Interval Management Systems Avionics Configuration Experiment (IMSACE)

Kara Latorella

NASA Langley Research Center

FAA Briefing

January 30, 2014

Overview

- **Flightdeck Interval Management**
- **IMSACE Objectives**
- **Methods**
  - Subjects & Environment
  - Scenarios
  - Apparatus
  - Independent Variables
  - Experimental Design
  - Data Acquired
- **Results**
- **Discussion**
  - Summary of Results
  - Considerations & Caveats

Flightdeck Interval Management (FIM)

- **Interval Management (IM)**
  - decreases variability of arrivals, and increases efficiency.
  - has both Flightdeck (FIM) and Ground (GIM) components.

- **FIM allows an IM equipped aircraft to space off another aircraft using Automatic Dependent Surveillance – Broadcast (ADS-B) in & out.**

- **IM equipped aircraft receives an IM Clearance that includes:**
  - Target To Follow (TTF)
  - The Path the TTF will be flying
  - The Spacing Interval to be Achieved
  - The Point at which the Spacing is to be Achieved

- **Onboard equipment issues speed commands, consistent with a speed profile, to achieve the spacing interval at the achieve-by point.**

IMSACE Study - Objectives

- **IMSACE – Interval Management System Avionics Configuration Experiment**

- **Investigated the relative acceptance of different avionics configurations that present**
  - FIM speed targets
  - FIM speed profile deviation information
  - Indications of conditions that require action
    - Reminders to enter the target speed
    - Speed profile conformance deviations

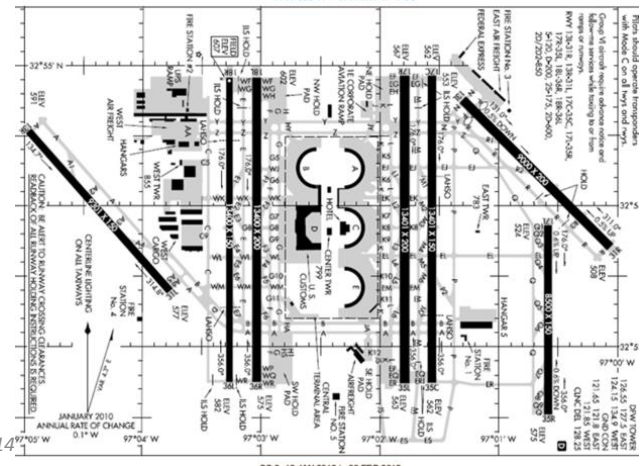
- **Three retrofit options, and one integrated option.**

Methods – Subjects & Environment

- **12 crews of two commercial pilots each**
  - From the same airline, currently type rated for 757
  - Typically one Captain and one First Officer, all over 400 commercial flight hours

- **Realistic traffic & ATC (Center, TRACON, Tower) communications**

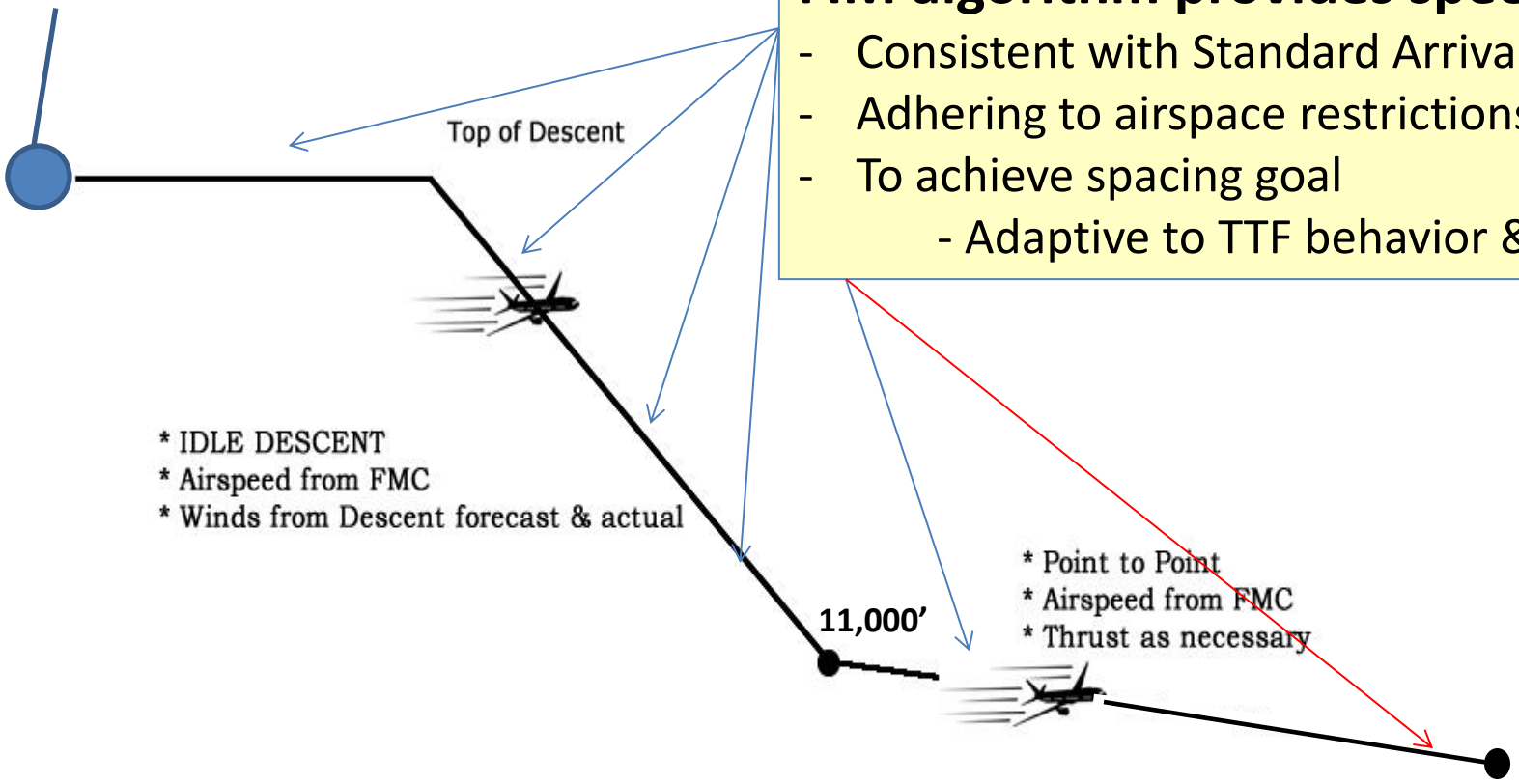
- **Arrivals into Dallas Forth Worth (KDFW)**
  - 4 corner-post system, 4 arrivals to 2 parallel runways
  - Traffic moderate to heavy (recorded from KDFW)
  - Insignificant, as-forecasted winds
  - No ADS-B Errors
  - Arrivals connected from approach to final approach fix



Methods – Scenarios

Straight and level FL200-FL260; ~ 290 KIAS
FIM & Descent clearance given

FIM algorithm provides speed targets
- Consistent with Standard Arrivals (STAR)
- Adhering to airspace restrictions
- To achieve spacing goal
  - Adaptive to TTF behavior & winds

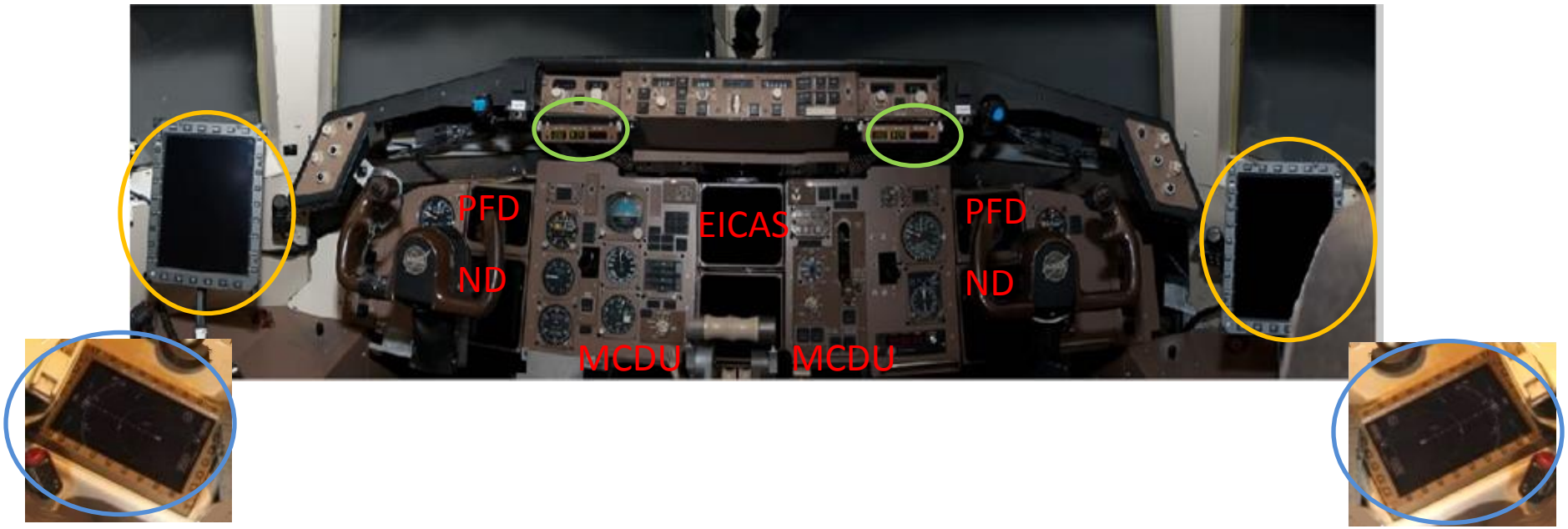


Unconstrained Descent — Constrained Descent

VNAV PATH | VNAV SPD | VNAV PATH | VTGT = VREF30+5 | Stabilized Approach at 1000' AGL, Guidance Removed

Methods - Apparatus

- **NASA Langley Integration Flight Deck (IFD)**
  - Similar to B-757 Aircraft



- **Retro-fit FIM Avionics Displays**
  - Electronic Flight Bag (EFB) Auxiliary Display in **Fore** and **Aft** position
  - ADS-B *(Automatic Dependent Surveillance – Broadcast)* Guidance Display **(AGD)**

- **Integrated Displays:** Primary Flight Display(PFD), Navigational Display(ND), Multi-function Control Display Unit (MCDU), Engine Indicating and Crew Alerting System (EICAS)

Independent Variables

- **Avionics Configuration**= Avionics Condition + Notification

- **Avionics Conditions (4) – Within Crew Factor**
  - Fore-EFB: FIM displayed only on EFB in Forward Position
  - Aft-EFB: FIM displayed only on EFB in Aft Position
  - Aft-EFB+AGD: Aft-EFB plus AGD gives speeds & deviation
  - Integrated: FIM displayed in existing glass displays

  Retrofit Solutions

- **Notification Events & Methods (3) – Between Crew Factor**
  - *Events: New Speed, Conformance Deviation, Reminder to Enter*
  - VVV: Visual, Visual, Visual
  - VAV: Visual, Visual+Aural, Visual
  - AAA: Visual+Aural, Visual+Aural, Visual+Aural

- **Aural Indications**
  - Gonzales, Lewis, Roberts, Pratt, & Baldwin, (2012)
  - Mid-level urgency, low annoyance

