



System Wide Safety

AIRPLANE STATE AWARENESS RESEARCH SAFETY ENHANCEMENTS

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*Briefing to Commercial Aviation Safety Team
Flight Safety Foundation, Alexandria VA
October 4, 2018*



CAST ASA Study Summary 2010-2014



System Wide Safety

CAST-recruited gov't-industry team:

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



TECHNOLOGIES for AIRPLANE STATE AWARENESS



System Wide Safety

CAST SE	Output / Description		TASA Technical Area
207 Attitude & Energy State Awareness	2	Stall Recovery Guidance	State and Prediction Technologies • Prediction and alerting for LOC and spatial disorientation • Crew and system interactions
	3	Energy and AutoFlight System State Prediction	
	4	SD Alerting	
208 Airplane Systems Awareness	1	Display of Current and Predicted System States	
	2	System State Alerting	
209 Simulator Fidelity	3	Stall Aero Model Definition	Simulator Fidelity • Simulator modeling requirements for stall training
210 Flight Crew Performance Data	2	Human Performance Eval Methods in Design	Flight Crew Performance • Tools and methods to collect and analyze flight crew performance
	3	Attention Evaluation in Design	
211 Training for Attention Management	1	Attention Detection in situ	Training for Attention Management • Detect and measure attention limitations • Develop methods and guidelines for training scenarios
	2	Attention Training Methods	
200 Virtual Day-VMC Displays	1	MASPS for Virtual VMC Displays	Virtual Day-VMC Displays • Technologies and standards for displays under upset or LOC conditions



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SE 209 – SIMULATOR FIDELITY



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Safety Enhancement Action

To improve pilot performance during recovery from a full stall, the aviation industry should perform research to determine the benefits of using various levels of prototype advanced aerodynamic modeling of full stall characteristics to perform full stall recovery training.

Statement of Work:

To reduce accidents and incidents due to loss of airplane state awareness and improve pilot performance during recovery from a full stall, the aviation community should perform research, in accordance with Public Law 111-216, to determine:

- (1) the upset and stall recognition and recovery learning objectives (i.e., metrics for satisfactorily completing the training);
- (2) the ability to satisfactorily model full stall characteristics across a variety of aircraft types;
- (3) whether the various model characteristics make a difference in full stall recovery training;
- (4) how to insert aircraft response characteristics into the simulator to ensure the skills learned in simulator training are directly usable in real flight

Output 1 (FAA lead)	Aviation industry associations and regulators should define the learning objectives (i.e., metrics) for upset prevention and recovery training.
Output 2 (FAA lead)	Training and research organizations should identify the benefits of using various levels of prototype advanced aerodynamic modeling of full stall characteristics to perform full stall recognition and recovery training.
Output 3 (NASA lead)	Defined aerodynamic model parameters, along with their availability and associated uncertainties, that are necessary for replicating full stall flight characteristics of various aircraft models, including wing-mounted twins, high-wing turboprops, and T-tail/aft engine configurations.
Output 4 (FAA lead)	Research organizations, in collaboration with training organizations, should determine whether the characteristics presented in the simulator enable pilots to recognize stalls and to perform realistic post-stall recoveries in an actual airplane. The data collected should be used to optimize stall training. Characteristics of particular note are: • Handling characteristics near stall angle of attack • Motion cue for realism of buffet near stall angle of attack • Motion cue for realism of stall g-break and nose drop if any



SIM MODELING REQUIREMENTS for STALL TRAINING



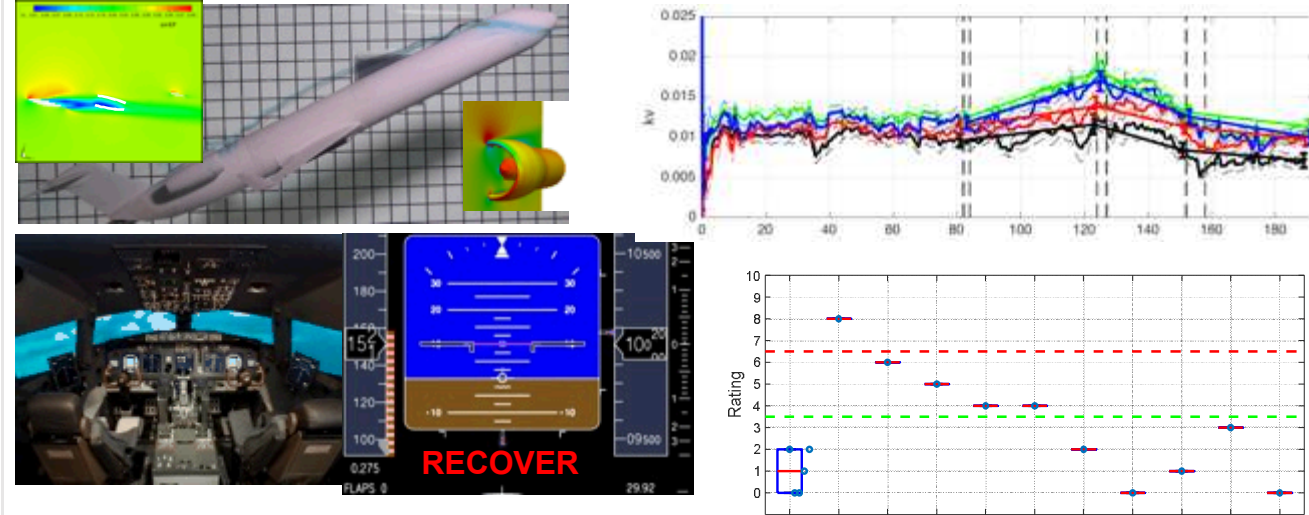
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Objective

- Identify sim modeling requirements for stall training
 - Aerodynamics
 - Propulsion
 - Motion Cueing
- NASA Focus on T-Tail Configuration
 - FAA/Boeing/NASA – Conventional Tail
 - FAA/UTIAS – High-Wing Turboprop
- Consider data sources and uncertainties

Approach:

- Conduct experimental and computational testing of a generic t-tail transport airplane configuration (LaRC)
- Develop propulsion model for high-AOA/stall conditions (GRC)
- Conduct motion-based sim studies of cueing methods (ARC)
- Develop high-fidelity piloted flight simulation
- Evaluate relevance/importance of flight dynamics aspects critical to stall conditions with NASA research and test pilots



Key Milestones

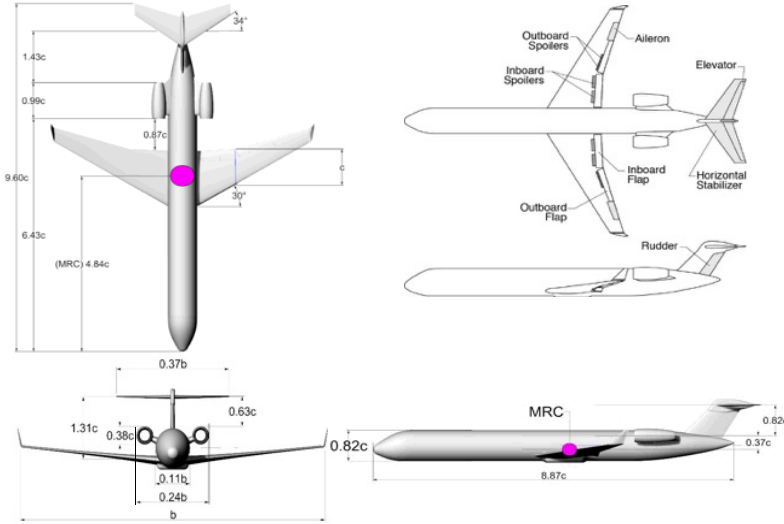
- | | |
|--|---------|
| • Aerodynamics models developed | 2016-17 |
| • Piloted simulation developed | 9/17 |
| • Aero, simulation development reported | 2017-18 |
| • Conduct piloted evaluations | 8/18 |
| • Identify/confirm modeling requirements | 9/18 |
| • Report-out to FAA, CAST | 9-10/18 |
| • Publish/present results | 1/19 |



