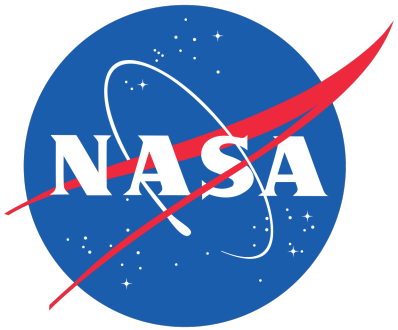
# Flight Deck Surface Trajectory-Based Operations (STBO): A Four-Dimensional Trajectory (4DT) Simulation




SJSU SAN JOSÉ STATE UNIVERSITY

**Deborah L. Bakowski, M.A.**
*San José State University*
*NASA Ames Research Center*

**Becky L. Hooey, Ph.D.**
*NASA Ames Research Center*

**David C. Foyle, Ph.D.**
*NASA Ames Research Center*

**Human-Centered Systems Lab**
**https://hsi.arc.nasa.gov/groups/HCSL**

# Flight Deck Simulation

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## Flight Deck (B737NG) Simulation:

- Pilot-in-the-Loop Simulation
- Far-Term Concept for Surface Operations
- Human-Centered Systems Lab (HCSL)
- Airport and Terminal Area Simulator (ATAS)

## Airport Surface Operations

- Concepts, research efforts, programs, and activities aimed at **improving operations on the airport surface**:
  - Coordinate surface movement to:
    - reduce congestion and excessive queues at departure runways
  - Improve the predictability of surface operations:
    - specifically, takeoff time
  - Reduce the environmental impacts of taxi operations:
    - reduce inefficient stop-and-go-taxi

## Surface Trajectory-Based Operations (STBO) Concept:

- Incorporates a time-component into taxi operations

# Surface Trajectory-Based Operations

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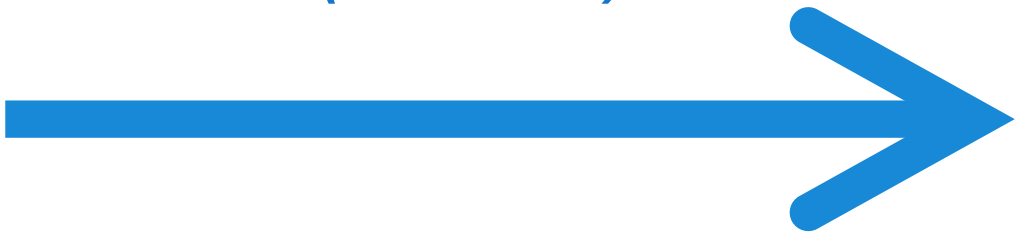
**Current-Day Surface Operations**

**Near-Term w/ Target Times**

**Far-Term with Flight Deck Component**

**Far-Term Full 4DT Operations**

*Increasing Use of **Time Information** in Surface Trajectory-Based Operations (STBO)*



# Surface Trajectory-Based Operations

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*Increasing Use of Time Information in STBO*

**Current-Day Surface Operations**

**Near-Term w/ Target Times**

**Far-Term with Flight Deck Component**

**Far-Term Full 4DT Operations**

**Flight Deck:**

1. Pushback Time

**ATC:**

1. Manage departure sequence

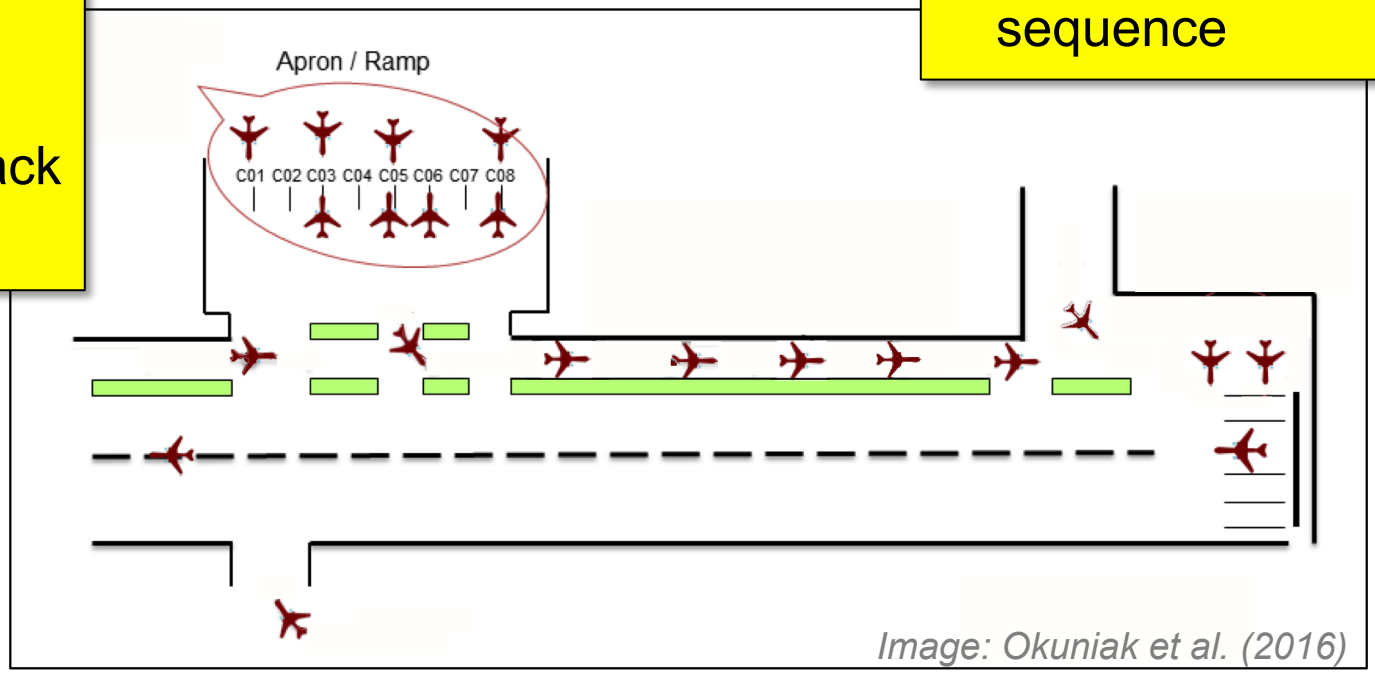


*Image: Okuniak et al. (2016)*

# Surface Trajectory-Based Operations

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*Increasing Use of Time Information in STBO*

**Current-Day Surface Operations**

**Near-Term w/ Target Times**

**Far-Term with Flight Deck Component**

**Far-Term Full 4DT Operations**

***Wheels-Up Time**

**Flight Deck:**

1. Pushback Time
2. Wheels-up Time

**No information about:**

- taxi duration
- queue size

**ATC:**

1. Manage to ensure flight meets its assigned wheels-up time

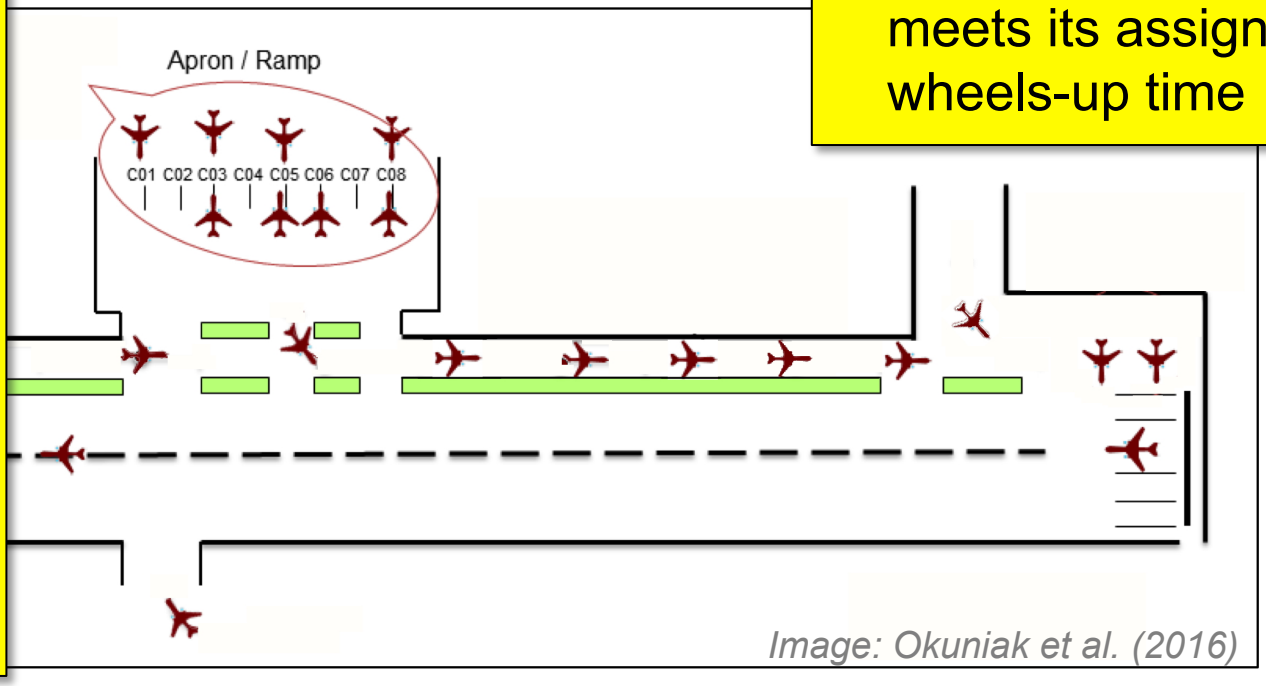


*Image: Okuniak et al. (2016)*

# Surface Trajectory-Based Operations

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*Increasing Use of Time Information in STBO*

**Current-Day Surface Operations**

**Near-Term w/ Target Times**

**Far-Term with Flight Deck Component**

**Far-Term Full 4DT Operations**

Controllers provide clearances to meet target times

**ATC/Ramp manages with Scheduling/ Decision Support Tools (DSTs):**

- Pushback Time (TOBT)
- Airport Movement Area Time (TMAT)
- Target Take-Off Time (TTOT)

**Flight Deck:**

1. Pushback Time

**No information about:**

- taxi schedule

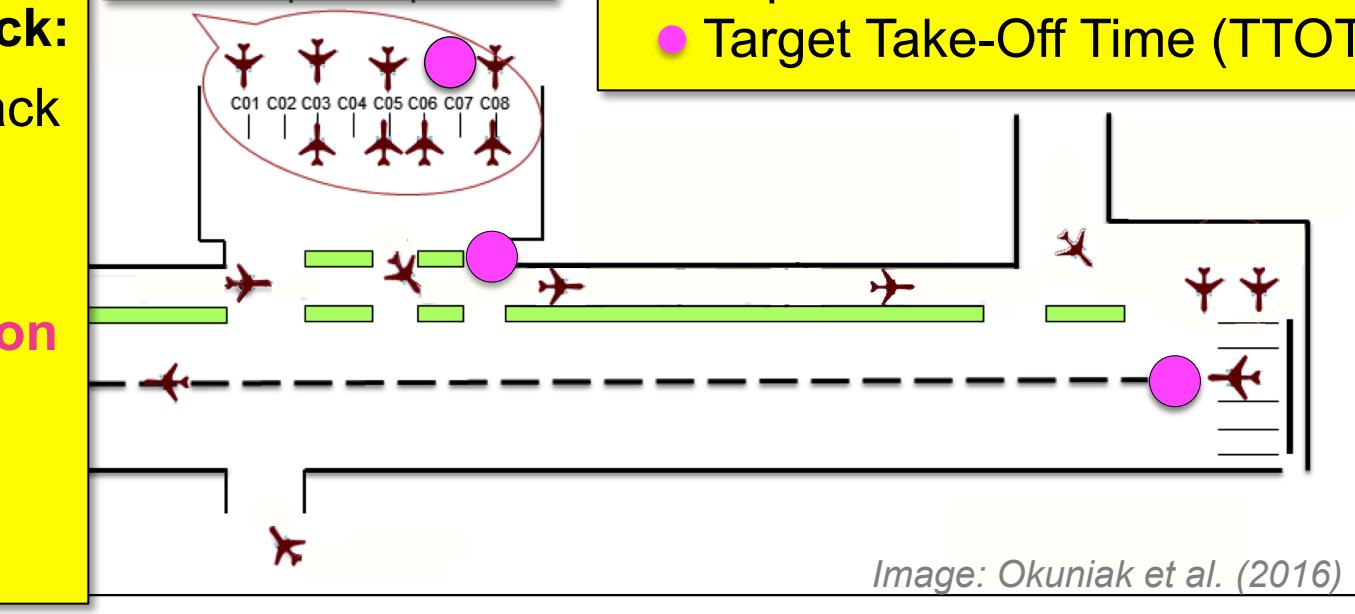


*Image: Okuniak et al. (2016)*

Example:

ATD2 IADS system to be deployed Charlotte Fall 2017.