Experiment Design

- **12 Crews**
- **Notification Method (3) – Between Crew Variable**
- **Avionics Condition (4) – Within Crew Variable**

	Notification Method	Avionics Conditions
Crews: 1,4,7,10	VVV Only	All 4 Avionics Conditions
Crews: 2,4,8,11	VAV Only	All 4 Avionics Conditions
Crews: 3,5,9,12	AAA Only	All 4 Avionics Conditions

- **Runs**
  - 2 Training runs, one in each role for each pilot
  - 8 Data collection runs
    - Each pilot serves as Pilot Flying & Pilot Monitoring

Data Acquired

- **Simulation Data**
  - Flightpath deviation, Speed deviation
- **Post-Run Questionnaire**
  - Scenario Workload/Acceptability/Situation Awareness
- **Post-Experiment Questionnaire**
  - FIM Operations in General Acceptability
  - Pairwise comparisons of Avionics Conditions
  - Operational acceptability of Avionics Conditions
  - Acceptability of Notification Methods with Aurals
  - Reminder & Conformance Deviation Threshold Acceptability
- **Oculometer Data**
  - Percent allocation to Areas of Interest, Scan Paths

Results

- **Test Validity and Effectiveness**

- **Flight Management**
  - Vertical Excursions
  - Speed Excursions & Out-of-Conformance Incidents

- **Attentiveness to IM Events:**
  - Reminder Counts
  - Response Times to New Speed Events (time to dial in speed)

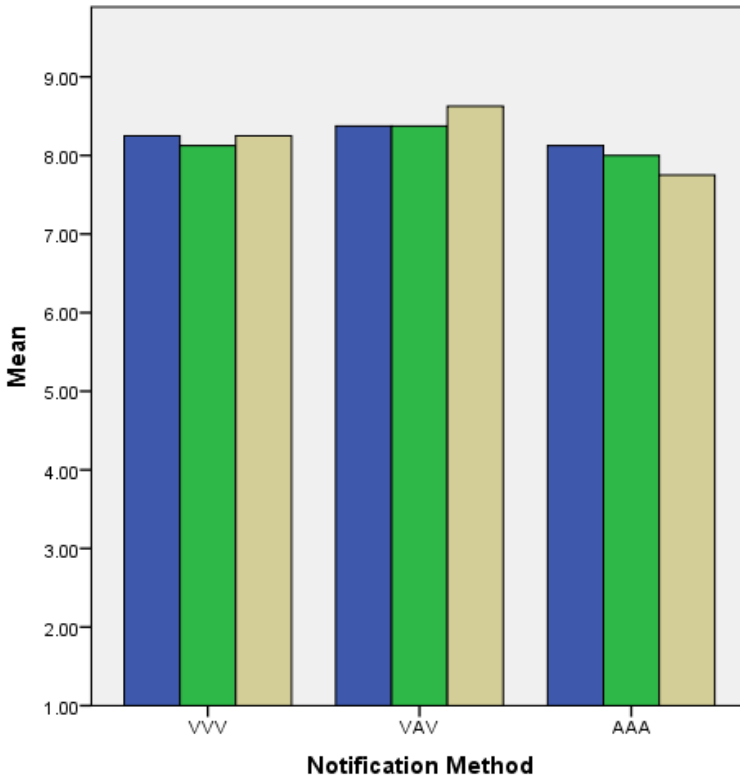
- **Post-run Questionnaire Data**
  - Workload
  - Situation Awareness
  - Usability
  - Scenarios / Operational Acceptability

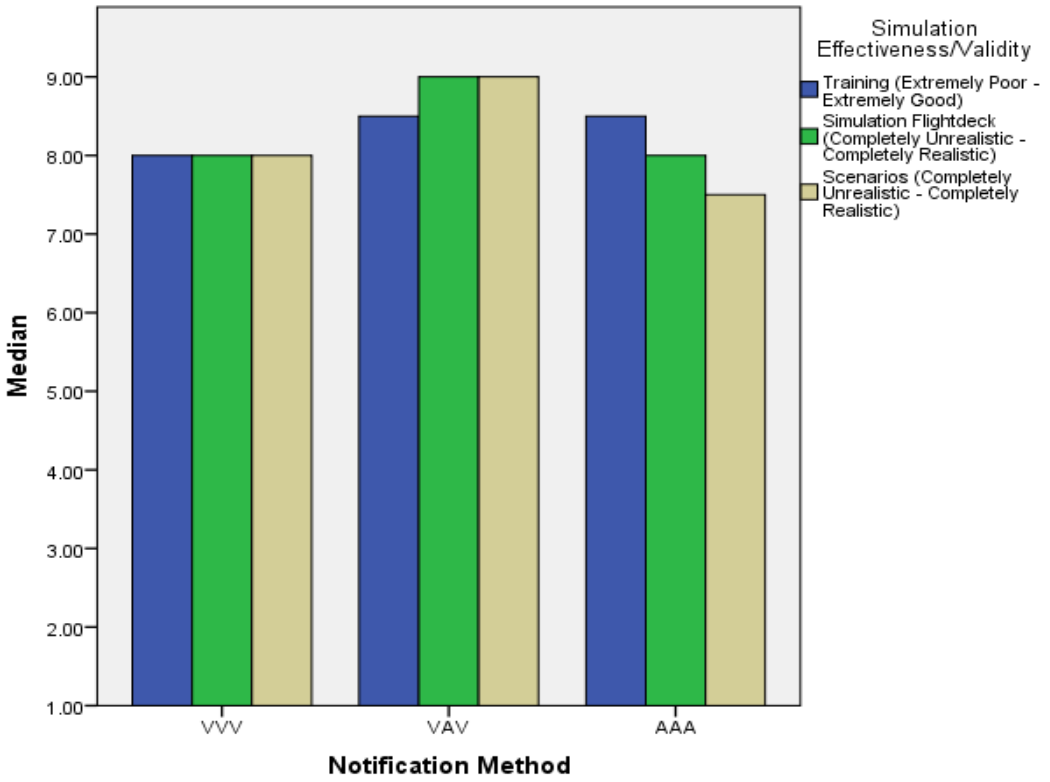
- **Post-experiment Questionnaire Data**
  - Simulation Validity and Effectiveness Ratings
  - Preference & Operational Acceptability Ratings
  - Ratings on Aural Notifications
  - Reminder & Conformance Thresholds Ratings
  - Operational Impact Ratings

- **Participant Comments**

Test Validity & Effectiveness (1-9 scale)

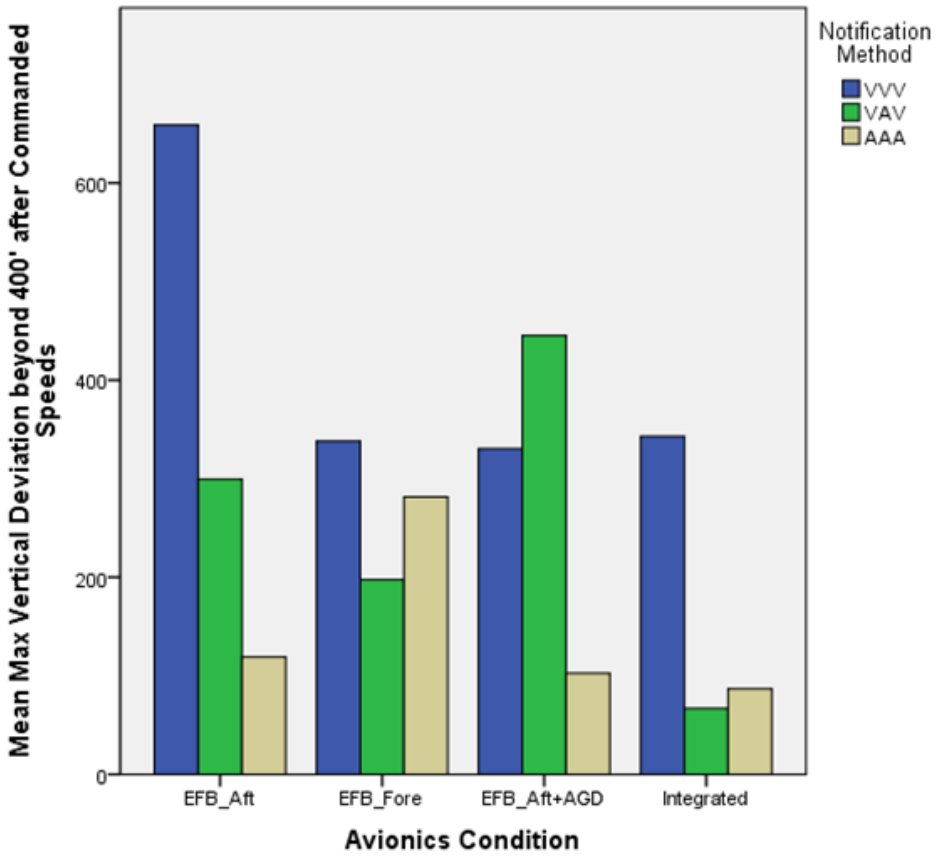
- Training Effectiveness, Simulation & Scenario Realism
- All ratings more positive than the midpoint rating ($p<0.001$).
- Notification Method experienced did not affect these ratings (all $p>0.352$).





Vertical Path Excursions (> 400')

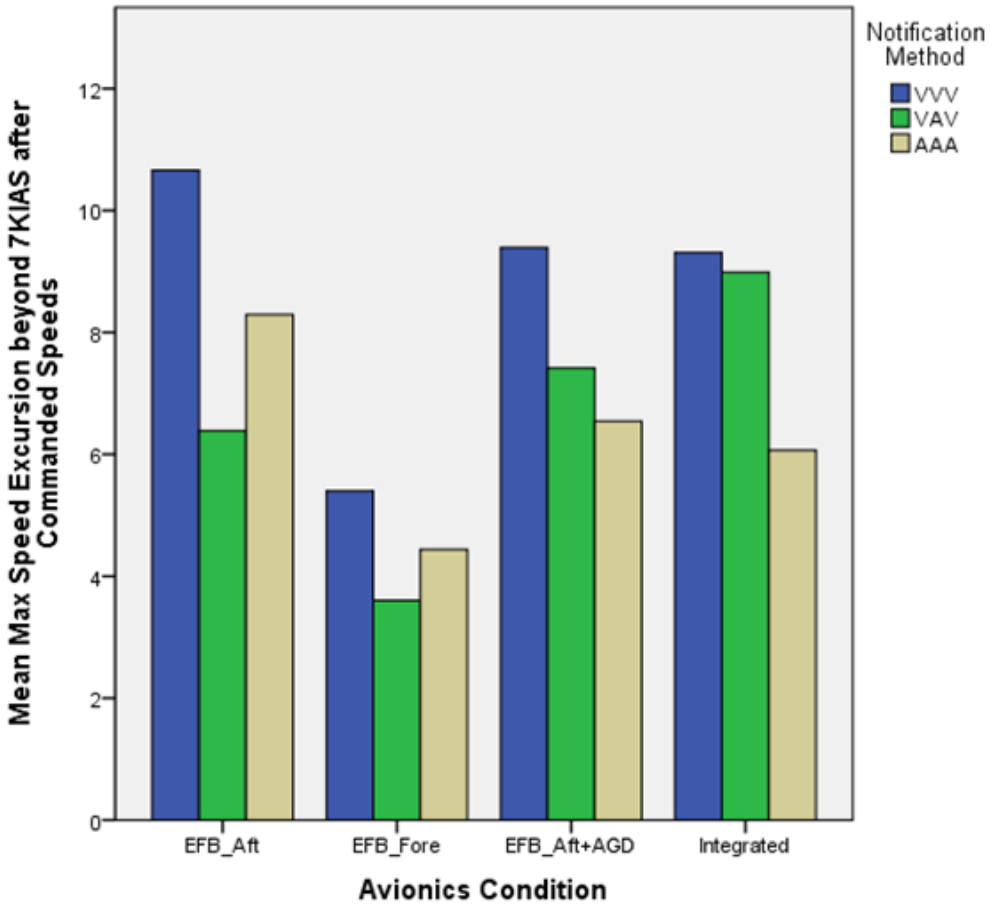
- Significant interaction between Notification Method and Avionic Condition ($p<0.025$).
  - VVV had more vertical excursions than the AAA method for the EFB-Aft condition.



