCHITECTURE TECHNOLOGY CORPORATION

DECISIONRESEARCH

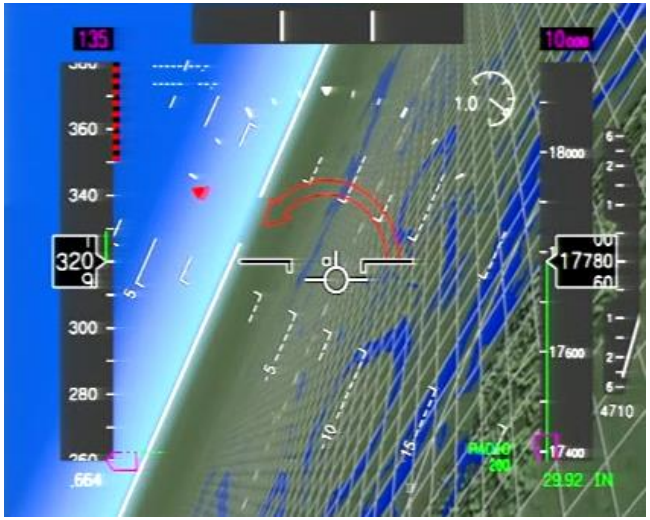
Safety Enhancement 200 (SE-200)

CHALLENGE

- Reduce fatalities caused by loss of control in-flight (LOC-I)
- Mitigate the problems and contributing factors that lead to flight crew loss of airplane state awareness
- Develop data, systems, models, training methods and technologies for transition to the aviation community

CAST SAFETY ENHANCEMENTS (SE)

- Commercial Aviation Safety Team (CAST) SE 200 – Virtual Day-Virtual Meteorological Condition Displays ("Virtual Day-VMC Displays")
- Evaluate display configurations representative of virtual day-VMC displays, such as Synthetic Vision Systems, as they support:
  - Attitude Recognition
  - Attitude Alerting and Awareness
  - Visual Dominance to prevent Spatial Disorientation
- Define minimum aviation system performance standards (MASPS)



IMPACT

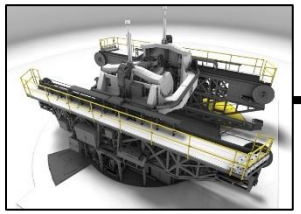
- Implementation of display concept requirements into new transport category airplane programs starting in 2020
- Equip 30% of worldwide aircraft fleet with virtual day-VMC displays to improve attitude awareness, recognition and visual dominance by 2035
- Reduce risk of loss of control in-flight incidents by 16% by 2035 (based on 30% fleet-wide equipage without retrofit solutions)

Virtual Day-VMC Displays

Traditional Display

Virtual Day-VMC Display

SE-200 Research Experiments

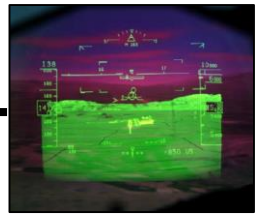
Energy and Attitude State Extreme Upsets and Recovery (October 2017)

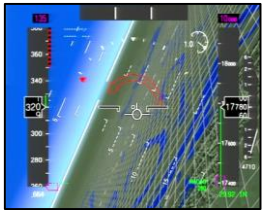
Low-Hour and International Pilots Line-Oriented Flight Training Scenarios (July 2017)



Display Transition Design During Recovery (March 2017)

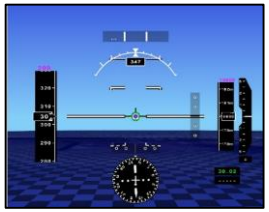
Head-Up and Head-Worn Display Simulator and Flight Test (August 2016)




Attitude Awareness and Unusual Attitude Recovery/ Special Purpose Operational Training Scenarios (May 2016)

Design of Virtual Day-VMC Displays (July 2015)

