Emerging Technologies for Airplane State Awareness and Prediction

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Outline

- Motivation
- Technologies
  - Trajectory Prediction
  - Safe Flight Envelope Estimation
  - Predictive Alerting
  - Synoptic Displays
  - Stall Recovery Guidance
- Concluding remarks

Link to source material (shortened URL)

http://goo.gl/######

MOTIVATION

Commercial Aviation Safety Team (CAST)

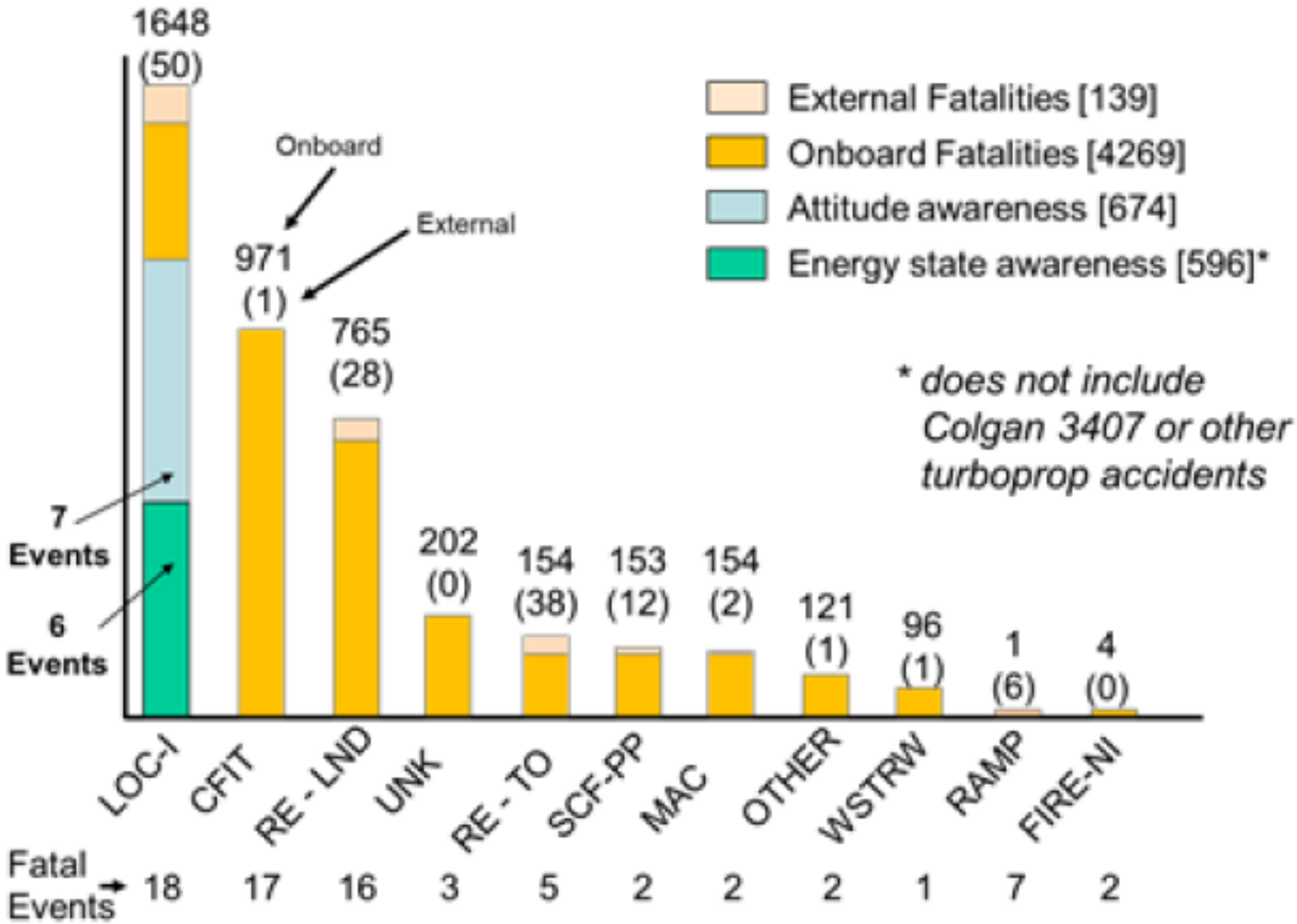
Airplane State Awareness (ASA) Joint Safety Analysis Team (JSAT)

- Subject matter experts from industry and government

Final Report - Analysis and Results, June 2014

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

Loss of Control – Inflight (LOC-I)



Boeing Statistical Summary of Commercial Worldwide Jet Transport Accidents, 2011

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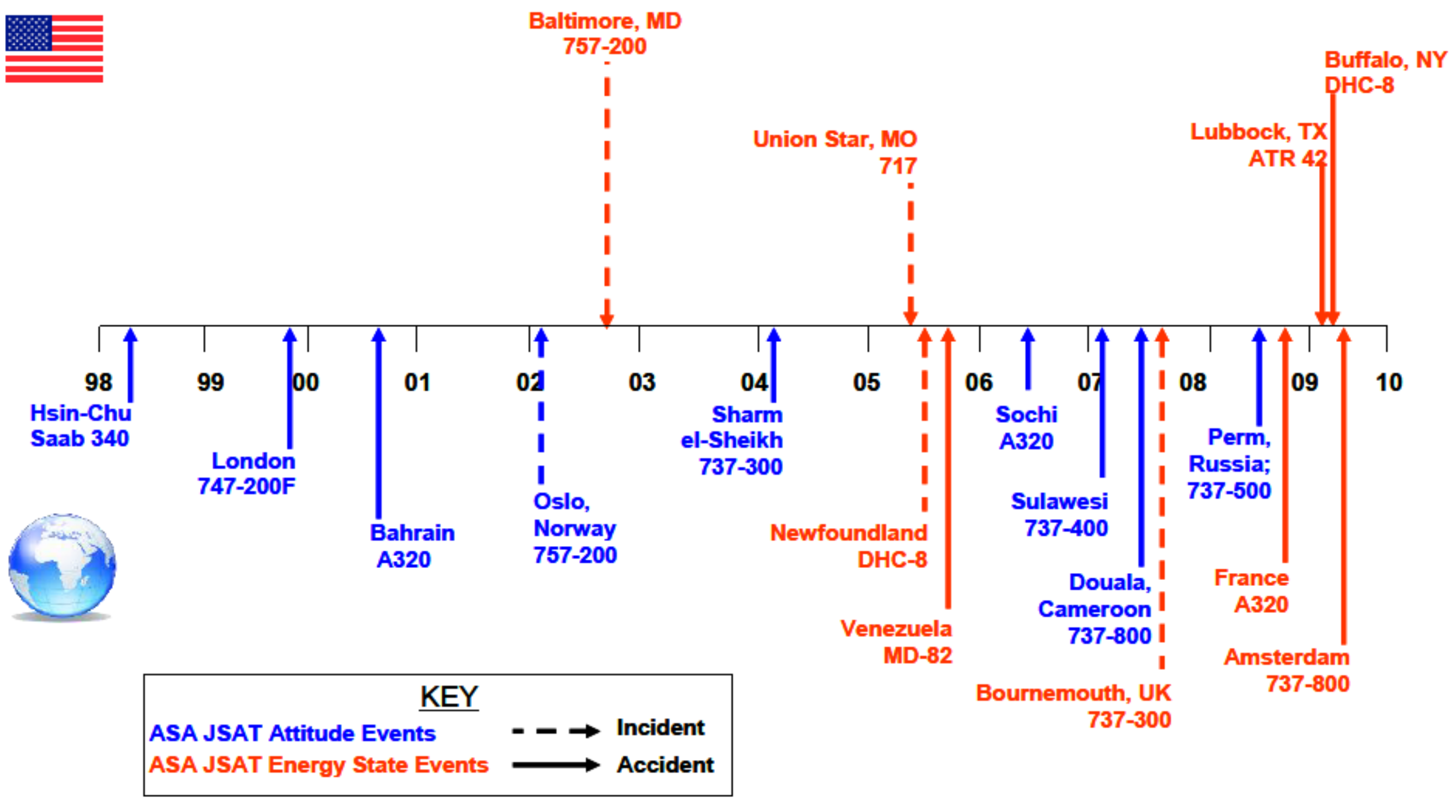
ASA JSAT Team Analysis

Industry and government experts studied 18 LOC-I accident/incident scenarios, with focus on cases where flight crew lost awareness of attitude or energy state



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Significant Themes

Energy Awareness Cases	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
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

No single technology will solve the LOC-I problem.

http://goo.gl/NAZ7MD

CAST Recommendations

- ASA JSAT Suggested 274 intervention strategies, and categorized them:
  - Aircraft Design
  - Flightcrew Training
  - Airline Operations and Maintenance
  - Safety Data
  - **Research**
    - **NASA/ARMD/AOSP/ATD/TASA Subprojects**
    - **This work focused on outputs of Safety Enhancements (SE) 207 and 208**

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SE207 Output Focus

- **Output 3**: Develop and refine systems that predict the future aircraft energy state and/or auto-flight configuration if the current course of action is continued and provide appropriate alerting.