Simulation Data

Speed Excursions (> 7 knots off profile)

- **Significant effect of Avionics Condition (p<0.001).**
  - EFB_Fore had less extreme speed excursions than all others (all p<=0.039)



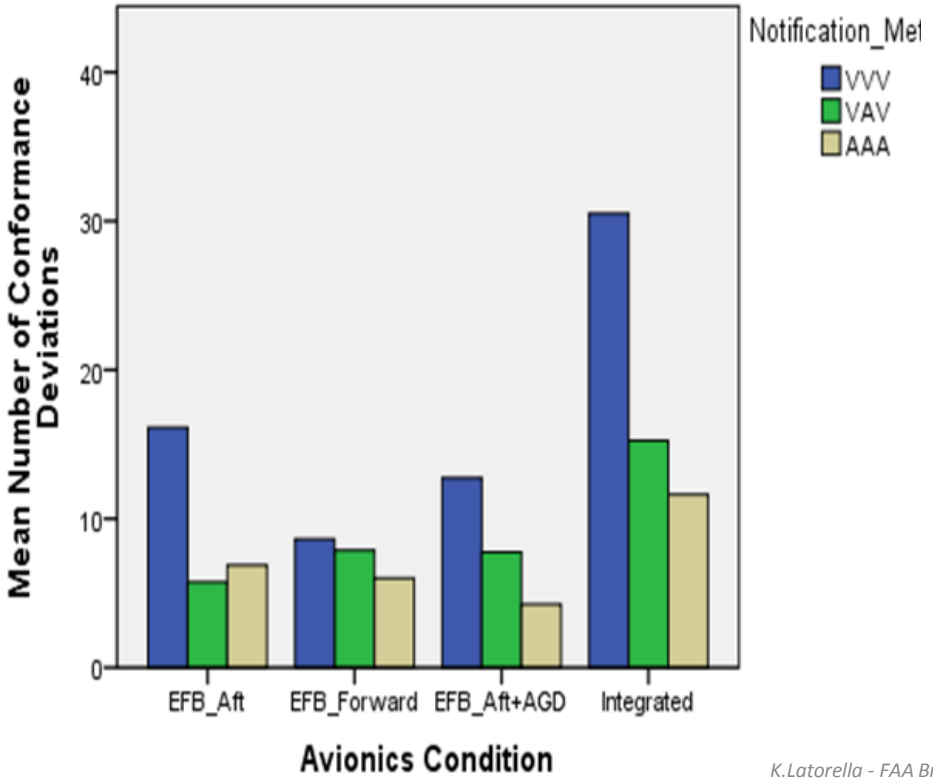
Simulation Data

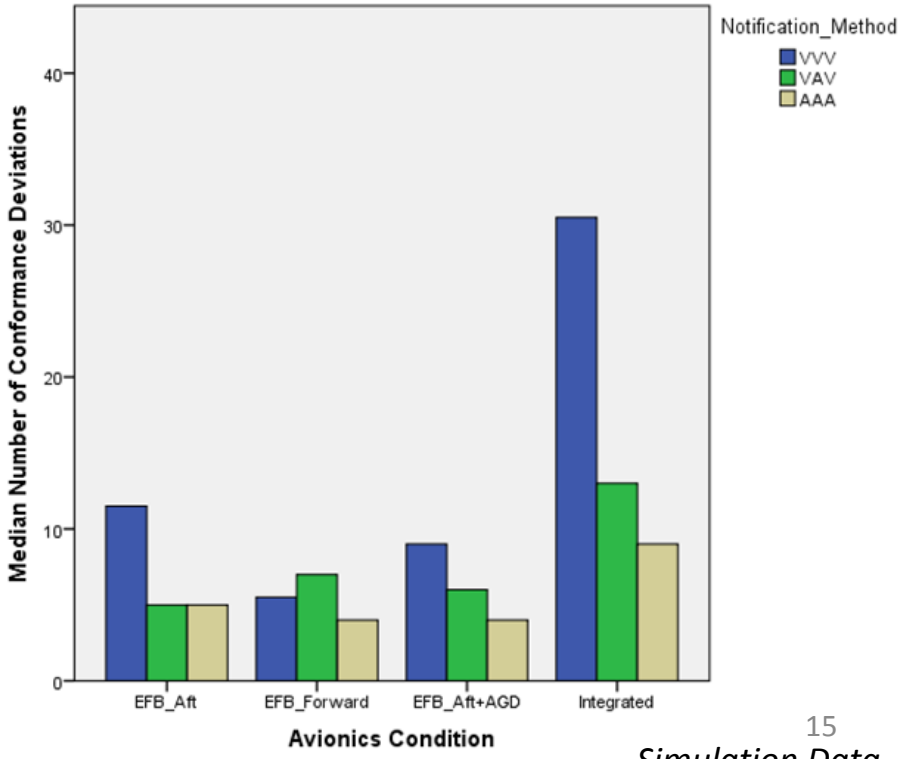
Out-of-Speed-Profile Indications

- **Significant Avionics Condition x Notification Method interaction (p=0.011)**
  - For both the EFB-Aft and Integrated: VVV >> VAV or AAA (all p<=0.089) {by a factor of 3}

- **Averaged over all levels of Avionics Condition**, VVV > AAA (p=0.049)

- **Averaged over all levels of Notification Method,** Integrated > all others (all p<=0.005)





Simulation Data

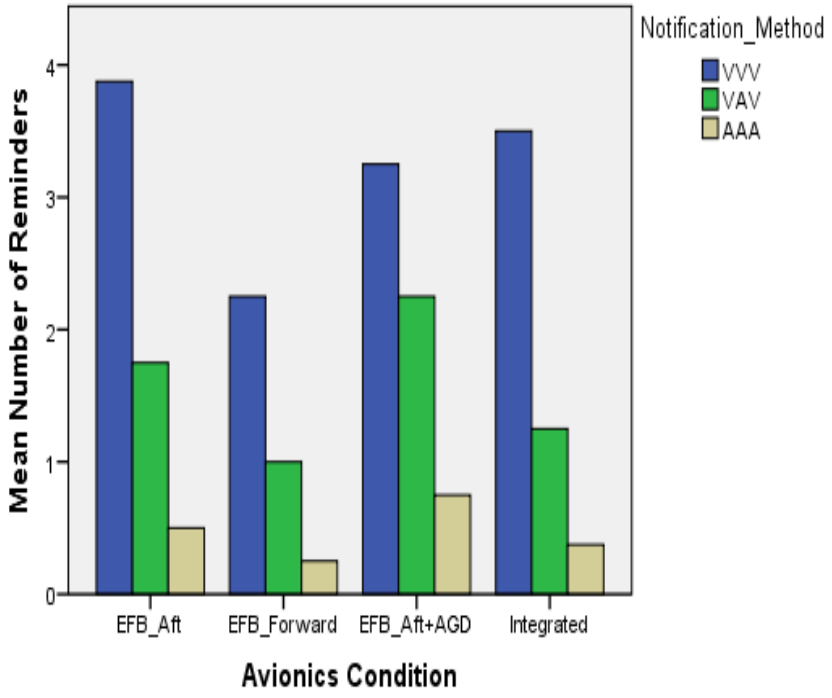
FIM Speed Reminders

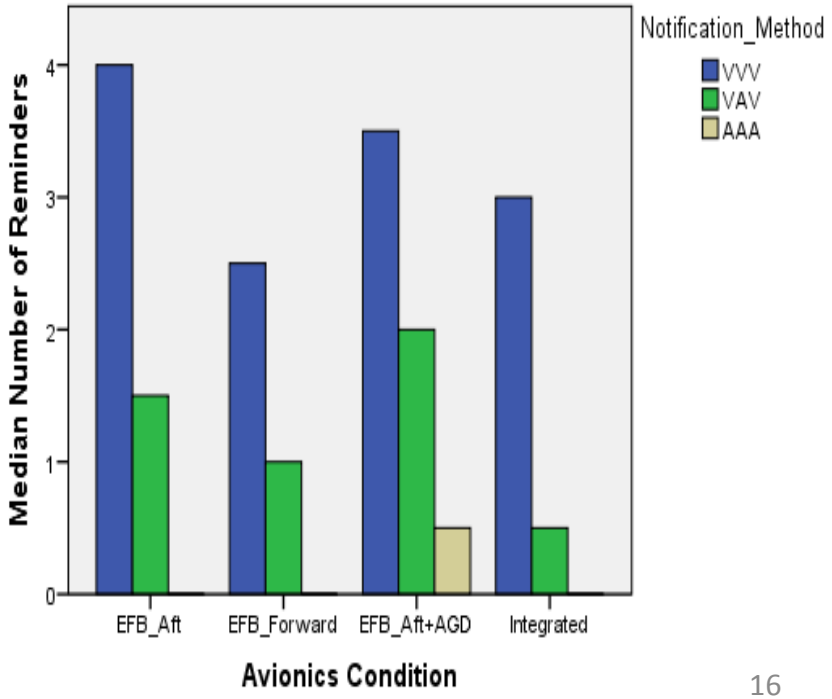
Avionics Condition (p=0.002)

- EFB-Fore < EFB-Aft (p=0.001) and EFB-Aft+AGD (p=0.094) {on average by about half.}

Notification Method (p<0.001)

- AAA < VVV (p=0.003) and VAV method (p=0.075)
- VAV < VVV (p=0.075)





Simulation Data

Response Times to New FIM Speeds

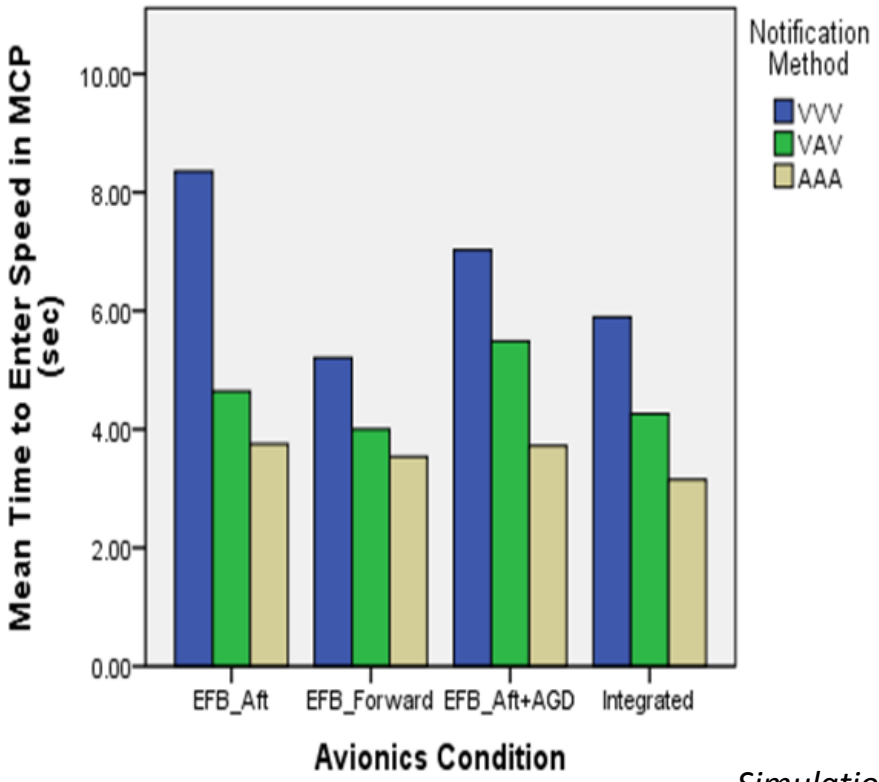
(statistics conducted on log(RT))