# Surface Trajectory-Based Operations

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*Increasing Use of Time Information in STBO*

**Current-Day Surface Operations**

**Near-Term w/ Target Times**

**Far-Term with Flight Deck Component**

**Far-Term Full 4DT Operations**

**Flight Deck: Avionics Display/ Algorithm** to support schedule conformance.

- Pushback
- AMA Time
- Takeoff Time
- Merge Points
- Active RWY
- RWY Queue

**Flight Deck / ATC Coordination**

Times included in Taxi Clr

**ATC/Ramp: Scheduling / Decision Support Tools (DSTs):**

- Pushback Time (TOBT)
- AMA Time (TMAT)
- Target Take-Off (TTOT)
- Merge, Queue, Active RWY

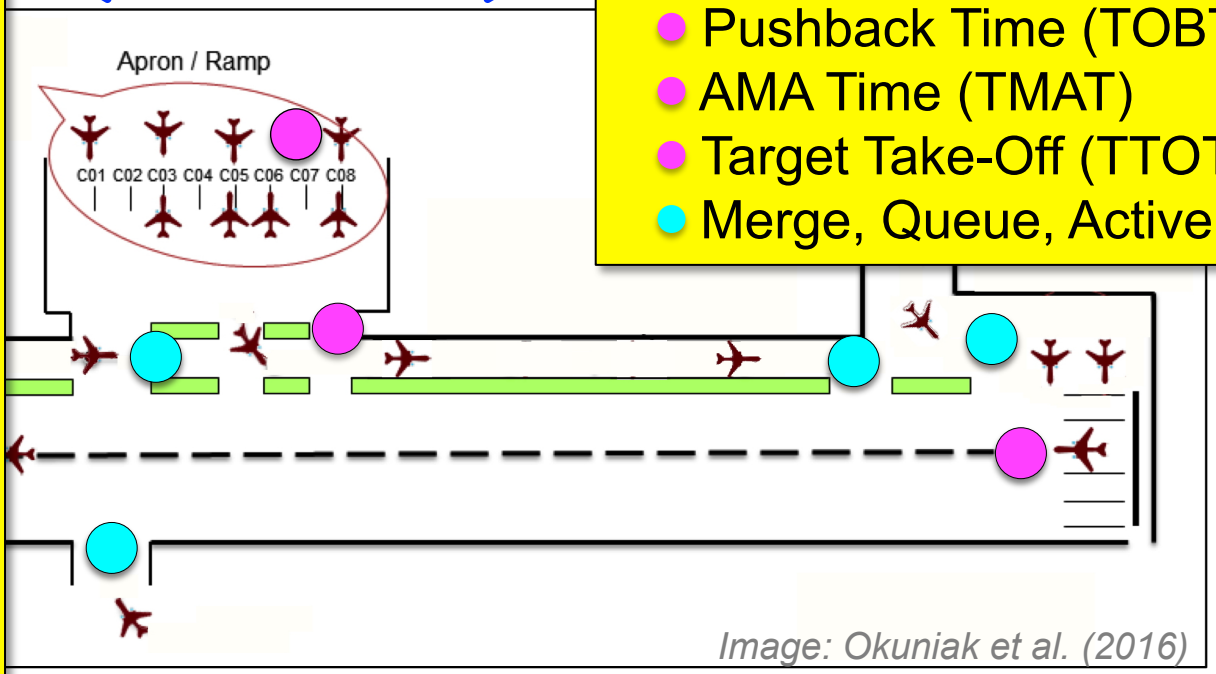


*Image: Okuniak et al. (2016)*

# Surface Trajectory-Based Operations

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*Increasing Use of Time Information in STBO*

**Current-Day Surface Operations**

**Near-Term w/ Target Times**

**Far-Term with Flight Deck Component**

**Far-Term Full 4DT Operations**

**Flight Deck / ATC Coordination**

Times included in Taxi Clr

**Flight Deck: Avionics Display/ Algorithm** to support 4DT schedule conformance.

- Expected 4DT Location

**4DT Operations: ∞ # of time points**

**ATC:**

Surface Management System generates conflict-free 4DT taxi clearances.

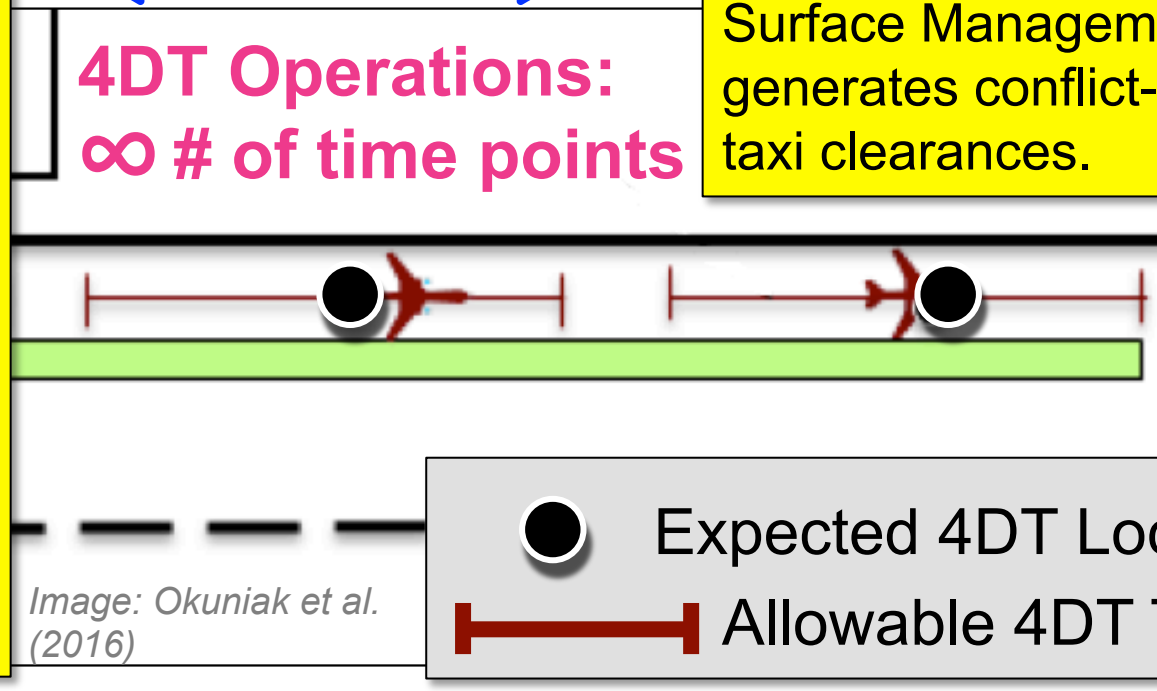

*Image: Okuniak et al. (2016)*

- Expected 4DT Location
- Allowable 4DT Tolerance

# Surface Trajectory-Based Operations

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*Increasing Use of Time Information in STBO*

**Current-Day Surface Operations**

**Near-Term w/ Target Times**

**Far-Term wit Flight Deck Component**

**Far-Term Full 4DT Operations**

**Flight Deck / ATC Coordination**

es included in Taxi Clr

**ight Deck: Avionics Display/ Algorithm**

support

conformance.

Expected 4DT Location

4D Operations: ∞ of time points

**ATC:**

Surface Management System generates conflict-free 4DT taxi clearances.

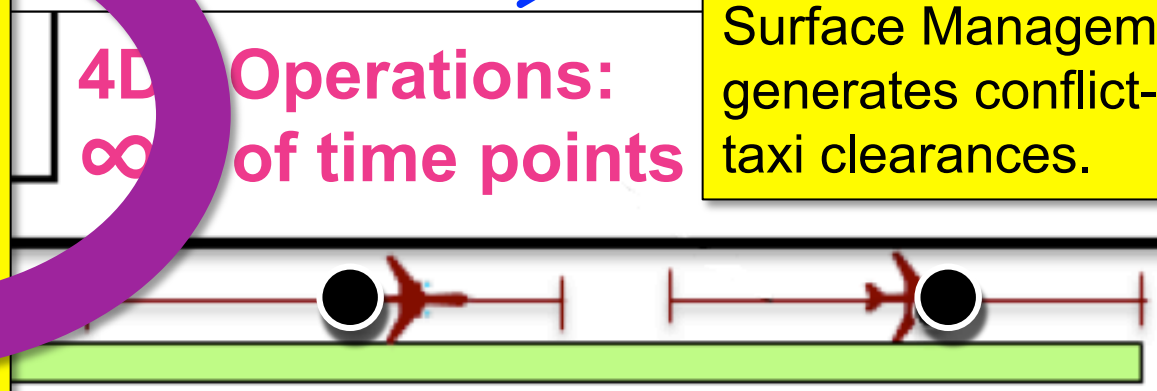

*Image: Okuniak et al. (2016)*

Expected 4DT Location

Allowable 4DT Tolerance

# 4DT Surface Trajectory-Based Ops

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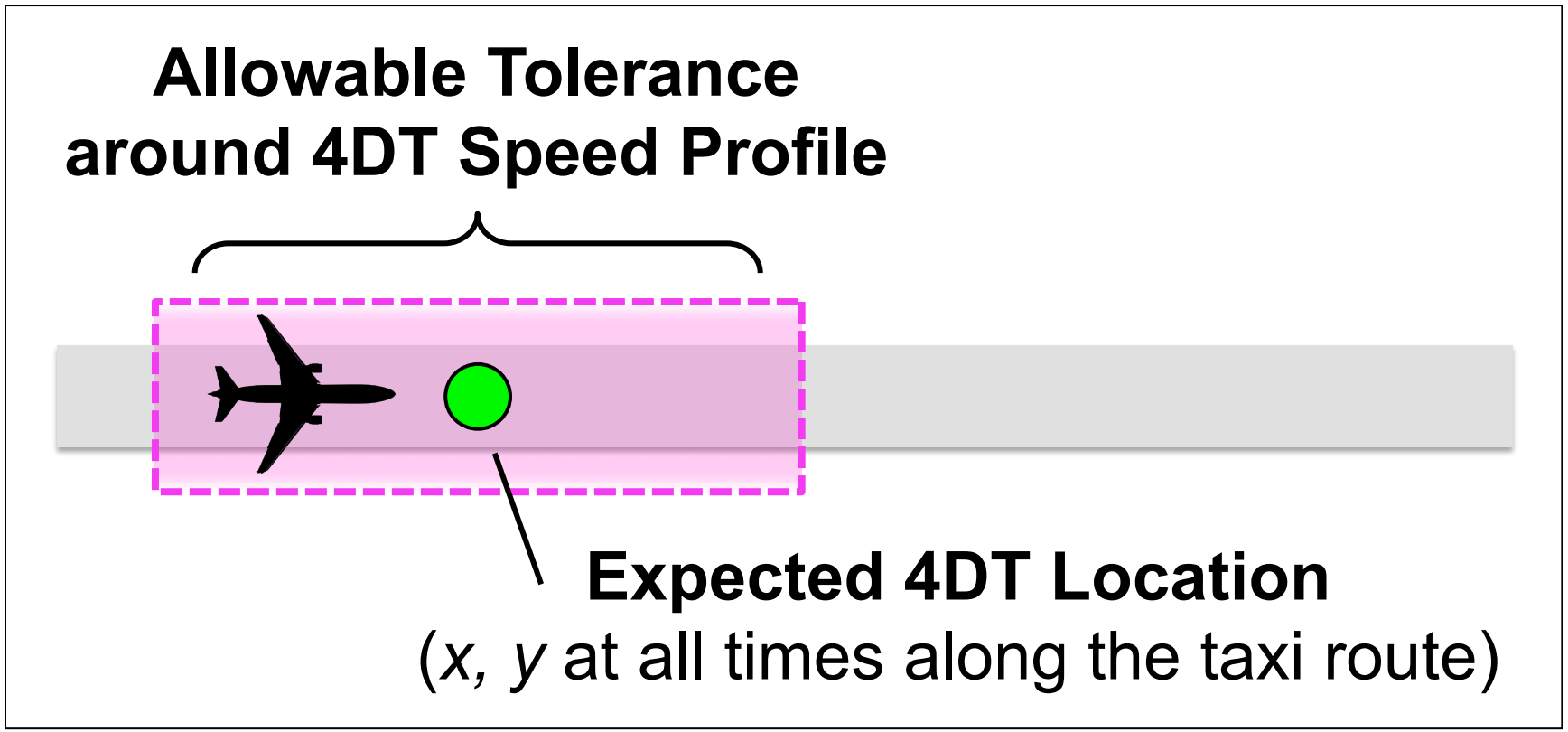
## Four-Dimensional Trajectory (4DT) Concept:

- Expected Location (*x, y)* based on 4DT Speed Profile
- At all times, *t,* along the taxi route
- Altitude is fixed on the surface

*Hooey, Cheng, & Foyle (2014)*
*Okuniak, Gerdes, Jakobi, Ludwig, Hooey, Foyle, Jung, & Zhu (2016)*



# 4DT Surface Trajectory-Based Ops

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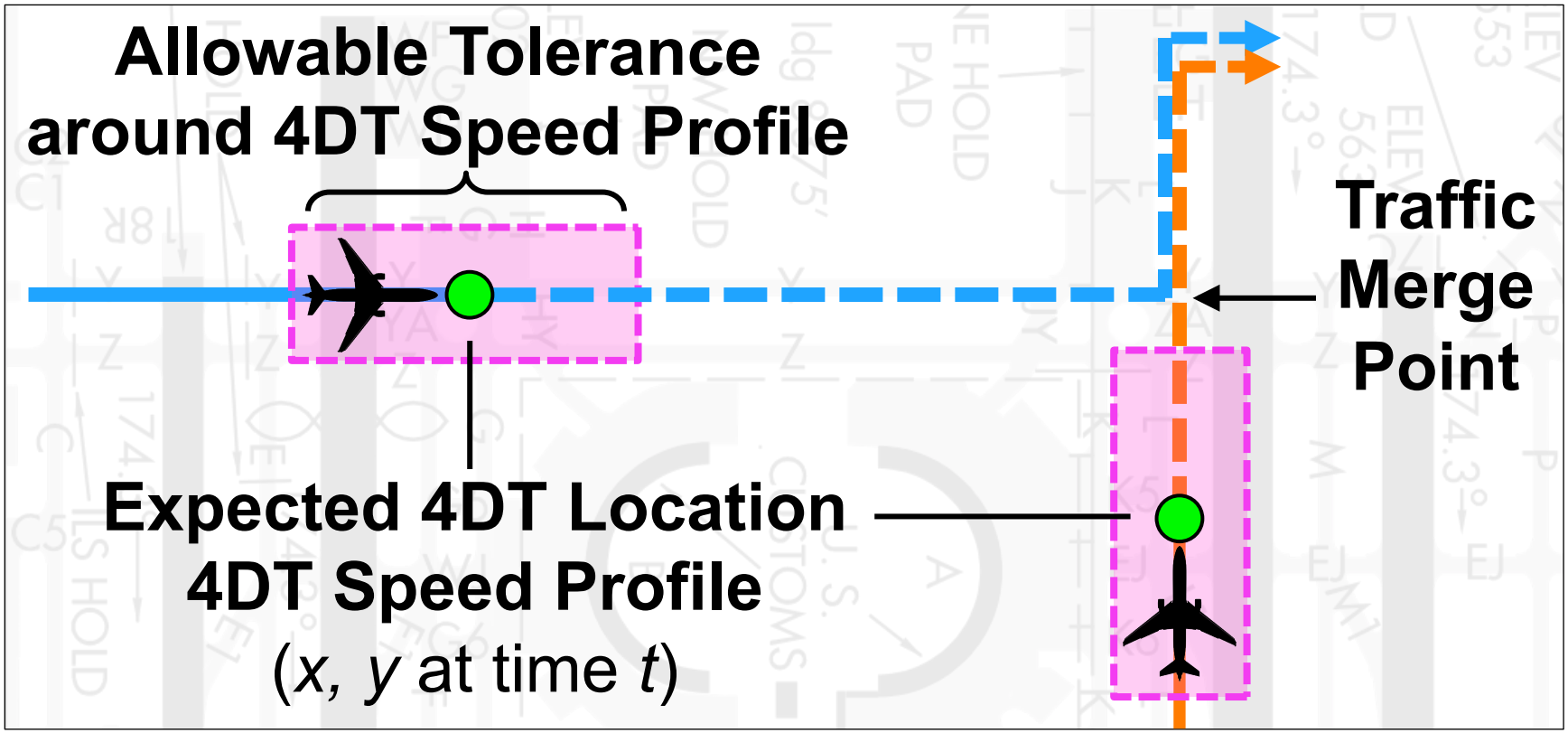
## Four-Dimensional Trajectory (4DT) Concept:

- Enables coordination of all surface traffic
- Ensures conflict-free taxi routes
- Goals: Improve efficiency, predictability; reduce fuel burn



# 4DT Surface Trajectory-Based Ops

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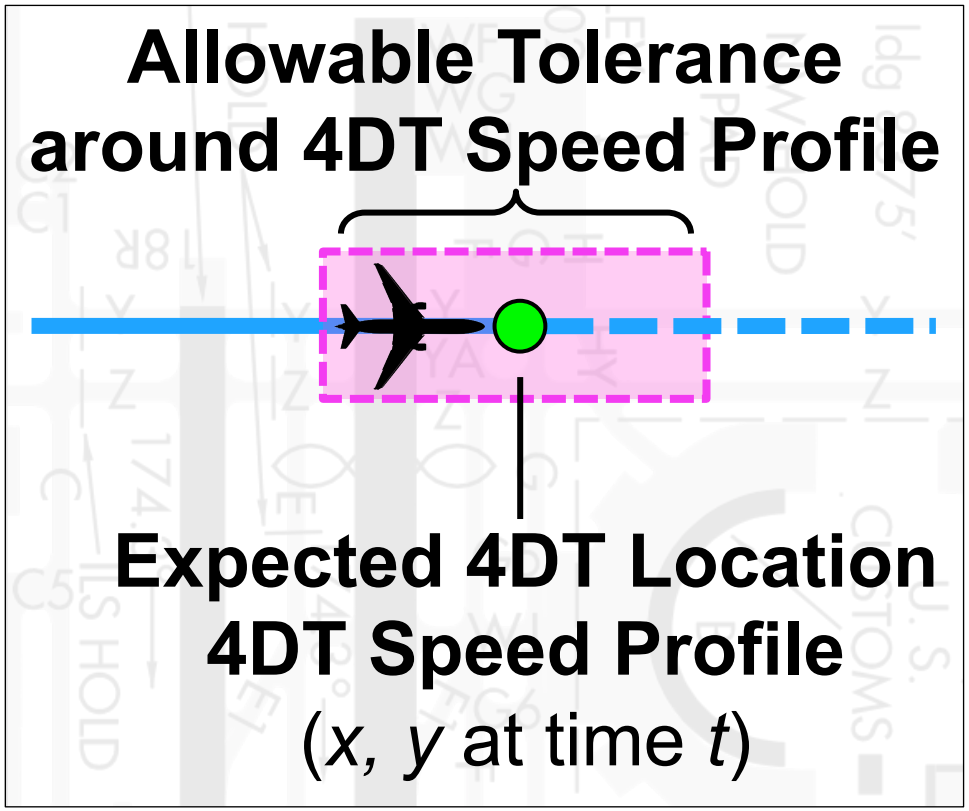
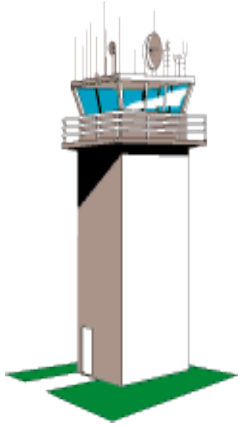
## Four-Dimensional Trajectory (4DT) Concept:

- Assumes the use of an ATC surface management system
- Schedules surface traffic, generates a 4DT clearance for each aircraft, monitors conformance, resolves conflicts




**Surface Management System**



- **German Aerospace Center (DLR)**
  - Research prototype system, *TRACC*

*Gerdes & Temme (2012)*

# 4DT Surface Trajectory-Based Ops

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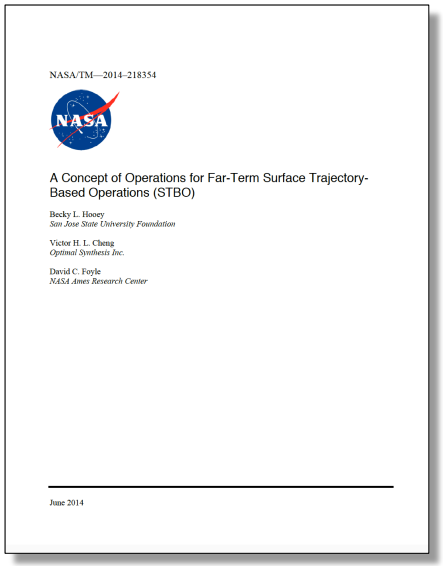
## 4DT Concepts of Operations (ConOps)



NASA/TM—2014–218354

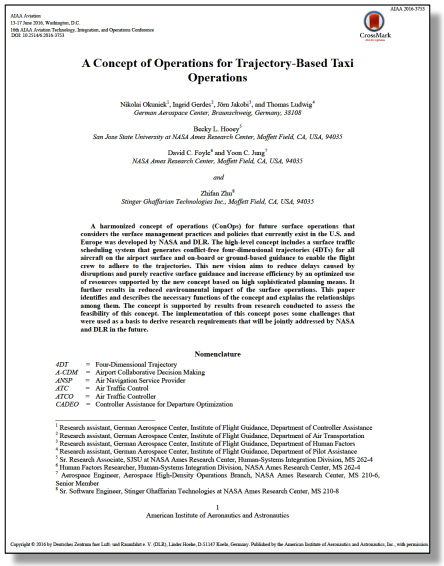
A Concept of Operations for Far-Term Surface Trajectory-Based Operations (STBO)

Becky L. Hooey
*San Jose State University Foundation*

Victor H. L. Cheng
*Optimal Synthesis Inc.*

David C. Foyle
*NASA Ames Research Center*

June 2014



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AIAA 2016-3753

A Concept of Operations for Trajectory-Based Taxi Operations

Nikolai Okuniak[1], Ingrid Gerdes[2], Jörn Jakobi[3], and Thomas Ludwig[4]
*German Aerospace Center, Braunschweig, Germany, 38108*

Becky L. Hooey[5]
*San Jose State University at NASA Ames Research Center, Moffett Field, CA, USA, 94035*

David C. Foyle[6] and Yoon C. Jung[7]
*NASA Ames Research Center, Moffett Field, CA, USA, 94035*

*and*

Zhifan Zhu[8]
*Stinger Ghaffarian Technologies Inc., Moffett Field, CA, USA, 94035*

**A harmonized concept of operations (ConOps) for future surface operations that considers the surface management practices and policies that currently exist in the U.S. and Europe was developed by NASA and DLR. The high-level concept includes a surface traffic scheduling system that generates conflict-free four-dimensional trajectories (4DTs) for all aircraft on the airport surface and on-board or ground-based guidance to enable the flight crew to adhere to the trajectories. This new vision aims to reduce delays caused by disruptions and purely reactive surface guidance and increase efficiency by an optimized use of resources supported by the new concept based on high sophisticated planning means. It further results in reduced environmental impact of the surface operations. This paper identifies and describes the necessary functions of the concept and explains the relationships among them. The concept is supported by results from research conducted to assess the feasibility of this concept. The implementation of this concept poses some challenges that were used as a basis to derive research requirements that will be jointly addressed by NASA and DLR in the future.**

**Nomenclature**

| | | |
|---|---|---|
| *4DT* | = | Four-Dimensional Trajectory |
| *A-CDM* | = | Airport Collaborative Decision Making |
| *ANSP* | = | Air Navigation Service Provider |
| *ATC* | = | Air Traffic Control |
| *ATCO* | = | Air Traffic Controller |
| *CADEO* | = | Controller Assistance for Departure Optimization |

[1] Research assistant, German Aerospace Center, Institute of Flight Guidance, Department of Controller Assistance
[2] Research assistant, German Aerospace Center, Institute of Flight Guidance, Department of Air Transportation
[3] Research assistant, German Aerospace Center, Institute of Flight Guidance, Department of Human Factors
[4] Research assistant, German Aerospace Center, Institute of Flight Guidance, Department of Pilot Assistance
[5] Sr. Research Associate, SJSU at NASA Ames Research Center, Human-Systems Integration Division, MS 262-4
[6] Human Factors Researcher, Human-Systems Integration Division, NASA Ames Research Center, MS 262-4
[7] Aerospace Engineer, Aerospace High-Density Operations Branch, NASA Ames Research Center, MS 210-6, Senior Member
[8] Sr. Software Engineer, Stinger Ghaffarian Technologies at NASA Ames Research Center, MS 210-8





**Far-Term Surface Trajectory-Based Operations (STBO) ConOps**

*Hooey, Cheng, & Foyle (2014)*

**Harmonized U.S. / European Trajectory-Based Taxi Operations ConOps**

*Okuniak, Gerdes, Jakobi, Ludwig, Hooey, Foyle, Jung, & Zhu (2016) (DLR and NASA)*

# Previous Flight Deck 4DT Study

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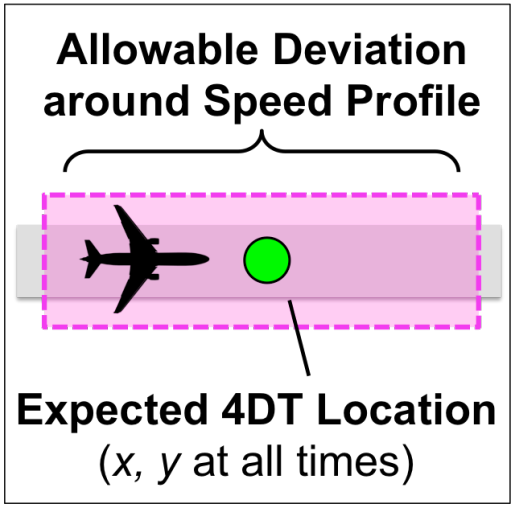
## Supporting 4DT STBO on the Flight Deck:

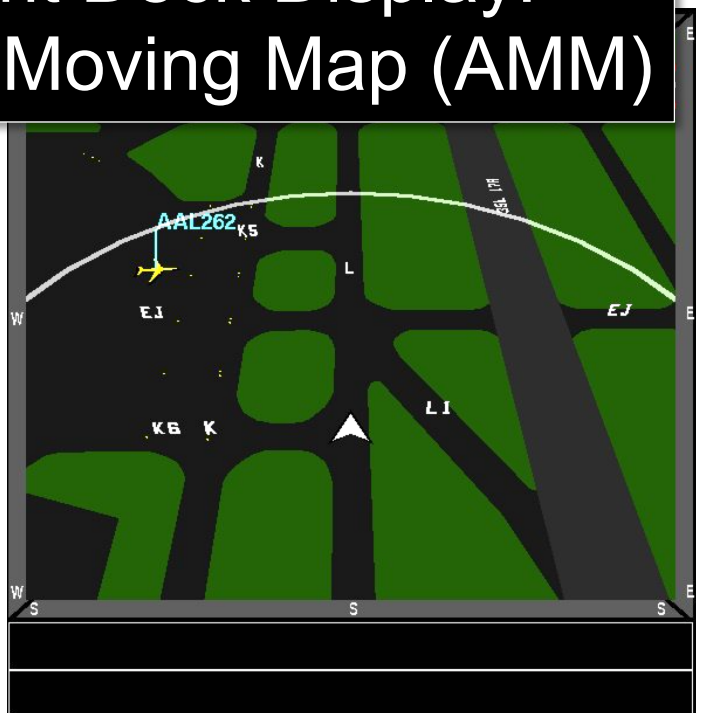
- Previous pilot-in-the-loop 4DT Flight Deck simulation
- Airport Moving Map (AMM) augmented with 4DT taxi clearance information.

*Bakowski, Hooey, Foyle, & Wolter (2015)*

### 4DT Speed Profile and Taxi Routing Information




### Flight Deck Display: Airport Moving Map (AMM)



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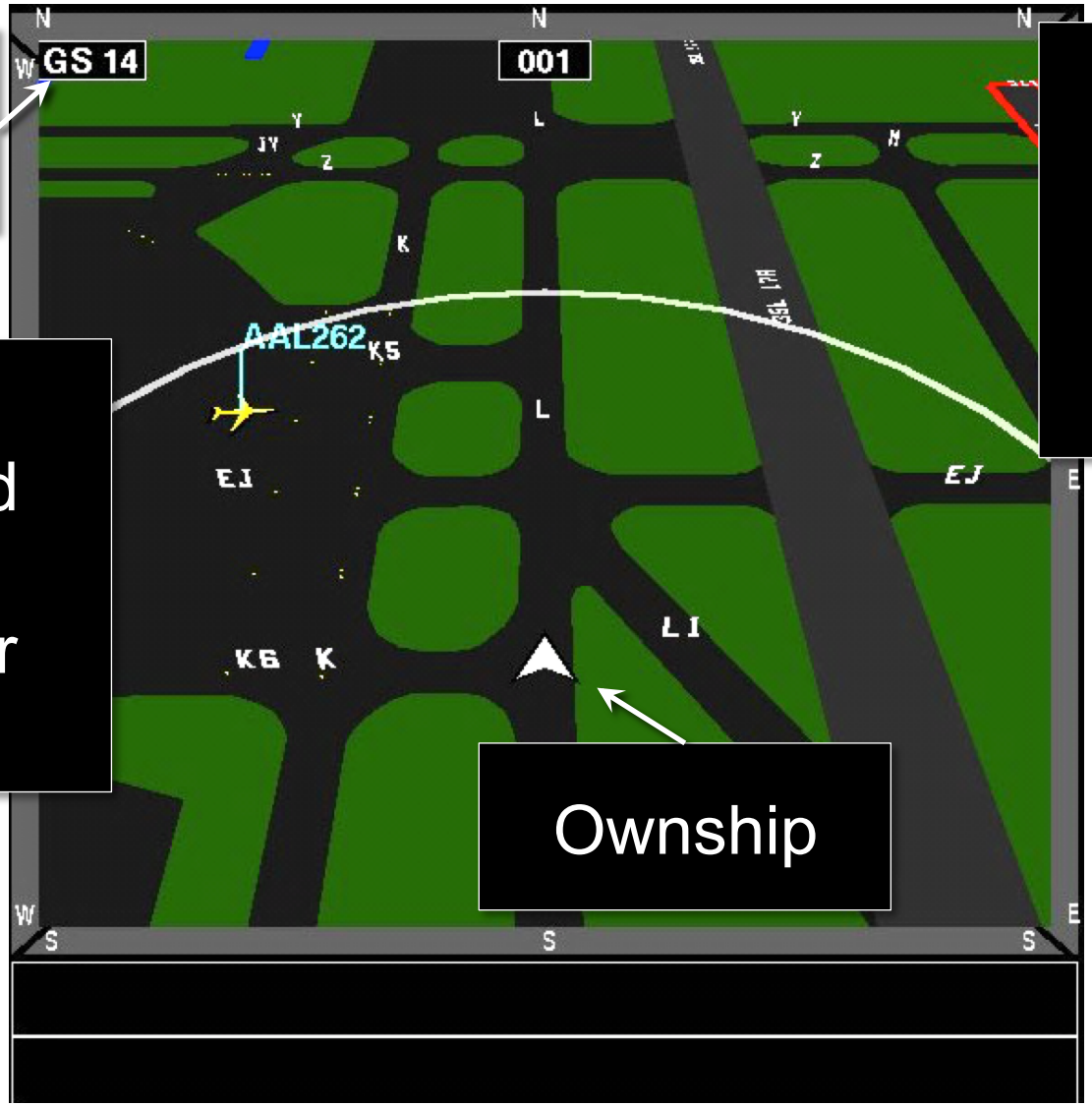
# Flight Deck Display: Airport Moving Map (AMM)