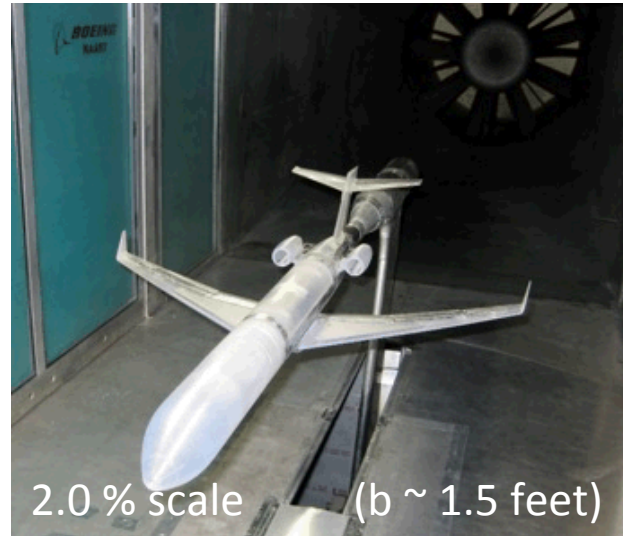
GENERIC T-TAIL – AERO DATA SOURCES



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Boeing R&T - NAART



2.0 % scale (b ~ 1.5 feet)

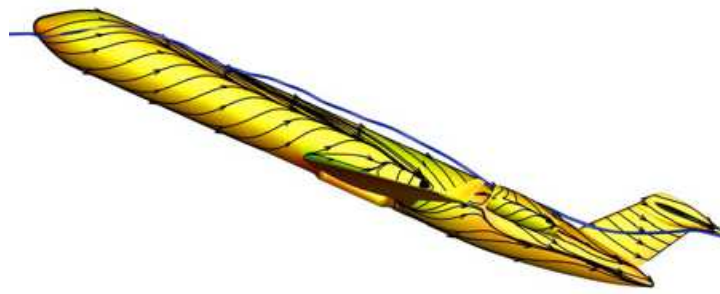
NASA LaRC – 12-FT LSWT



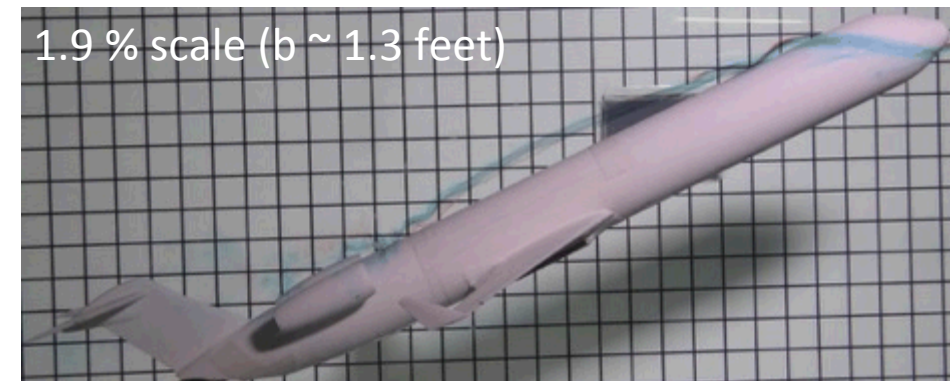
5.7 % scale (b ~ 4 feet)

Reference	Dimension
$\bar{c}$	11 feet
b	76 feet
S	754 feet ²
Weight	55,847 lbs.

NASA - TetrUSS/USM3D-SA



Boeing R&T - FVWT



1.9 % scale (b ~ 1.3 feet)

Designed by NASA & Area-I, Inc.
UAS & OML by Area-I, Inc. (info@areai.aero)



PILOT EVALUATION OF MODEL CHANGES



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- NASA Cockpit Motion Facility – Research Flight Deck
- Multiple stall maneuvers with variation in aerodynamic model parameters
- Assess difference/importance of cues, S&C, handling / characteristics

$$Cl_{\{total\}} = Cl(\alpha, \beta) + \Delta Cl_{\{ail\}}(\alpha, \beta, \delta_a) + \Delta Cl_{\{rud\}}(\alpha, \beta, \delta_r) + \Delta Cl_{\{spL\}}(\alpha, \beta, \delta_{\{spL\}}) \\ + \Delta Cl_{\{spR\}}(\alpha, \beta, \delta_{\{spR\}}) + \Delta Cl_{\{asymmetry\}}(\alpha, \beta) + Cl_{\hat{p}}(\alpha, \hat{p}) \hat{p} + Cl_{\hat{r}}(\alpha, \hat{r}) \hat{r}$$



Stick Pusher

Stall Asymmetries

Static Stability

Dynamic Stab. = f(AoA)

Ctrl. Effectiveness

Unsteady Aero. Effects

Dyn. Stab. = f(AoA, rate)