Avionics Condition (p<0.001)

- EFB-Aft > Integrated & EFB-Fore (all p<=0.003); *EFB-Aft took longest*

Notification Method (p=0.002)

- VVV > VAV and AAA (all p<=0.033); *VVV took longest*



Simulation Data

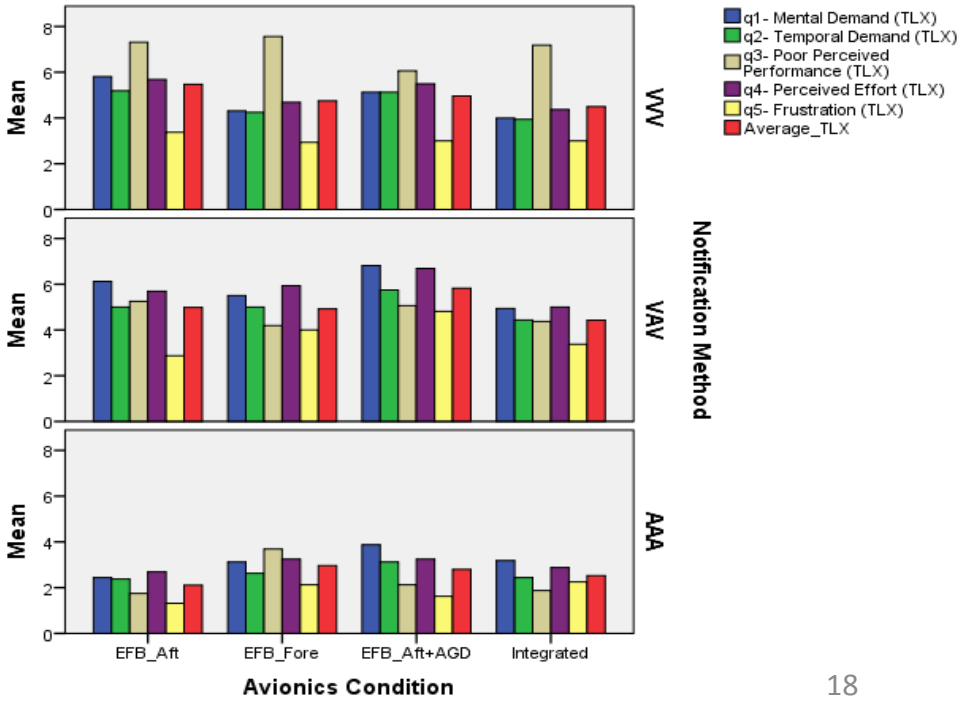
Workload

Modified Cooper-Harper (1-10) (*Wierwille* and Casali, 1986)

- All average workload ratings <= 4 (*"Moderately high .."*)
- No significant effect of Avionics Condition (p>0.10)
- No significant effect of Notification Method (p>0.10)

NASA TLX *(Hart & Staveland, 1988)*

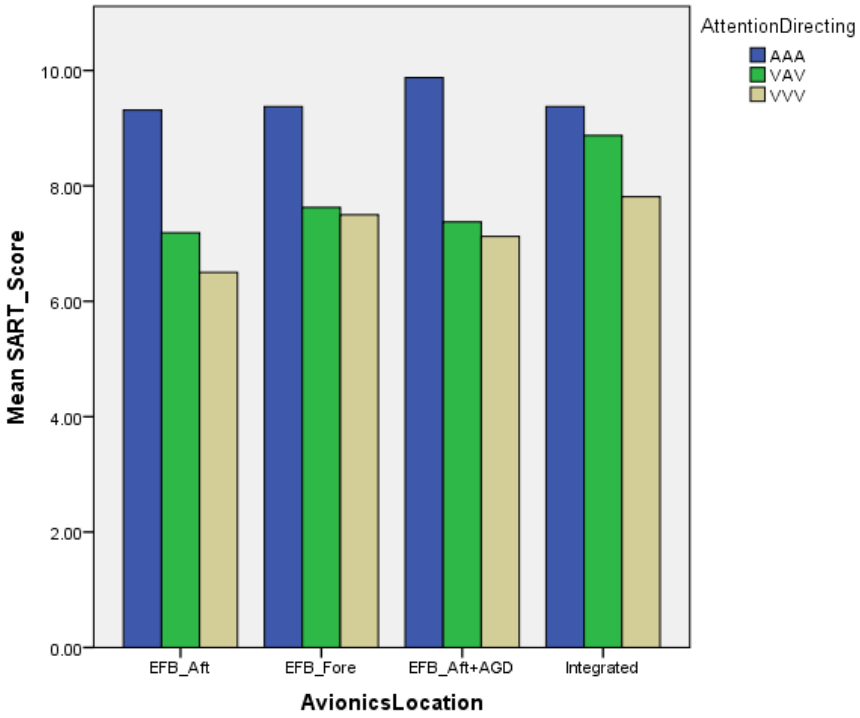
- For all scales, over 80% scores below midpoint
- Notification Method effect
  - VVV > AAA (total score, p=0.083)
  - VAV > AAA (total score, p=0.083)
  - VAV > AAA (frustration, p=0.027)

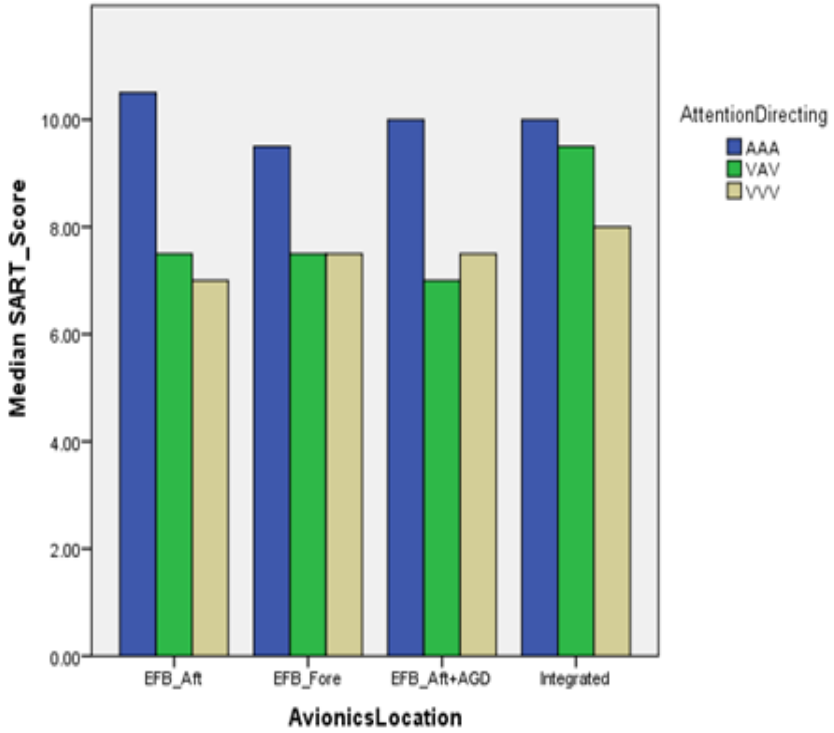


Situation Awareness (SART (0-18))

- Avionics Condition
  - Integrated > EFB-Aft (p=0.090)

3D-SART (Selcon & Taylor, 1989)
= Understanding
- Attentional Demand
+ Attentional Supply.





Post-Run Q

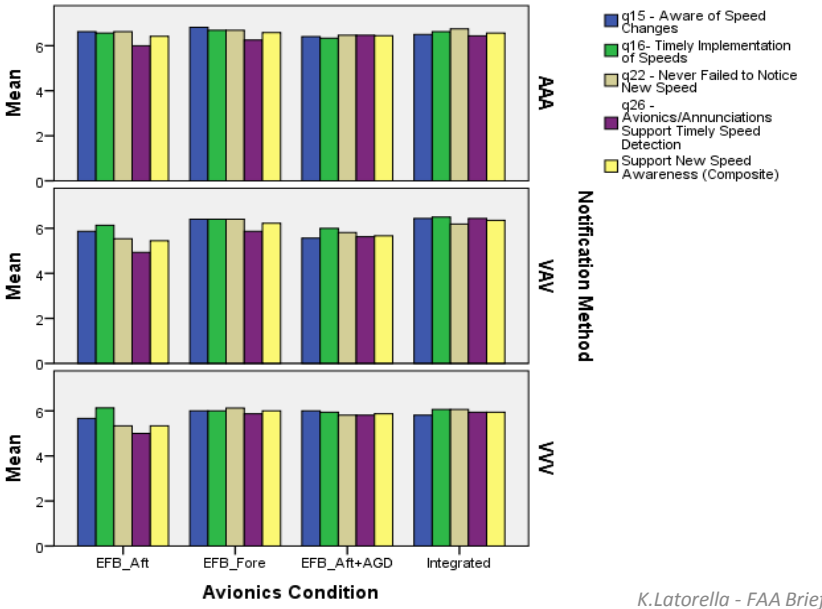
Speed Awareness items (1-7)

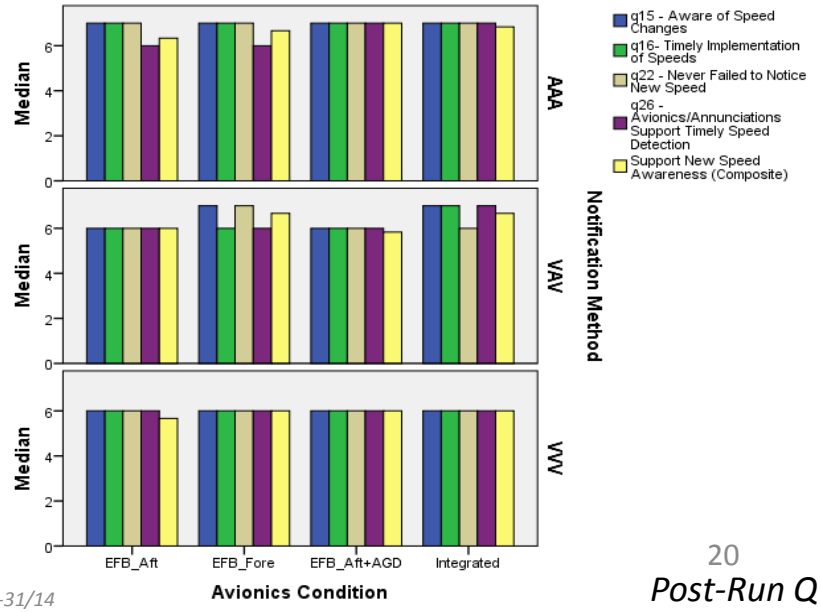
Avionics Condition

- all > EFB-Aft (all p<=0.041)
- EFB-Fore > EFB-Aft+AGD (all p<=0.063)
- Integrated > EFB-Aft+AGD (p=0.094)