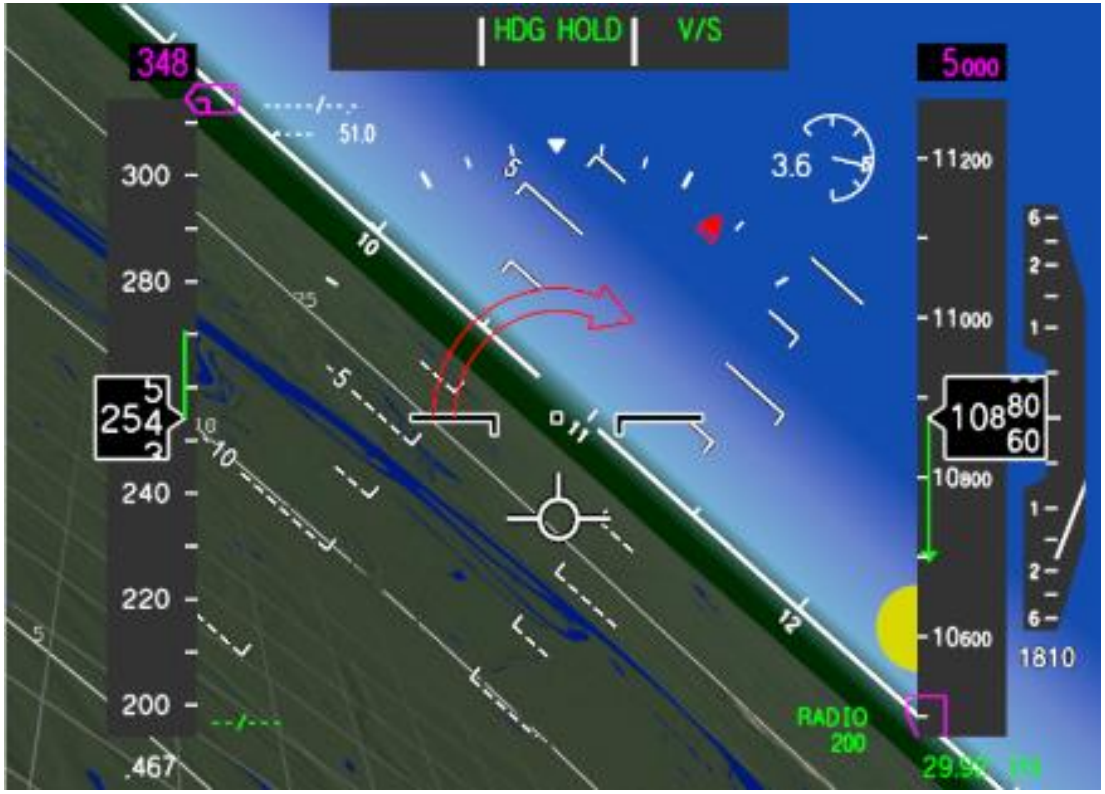




Attitude Recognition (March 2015)

What Are We Doing in Miami?