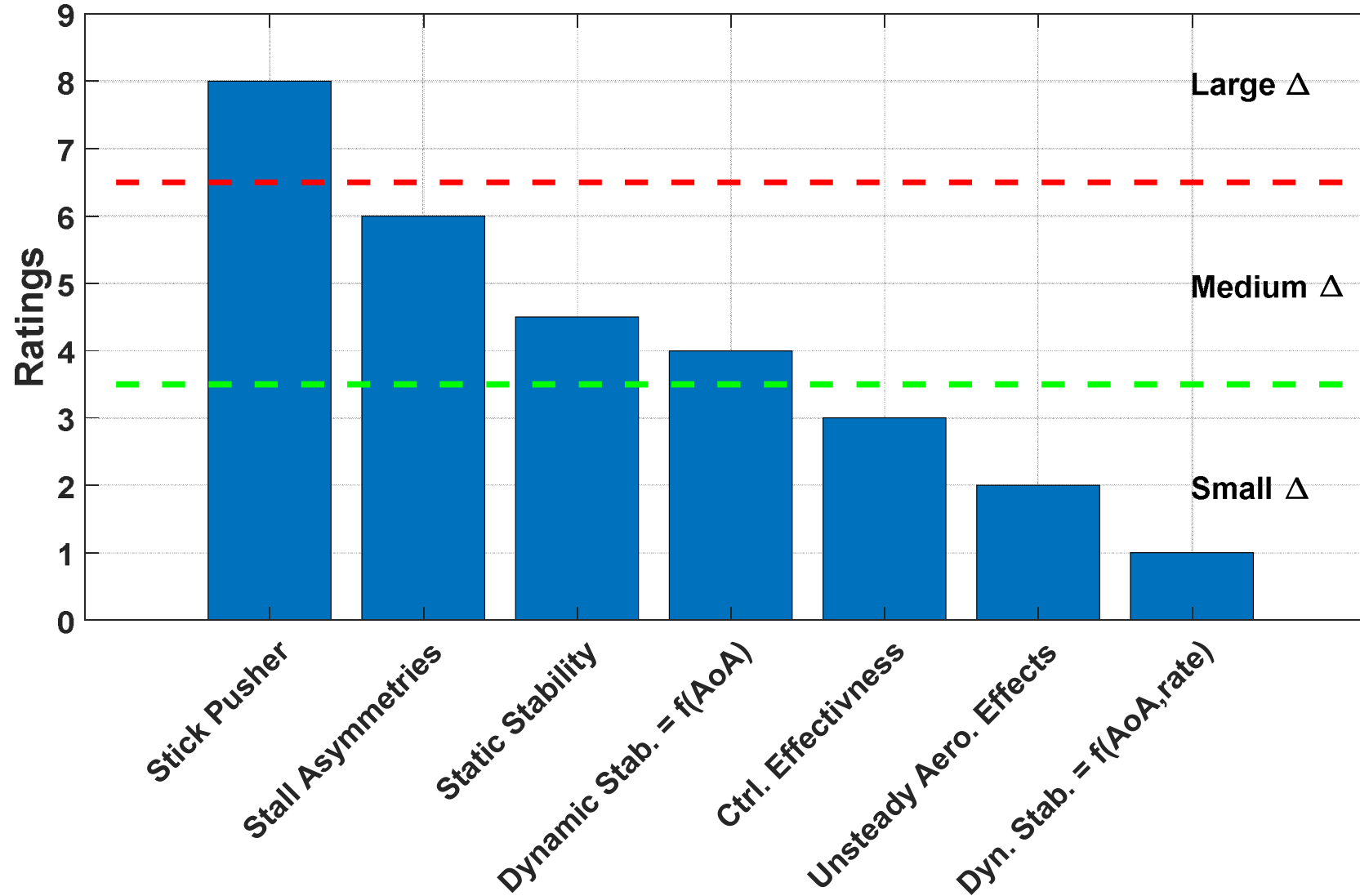


PILOT EVALUATION OF MODEL CHANGES



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Presented at JIMDAT 10/2,
not at CAST 10/4





KEY SIGNIFICANT CHARACTERISTICS



General consistency across configurations

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- **Stick pusher** – accurately represent the mechanization
- **Stall asymmetries** – flight test, wind-tunnel
- **Static stability** – wind-tunnel, CFD, flight test
- **Dynamic stability** (vary with AOA) – wind-tunnel, flight test, CFD
- **Control power** – wind-tunnel, CFD, flight test
- **Propulsion effects at high-AOA** – CFD, flight test (configuration dependent)

Reporting/Dissemination

- FAA report DOT/FAA/TC-17/56 (Gato, Tran, Brown) – Conventional-Tail
- UTIAS AIAA-2018-2937 (Grant, Moszczynski, Schroeder)– High-Wing
- NASA AIAA-2018-0529, -1168 (Cunningham, Shah, et al)– T-Tail (model / sim dev)
- Outbriefs to FAA, JIMDAT/CAST, industry partners
- AIAA SciTech 2019
- Industry/govt outreach – 2018-2019
- Formal NASA report



EXTENDING THE ENVELOPE



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NASA research focused on stall+10° AOA region

- Conventional simulation flight dynamics modeling techniques were successful in attaining pilot recognition
 - More complex (less conventional) methods (rate/frequency effects, unsteady aerodynamic effects) do not appear to be required for transport airplane stall recognition & recovery training simulator mission
- Typical testing and modeling techniques may not be adequate for $AOA > \sim 35^\circ$
 - Significant rate / frequency effects for roll damping at high AoA
 - Fuselage vortex symmetry decreases at high-AoA
 - Significant yaw asymmetry increases for $\sim 35^\circ < AOA < \sim 50^\circ$
 - Additional testing/analysis/modeling utilizing forced oscillation test techniques needed
 - Rotary balance test technique and spin dynamics modeling considerations



Hexapod Motion Cueing Guidelines for Stall-Recovery Training



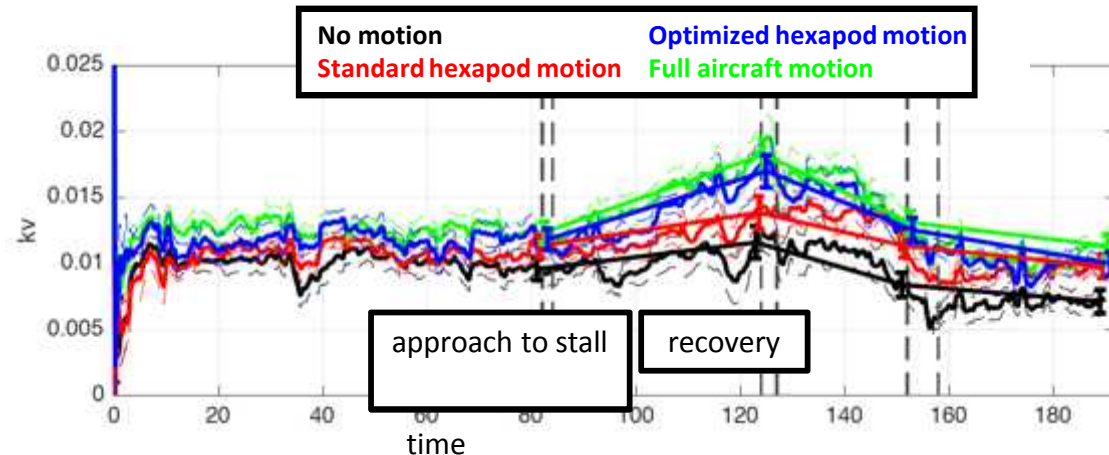
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Presented at JIMDAT 10/2,
not at CAST 10/4

- Sixteen pilots participated in an experiment on the vertical motion simulator (VMS) in October 2017, investigating how different hexapod motion cueing strategies affect multi-axis manual control behavior and performance during a stall
- Results suggest that pilot control behavior and performance with our enhanced hexapod motion is more similar to that measured with full aircraft motion compared to the motion currently provided by hexapod training simulators (see figure in lower right). Paper presented in June at AIAA AVIATION 2018.
- VMS experiment focusing on adaptive motion based on aircraft model state July/August 2018
- Validation experiment on NASA's B747 flight simulator conducted in September. This experiment tests the developed enhanced motion cueing strategy on an actual level-D full flight simulator. Aircraft dynamic model updates have been made to improve stall characteristics with the support of NASA Langley.



Pilot roll rate gain





Objectives

1. Develop a historical database of flight crew performance in situations associated with loss of energy and/or attitude state awareness, for use in the design process. (FAA led)
2. Enhance methods and guidelines used in the design process to assess flight crew performance in situations associated with loss of energy and/or attitude state awareness.
3. Develop and validate prototype technologies for detection and mitigation of attention issues associated with loss of energy and/or attitude state awareness, for use in design evaluation.



Approach

1. Support an FAA led industry group analyzing a large set of aircraft data for flight crew response to aircraft alerts.
 - Support for the FAA-industry working group
2. Apply state of the art knowledge for development of enhanced methods that are usable for design and evaluation.
 - Focus on evaluation tools, methods, and alerting standards
3. Develop and assess technologies to detect, monitor and mitigate attention problems contributing to loss of energy or state awareness.
 - Focus on application of COTS tools



SE210-2 GUIDANCE for DESIGN EVALUATION for FLIGHT CREW PERFORMANCE



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- Coordination with FAA Aircraft Certification and Industry Human Performance experts on current design and evaluation methods
- Participating in Avionics Harmonization Standards Working Group for alerting metrics
- Reports on:
 - Alerting, Evaluation Methods, Scenario Development, Monitoring and Attention, and Assessment of of Attention.
- Interest from FAA and Industry