Notification Method

- AAA > VVV (p<=0.008)
- AAA > VAV (p<=0.072)





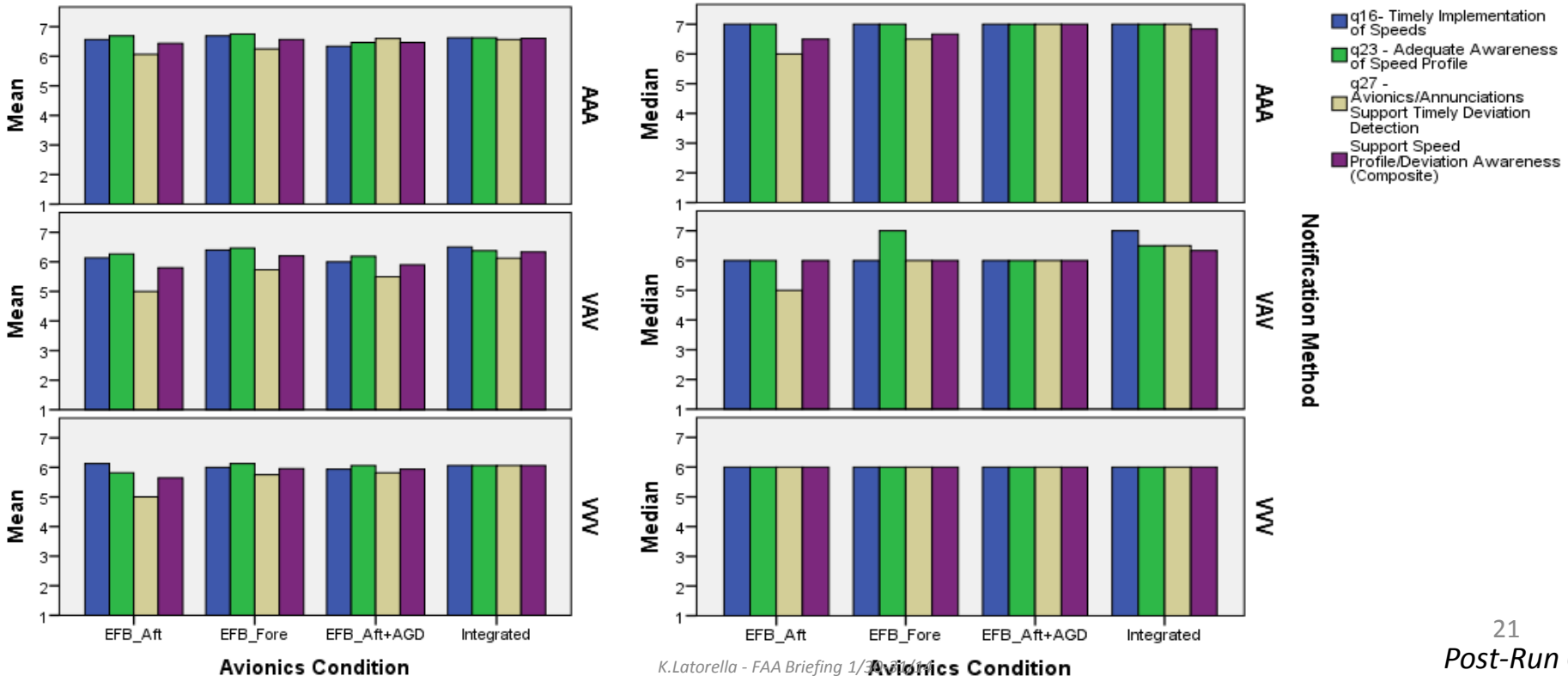
Speed Profile Deviation Awareness (1-7)

Avionics Condition

- For Q27 *"Timely deviation detection"* (p=0.028), EFB-Aft < all others
  (EFB-Fore, p=0.078; EFB-Aft+AGD, p=0.044; Integrated, p=0.047)

Notification Method

- for all items and the composite (all p<0.029), AAA > VVV
- For Q27 (p=0.033) and composite (p=0.092), AAA > VAV

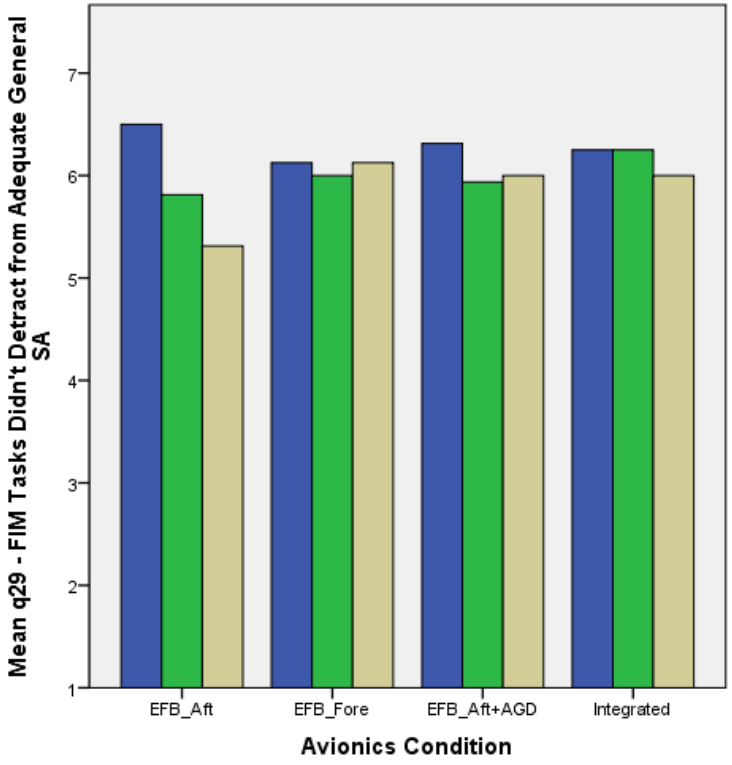


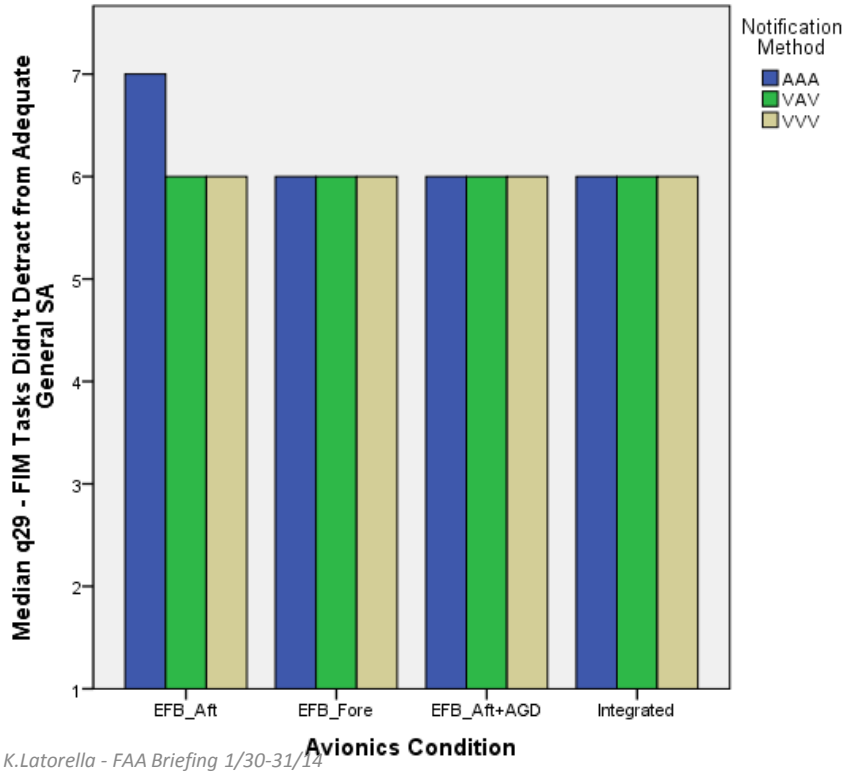
General Awareness (1-7)

"Time required for IM tasks did not detract from having appropriate SA for other aspects of flight"

Significant Avionics Condition x Notification Method interaction (p=0.028)

- When using the EFB-Aft condition, AAA > VAV (p=0.026) and VVV (p=0.002)





Usability Factors (1-7)

Distraction

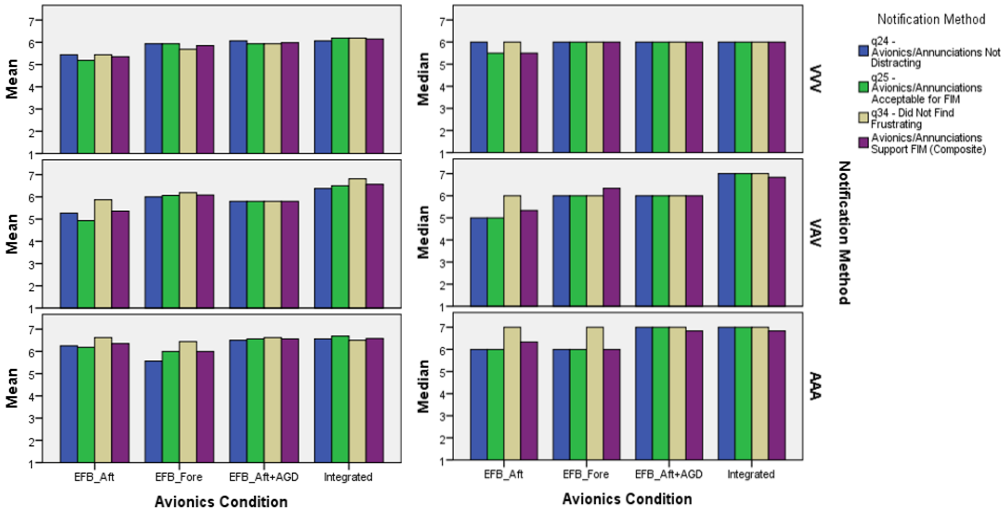
- Avionics Condition x Notification Method interaction significant
  - AAA < VAV for EFB-Aft (p=0.015), and for Integrated (p=0.098).
- Avionics Condition, averaged over Notification Methods (p=0.003)
  - Integrated < EFB-Aft (p=0.016) or EFB-Fore (p=0.022)
  - EFB-Aft+AGD < EFB-Aft condition (p=0.016)

Operational Acceptability

- Avionics Condition (p=0.001)
  - All > EFB-Aft (all p<=0.064)
  - Integrated > all (all p<=0.074)

Frustrating

- Notification Method (p=0.037)
  - AAA < VVV (p=0.019)