Operational Realistic Line-Oriented Flight Training Scenarios

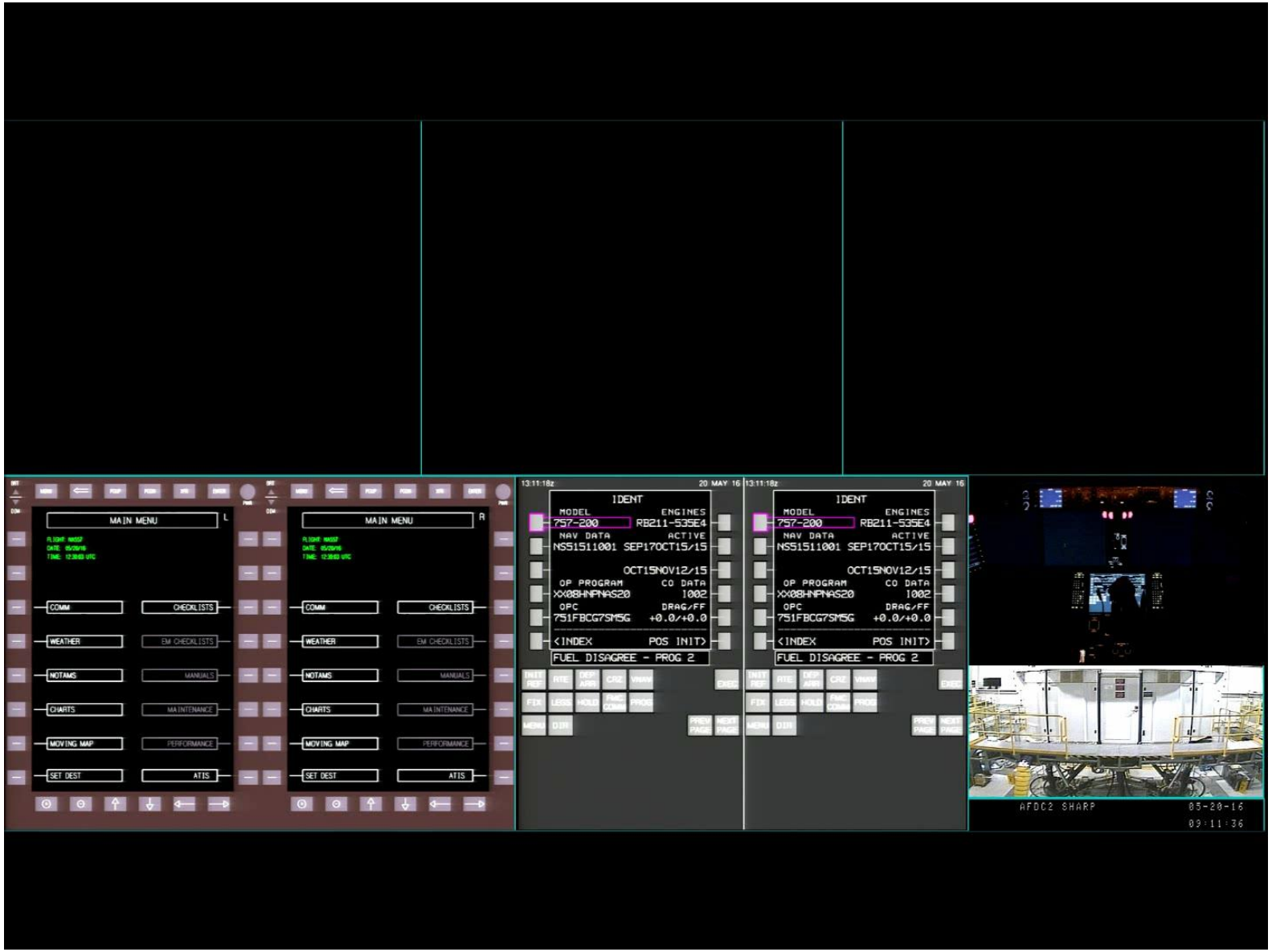
Virtual Day-VMC Display Video



Types of Scenarios

- Unusual Attitude Recovery
- Special Purpose Operational Training
- Line-Oriented Flight Training

Sample Unusual Attitude Recovery



Special Purpose Operational Training Examples

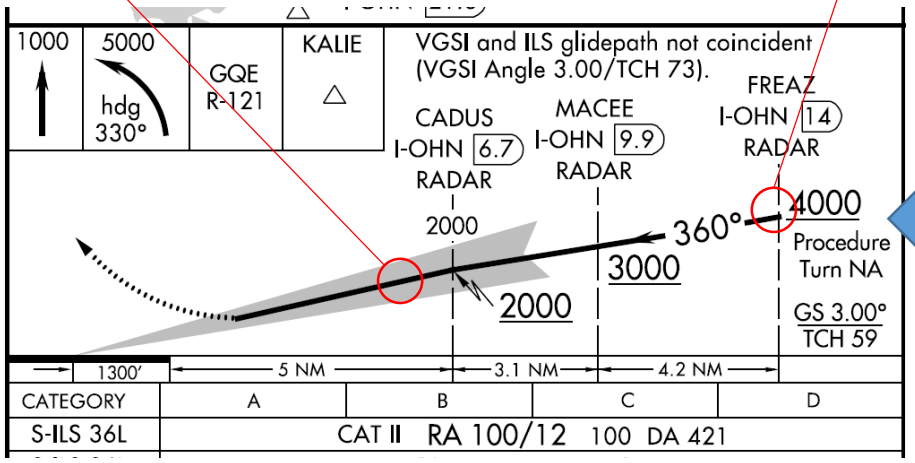
- False Glideslope with Radar Altimeter Fail
- Fuel Leak with Clear Air Turbulence and Instrument Fail
- Reduced Engine Performance with High-Alpha Aerodynamic Effects
- Missed Approach with Degraded Autopilot
- Wake Vortex Encounter