Publications		
Journal Articles	Conference Papers	Tech Pubs
6	2	10*

**** Some reports still in publication process***



SE210-3 TECHNOLOGIES for DETECTION and MITIGATION of ATTENTION ISSUES

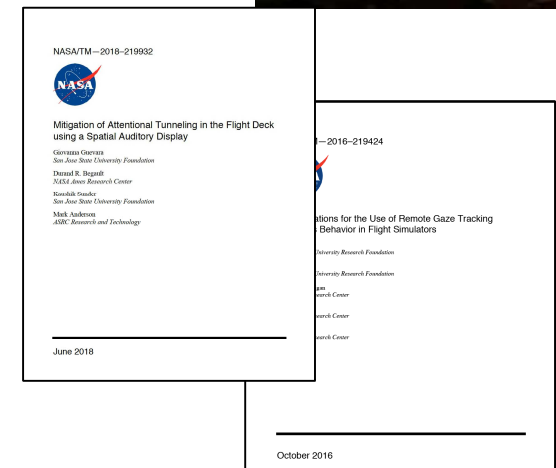


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- Analysis of off-the-shelf physiological measurement technologies for suitability in aviation applications
- Developed and validated spatial audio display to mitigate attentional tunneling
- Reports on analyses results and technologies developed
- Interest from FAA and industry



Publications		
Journal Articles	Conference Papers	Tech Pubs
3	6	4





SE-210 DESIGN for FLIGHT CREW ATTENTION



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SUMMARY

- Supported FAA-led industry group analyzing large set of aircraft data for flight crew response to aircraft alerts
- Developed and assessed design and evaluation methods and technologies to monitor, detect and mitigate flight crew attention vulnerabilities
 - Focus on use COTS technologies, and high TRL methods
 - Reports on:
 - Alerting system failures as contributors to accidents
 - Identifying proper context for evaluation
 - Identifying metrics for evaluation of attention
 - Auditory displays for attention management
 - Analysis of attention as contributing to Aircraft State Awareness accidents
- Continuing participation with FAA-Industry groups to support standards development for alerting, monitoring

Publications		
Journal Articles	Conference Papers	Tech Pubs
8*	5	11

*5 journal articles listed on “most read” list



SE 211 - TRAINING for ATTENTION MANAGEMENT



System Wide Safety

Research for safety enhancements to improve commercial pilot training for attention management to address attention-related human performance limitations observed in flight incidents.

- Channelized Attention
- Startle / Surprise
- Diverted Attention
- Confirmation Bias

- Output 1: Develop methods to **detect** and measure attention-related human performance limiting states (AHPLS), and validate those methods in simulation
- Output 2: Develop realistic training scenarios to **induce** attention-related human performance limitations, validated by pilot state measures
- Output 2: Develop and assess training-based **mitigations** to these issues

**Crew
State
Monitoring**

Scenarios for Human Attention Restoration using Psychophysiology (SHARP) Experiment Series

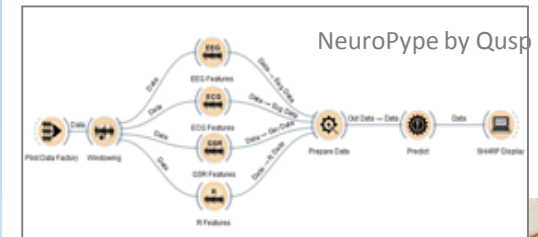
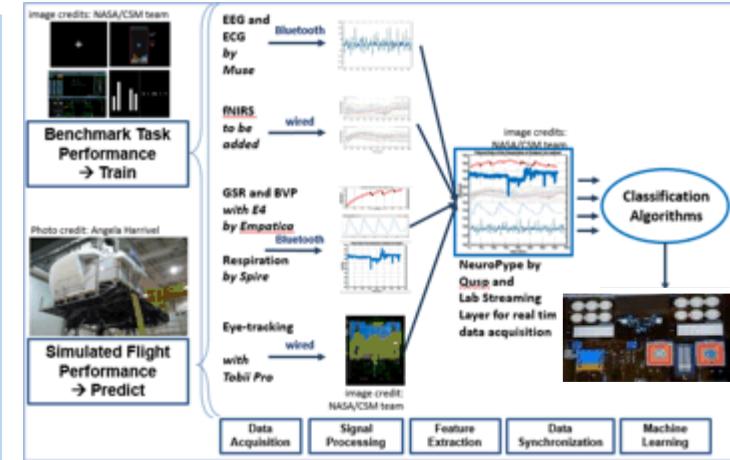


CREW STATE MONITORING – SHARP-1/2 - 2016/17



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- Integrated multiple existing psychophysiological measures
- Airline pilots, LaRC Cockpit Motion Facility, fixed- and motion-based
- CSM prototype translational system (CPTS) w/ developed flight scenarios
- Develop and improve benchmark tasks for classification of pilot states during simulation
- AHPLS detected with CSM
 - Channelized Attention
 - Startle / Surprise
 - Diverted Attention
 - Confirmation Bias
- Explore methods of increasing ease of use and portability of sensors with minimal loss of state prediction accuracy
- Iterative development of mobile recording systems for application to operational training facilities
- State prediction accuracy for CA w/small, 4-channel EEG comparable to more cumbersome system
- Kaggle Competition to crowd-source classification methods/accuracy
- Multiple conferences/invited papers/patents



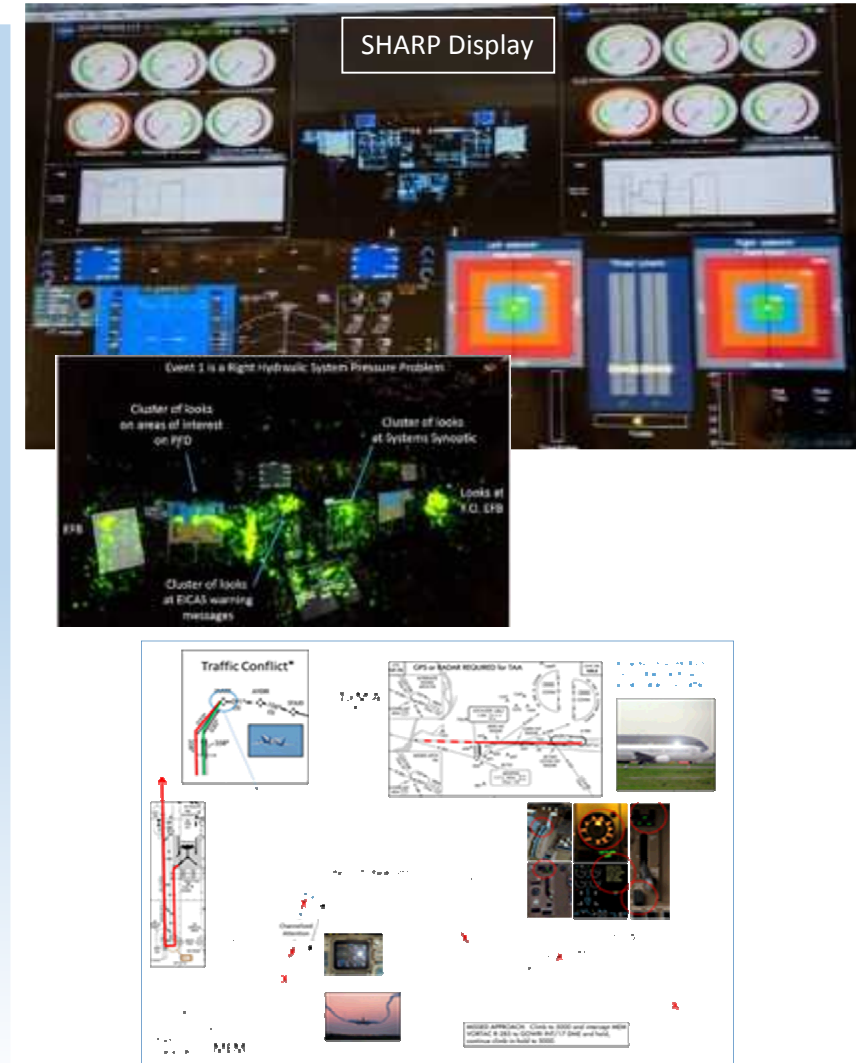


INDUCING of AHPLS – SHARP-1/2 – 2016/17



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- LOFT and SPOT scenarios to induce AHPLS
 - Channelized Attention
 - LOFT Hydraulic system pressure alert; flap asymmetry
 - SPOT fuel leak; display failure
 - Startle / Surprise
 - LOFT wake turbulence; runway incursion (truck)
 - SPOT imbalance + turbulence; altimeter failure
- SHARP Instructor Display and Instant Replay Tool
 - Real-time state information feedback to augment the instructor
 - Correlation of instructor/student observations
- Instructor SME assessments of SHARP-2 videos confirmed induction of AHPLS states
 - Channelized Attention
 - Startle / Surprise
 - Diverted Attention
 - Confirmation Bias