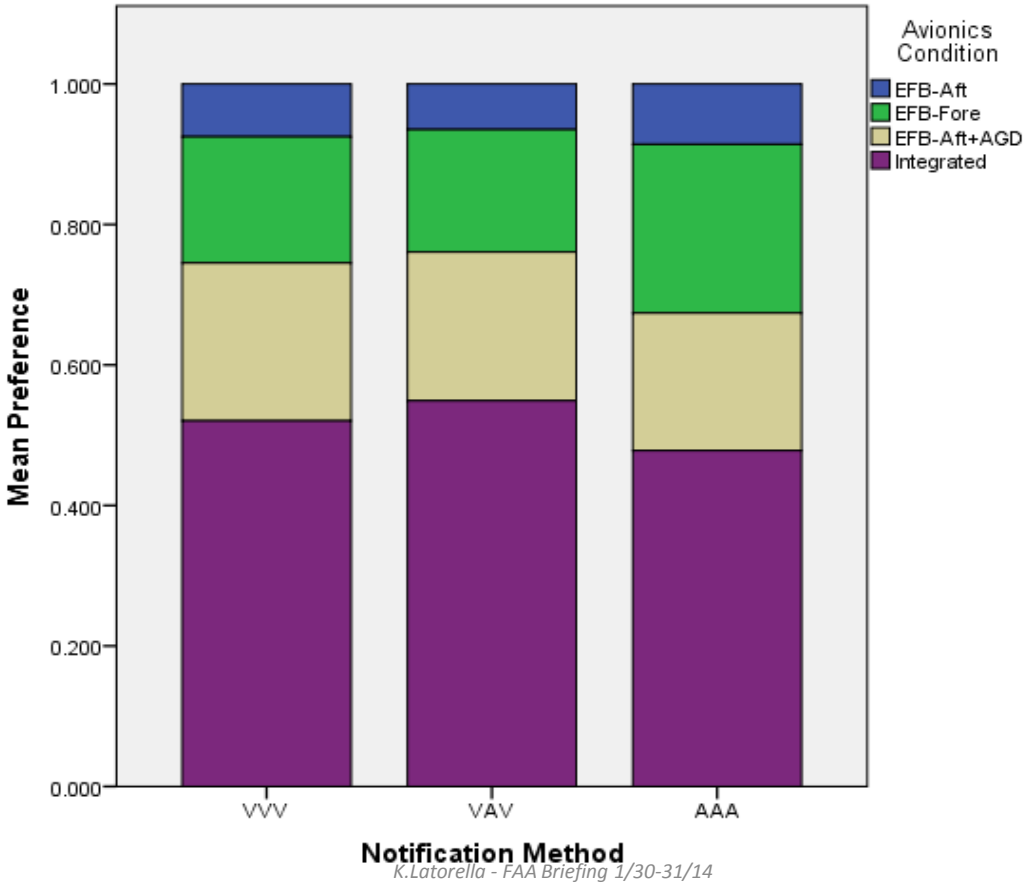


While these ratings show significant differences, medians have only one or two scale point differences, and ratings are relatively high for all configurations.

Preference Rating Scores

Analytical Hierarchy Process (Saaty, 1980)

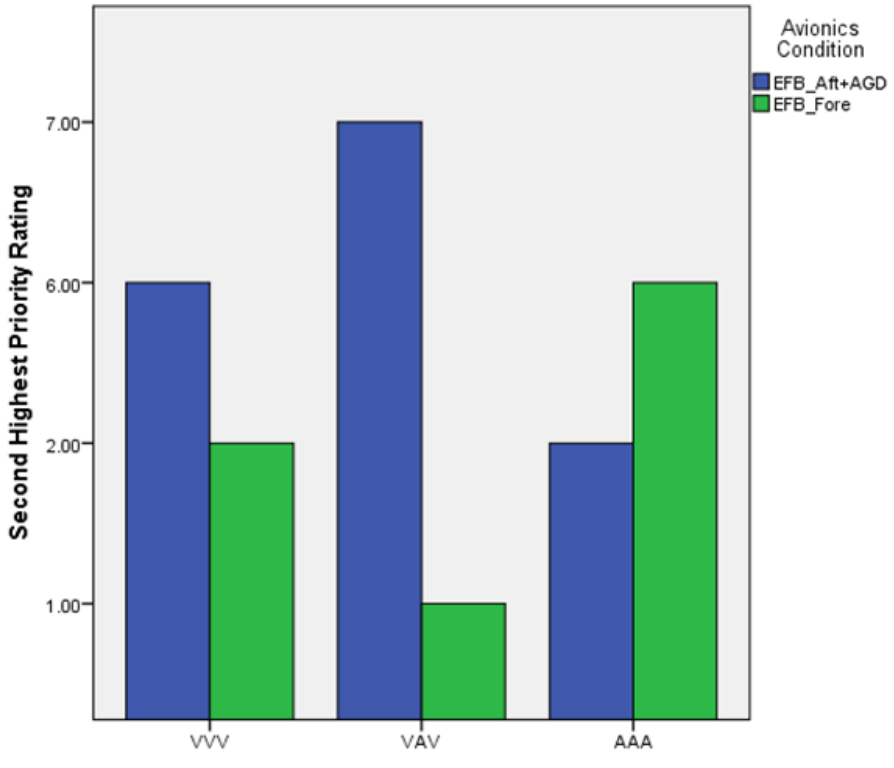
- Pairwise comparisons resulting in percent-preferred
- Highly consistent across participants
  - All but one most preferred Integrated and least preferred EFB-Aft
  - This one least preferred Integrated and most preferred EFB-Fore



Preference – Second Place (AHP)

It depends…

- If aurals used for all IM events, EFB-Fore preferred
- If aurals used only for conformance deviations, EFB-Aft+AGD preferred
- If no aurals used, EFB-Aft+AGD preferred (but not by as much)



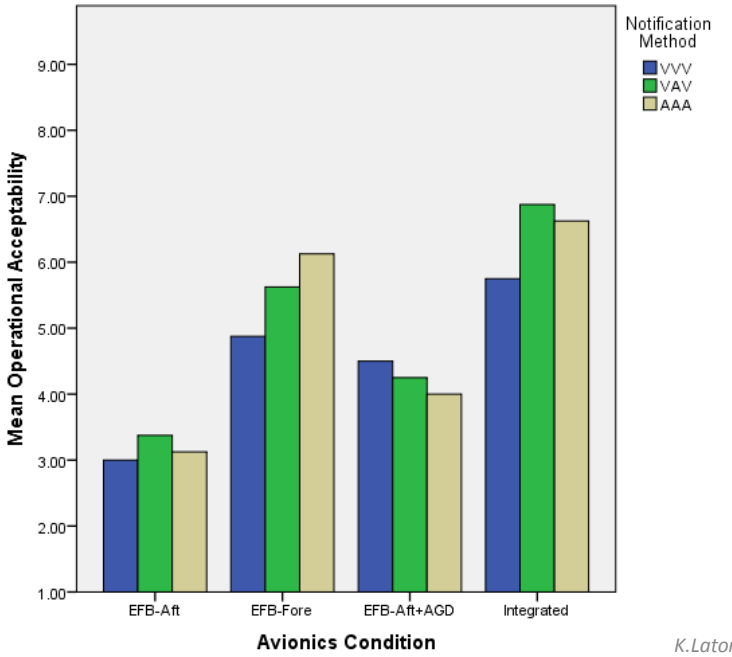
Post-Experiment Q

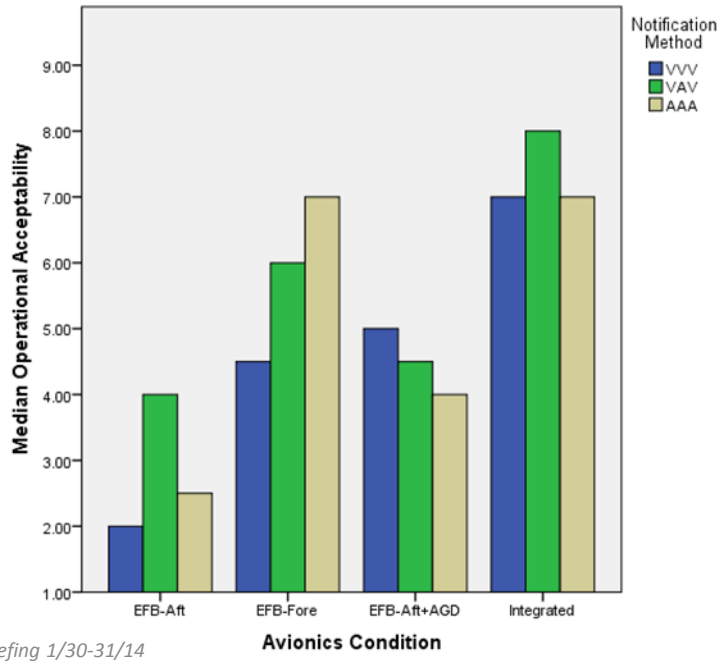
Operational Acceptability (1-9)

Avionics Conditions (p=0.001)

- Integrated > EFB-Fore > EFB-Aft+AGD > EFB-Aft (all p<0.038)
- EFB-Fore and Integrated ratings were better than midpoint (p=0.023, p=0.002)
- EFB-Aft+AGD ratings indistinguishable from the scale midpoint (“Borderline”)
- More than half of the EFB-Aft ratings were in the lower half of the scale (p=0.023)

Notification Method experienced did not affect ratings (p=0.741).





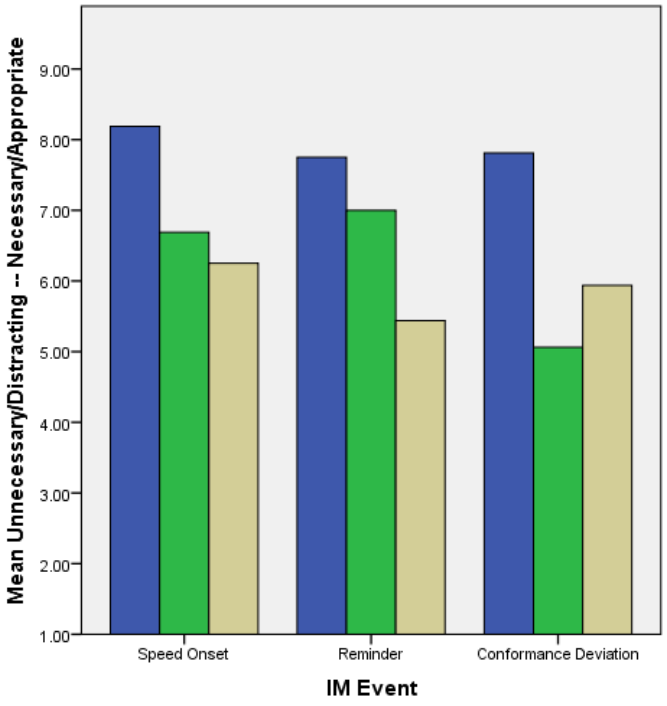
Utility of Aural Notifications (1-9)

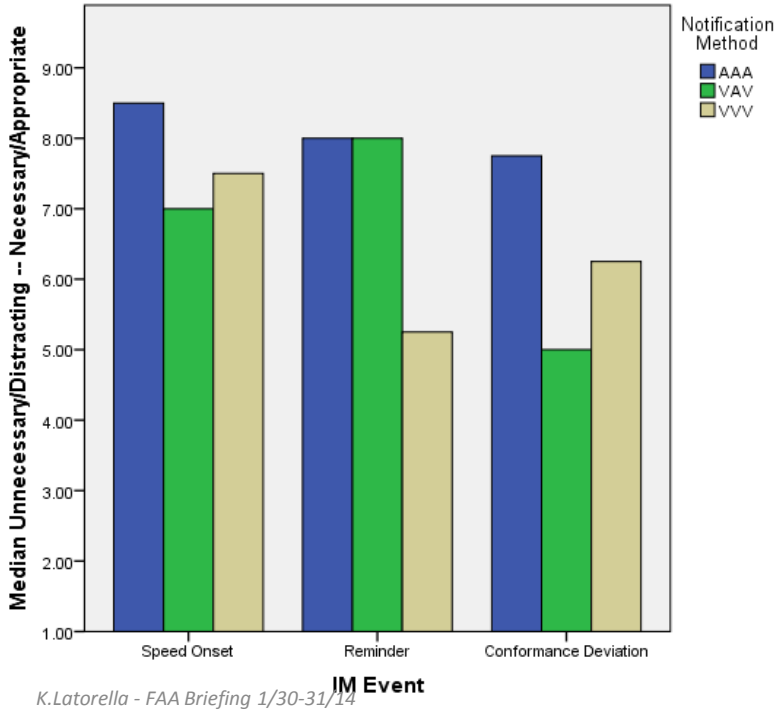
Ratings did not differ by IM Event (Onset, Deviation, Reminder) (p=0.402)

- However, ratings for aural onsets and reminders were in the more positive half of the scale (p<0.023), whereas ratings for aura speed deviation indications were indistinguishable from the middle (p=0.152).