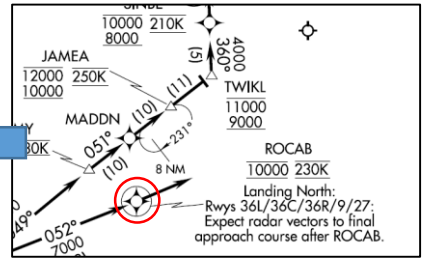
False Glideslope with Radar Altimeter Fail

Radar Altimeter Failure

False Glideslope

CAT II





Initial Starting Point

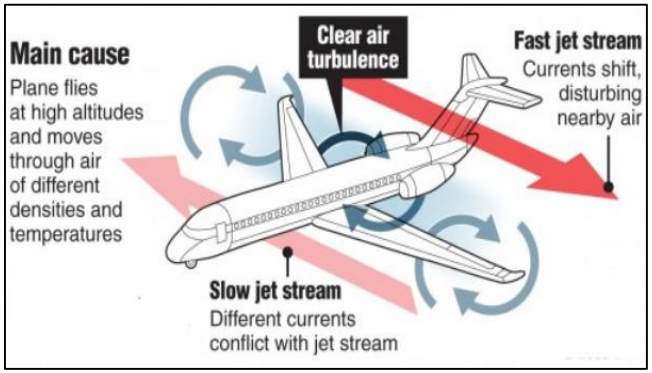
Fuel Leak with Clear Air Turbulence and Instrument Fail

Fuel Leak *leads* In-Flight Engine Shutdown

Clear Air Turbulence (CAT)*

Causes pitch up and roll due to forces of CAT
And results in Autothrottle and Autopilot Disconnect

Frozen Instrument

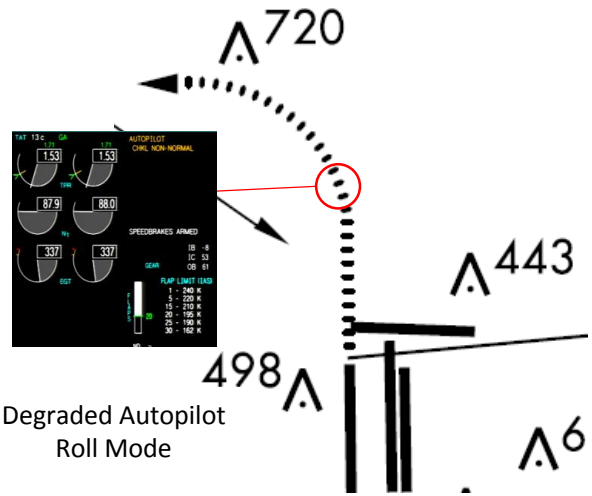


*moderate turbulence throughout scenario

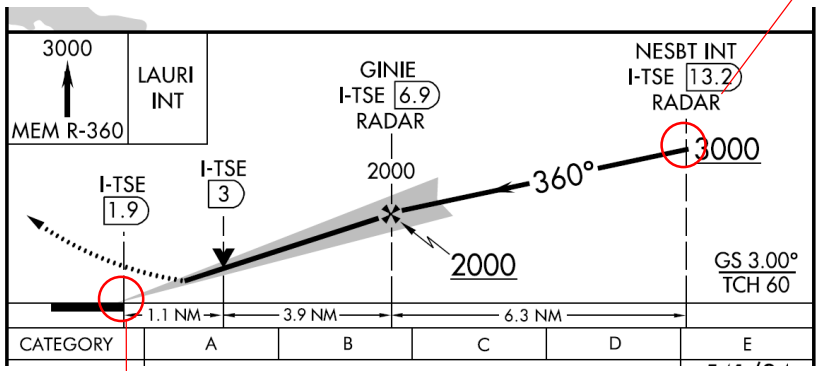
Reduced Engine Performance with High-Alpha Aerodynamic Effects

Missed Approach with Degraded Autopilot

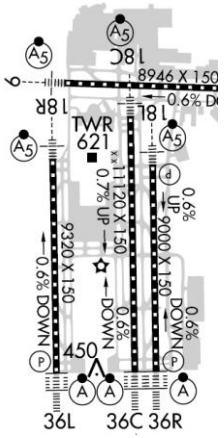
AUTOPILOT	Caution	AUTO PILOT	Beeper	The engaged autopilot is operating in a degraded mode. Engaged roll and/or pitch mode may have failed.
AUTOPILOT DISC	Warning	A/P DISC	Siren	The autopilot has disconnected.
AUTOTHROT DISC	Caution	A/T DISC	Beeper	The autothrottle has disconnected.