LOFT scenario details presented to JIMDAT/CAST/Infoshare 2017

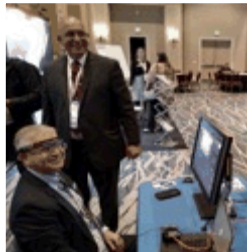


MITIGATION / DISSEMINATION – SHARP 3 – 2018



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- SME workshop to capture community training needs and current best practices
- In-person system demonstration and focus group with flight instructors
 - Boeing Training and Flight Services
 - American Airlines
 - Southwest Airlines
- Fully operational data collection system deployed in NAMRU Disorientation Research Device at WPAFB, OH
- Worldwide Aviation Training Summit, Orlando FL, April 16-19, 2018
 - Attendee feedback that NASA LaRC TfAM work “is the future.”
 - Distraction, workload, and startle are real issues presented/discussed by many at WATS
- Aerospace Medical Association conference - briefings related to attentional state prediction and operator performance
- Neuroergonomics 2018 – invited guests/panelist
- HCI International – invited briefing, “Biocybernetic Adaptation Strategies: Machine Awareness of Human Engagement”
- SHARP Display patent application allowed
- Brain sensing patent issued and licensed





SE 211 TRAINING for ATTENTION MANAGEMENT



System Wide Safety

Objective

- Develop methods to detect and measure attention-related human performance limiting states (AHPLS), and validate in simulation
- Develop realistic training scenarios to induce AHPLS, validated by pilot state measures
- Develop and assess training-based mitigations to these issues

Commercial Aviation Safety stakeholders benefit:

- From research and feedback regarding training methods to improve attentional management
- To address distraction (AHPLS) as a prevalent causal factor in accidents and incidents.

Approach

- Crew State Monitoring technologies applied to the detection of AHPLS
 - Fully operational data collection system deployed in operating Disorientation Research Device
 - Kaggle Competition to crowd-source classification methods/accuracy
- Scenarios for Human Attention Restoration using Psychophysiology (SHARP) Experiment Series
 - SHARP-1 Motion-base simulation study with realistic LOFT scenario events and full physiological data
 - SHARP-2 Fixed-base simulation Comparative Analysis study
- SHARP-3 'Road Show' - SHARP Display debrief mitigation concept *demonstrated* and feedback collected from Worldwide Aviation Training Summit, Boeing Training & Flight Services, and American Airlines.



Key Milestones

- Mature scenarios and AHPL training mitigation methods documented and transitioned to training providers
- Scenarios described and operational CSM methods demonstrated
- Prototype CSM systems for use in "beta testing" in at least two commercial aviation training facilities
- Two commercial aviation training facilities plus pending third, plus DRD and WATS.
- To obtain feedback improving feasibility of AHPL detection and training effectiveness.
- Feedback also requested from Airbus and the FAA.



Safety Enhancement 200 (SE-200)



System Wide Safety

Presented at JIMDAT 10/2,
not at CAST 10/4

BACKGROUND

- Joint Safety Analysis Team (JSAT) study (2014) identified 12 major themes that may be representative of common issues identified in these LOC-I events
- “Lack of external visual references” (i.e., darkness, instrument meteorological conditions, or both) was associated with flight crew loss of attitude awareness or energy state awareness in 17 of 18 studied events

SAFETY ENHANCEMENT ACTION

- To provide visual cues necessary to prevent loss-of-control resulting from flight crew spatial disorientation and loss of energy state awareness, manufacturers should develop and implement virtual day-VMC display systems, such as synthetic vision or equivalent systems, which support flight crew attitude awareness similar to a day-VMC-like environment (IS 1003, IS 1010)

POTENTIAL IMPACT

- 16% estimated risk reduction based on conservative 30% implementation of new Transport Category Aircraft by 2035 (retrofit implementation not estimated)

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 / Ineffective Alerting	Inappropriate Control Actions
Formosa Airlines Saab 340	x	x			x		x	x	x		7
Korean Air 747-200F	x			x		x	x		x		6
Flash Airlines 737-300	x		x		x				x	x	8
Adam Air 737-400	x		x	x			x	x	x	x	9
Kenya Airways 737-800	x		x						x	x	7
Aeroflot-Nord 737-500	x	x	x	x	x		x	x	x	x	11
Gulf Air A320	x		x				x		x		6
Icelandair 757-200 (Oslo)	x						x		x	x	6
Armavia A320	x	x			x		x		x	x	8
Icelandair 757-200 (Baltimore)	x				x	x	x	x	x	x	9
Midwest Express 717	x				x	x	x			x	7
Colgan Air DHC-8-Q400	x	x	x		x		x	x	x	x	10
Provincial Airlines DHC-8	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	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	8
Empire Air ATR-42	x	x			x	x	x		x	x	7
Overall	17	7	9	6	12	5	18	7	16	14	12

Major Themes Identified



SE 200 VIRTUAL DAY-VMC DISPLAYS



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OUTPUT 1

- Conduct research studies and publish findings to support definition of minimum requirements for virtual day-visual meteorological conditions (VMC) displays to accomplish the intended function of improving flight crew awareness of airplane attitude. **Lead Organization: NASA**



**Airplane State Awareness
Joint Safety Implementation Team**

OUTPUT 2

- Minimum Aviation System Performance Standards (DO-371, ED 249) document development. **Lead Organization: RTCA SC-213**



**Final Report
Analysis and Recommendations**

June 17, 2014

OUTPUT 3

- Manufacturers establish implementation plans to incorporate virtual day-visual meteorological conditions (VMC) displays in applicable new transport category airplane (TCA) programs. **Lead Organization: AIA/JIMDAT**



SE 200 VIRTUAL DAY-VMC DISPLAYS



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- Provides continuous attitude, altitude, and terrain information through a computer-generated image of the external scene topography
 - Derived from aircraft attitude, high-precision navigation solution of position, and a coordinate-reference database of terrain, obstacles, and relevant cultural features
- Includes additional symbology and display elements to enhance attitude and energy state awareness and aircraft motion, to include:
 - Earth-referenced flight path vector (FPV)
 - Acceleration cue
 - Speed error indicator
 - Roll recovery guidance
 - Depiction of the intended runway
- Displays optical flow motion cues that enhance the pilot's ability to detect and recognize the potential entry into, onset of, and recovery from unusual attitudes and flight path divergence