Notification Method affected how appropriate pilots thought aurals were (p=0.006)

- Those using AAA rated AAA> VAV (p=0.029), and AAA > VVV method (p=0.018).
- No significant difference in ratings for VAV and VVV (p=0.648).





Participant Comments on Use of Aurals

"What's an appropriate use of aural indications?"

IM Events (Notification Method tested)	VVV (8 total)	VAV (8 total)	AAA (8 total)	Total (%)
Onset, Reminder & Conformance (AAA)	5	1	6	12 (50%)
Onset & Reminder	0	1	0	1 (4.2%)
Onset & Conformance	1	0	1	2 (8.3%)
Reminder & Conformance	0	2	0	2 (8.3%)
Onset only	2	1	0	3 (12.5%)
Reminder only	0	2	0	2 (8.3%)
Conformance only (VAV)	0	0	0	0 (0%)
Visual only (VVV)	0	1	1	2 (8.3%)

Summary – Avionics Conditions

- **Preference ratings**
  - Integrated most & EFB-Aft least preferred
  - EFB-Fore & EFB-Aft+AGD close; if AAA - EFB-Fore.

- **Operational acceptability**
  - Integrated > EFB-Fore > EFB-Aft+AGD > EFB-Aft
  - EFB-Aft not operationally acceptable
  - EFB-Fore and EFB-Aft+AGD close; both “borderline” acceptable
  - No significant effect of, or interaction with Notification Method

- **Flightpath Management – Vertical Excursions**
  - Only EFB-Aft condition affected by Notification Method (VVV worse than AAA)

Summary – Avionics Conditions

- **FIM Speed Monitoring and Control**
  - EFB-Fore had less extreme speed excursions than all other conditions
  - Integrated with no aural indications (VVV) had most frequent deviations
  - EFB-Fore had significantly fewer speed reminders than the EFB-Aft conditions
  - Integrated & EFB-Fore supported faster responses to new speeds than EFB-Aft
  - Situation awareness rated higher for Integrated than EFB-Aft
  - Ratings of New Speed awareness, summarized:
    - EFB-Aft < all others (most contrasting with EFB-Fore)
    - EFB-Aft+AGD < Integrated
  - Ratings of Speed Deviation awareness
    - EFB-Aft < all others

- **No significant effects on**
  - Workload (NASA-TLX, MCH)
  - Situation Awareness (SART)

Summary – Notification Methods

- **Perponderance of preference for condition, if not Integrated..**
  - If using VVV or VAV, then EFB-Aft+AGD
  - If using AAA, then EFB-Fore
  - *No significant effect of Notification Method used on operational acceptability*

- **FIM Speed Monitoring and Control**
  - Speed deviations were much worse with VVV for both the EFB-Aft and Integrated conditions (most obvious with Integrated)
  - VVV associated with the most speed reminders, and AAA required the fewest
  - VVV associated with longer response times to new speeds than others
  - VVV associated with worse ratings of speed awareness than AAA
  - VVV associated with worse ratings of speed deviation awareness than others

Use of Aural Indications Suggested

- **AAA best for**
  - Not detracting from SA of other aspects of flight
  - Minimal distraction (over VAV for EFB-Aft & Integrated conditions)
  - Mitigating vertical excursions over VVV for EFB-Aft
  - Minimal NASA-TLX workload and frustration (subscale and post-run item)
  - Fewest speed reminders
  - Best rating of new speed awareness

- **Subjects who received aurals for all IM events provided higher preference ratings for use of aurals** than those in VAV, and those in VVV conditions.

- **~92% of subjects indicated a preference for aurals** for at least one event
  - *Only one from VAV and one from AAA did not – all VVVs did!*

- **Aurals were suggested most for use to indicate**
  - All IM events (50% of participants)
  - Speed onset only (12% of participants)
  - Use of aurals for speed deviations was seen as less appropriate than others

Designing FIM-Supportive Avionics

- **Considerations**
  - Salience of indicators
  - Differentiation of annunciations for IM events
  - Thresholds for providing reminders and deviation indicators
  - Separate displays & not seeing; Integrated displays & not noticing
  - Ergonomics of viewing angle, glare, focal length

- **Caveats**
  - Small sample size, Notification Method between subject factor
  - Generalize beyond these specific designs with caution
  - Subjective data can dissociate from performance data

Questions?

K.A.Latorella@nasa.gov

Acknowledgements

Experiment Development & Conduct

Gary Lohr & Brad Perry, Kurt Swieringa, Jennifer Murdoch, Mike Palmer, Bob Cameron & Buddy Merritt, Clay Hubbs & Rick Shay

Simulation Operation & Development

Dale Ashcomb, Charles "Tom" Feigh, Dennis Frasca, Kemper Kibler, Paul Sugden, Mike Cronauer, Al Douglas, Missy Hill, Darrell Sacra

Oculometer Support

Bill Lynn, Lon Kelly, Ming Shih, Omar Scott, Julie Timmons, Magnus Sjolin

Data Reduction Support

John Barry & Janette Spangler

Audio Recording

Anthony Fox, Kathy Guild, Darrell Mohr, Steve Whitlow

Pretest Pilots

Don Bagwell, Brian Baxley, Greg Slover, Mike Wusk, Rick Yasky, Mike Norman

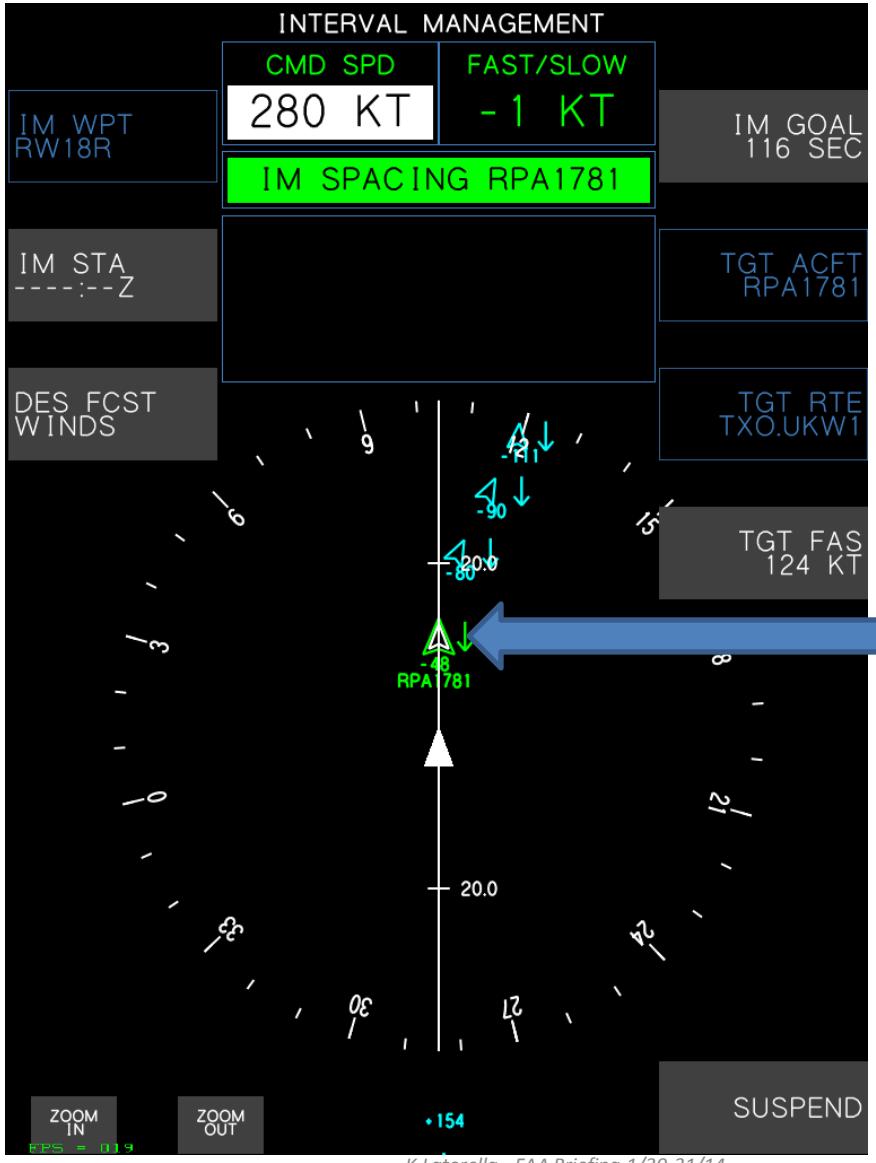
Management & Admin.

Miguel Alvarez, Bryan Barmore, Brian Baxley, Victoria Chung, Sonia Herndon, Sean Kenney, Lisa Rippy, Wayne Burge, Catherine Buttrill, Regina Johns, Keisha Newsome

FAA Sponsors

Colleen Donovan & Tom McCloy

EFB: New Speed Target

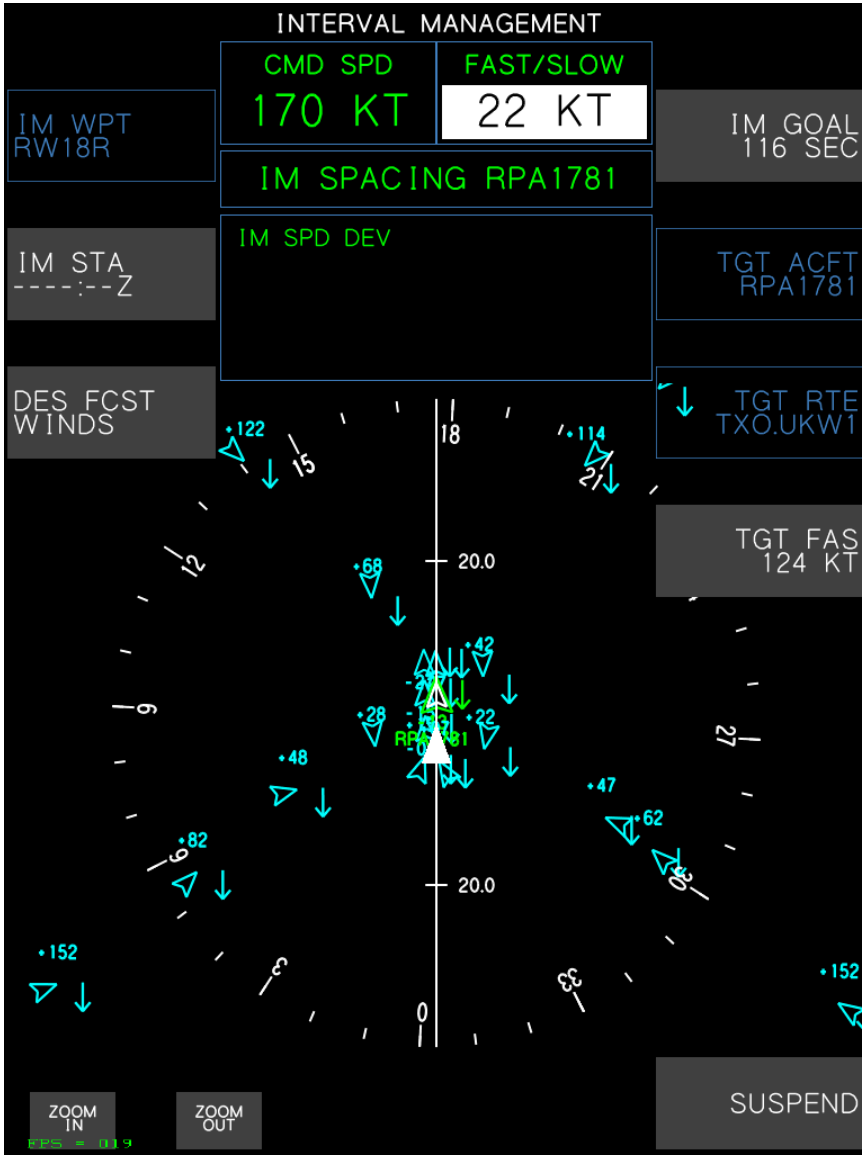


Reverse highlight white, until you dial it in.