Degraded Autopilot Roll Mode



Runway 36C Approach



Runway Change*

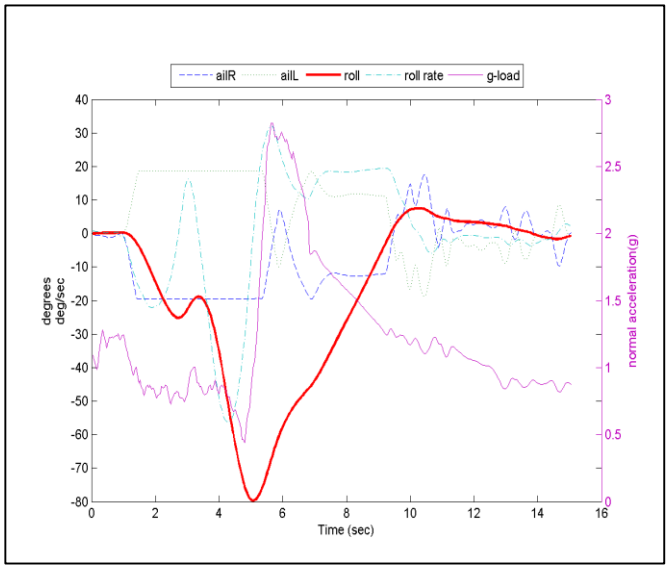
RWY 36L Missed Approach (not RWY 36C)