Virtual Day-VMC Display



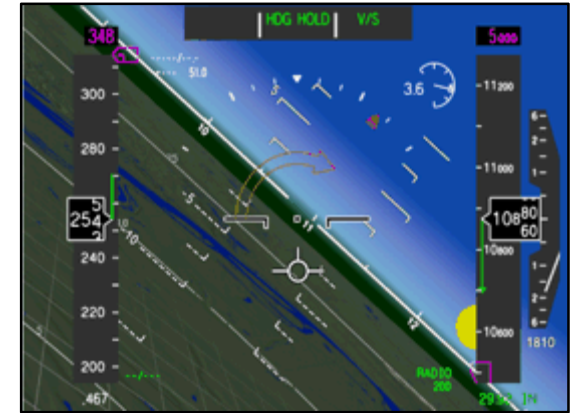
MINIMUM DESIGN REQUIREMENTS RESEARCH



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RESEARCH NEED

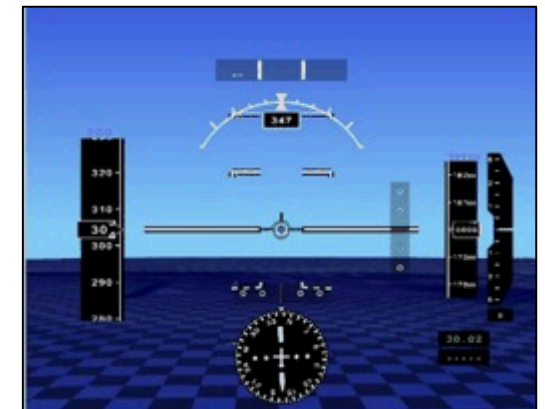
- Output 1 specified that research be conducted to define minimum design requirements to include:
 - a) Field-of-View/Image Minification
 - b) Optical Flow Cues – Use of Color and Texture
 - c) Optical Flow Cues – Display Elements Over Water or Featureless Terrain
 - d) Presentation/Removal of Virtual Day-VMC displays in unusual attitudes
 - e) Potential unintended consequences (e.g., attentional issues, CRM impacts)



Optical Flow Cues

RESEARCH ACTIONS

- Conducted series of simulator research studies and usability evaluations to determine the minimum design requirements for efficacy of virtual day-VMC displays for intended function of improving flight crew awareness of airplane attitude



Water and Featureless Terrain Display Elements

RESEARCH OUTCOMES

- Yielded significant research publications that documented the findings and recommendations for minimum display requirements and contributed to RTCA SC-213 publication of DO-371 (ED-249)



ADVANCED DISPLAY CONCEPTS



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RESEARCH NEED

- Evaluate implementation display alternatives to primary flight display that may extend the potential of Virtual Day-VMC displays for enhanced airplane state awareness and mitigation of unusual attitudes, spatial disorientation, and loss-of-control

RESEARCH ACTIONS

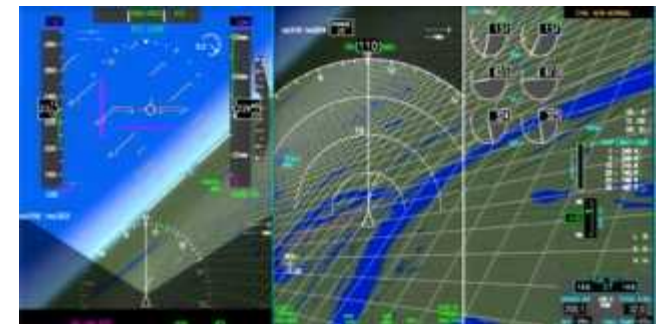
- Conducted high-fidelity simulator research study that examined head-up and head-worn displays for attitude awareness and unusual attitude recovery
- Evaluated “background attitude indicator” concept that extended the artificial horizon of head-down primary flight display

RESEARCH OUTCOMES

- Results demonstrated that the head-worn display can be an equivalent display to HUD (AC 20-167A, AC 90-106A, §91.176)
 - Equal performance for unusual attitude recoveries, but better qualitative ratings
 - Unlimited conformal field-of-regard better for attitude awareness
- Extended horizon of background attitude indicator significantly enhanced attitude awareness and detection, and prevention, of entry into unusual attitudes



Head-Worn Display



Background Attitude Indicator



OPERATIONAL TRAINING SIMULATOR RESEARCH



System Wide Safety

RESEARCH NEED

- Past research was conducted in NASA research simulators that utilized highly experienced U.S. pilots (> 24,000 hours average experience). Because events studied by CAST involved international pilots often with significantly less experience, efficacy of Virtual Day VMC display technology was tested with target pilot population

RESEARCH ACTIONS

- Leveraged Space Act Agreement with Boeing to conduct research in B-787 simulator at Miami Training Center, and collaborated with international airline that provided low-hour type-rated flight crews (24 pilots)
- Compared traditional and virtual day-VMC displays for unusual attitude recoveries and for attitude awareness utilizing a challenging flight scenario designed to channelize the attention of the flight crew and create a potential aircraft upset

RESEARCH OUTCOMES

- No performance differences were found for unusual attitude recoveries
- Significant qualitative results favored virtual day-VMC displays for enhanced situational awareness
- The technology was found to be especially beneficial during recoveries where both energy (stick shaker) and terrain avoidance (terrain warning) were alerted events



Boeing 787 Simulator



Unusual Attitude Recovery



NAMRU DISORIENTATION RESEARCH DEVICE



System Wide Safety

RESEARCH NEED

- Past research was conducted in Level D simulators that utilized acceleration onset cueing and other methods but were limited in capability to simulate what a pilot may actually experience during actual flight when subjected to unusual attitude recovery and spatial disorientation induced by vestibular illusions

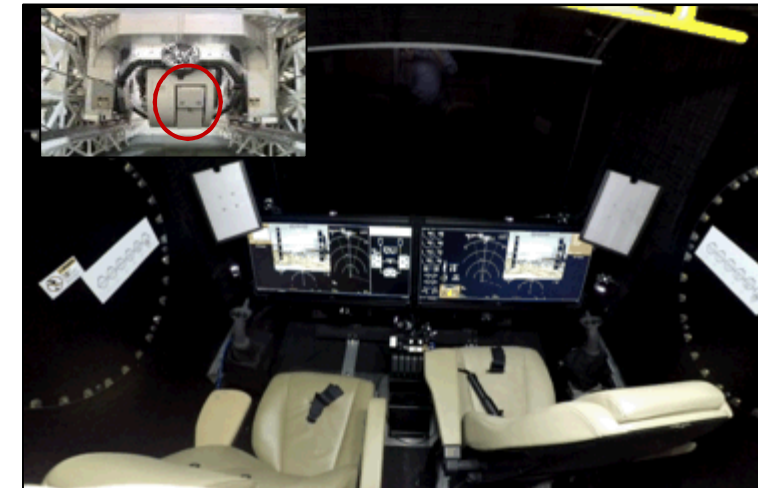
RESEARCH ACTIONS

- Established Inter-Agency Agreement with Navy to conduct research in the Disorientation Research Device (DRD)
- Twenty (20) pilots evaluated displays during unusual attitude recoveries and scenarios designed to induce vestibular illusions by utilizing the “Big Stewart” and planetary acceleration capability of the DRD

RESEARCH OUTCOMES

- No statistically significant quantitative results were found – although pilots had more roll reversals and incorrect control inputs with traditional primary flight display
- Significant qualitative results were shown in favor of virtual day-VMC displays
- Background attitude indicator concept enhanced attitude awareness

Disorientation Research Device Video



Flight Deck “Capsule”



SE 200 OP1 CONCLUSIONS



System Wide Safety

CONCLUSIONS

- Completion of Output 1 and contributions to completion of MASPS (DO-371, ED 249) document for Output 2
- Virtual Day-VMC displays enhances attitude awareness and helps recognition and prevention of entry into an unusual attitude
- Symbology is more critical for successful recovery and the roll arrow significantly aided recovery from unusual attitudes
- Technology may also be of significant benefit to less experienced flight crews and during unusual attitude recoveries where temporal demands are high to recover aircraft in which energy management is also needed and terrain hazards are present

FUTURE CONSIDERATIONS

- Further development of recovery guidance symbology
- Additional research on head-worn displays and background attitude indicator
- Fusion of display technologies for energy awareness (SE 207/208) and attitude awareness (SE 200)



Recovery Guidance



Energy Awareness



SE-207/8 – STATE AWARENESS and PREDICTION TECHNOLOGIES



System Wide Safety

Objectives (derived from SE-207/208 descriptions)