Ownship Speed

Traffic displayed within de-clutter circle




Airport Layout to aid with Navigation

# Airport Moving Map (AMM)

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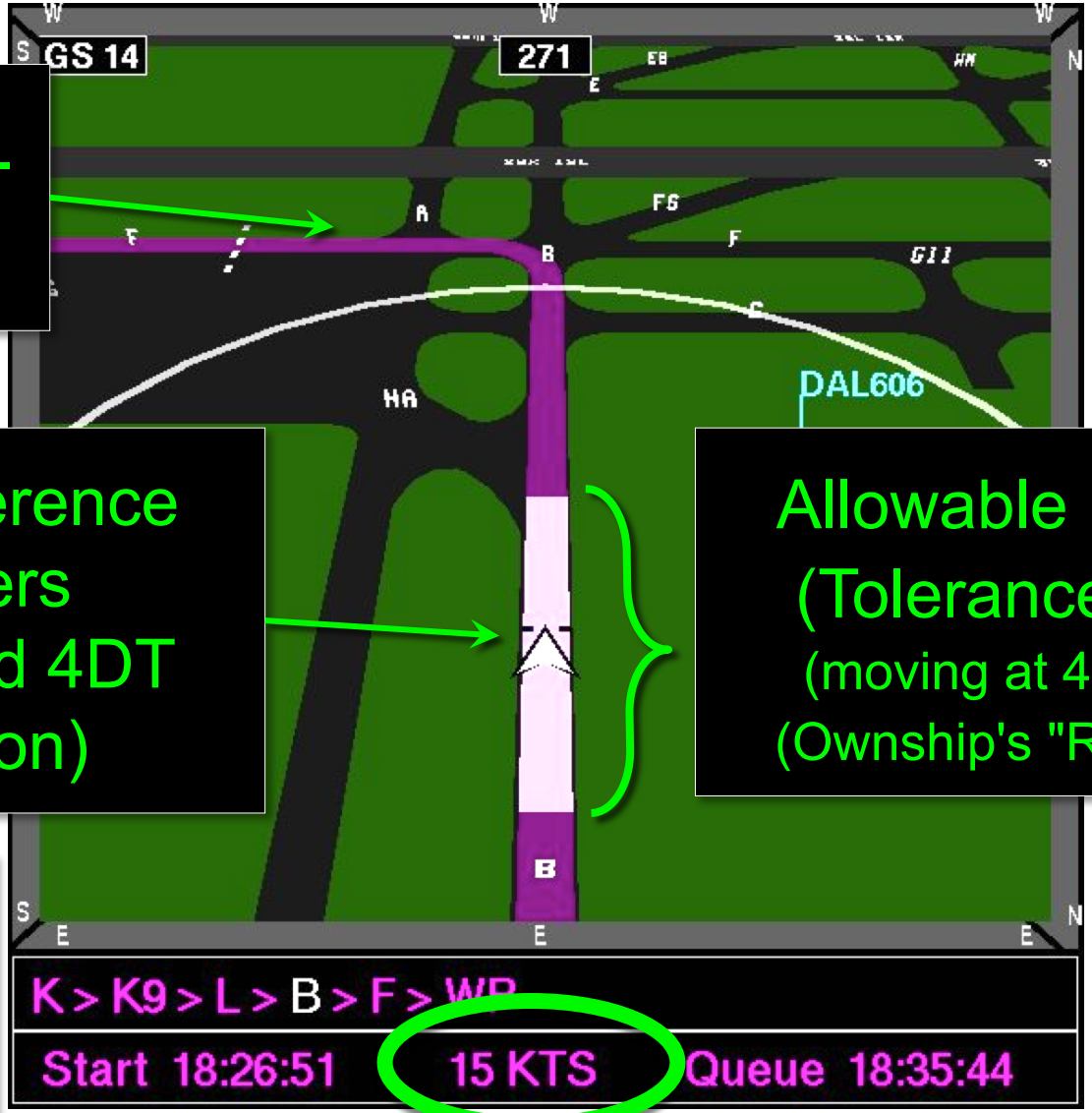
## 4DT Information on Airport Moving Map (AMM)




Cleared-to-Taxi Route

4DT Reference Markers (Expected 4DT Location)

Allowable Deviation (Tolerance Bound) (moving at 4DT Speed) (Ownship's "Real Estate")

4DT Clearance Speed

4DT Clearance Text

# Previous Flight Deck 4DT Study

## Previous Pilot-in-the-Loop 4DT Simulation:

– Along-Route Conformance: % Time in Allowable Tolerance

*Bakowski, Hooey, Foyle, & Wolter (2015)*

### Speed-Advisory (No 4DT on AMM)


Verbal Clearance: "Taxi at 14 kts"

### 4DT +/- 30 sec


4DT Info on AMM

### 4DT +/- 15 sec


4DT Info on AMM

# Previous Flight Deck 4DT Study

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## Previous Pilot-in-the-Loop 4DT Simulation:

– Along-Route Conformance: % Time in Allowable Tolerance

*Bakowski, Hooey, Foyle, & Wolter (2015)*

### Speed-Advisory (No 4DT on AMM)


**Along-Route Conformance**

**+/-15 sec 20%**

**+/-30 sec 72%**

### 4DT +/- 30 sec


**Along-Route Conformance**

**99%**

### 4DT +/- 15 sec


**Along-Route Conformance**

**99%**

# Present Flight Deck 4DT Study

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| Previous Simulation | Present Simulation |
| --- | --- |
| One 4DT Display Format | ⇨ 4DT Format Comparison |
| 4DT Straightaway Speed held constant in each trial | ⇨ 4DT Speed Changes Mid-Taxi |
| 4DT Speeds: 14, 15, or 16 kts | ⇨ Range of Realistic Taxi Speeds: 8 kts – 25 kts |
| 4DT Route Start: Spot | ⇨ 4DT Route Start: at Gate |
| Time-based Tolerance | ⇨ Distance-based Tolerance |
| Dallas/Fort-Worth Airport | ⇨ Charlotte Douglas Airport |
| *Bakowski, Hooey, Foyle, & Wolter (2015)* | *Bakowski, Hooey, & Foyle (2017)* |

# Airport and Terminal Area Simulator

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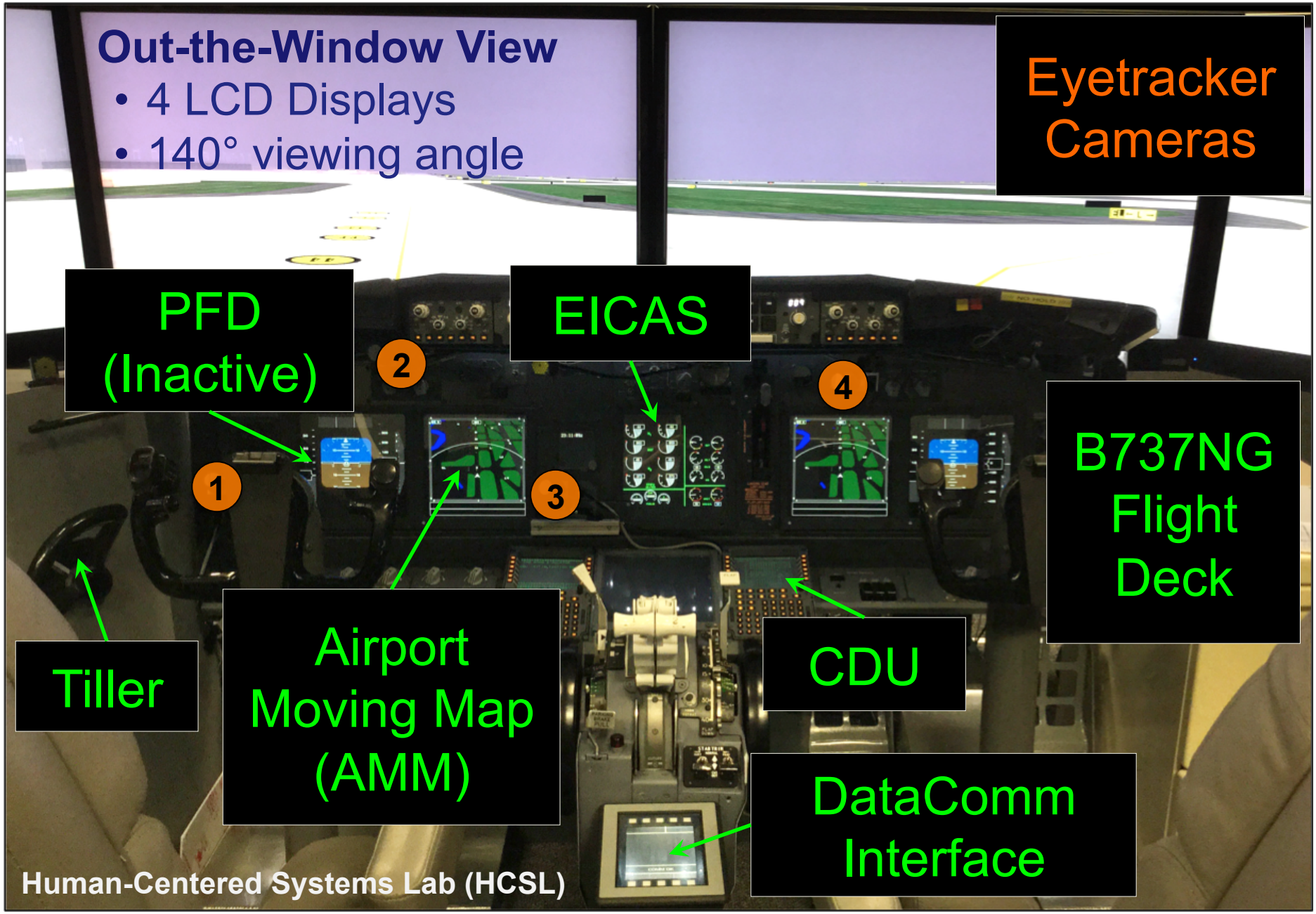
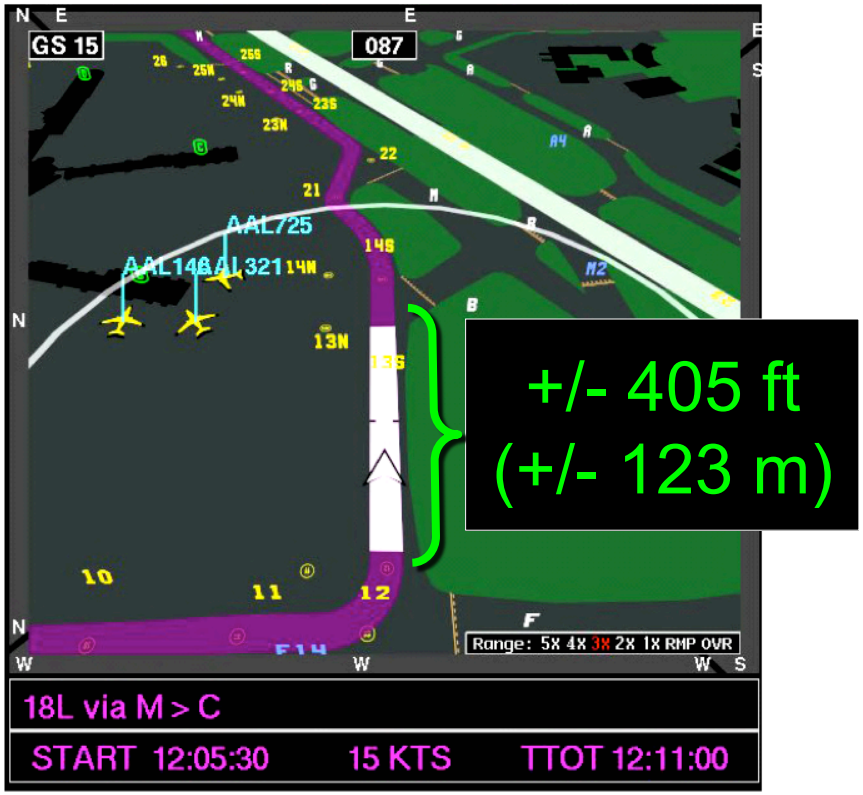


# 4DT Display Formats

## *Defined*-Conformance Display Format

– Distance-based Tolerance Bands (length constant)


Proposed distance threshold in DLR's TRACC system for conformance monitoring.




Approximates the length of smaller band from the previous study.