ATC Provides Erroneous Missed Approach Instructions

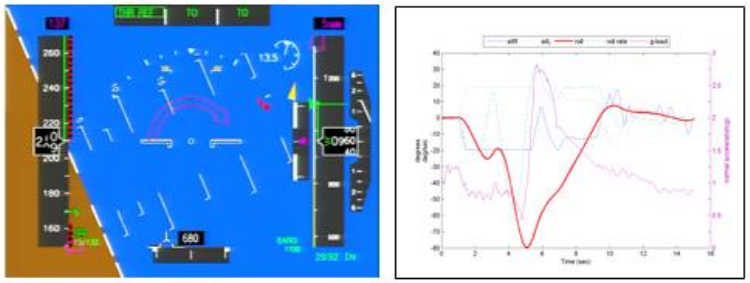
Runway Incursion – Missed Approach

*Due to C HYD SYS Caution and Need for Longer Runway

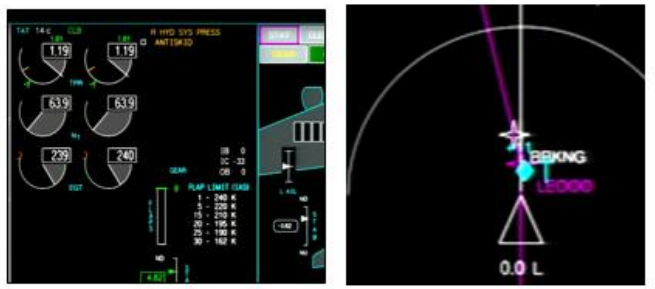
Wake Vortex Encounter



Line-Oriented Flight Training Example



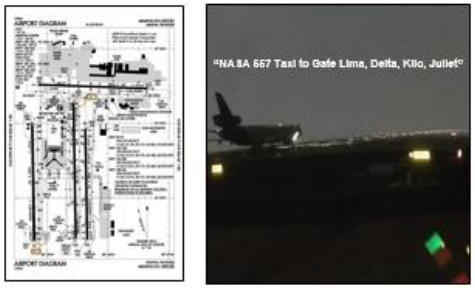
Wake Vortex Encounter



Hydraulic/Anti-Skid Failure with Proximate Traffic

Trailing Edge Flap Asymmetry

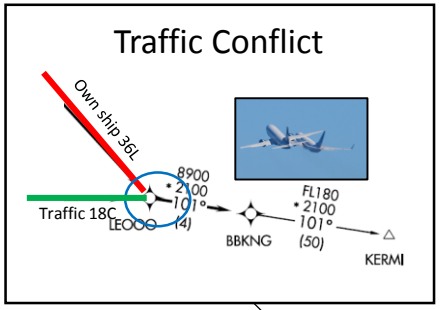
Runway Incursion



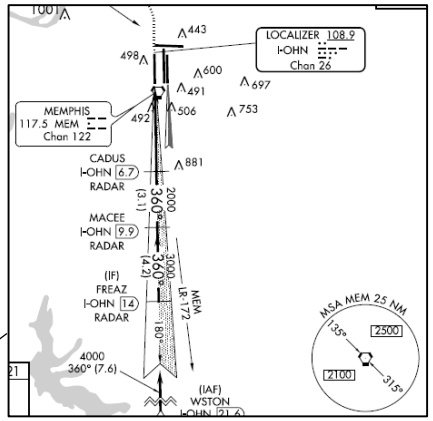
ATC Taxi-In Clearance Error

Line-Oriented Flight Training Example Cont.

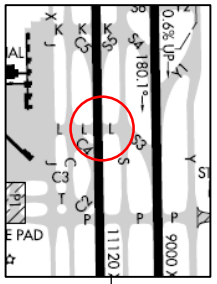
LIVE ATC

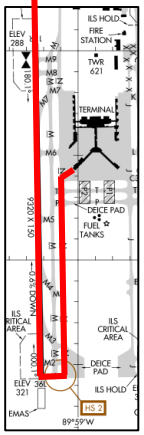


To MIA



Runway Incursion





5000’

Return to KMEM

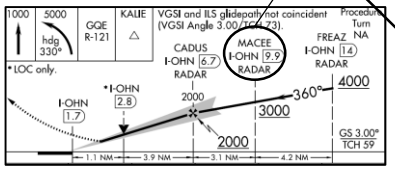
R HYD SYS PRESS ANTISKID

Switch to Center Frequency

Hold LEOOO if Flight Crew Request

Cleared Direct MACEE
Descend and Maintain 3000’

Direct MACEE 3000’



*AT FLAPS 30

CADUS

TE FLAP ASYM*

ATC ISSUES GO AROUND RWY 36L

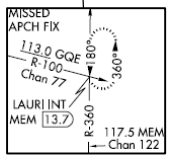
HOLD

1000’

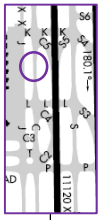
ATC Go-Around:
ATC verbiage error + 3000’ (not 5000’) as published

ATC Vectors or Direct to Land RWY 36C

RWY 36L



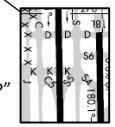
C5, C, C3, RAMP



RWY 36C

Taxi / Clearance Error

Gate



Says: “S5, C, C, C3, RAMP”
NOT
Correct: “C5, C, C3, RAMP”

TAXI

RAMP

T/O RWY 36R

Traffic T/O RWY 36L

Traffic T/O RWY 18C

KMEM

Wake Encounter
(700 – 1000 MSL)

NON-RADAR

MISSED APPROACH: Climb to 1000 then climbing left turn to 5000 via heading 330° and GQE VOR/DME R-121 to KALIE INT/GQE 15 DME and hold, continue climb-in-hold to 5000.

How Can Avianca Help NASA?

- CAST identified that hours of experience may be factor in loss-of-control inflight accidents and incidents
- Research is focused on developing flight deck technologies and training methodologies to address problem
- NASA research has collected data on U.S. domestic airline pilots
- There exists a research need on low-hour and international pilots to close gap in our understanding of issue and how best to mitigate
- Avianca Airlines would be an important partner in addressing the leading category of worldwide commercial airline accidents


SPD
LOC
ROLLOUT
G/S
FLARE
LAND 3
134
10000
ITSE/360
DME 2.2
ILS 10
180
160
120
100
80
800
600
400
200
0480
710
140
RADIO
200
29.92 IN
QUESTIONS?