- Raise the TRL for the selected new technologies via testing and demos in high-fidelity flight sim environs
- Evaluate usability and acceptability
- Discover previously-unknown vulnerabilities in complex situations involving cascading sequences of events

Approach

- Develop new displays and predictive algorithms for improving attitude*, energy, and system state awareness
- Work w/FAA and industry partners to advance to TRL>5
- Perform series of high-fidelity sim evaluations fed by incremental lower TRL studies

Progress (FY18)

- Relevant milestone completed and extended to include broader scope based on FAA inter-agency agreement
 - AIME-2 completed (May 8) (techs 2,4,5) (12 airline crews)
 - AIME-OKC completed (Sep 7) (techs 4,5) (12 airline crews)
 - AIME-2.5 (Oct-Dec) (techs 1,6)
 - AIME-3 (Q3, FY19) (techs 7-11)

Tech No.	Tech Name
1	TPS
2	SIS/eSyn/sECL
3	ME
4	EACI
5	SRG
6	PAE (NRA)
7	PMSW (NRA)
8	PMSSOT (NRA)
9	IDADM (NRA)
10	ADW (NRA)
11	FD-AFC (NRA)



- 207 total sorties flown (26 training, 181 data); 78 sorties pilots were asked to fly to near stall or buffet; 103 sorties covered 8 scenarios emulating complex situations w off-nominals
- Data collected includes: audio/video, eye-tracking, questionnaires, aircraft/system states, pilot inputs





Selected AIME-2 Results



System Wide Safety

Presented at JIMDAT 10/2,
not at CAST 10/4

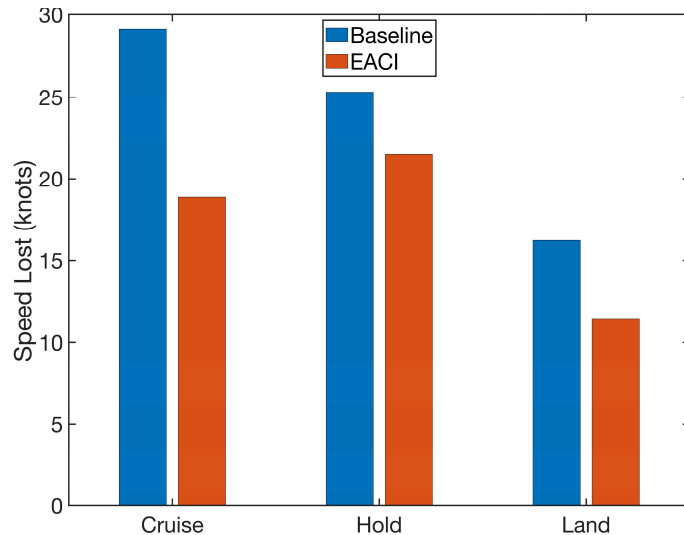
Technologies Evaluated:

(#2) Enhanced Synoptics with Simplified Electronic Checklists (eSyn/sECL)

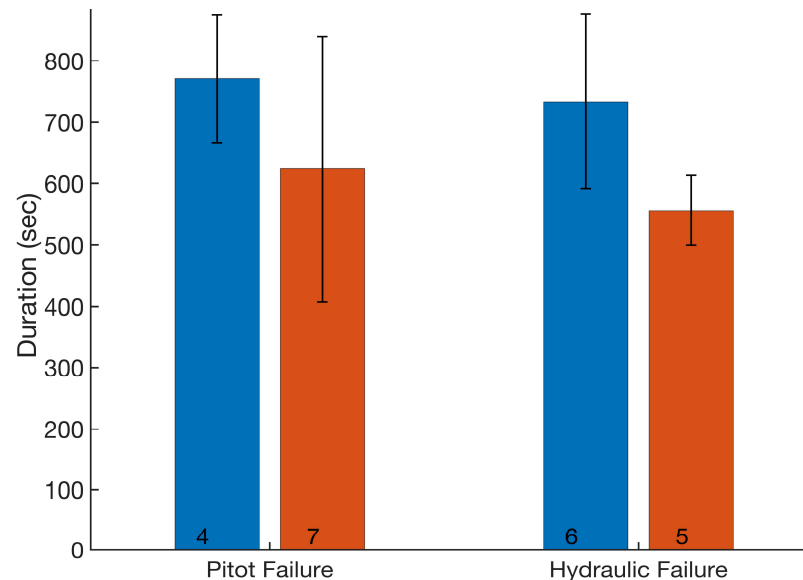
(#4) Enhanced Airspeed Control Indicator (EACI)

(#5) Stall Recovery Guidance (SRG)

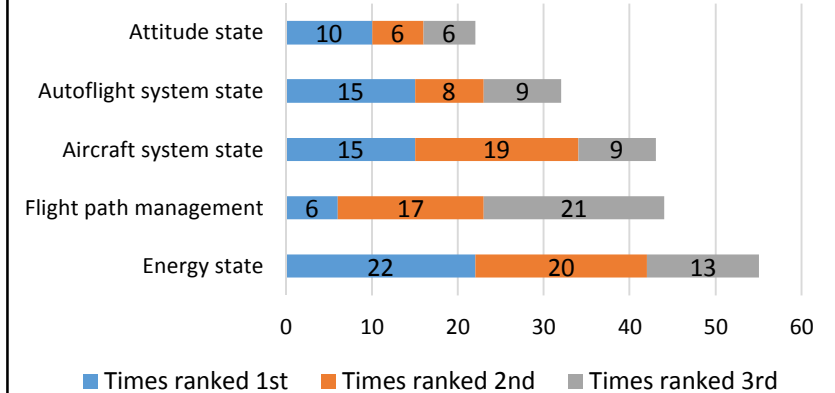
Mean Airspeed Loss
(A/T Disconnect Scenarios)



Mean Procedure Execution Duration



Top Decision Making Factors for PF + PM



AIME-2 results and findings
to be published as multiple
reports

- AIAA SciTech Forum (Jan, 2019) (4 papers)
- IEEE Aerospace Conference (Mar, 2019) (eye-tracking analysis)