# 4DT Display Formats

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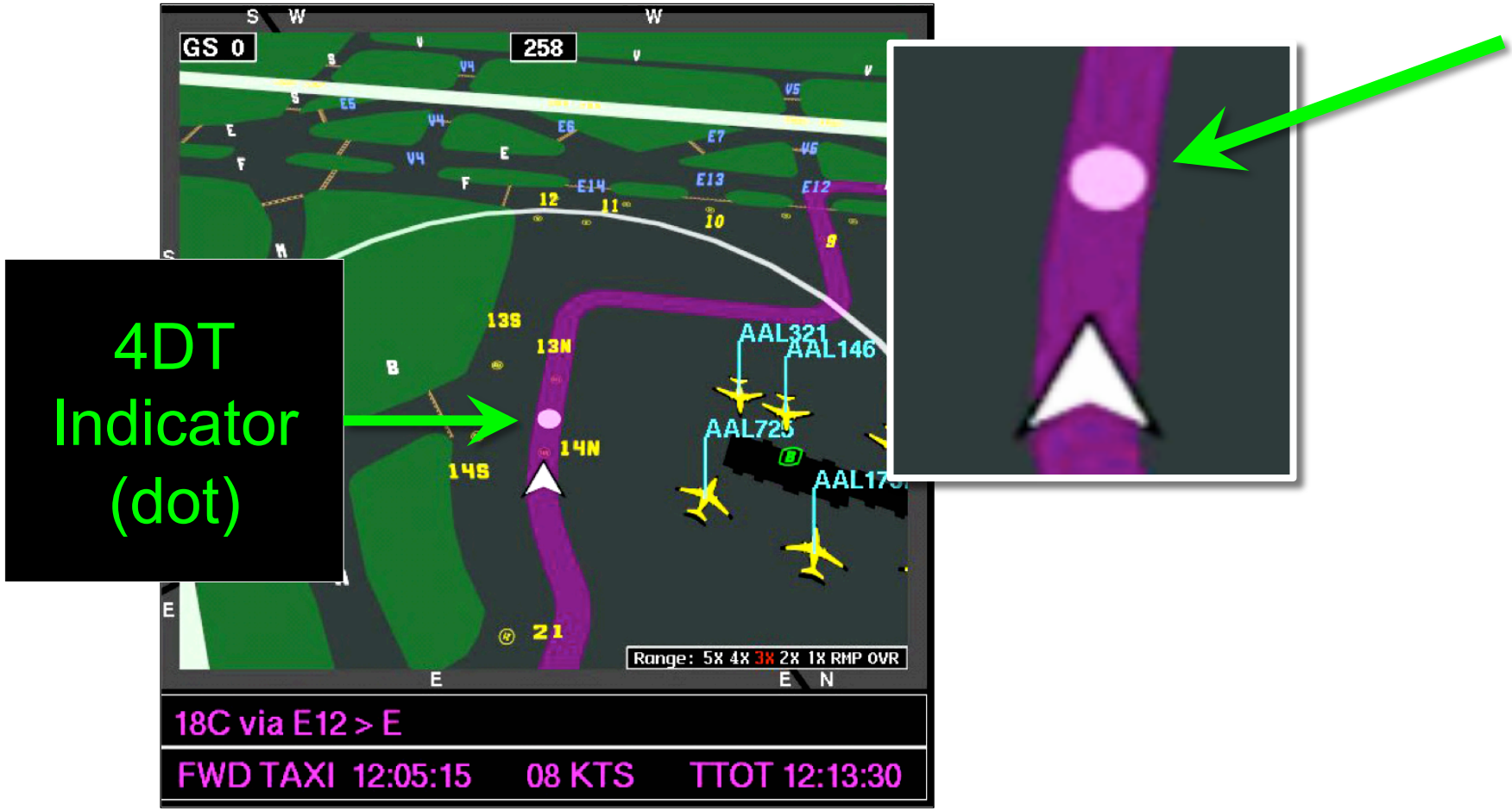
## *Undefined*-Conformance Display Format

- 4DT Indicator: Expected 4DT location (*x, y* at all times, *t*)
- No Allowable Tolerance displayed; Undefined 4DT deviation



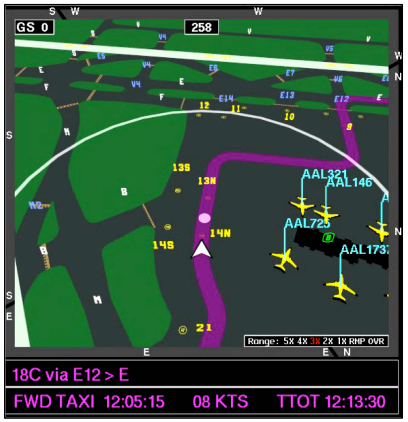
# 4DT Display Formats

## Instructions to Pilots

### *Defined*-Conformance Format


- "You are in compliance with the 4DT clearance when the ownship icon is within the tolerance band."
- "No need to track the 4DT reference markers precisely."

### *Undefined*-Conformance Format




- "You decide how "close is close enough" to taxi to the dot and you can taxi ahead of, or behind, the 4DT dot."
- **Pilots defined conformance as they saw fit.**

# 4DT Taxi Route

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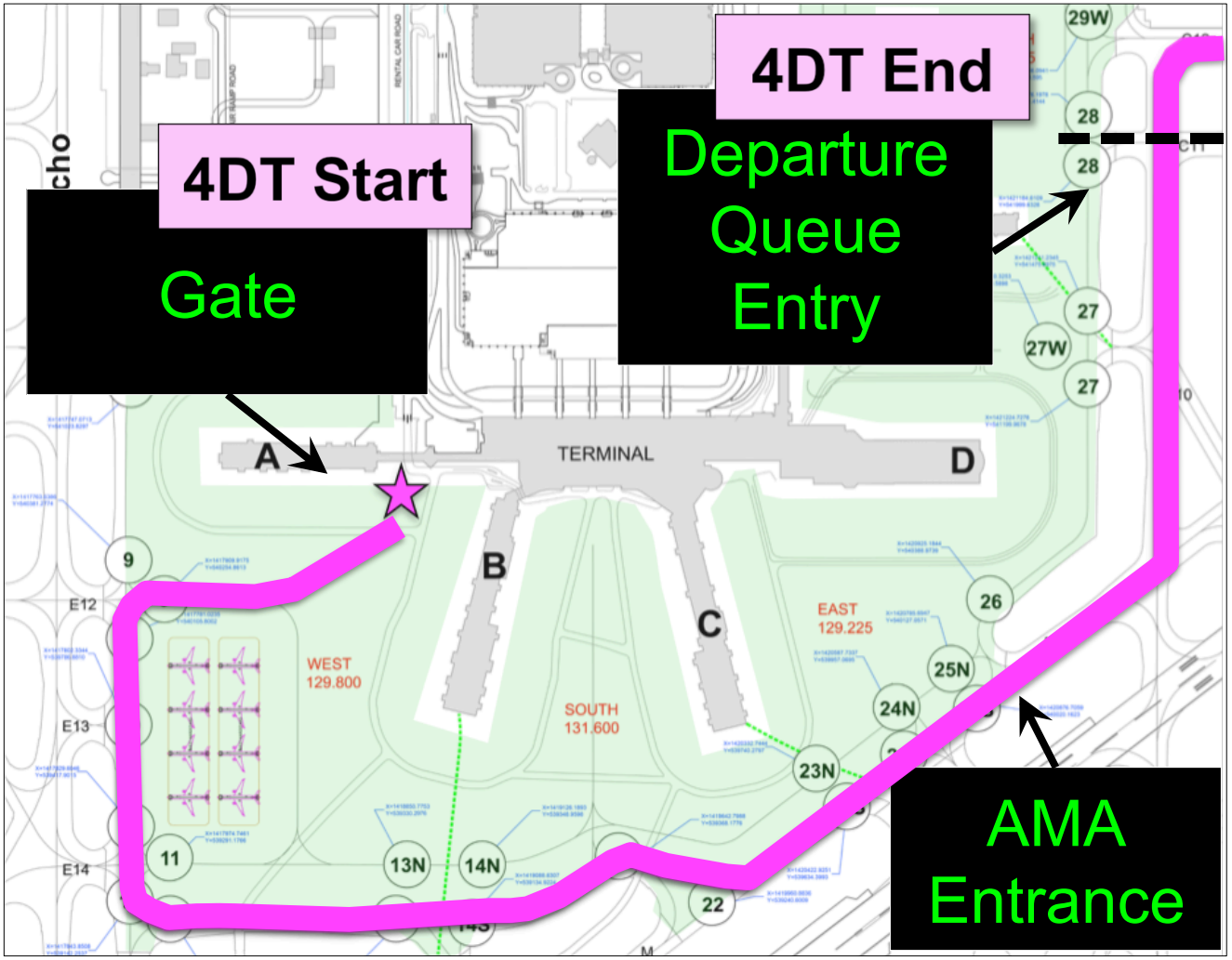
## 4DT Taxi Clearance

– One continuous clearance from Gate to RWY Queue




Average Taxi Distance: 6,633 ft

Average Trial Duration: 12 min

# 4DT Speed Changes During Taxi

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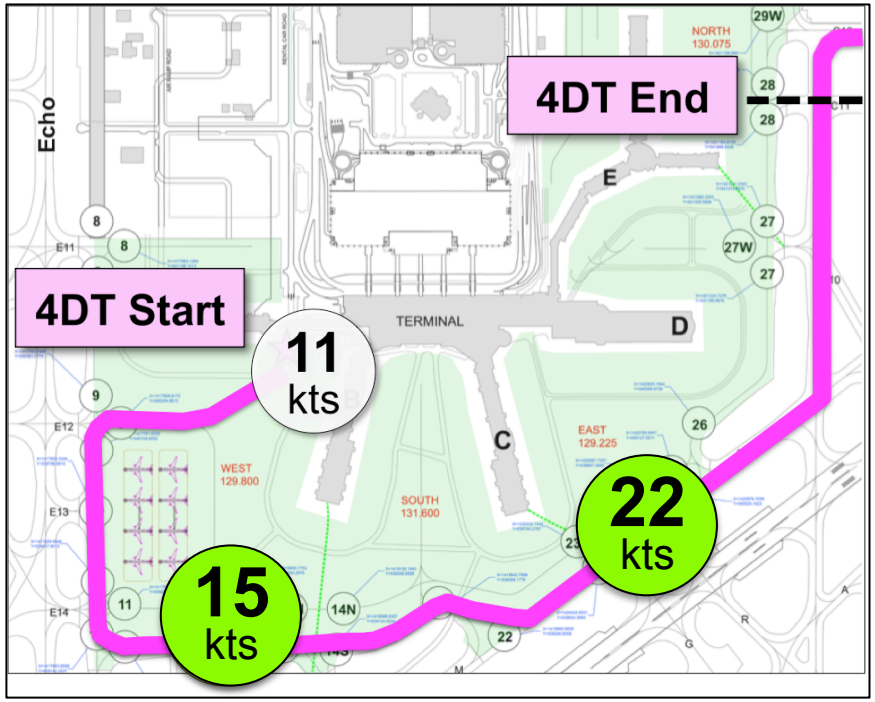
## 4DT Speed Changes

- Each trial included 2 or 5 4DT Speed Changes during taxi
- Flight deck alerted to speed change by auditory tone

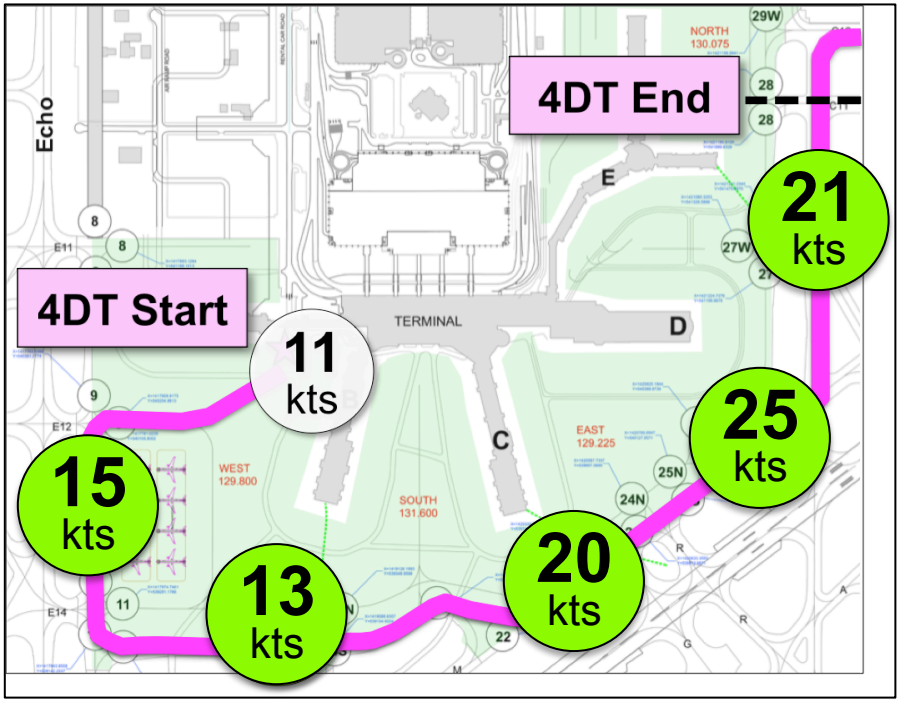
## 2 Speed Changes

(Segment distance: 1,645 ft – 2,834 ft)




## 5 Speed Changes

(Segment distance: 887 ft – 1,630 ft)



# 4DT Taxi Speeds

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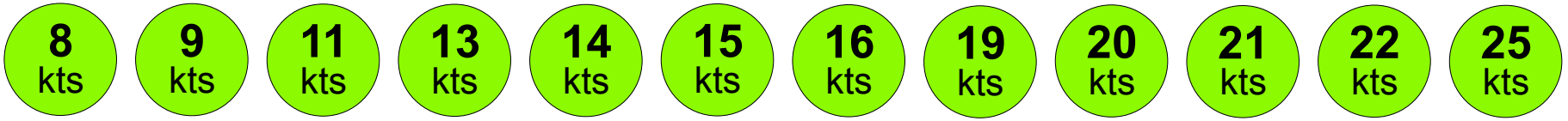
## Range of Realistic Taxi Speeds, 8 kts – 25 kts

- Assigned speeds to taxi segments in such a way as to create 'Slow' and 'Fast' average speed trials.
- Slower speeds used in the Ramp Area than in AMA because of proximity to terminal, other aircraft, and turns.




| | Ramp | Airport Movement Area (AMA) |
|---|---|---|
| **'Slow' Avg. Speed** | 10 kts | 16 kts |
| **'Fast' Avg. Speed** | 13 kts | 22 kts |

# Flight Deck Crew

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## Pilot Participants

- Assumed the role of Captain in the simulation
- 12 Commercial/Cargo Pilots participated in the simulation:
  - 11 were Captains, one was a First Officer
  - 11 were Current, one was recently retired
  - Average age: 56 years
  - All 12 pilots had taxi experience

## A member of the research team assumed the role of the First Officer in the simulation to create 2-person crews:

- First Officer provided navigation and traffic awareness support in a consistent manner to each pilot
- Acknowledged 4DT speed changes, "Speed Change"

# Experimental Taxi Scenario

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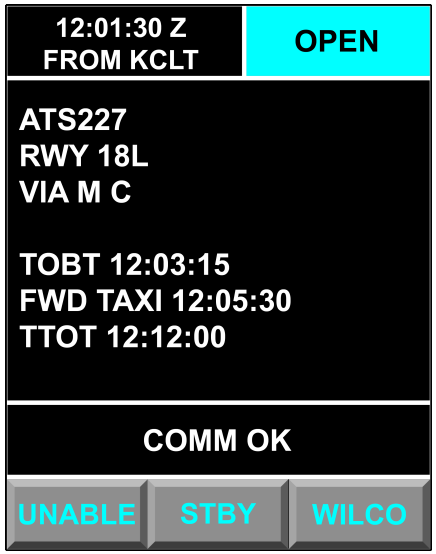
## 4DT Taxi Clearance