- **Output 2**: Develop and refine algorithms and display strategies to provide control guidance for recovery from approach-to-stall or stall.

SE208 Output Focus

- **Output 1a**: Displays that present the current and future expected state of automated systems in an intuitive manner.
- **Output 1b**: Displays that show, in a simple, integrated manner (e.g, a synoptic), the aircraft flight-critical data systems in use by automated systems and primary flight instruments
- Should do so for both the mode currently selected and any impending mode transitions expected per design of these systems.

http://goo.gl/CBqsnD

SE207/SE208 Themes

- **Automation Confusion/Awareness.**
  - Trajectory prediction, synoptic displays
- **Inappropriate Control Input.**
  - Safe flight envelope estimation, and stall recovery guidance
- **Ineffective Alerting.**
  - Predictive alerting, Synoptic displays, Multiple-hypothesis prediction
- **Systems Knowledge.**
  - Synoptic displays

- Other SE207/208 outputs and additional themes are addressed by other subprojects and external work.

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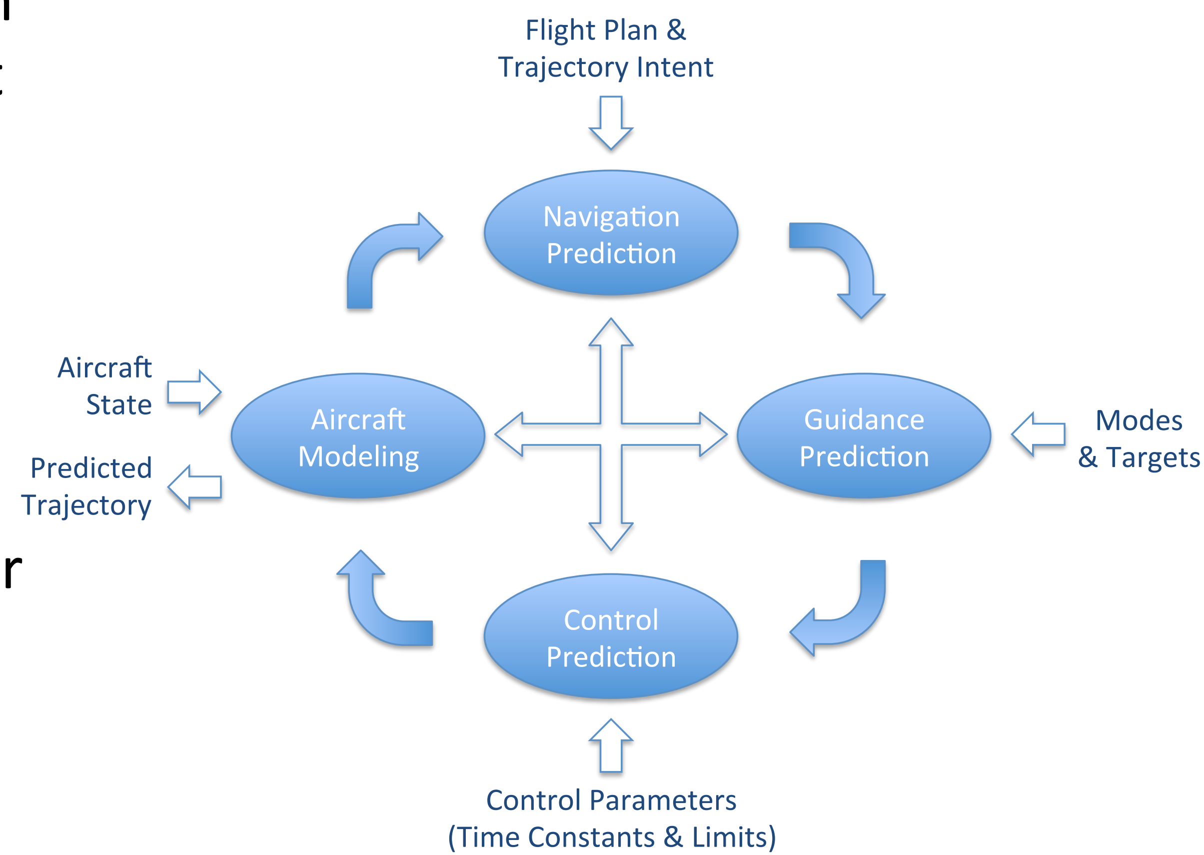
TECHNOLOGIES

Trajectory Prediction
Safe Flight Envelope Estimation
Predictive Alerting
Synoptic Displays
Stall Recovery Guidance

Trajectory Prediction

- Fast-time simulation of simplified aircraft dynamics
- Models behavior of FMS, APS, ATS
- Bank, flight path angle, thrust commands (1st order system with rate limits)
- 5 minute prediction horizon



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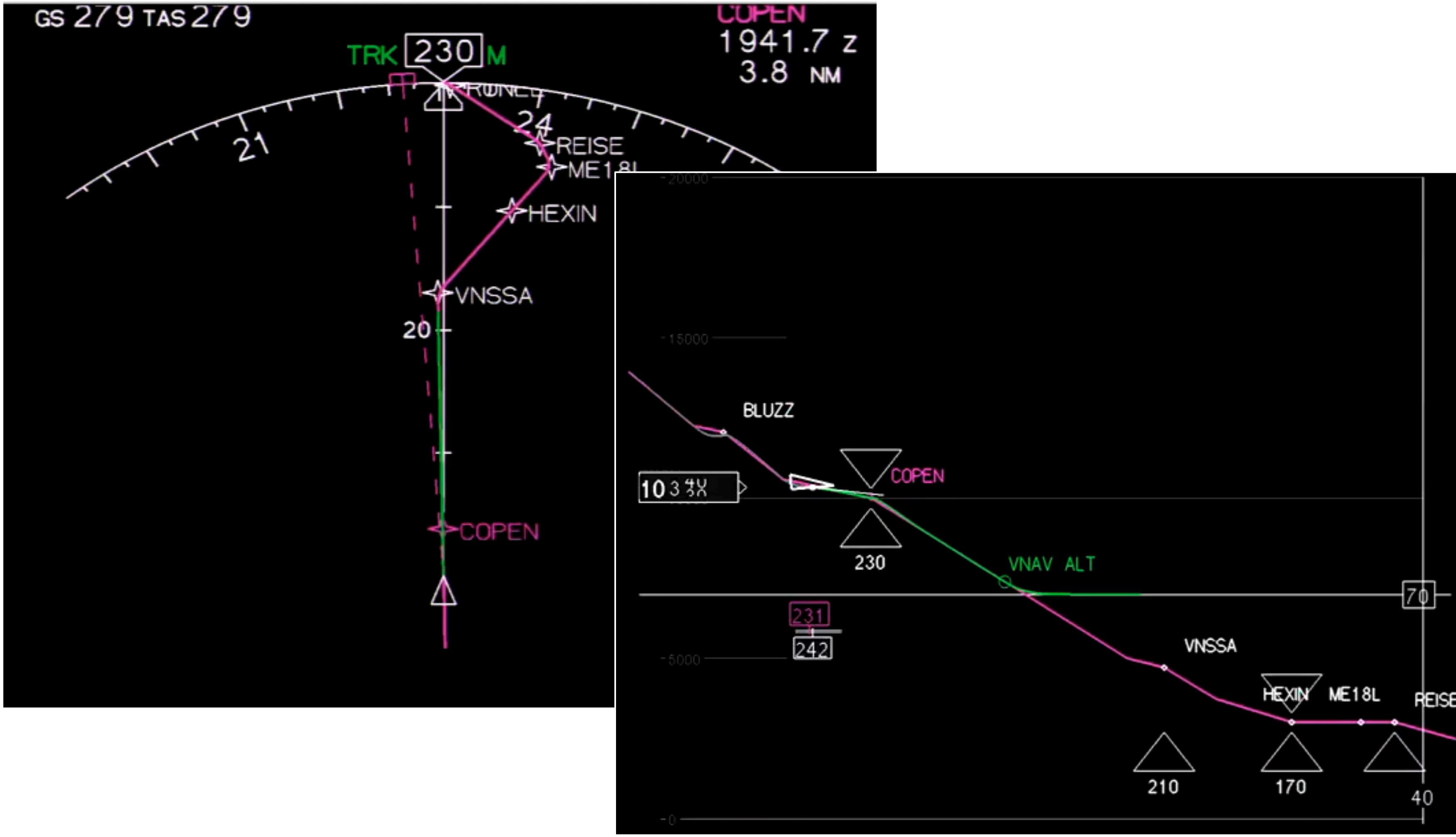
Trajectory Prediction