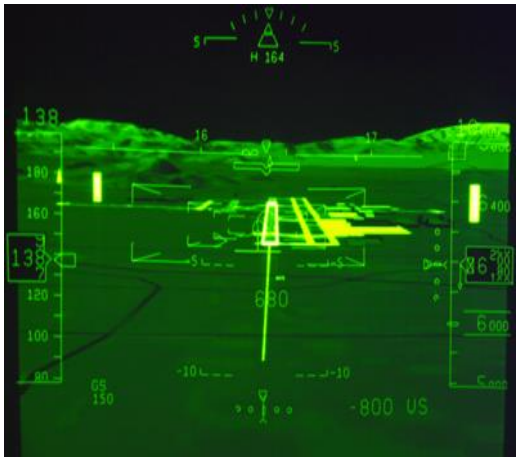

SPD
LOC
ROLLOUT
G/S
FLARE
LAND 3
ITSE/360
DME 2.2
ILS
134
10000
180
160
120
100
80
800
600
400
200
0480
710
140
RADIO
200
29.92 IN
BACK-UP SLIDES

Disorientation Research Device Research

The “Kraken” Video

Types of Synthetic Vision Displays Researched

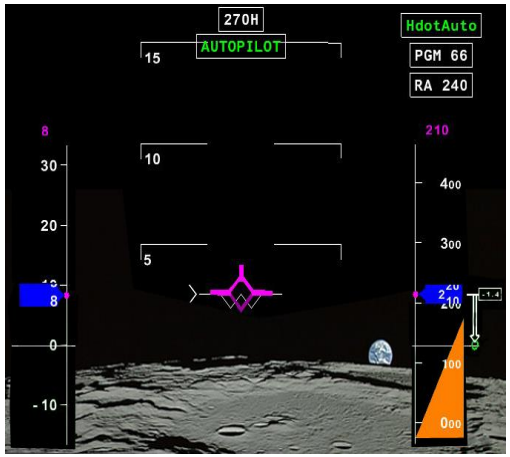
Primary Flight Display



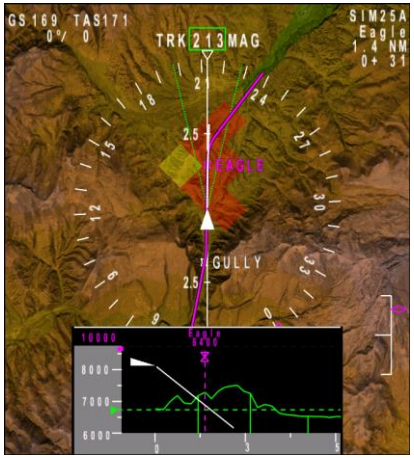
Head-Up Display

Electronic Flight Bag

Head-Worn Display



Lunar Lander



Navigation Display

Training for Attention Management

To detect, induce, and mitigate attentional human performance limiting states (AHPLS)

- Detect with psychophysiological sensors and machine learning state prediction
- Assess the induction of AHPLS via realistic simulated flight scenarios
- Develop training methods for the avoidance of and recovery from AHPLS

Loss-of-Energy State Awareness Research

Series of SE-207/208 studies to advance TRL and evaluate usability/acceptability for:

- "Systems that predict the energy state and/or autoflight configuration …" (SE-207, Output 3)
- "Displays that present the future expected state of automated systems…" (SE-208, Output 1(a))
- "Displays that show … (e.g, a synoptic) the flight-critical data systems in use by automated systems and primary flight instruments…" (SE-208, Output 1(b))

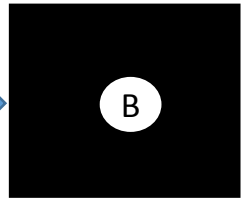
AIME-1 (completed, Jan-2016); AIME-2 (Fall-2017)(SE-208); AIME-3 (Mar-2019)(SE-208)

Terminal Area Operations
- ATC DataComm
- Dense traffic
- Paperless cockpit
- Area Navigation (RNAV) & ILS

Independent Variables
- Weather; traffic pattern
- Path/procedure; Crew
- Technology condition
- Off-nominal condition(s)

Unusual Attitude Recovery Method

Initial Condition



Displays Blank and Simulator Moves to Pre-UAR Attitude Based on Condition of Trial

Displays Un-blank

Simulator Continues to Move

Once UAR criteria met (~2 seconds later), a tone is sounded

After UAR performed and pilot announces “recovered”, the trial is over.