- 4DT Taxi Clearance sent to the Flight Deck via DataComm
- 4DT information propagates into Flight Deck Avionics

**4DT Taxi Clr. DataComm**

- Taxi Route/RWY
- 4DT Schedule Info





**Cleared-to-Taxi Route**

**Cleared-to-Taxi Route**

**4DT Clearance Information**

# 4DT Clearance Info on the Flight Deck

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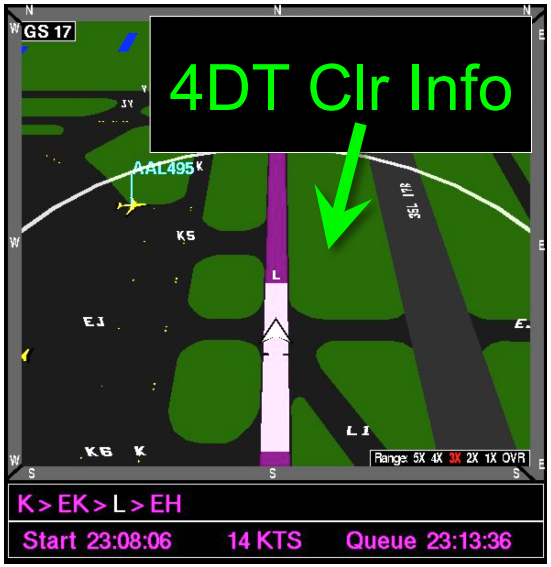
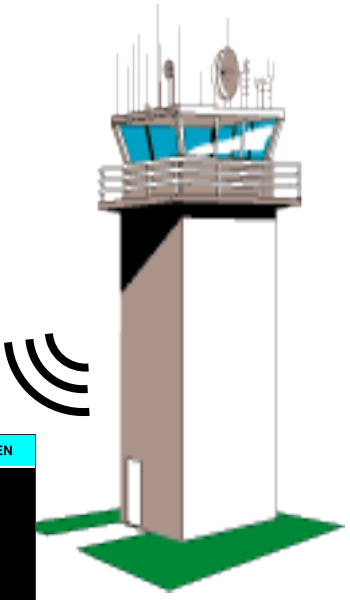
## DataComm Enables Flight Deck / ATC Coordination in 4DT Operations

**Flight Deck Avionics:**
Airport Moving Map




**ATC Surface Management System:**
Generates conflict-free 4DT taxi clearances




**4DT Clearance to Flight Deck via DataComm**


**4DT Clearance Loaded into Flight Deck Avionics**

# Airport Environment

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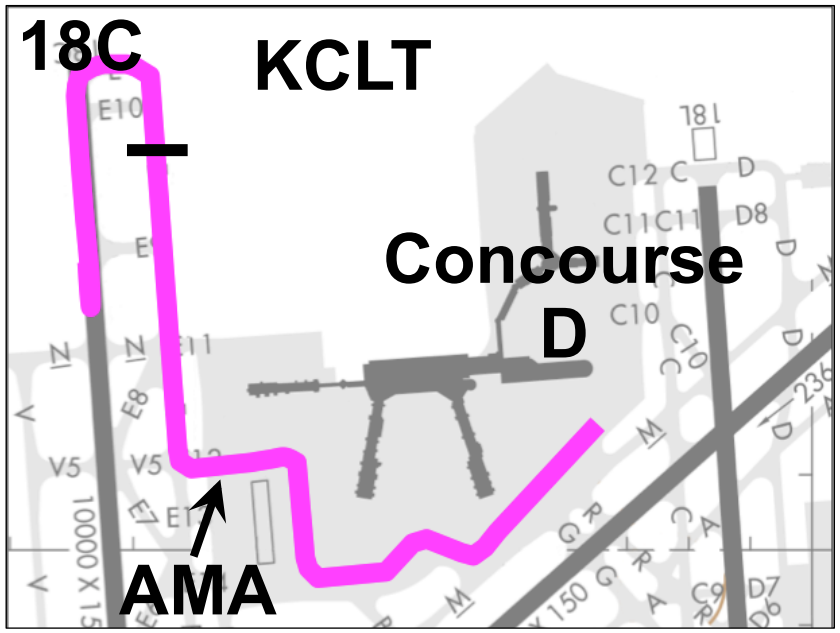
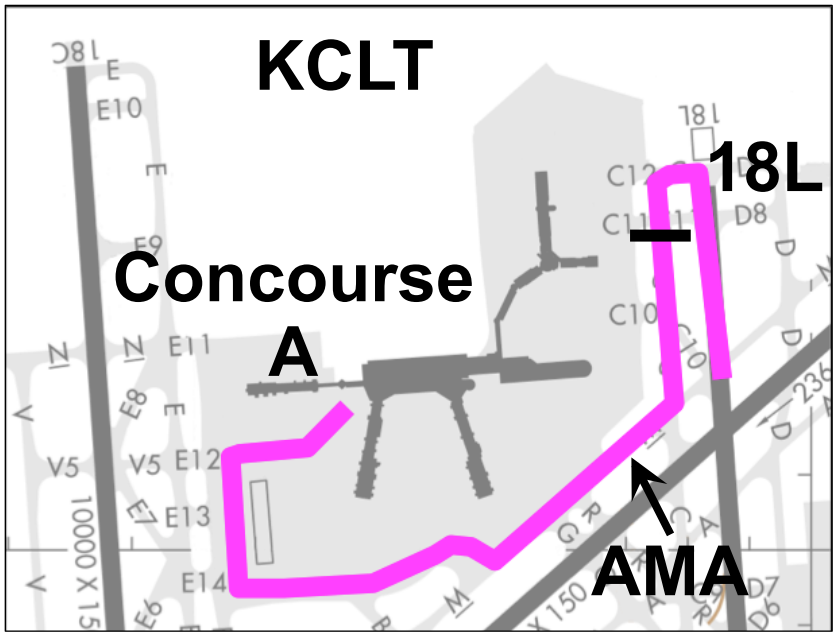
## Charlotte Douglas Airport (KCLT)

- Departure taxi-out trials
- Two taxi routes
- 4DT Route extends from Gate to RWY queue
- Traffic in the Ramp Area and at the RWY (did not conflict)

### Concourse D to RWY 18C




### Concourse A to RWY 18L

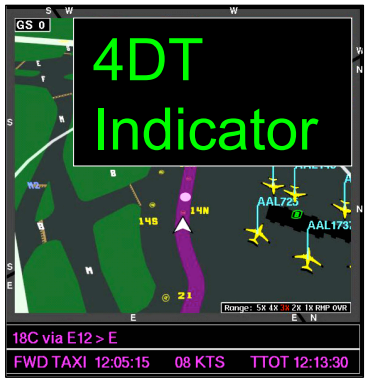


# Taxi Simulation Trials

## 12 Experimental Trials

- Created by repeating the four Speed Change/Speed trials:
  - **2** Speed Changes / '**Slow**' Average Speed
  - **2** Speed Changes / '**Fast**' Average Speed
  - **5** Speed Changes / '**Slow**' Average Speed
  - **5** Speed Changes / '**Fast**' Average Speed
- In each of the three Display Format conditions:





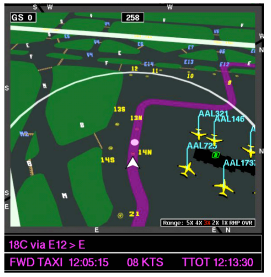

- Display conditions were blocked and counterbalanced
- Practice trial before each Display Format block

# Present Study

## Taxi Simulation Variables

- 4DT Display Formats
  - Defined Tolerance +/- 164 ft (+/- 50 m)
  - Defined Tolerance +/- 405 ft (+/- 123 m)
  - Undefined Tolerance (dot)
- 4DT Speed Changes (2 or 5 per trial)
- 4DT Speeds (8 kts – 25 kts) ('Slow' or 'Fast')





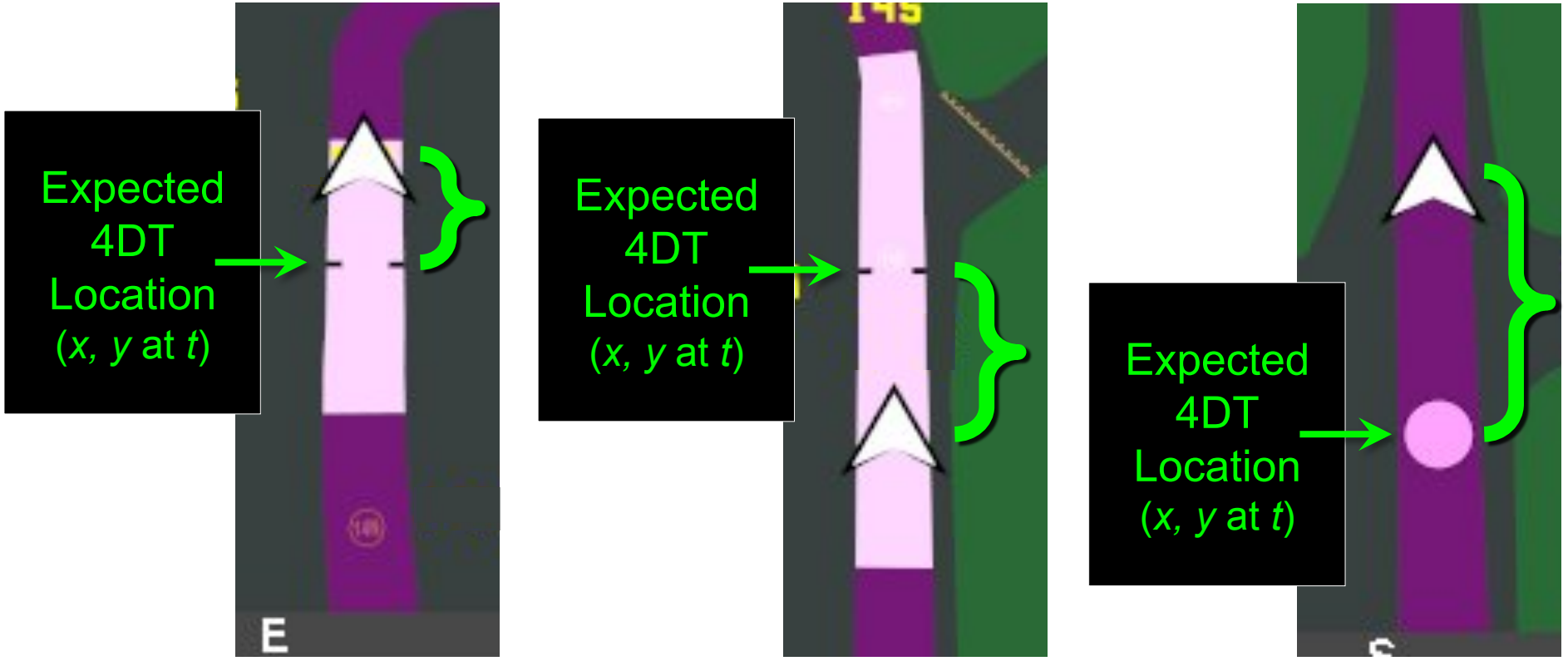

## Results

- Conformance to the 4DT Clearance
  - Distance between Ownship and Expected 4DT Location
  - Percent Time Ownship within a Distance Range
- Eyes-Out Time (eye-tracker data)
- Pilot ratings of eyes-out time, safety, and workload

# Results

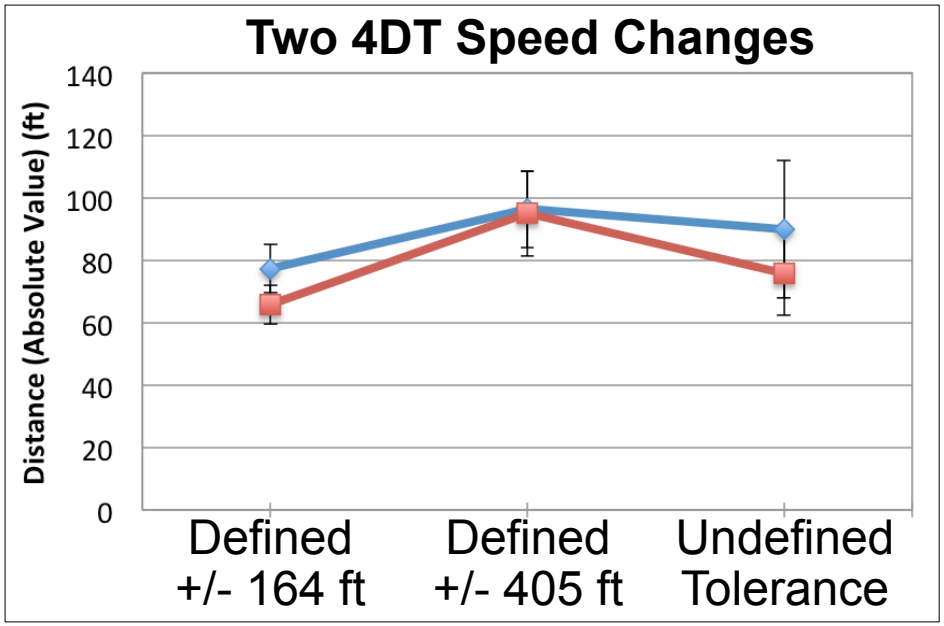
## Distance (Absolute Value) from 4DT Indicator

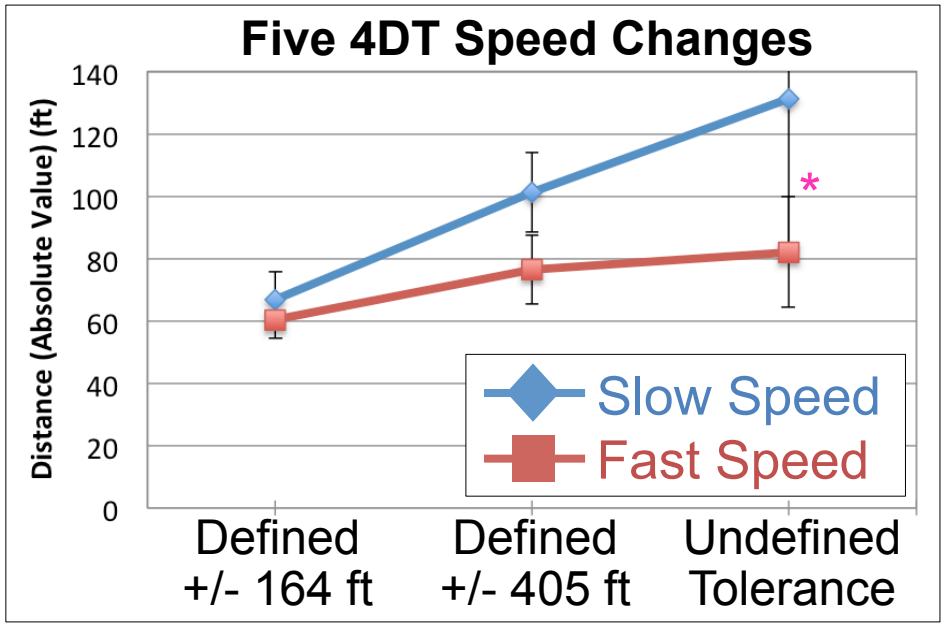
- Distance between Ownship and Expected 4DT Location
- Distance from 4DT Location recorded during taxi (20 hz)
- Absolute Value: Ownship in front of or behind 4DT location