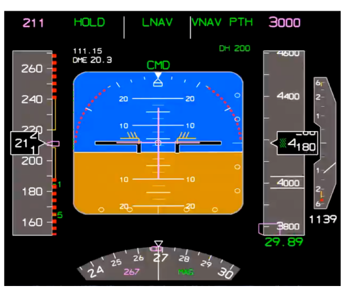


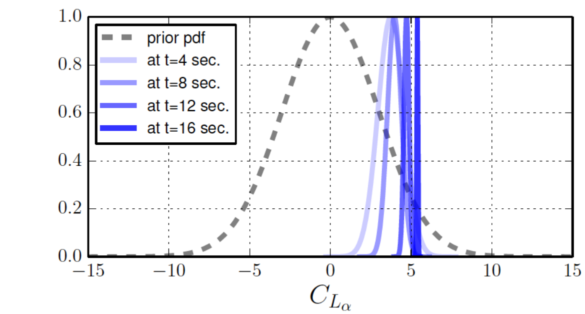
Trajectory prediction on the Navigation Display (ND) and Vertical Situation Display (VSD)

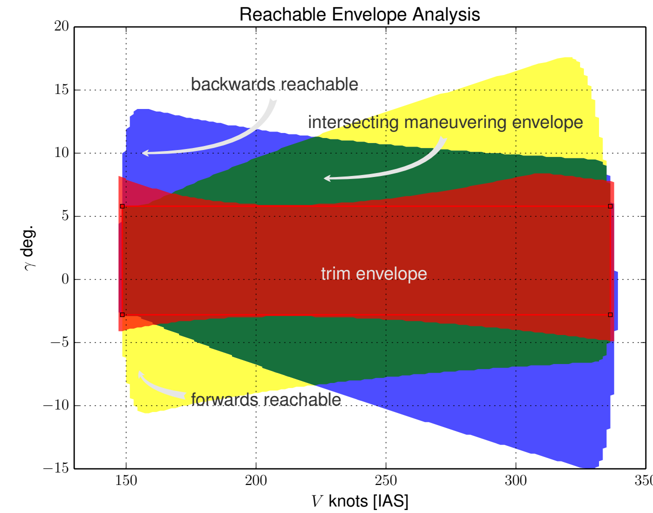
https://goo.gl/5FYhvv

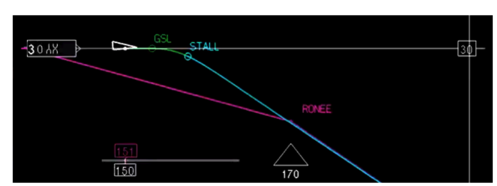
Safe Flight Envelope Estimation

Air Data
20 ms
Aircraft Model Identification
Thrust and AoA Limits
30 ms
Trim Envelope Estimation
2 s
Maneuvering Envelope Estimation
Nonlinear Physics Model Based
Cockpit Displays
Predictive Alerting









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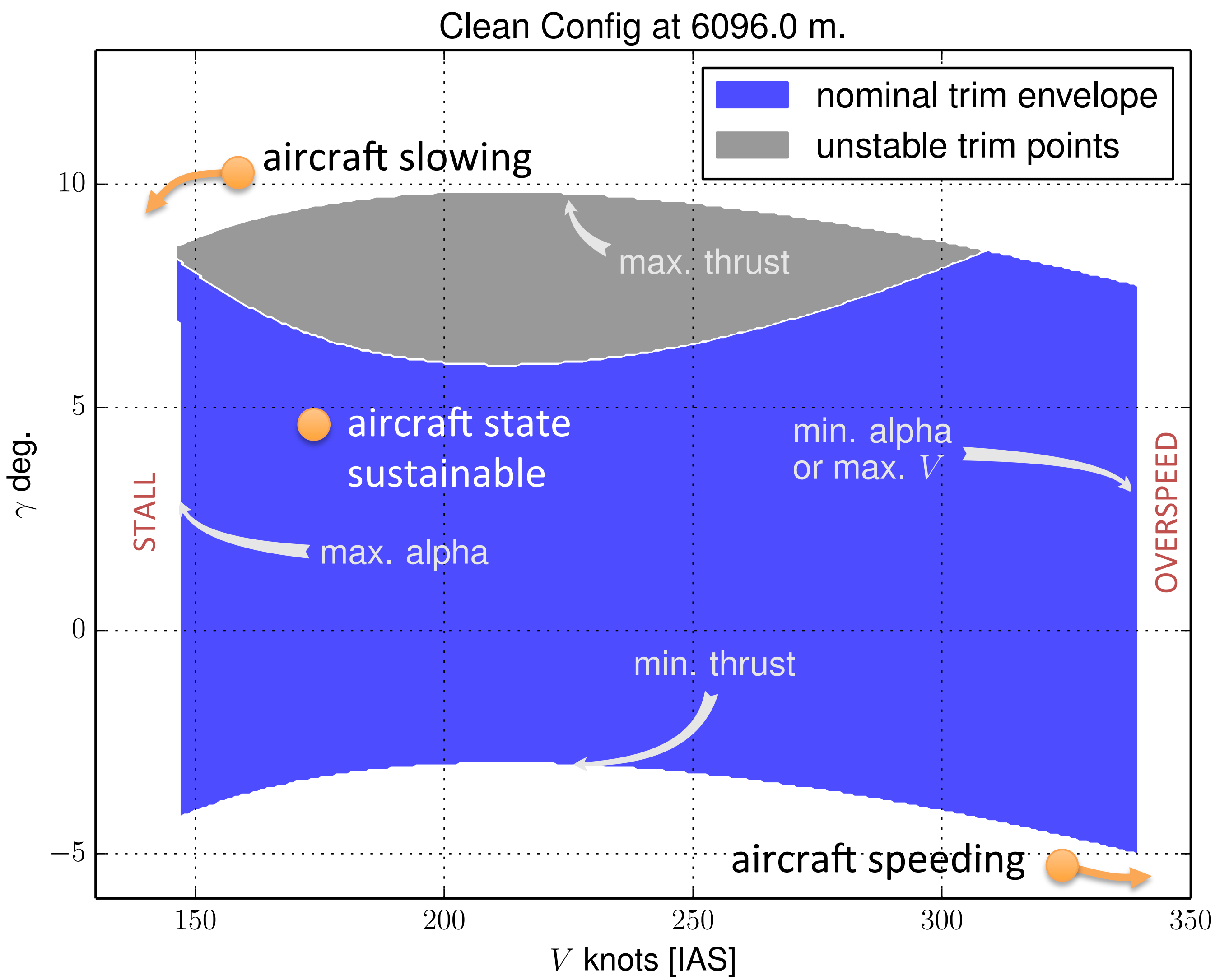
Trim Envelopes