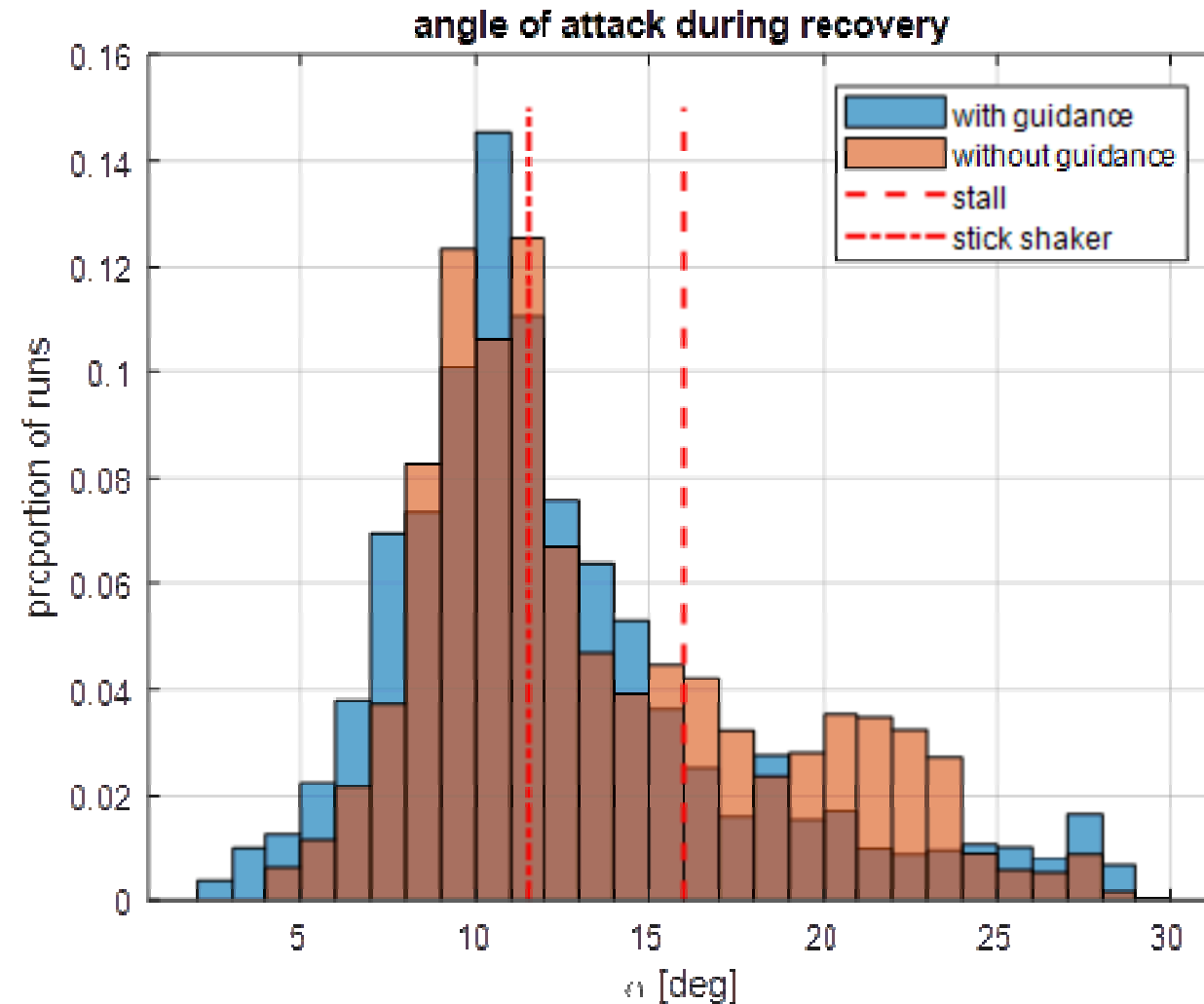


Example SRG Finding



System Wide Safety

Presented at JIMDAT 10/2,
not at CAST 10/4





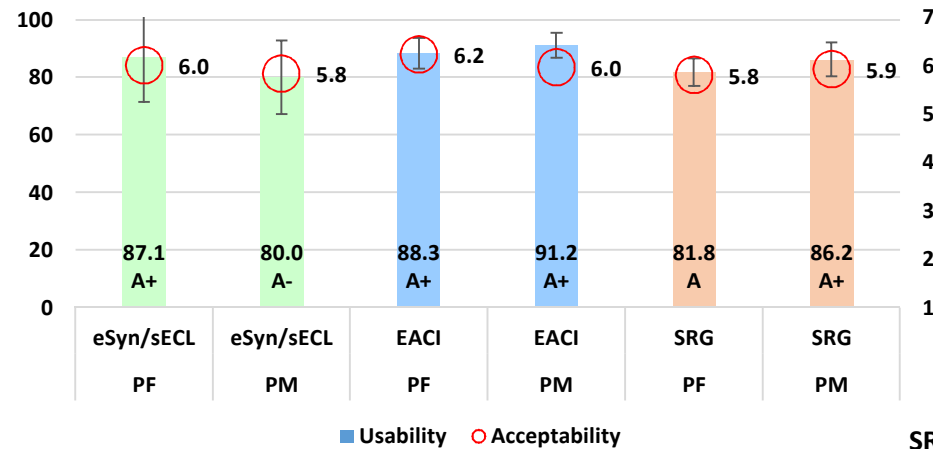
Selected AIME-2 Results



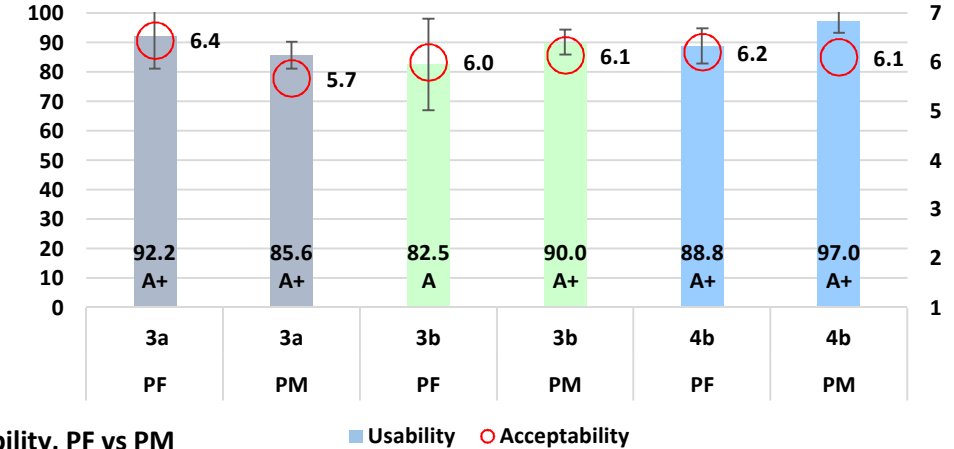
System Wide Safety

Presented at JIMDAT 10/2,
not at CAST 10/4

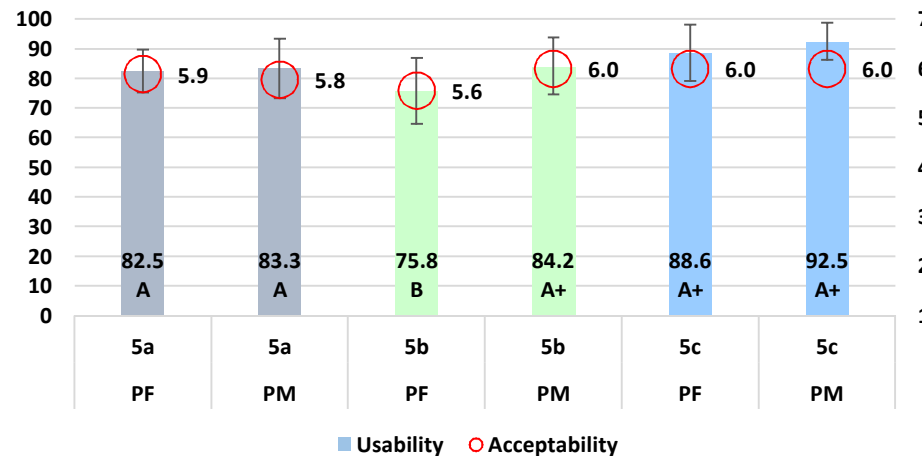
Overall Usability & Acceptability
(+/- 2 SE for usability)



EACI Mean Usability & Acceptability, PF vs PM
Scenarios 3a, 3b, 4b (SUS +/- 2 SE (95% CI))



SRG Mean Usability & Acceptability, PF vs PM
Scenarios 5a, 5b, 5c (SUS +/- 2 SE (95% CI))





TECHNOLOGIES for AIRPLANE STATE AWARENESS



System Wide Safety

- **Safety Enhancements Completing 2018**
 - SE 209 OP 3
 - SE 210 OP 2, 3
 - SE 211 OP 1, 2
 - SE 200 OP 1
 - *Research and analysis activities completed*
 - *Extensive body of reports published/released*
 - *Multiple report-outs to JIMDAT/CAST and industry 2018-19*
- **Safety Enhancements Completing 2019**
 - SE 207, 208
 - Expanded research with FAA partnership
- **Additional formal NASA reports in editorial review**
- **AIAA SciTech 2019 – Special Sessions for TASA research – 1/8/2019**



System Wide Safety