If correct speed not in MCP 10sec after received, CMD SPD blinks as a Reminder

Target Aircraft

EFB: Conformance Deviation



Conformance deviation Highlights white and blinks When 7 knots off for over 12 seconds and not converging.

22 KT means you are 22 knots fast.

-11 KT would mean you are 11 knots slow.

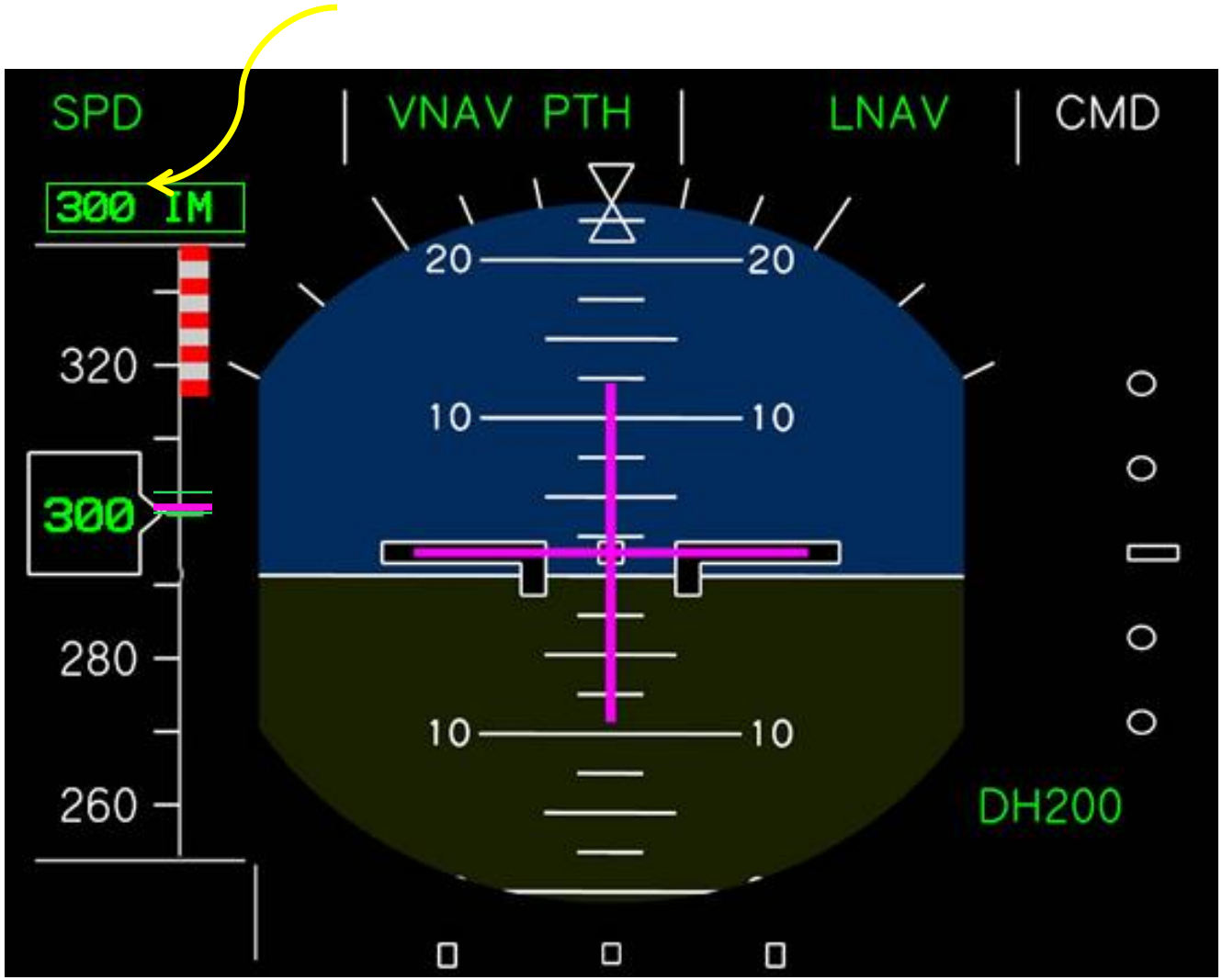
ADS-B GUIDANCE DISPLAY

- **New Speed: New CMD SPD with white light**
  - Turns off when you have dialed it in to MCP
- **Reminder: CMD SPD blinks if correct speed not dialed in by 10 seconds after occurrence.**
- **Conformance Deviation: Fast/Slow indicator blinks**

INTEGRATED – PFD: Speed Onset

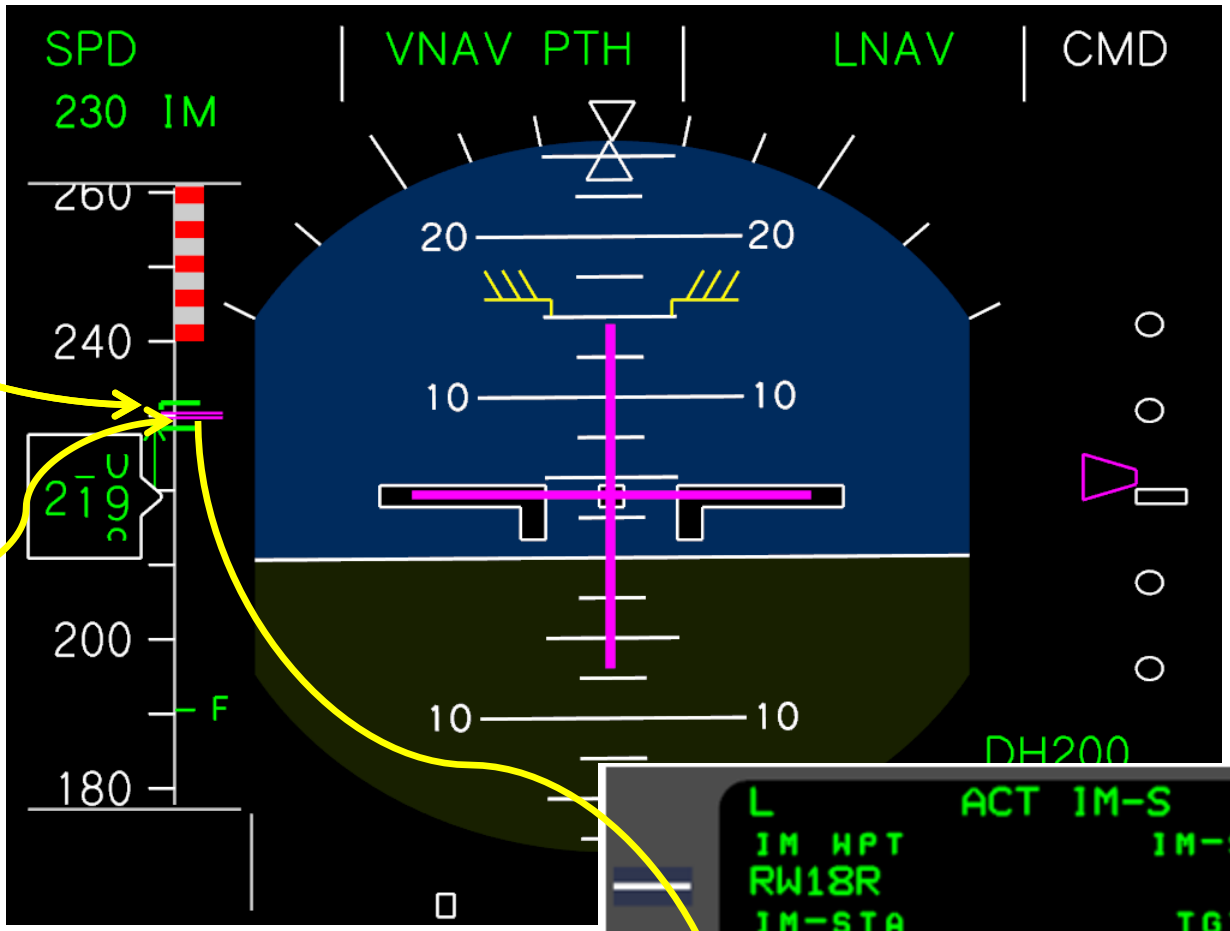
Boxed speed on Occurrence.

Reminder: Box blinks after 10 seconds if correct speed not entered.



INTEGRATED PFD:

Speed Deviation

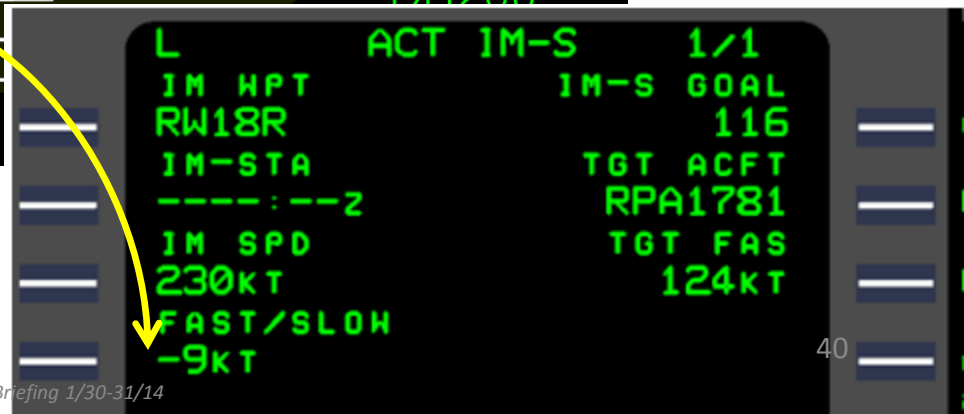


Profile Bug

CMD Spd

EICAS message

MCDU IM Page



INTEGRATED: MCDU IM PAGE

- IM WPT (RWY)
- IM SPD (230 KT)
- FAST/SLOW (-9 KT)
- IM-S Goal (116 sec)
- Target Aircraft (RPA1781)
- Target FAS (124 kt)
- SUSPEND

INTEGRATED - Navigational Display