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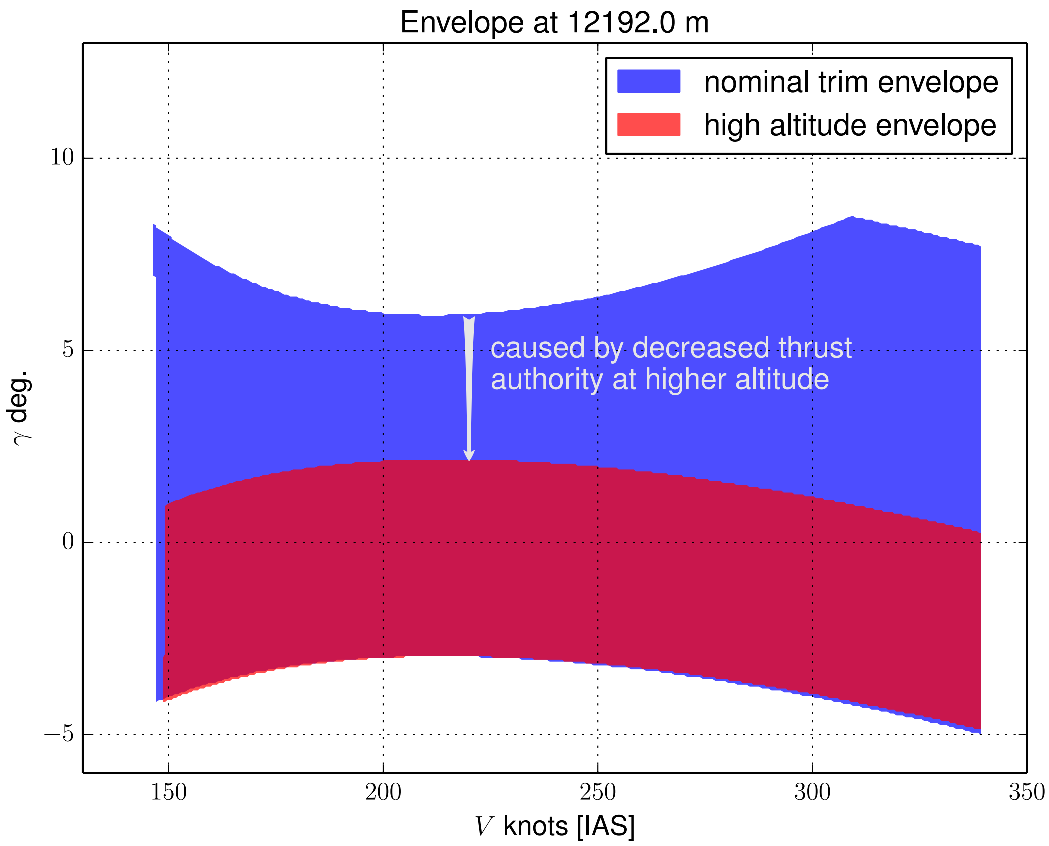
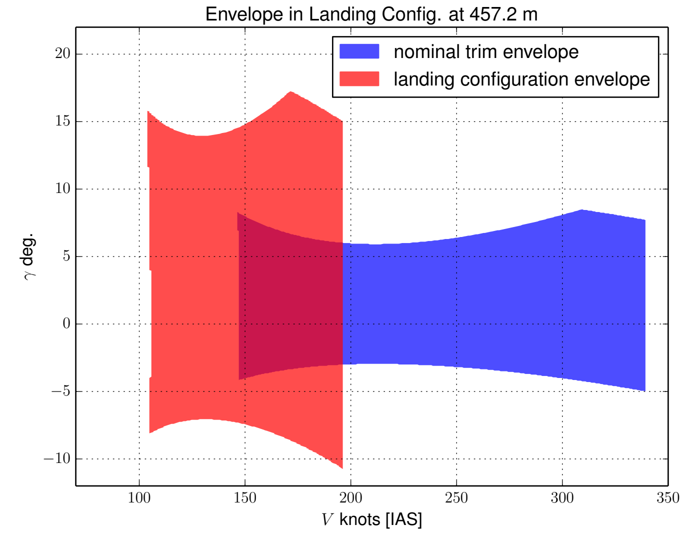
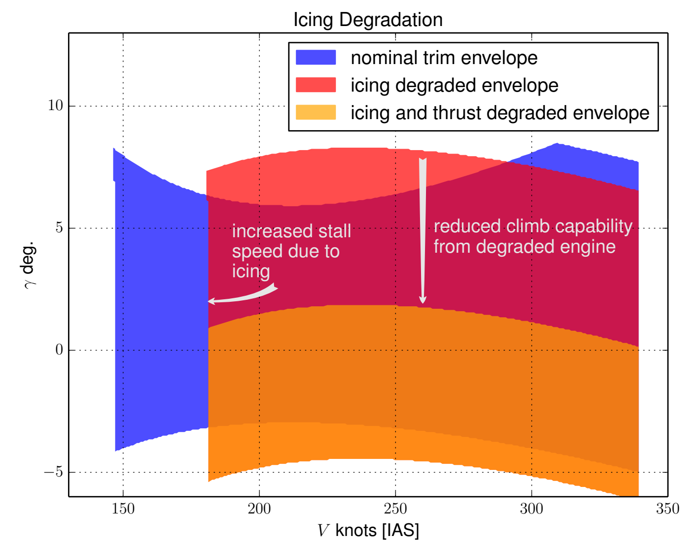
Dynamic Effects







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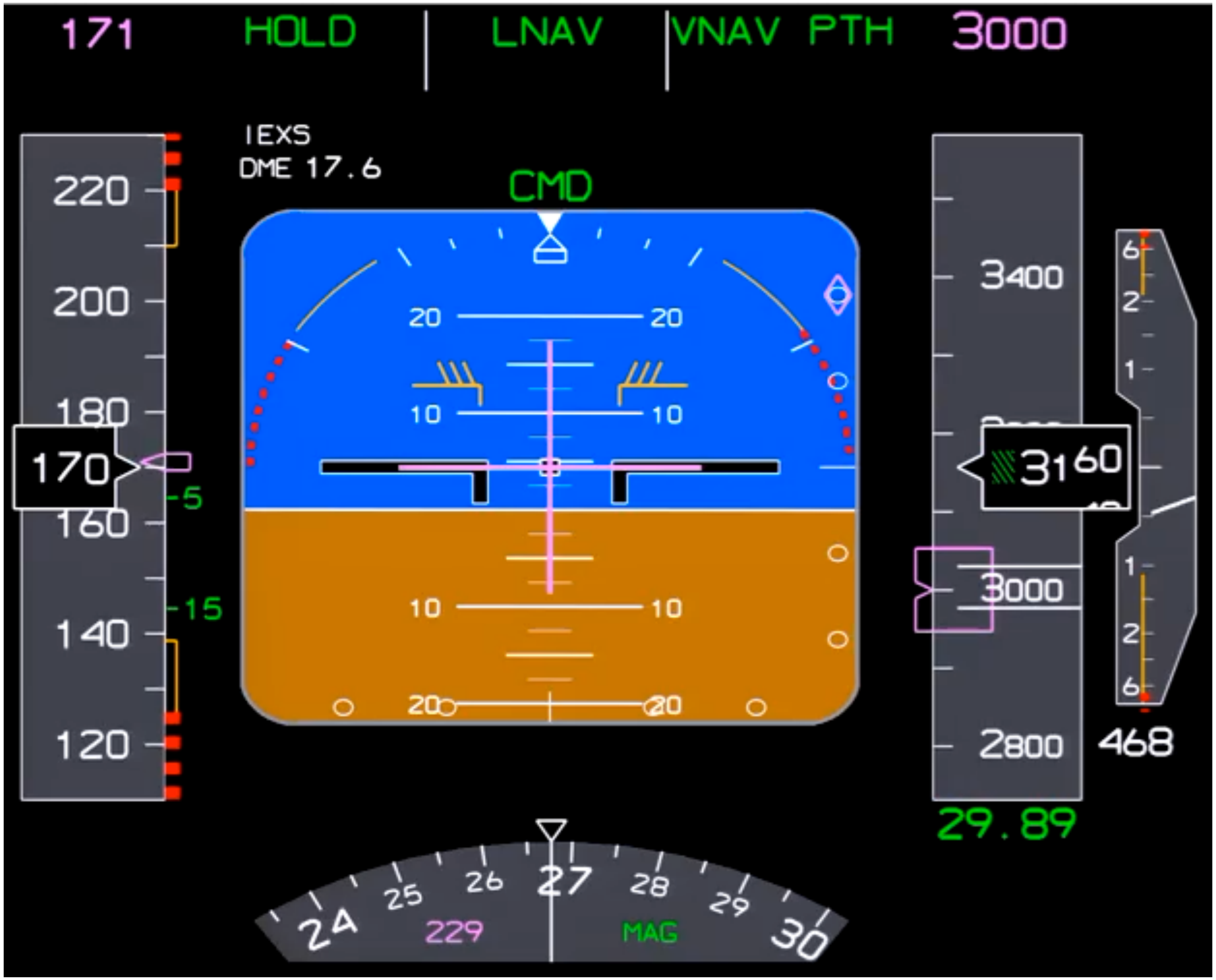
Flight Envelope Driven PFD