# Results

## Distance (Absolute Value) between Ownship and Expected 4DT Location



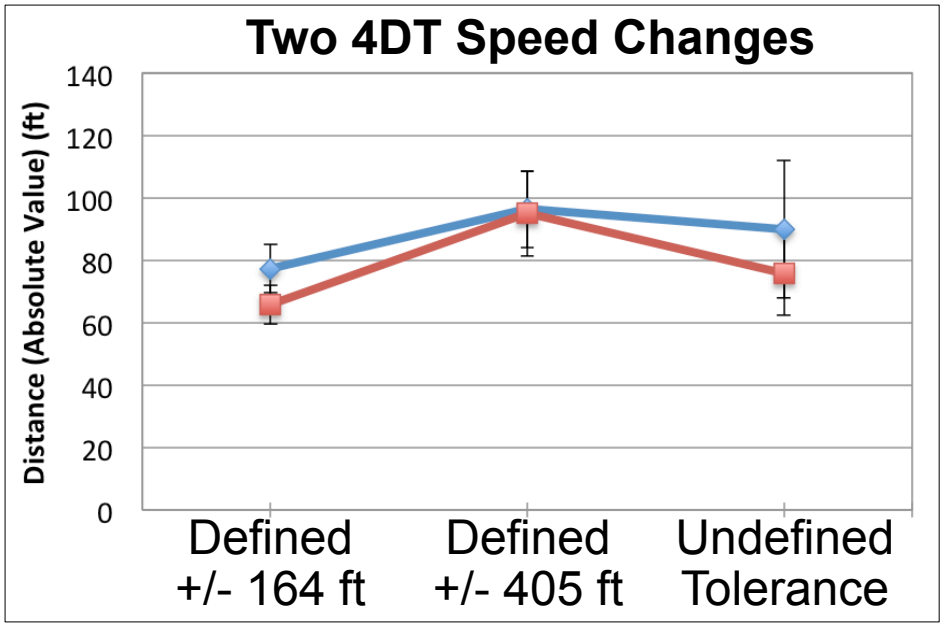

**3 (4DT display format) by 2 (4DT speed) by 2 (4DT speed changes) repeated-measures ANOVA:**
4DT speed by number of 4DT speed changes interaction, $F(1,11) = 5.13$, $p < .05$*

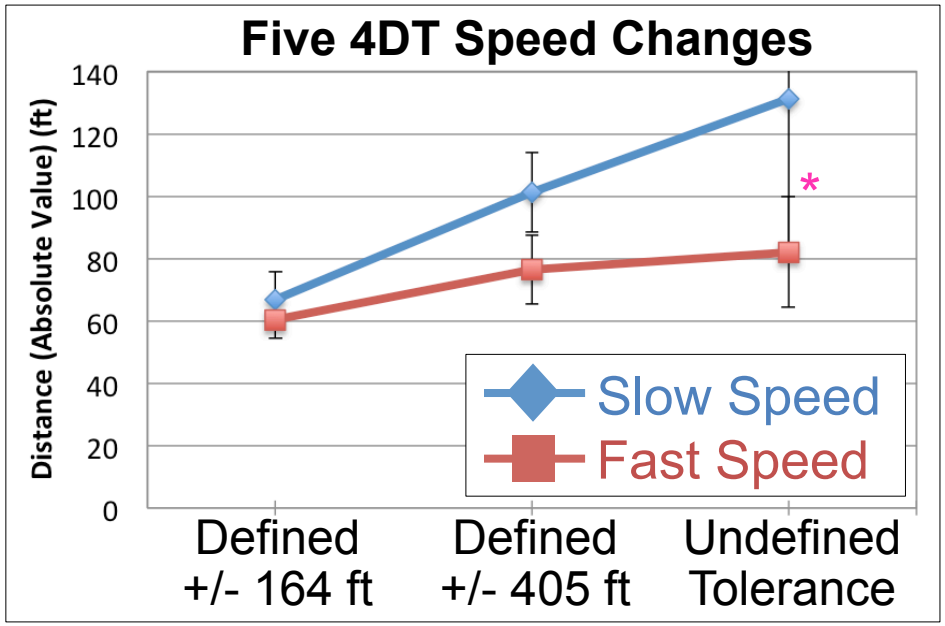
## Pilots taxied a greater distance from the expected 4DT location:

- In the +/- 405 ft Defined-Tolerance Condition (92.2 ft) than in +/- 164 ft (67.5 ft).
  - However, in both conditions, pilots taxi well-within the defined-conformance bounds.
- In the 'slow' avg. speed condition (93.8 ft) than in 'fast' avg. speed (75.9 ft).
  - Pilots indicated that it may be challenging to maintain slower speeds (8 or 9 kts) and may require more control inputs (e.g., braking). Pilots use their brakes sparingly during taxi.
- In the 5 4DT speed change condition (86.3 ft) than with 2 changes (83.3 ft).
  - Considerations for the frequency, and magnitude of, 4DT speed changes in 4DT operations.

# Results

## Distance (Absolute Value) between Ownship and Expected 4DT Location



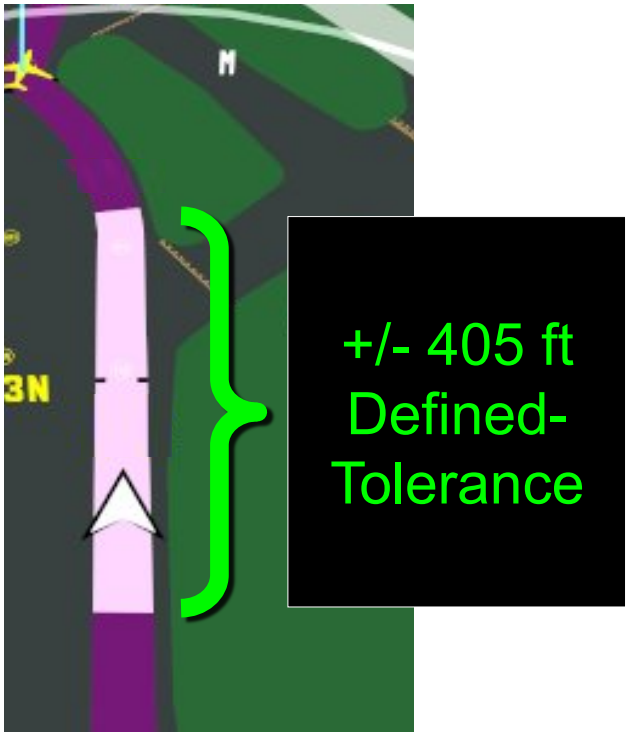

3 (4DT display format) by 2 (4DT speed) by 2 (4DT speed changes) repeated-measures ANOVA:
4DT speed by number of 4DT speed changes interaction, $F(1,11) = 5.13$, $p < .05$*

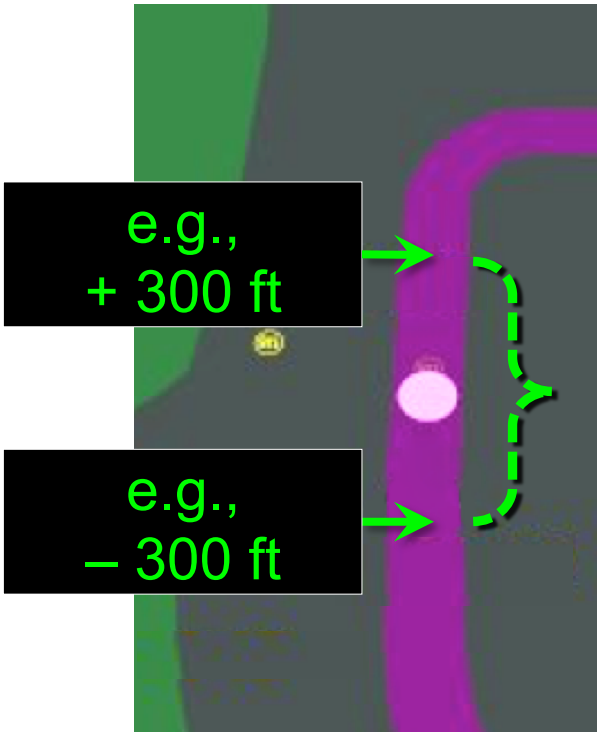
## Pilots taxied a greater distance from the expected 4DT location:

- Average distance in the +/- 405 ft and Undefined (dot) are similar.
  - However, the *range* of distances was larger in the Undefined-Tolerance Format (taxi strategy).
  - The Undefined-Tolerance (dot) Display Format allowed pilots to interpret ‘conformance’ and employ different taxi strategies.
  - One pilot maintained a distance well ahead of the 4DT indicator in the 'slow' average speed/five-speed change trial to ensure precise arrival at the queue.*

## Percent Time Ownship in a Distance Range

- Percentage of total route time the ownship taxied within:
  - A tolerance bound in the Defined-Tolerance Display condition, or
  - A given distance range (+/- x ft) around the expected 4DT location



# Results

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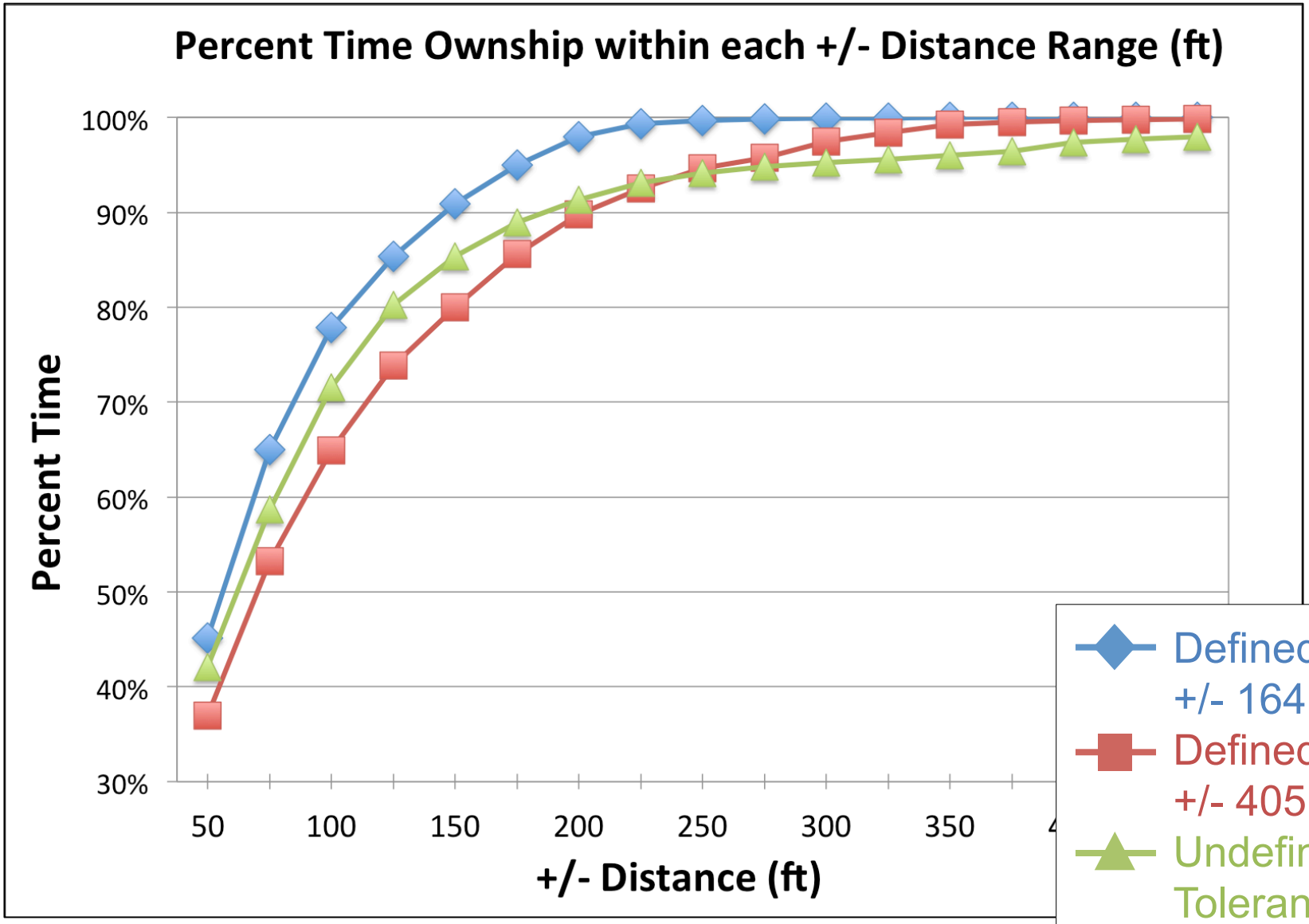
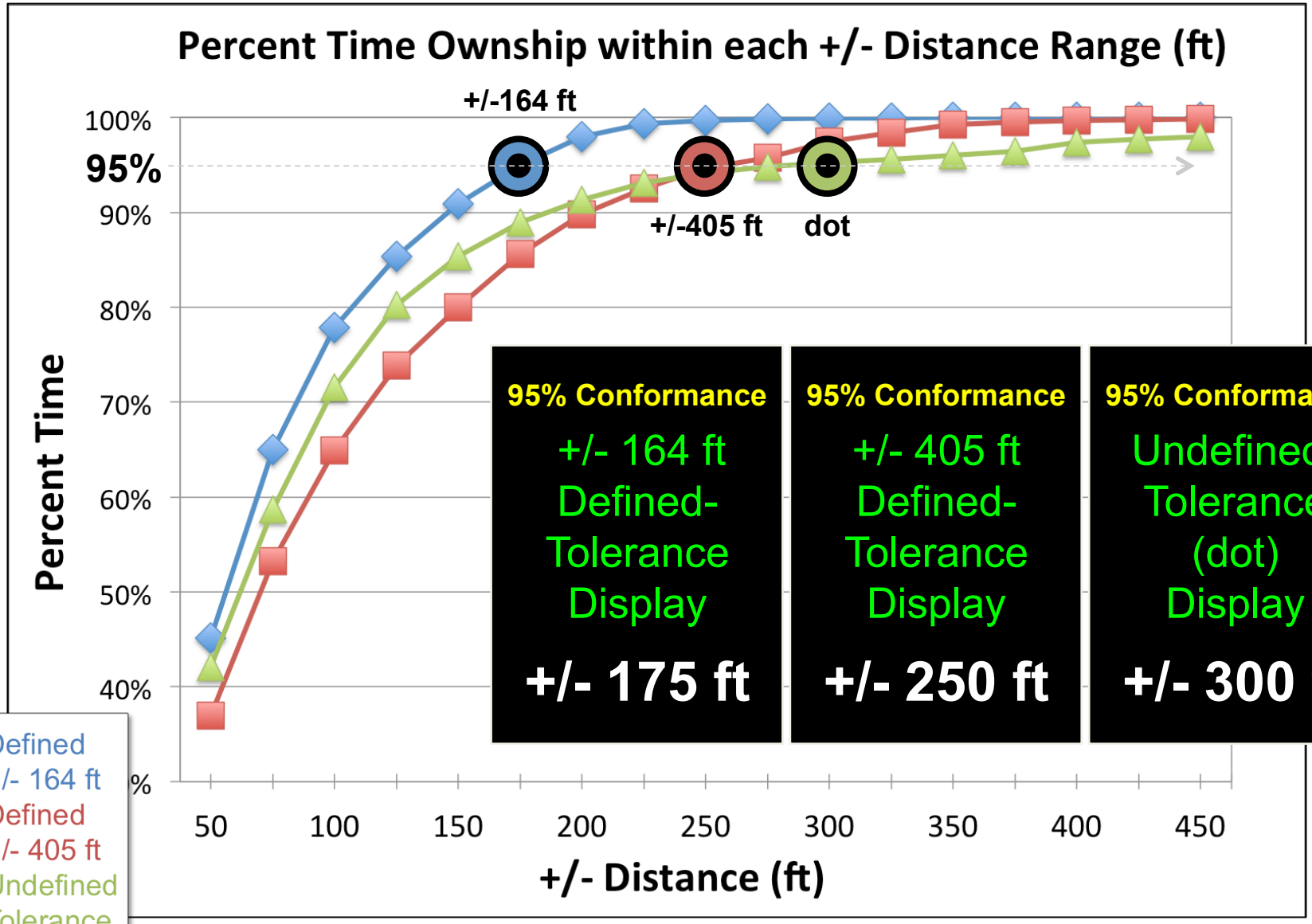
## Percent Time the Ownship was in a given Distance Range