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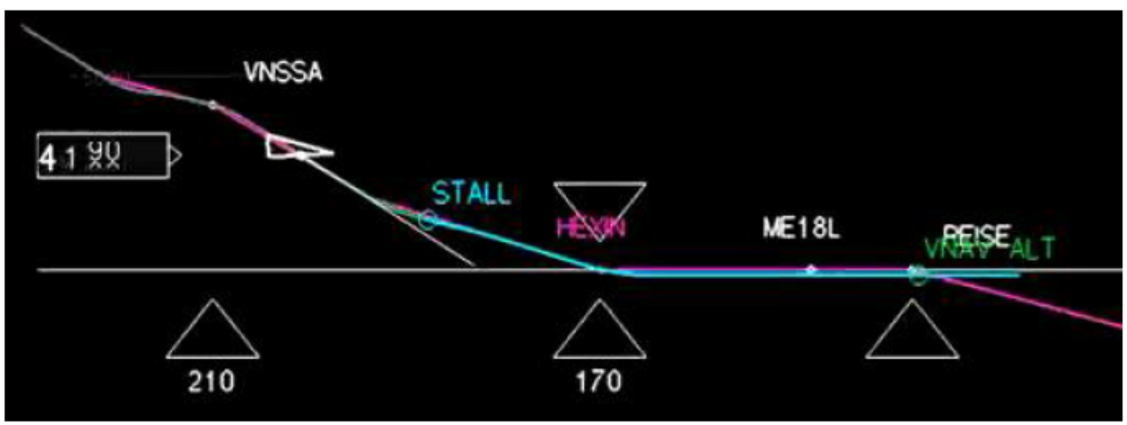
Example Icing Scenario

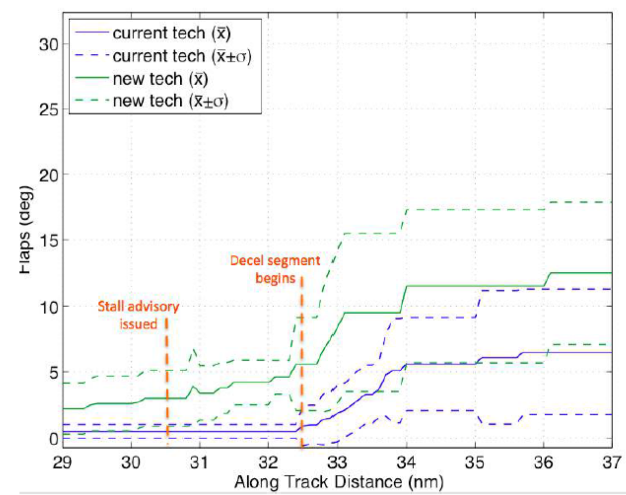
Current technology

New technology

Flap usage across experiments

Predicted Stall Advisory on VSD





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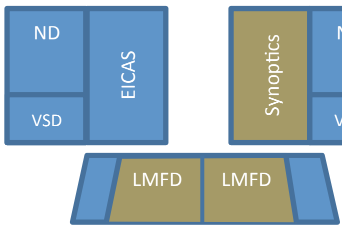
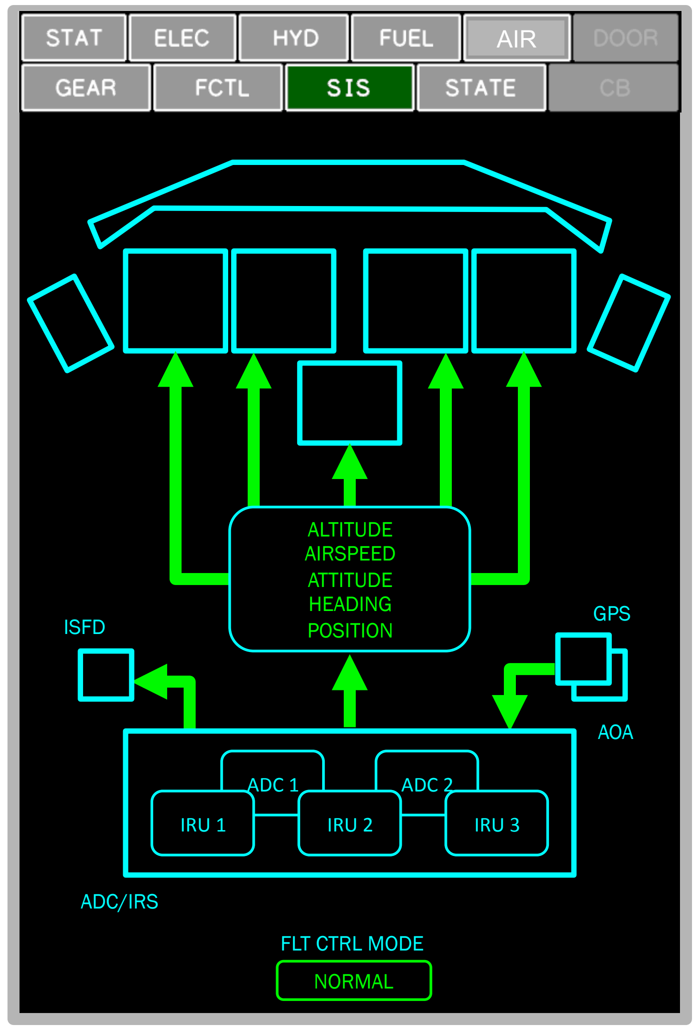
System Interaction Synoptic

Normal



Available on any of these display spaces



Mode control panel

Display panels

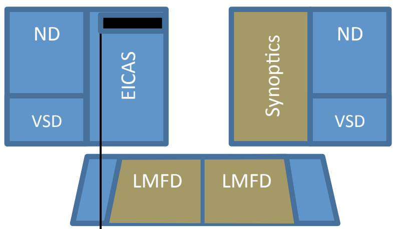
Flight-critical information

Flight-critical data systems

:ISFD – standby instrument :Flight control mode

http://goo.gl/Jl7tJE

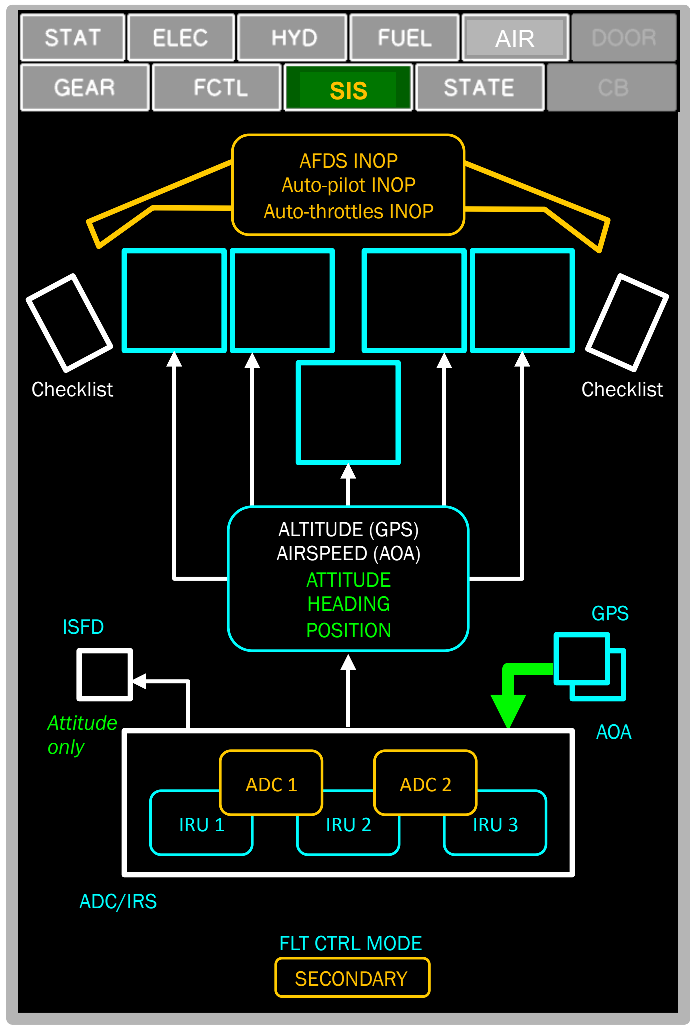
System Interaction Synoptic



Available on any of these display spaces

EICAS Msg:

❑ NAV AIR DATA SYS



Non-normal

(example)

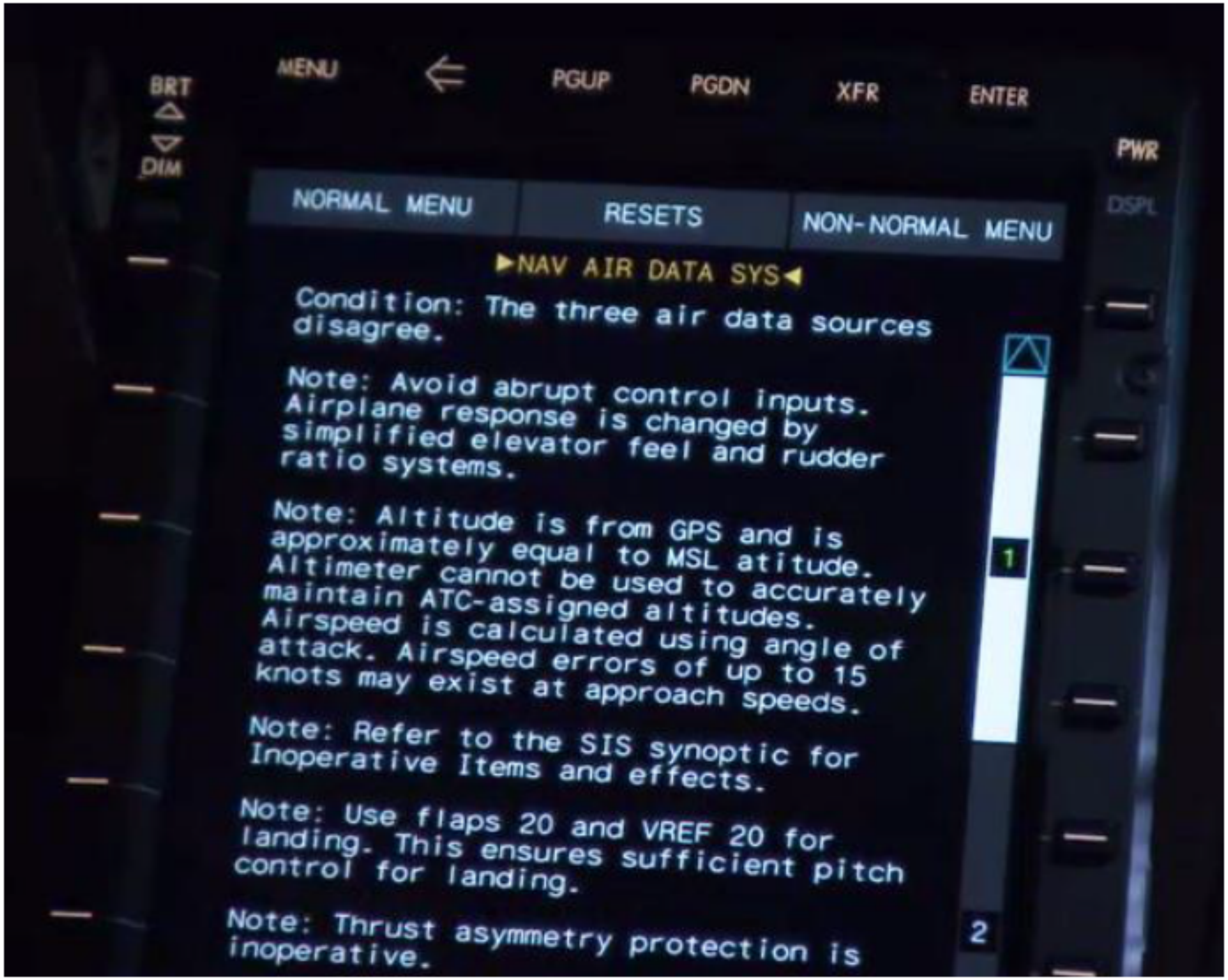
Associated checklist(s) available on both Electronic Flight Bags (EFBs)

Checklist(s) will be simplified:

1. Removes information now provided on this display
2. Context-relevant data provided rather than lists, or needs to look in reference documents

http://goo.gl/Jl7tJE

Simplified Check List



Stall Recovery Guidance (SRG)

FAA Stall Recovery Template AC120-109A*, 2015

1	**Disconnect autopilot and autothrottle/autothrust** Rational: Leaving the autopilot or autothrottle/autothrust connected may result in inadvertent changes or adjustments that may not be easily recognized or appropriate, especially during high workload situations.
2	**(a) Nose down pitch control until impending stall indications are eliminated.** **(b) Nose down pitch trim as needed.** Rational: Reducing the angle of attack is crucial for recovery. This will also address autopilot-induced excessive nose up trim. If the control column does not provide sufficient response, pitch trim may be necessary.
3	**Bank wings level.** Rational: This orients the lift vector for recovery.
4	**Apply thrust as needed.** Rational: Amount of thrust depends on aircraft configuration and in some cases applying maximum thrust may create a strong nose-up pitching moment if airspeed is low.
5	**Retract speed brakes/spoilers.** Rational: This will improve lift and stall margin.
6	**Return to the desired flightpath.** Rational: Apply gentle action for recovery to avoid secondary stalls then return to desired flightpath.

* Abbreviated table for brevity

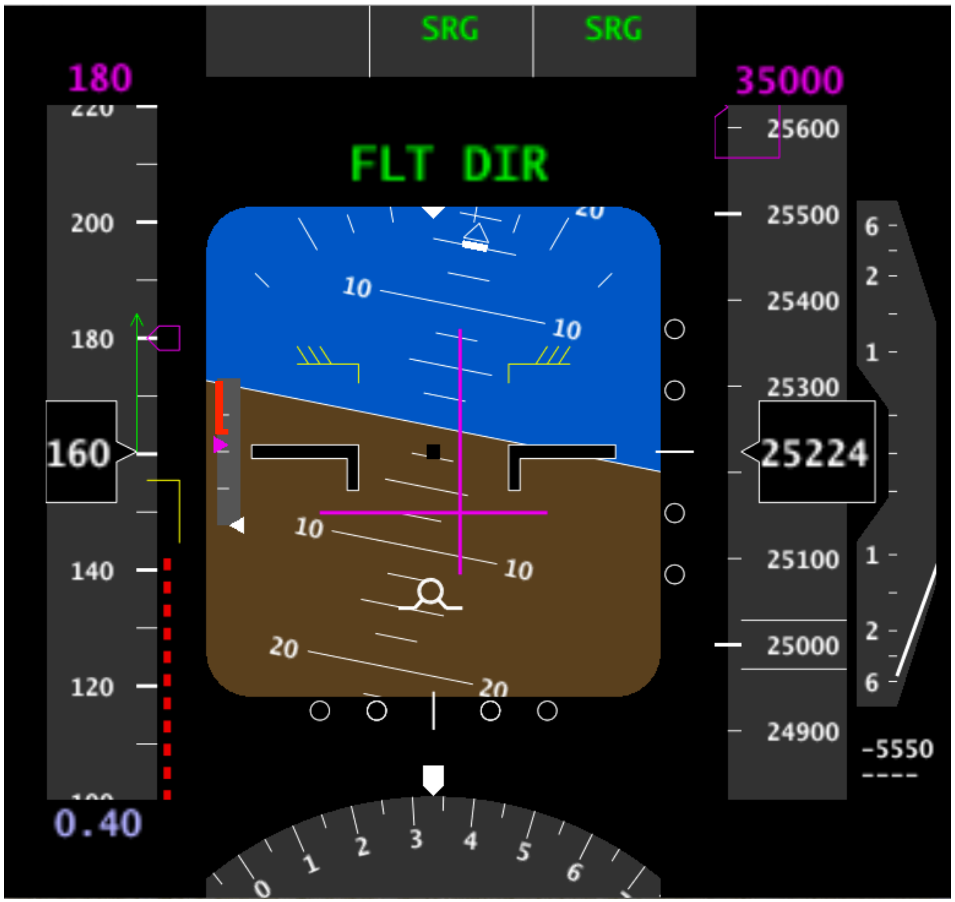
http://goo.gl/q0y74v

How to achieve a stall recovery?

- In a high-stress/workload environment, recalling the template is difficult
- FAA template does not specify:
  - Pitch down target
  - Airspeed to begin pitching up
  - Pitch up rate, without causing secondary stall
- Issues can be solved by guidance algorithms
  - Model predictive control, energy based, pseudo-control hedging.

SRG Guidance Display

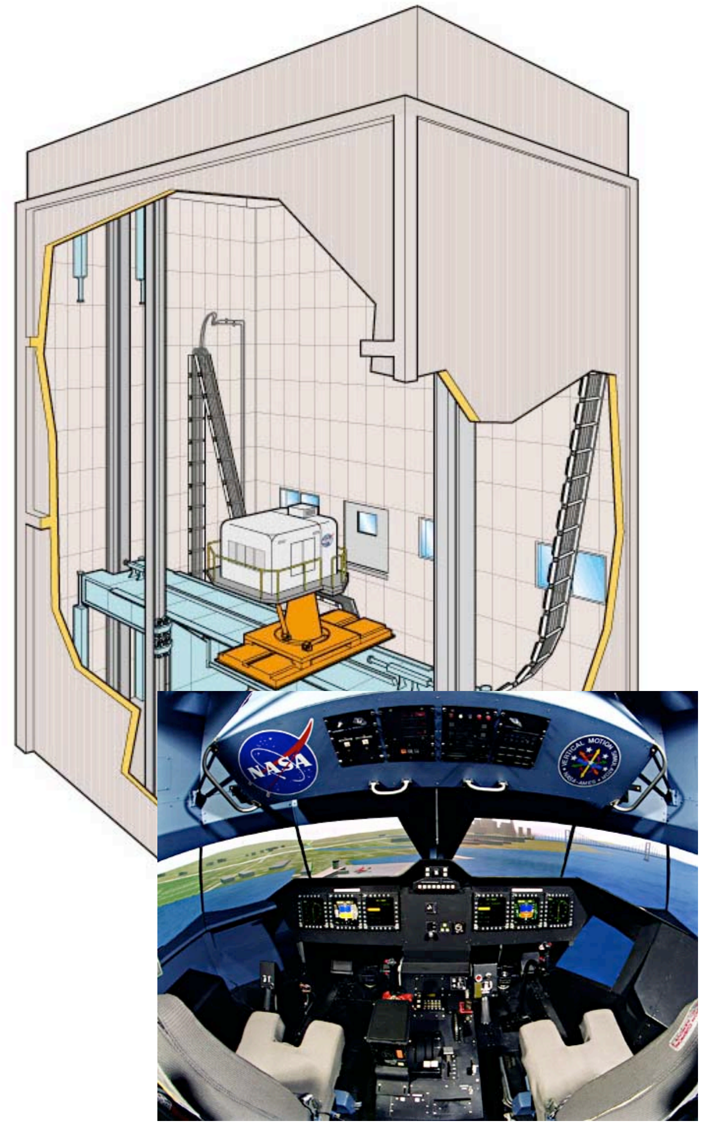
- Pilot only sees the resulting guidance signal
  - Provides only the immediate control action



Flight-director with augmented, pitch limited, thrust guidance

SRG Evaluation Plan

- Vertical Motion Simulator
- Integrate stall dynamics modeling
- Evaluate recovery algorithms
  - optimal control based, energy based, and pseudo-control hedging based.
- Across three scenarios:
  - High altitude, climb out, pitch trim issue on approach. Based on AC120-109A
- Dependent variables:
  - Cooper-Harper ratings
  - stick activity, number of secondary stalls, inappropriate inputs



Evaluation Roadmap

Sept. 2019 Technology transition demo

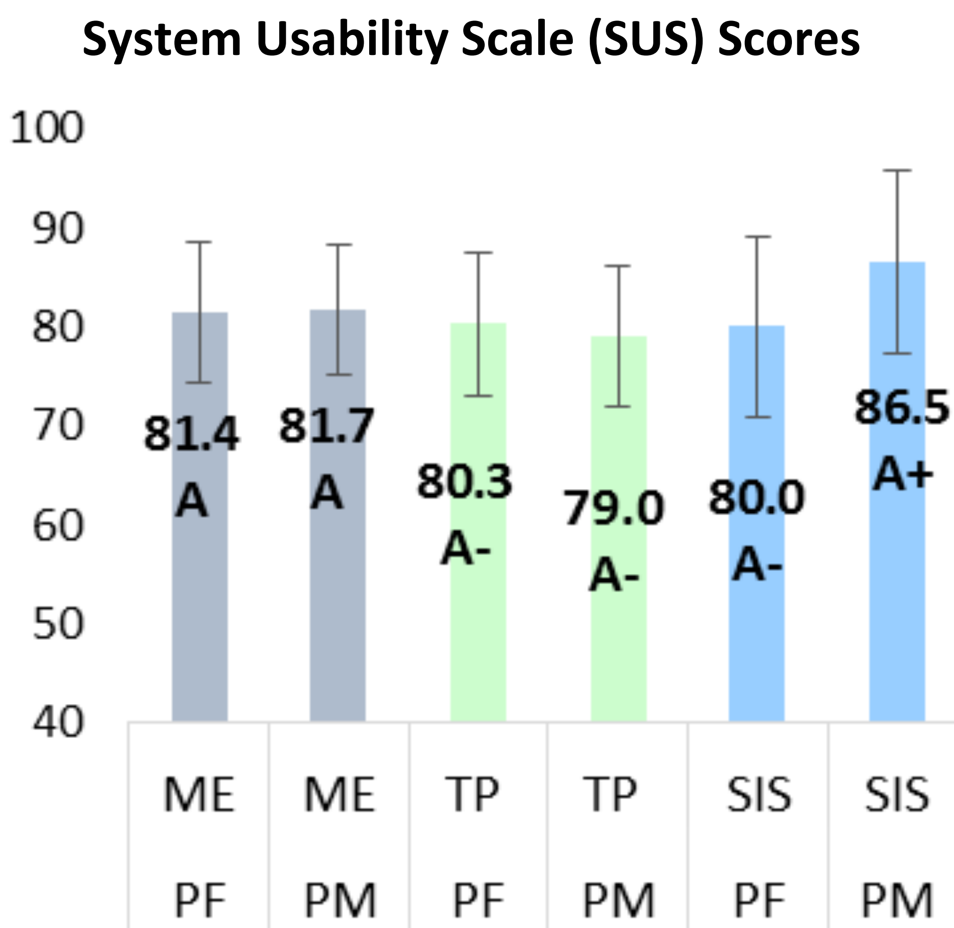
Jan. 2018 AIME 2

Apr. 2017 SRG

Jan. 2016 Automation and Information Management Experiment (AIME) – 12 crews, 250 flights
http://goo.gl/Jl7tJE, and analysis at DASC 2016, and SciTech 2017

Aug. 2014 Tactical Flight Management System with Maneuvering Envelope (TFMS-ME) Experiment – 10 crews, 80 flights
https://goo.gl/5FYhvv

AIME Usability Outcome



Standardized scale based on questionnaire filled out by pilots.

ME = Maneuvering Envelope
TP = Trajectory Prediction
SIS = System Interaction Synoptic
PF = Pilot Flying
PM = Pilot Monitoring

Formal results to be presented at the 2016 Digital Avionics Systems Conference

Evaluation Objectives

- Development and Demonstration
  - Raise the TRL for new technology via testing and demo in a high-fidelity flight sim environment (e.g. confirm performance across span of targeted conditions)
  - **Study the effects of growing automation and information complexity**
- Evaluate the usability and acceptability of new technology concepts
  - Is project on correct path, or need a change of direction?
- Discovery ("learn by doing")
  - Design characteristics requiring refinement for future studies
  - Unknown unknowns related to state awareness and prediction
- Advance test infrastructure capability for future experiments
  - Evaluate the use of the eye-tracking system and physio measurement system for potential to validate design effectiveness, and to detect attention issues
  - Establish confidence in test platform performance given new modifications
  - Identify gaps and capabilities to be improved for subsequent studies

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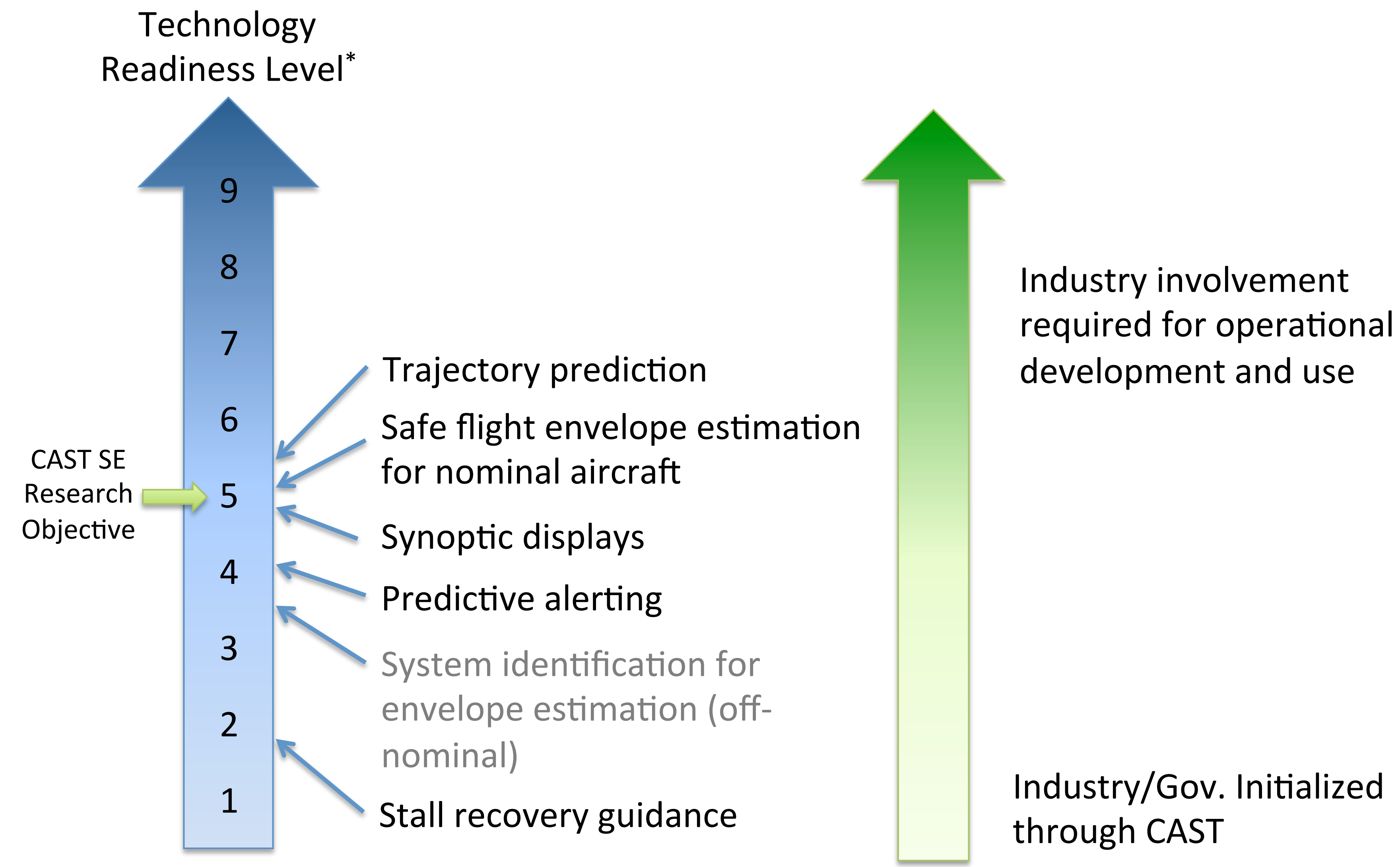
CONCLUSION

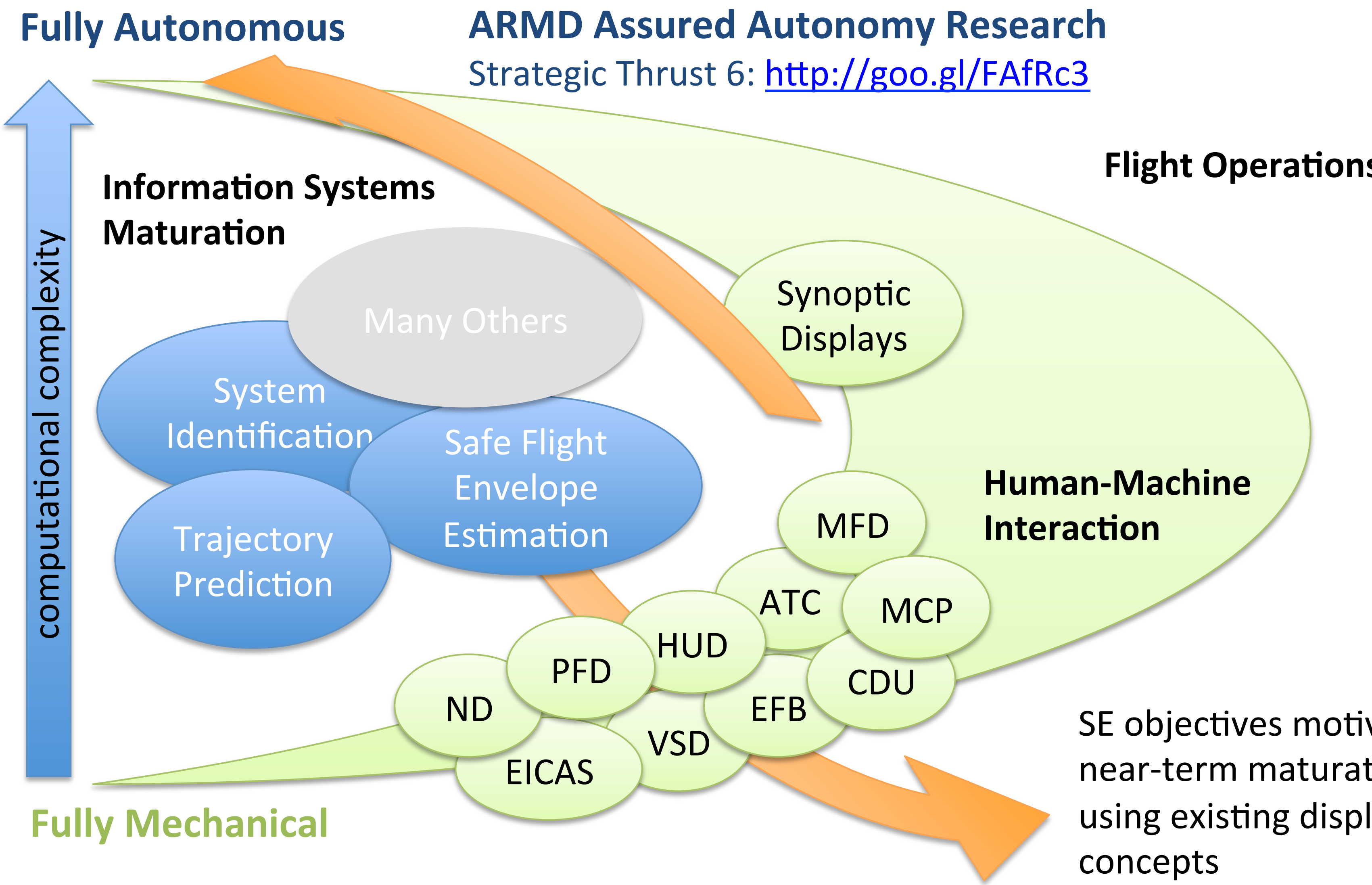
Current Tech. Readiness Levels



* not including operational readiness

The Autonomy Long Game

ARMD Assured Autonomy Research
Strategic Thrust 6: http://goo.gl/FAfRc3



SE objectives motivate near-term maturation using existing display concepts

Conclusion

- Presented CAST motivated research objectives
- Looked at some of the resulting technologies
  - Now at various readiness levels
- Looking for increased industry feedback and interaction as technologies are matured
  - Email: stefan.r.schuet@nasa.gov
  - Software licensing
  - Space Act Agreements
  - NASA Research Announcements
- More info:
  - https://ti.arc.nasa.gov/tech/asr/aces/tfmsme/

References

Slides 5-10

Airplane State Awareness Joint Safety Analysis Team, "Final Report Analysis and Results," provided to the Commercial Aviation Safety Team, June 17, 1014.

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Slides 13-19

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Slide 23

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Slides 20-22, and 27-29

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