# Results

SJSU

## 95% Conformance: Distance Range in which Pilots Taxied 95% of Route



# Results

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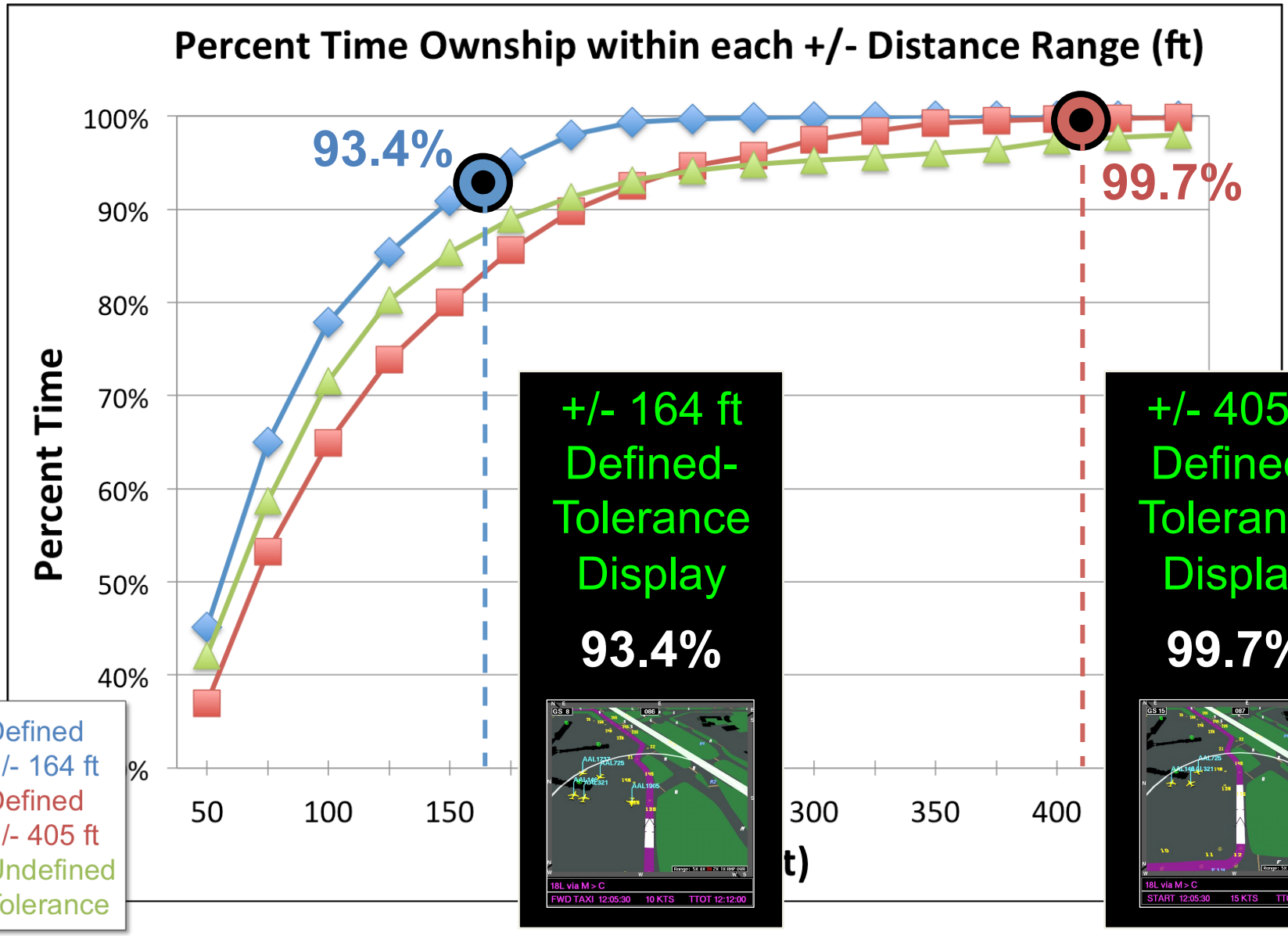
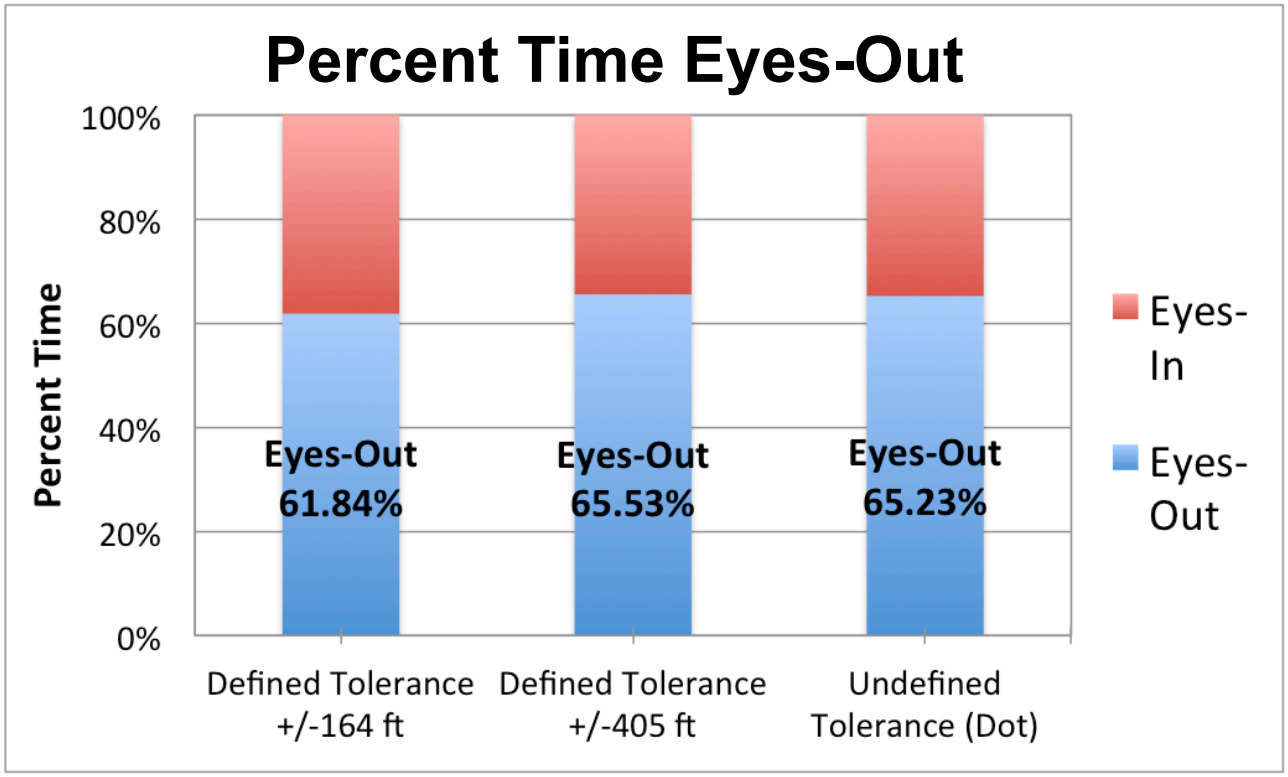
## Conformance in the Defined-Tolerance Band Conditions



# Eyes-Out Time

SJSU

## Time spent scanning Out-the-Window (OTW) during taxi




**3 (4DT display format) by 2 (4DT speed) by 2 (4DT speed changes) repeated-measures ANOVA:**
Main effect of 4DT Display Format $F(2,16) = 3.17$, $p = .069$; Main effect of 4DT Speed Changes $F(1,8) = 5.24$, $p = .051$

## Less Time Scanning OTW:

- In the smaller +/- 163 ft Defined-Conformance Condition (61.8%).
- In the five-speed change condition (63.1%) vs. two changes (65.3%).

# Pilot Assessment of Eyes-In Time

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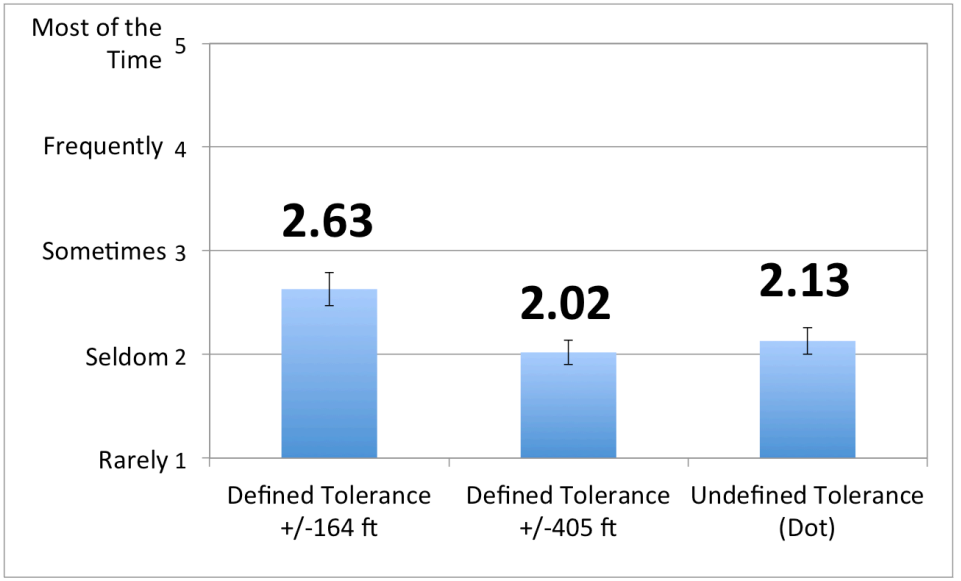
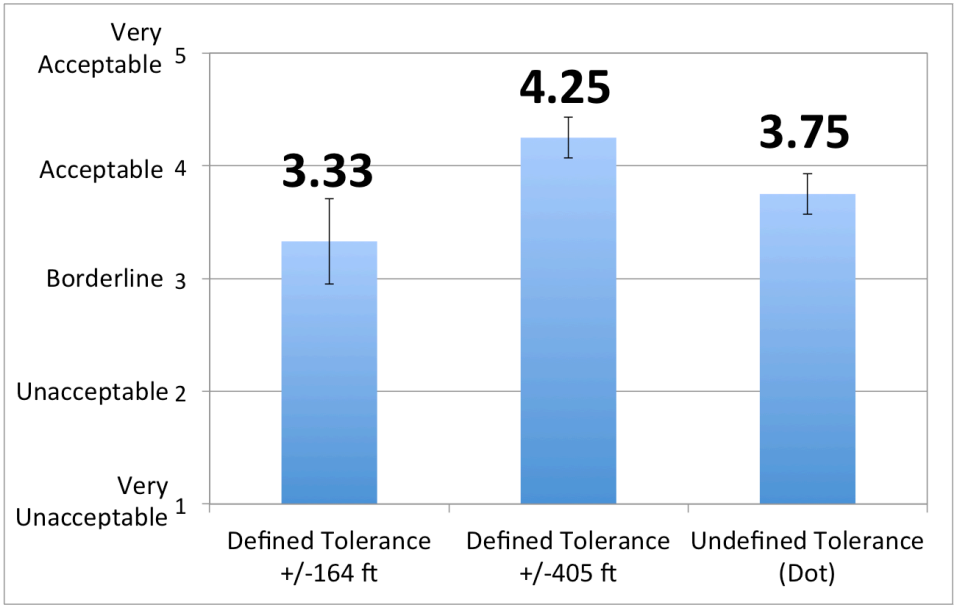
## Eyes-In Time Frequency

During this trial, how often did you find yourself focusing on the speed and/or time displays when you should have been paying attention to the external taxiway environment?




## Eyes-In Time Acceptability

Rate the acceptability of the eyes-in time required for each 4DT display format.




*Pilots rated the +/- 405 ft band as more acceptable than +/- 164 ft band.

# Workload / Safety (Subjective Ratings)

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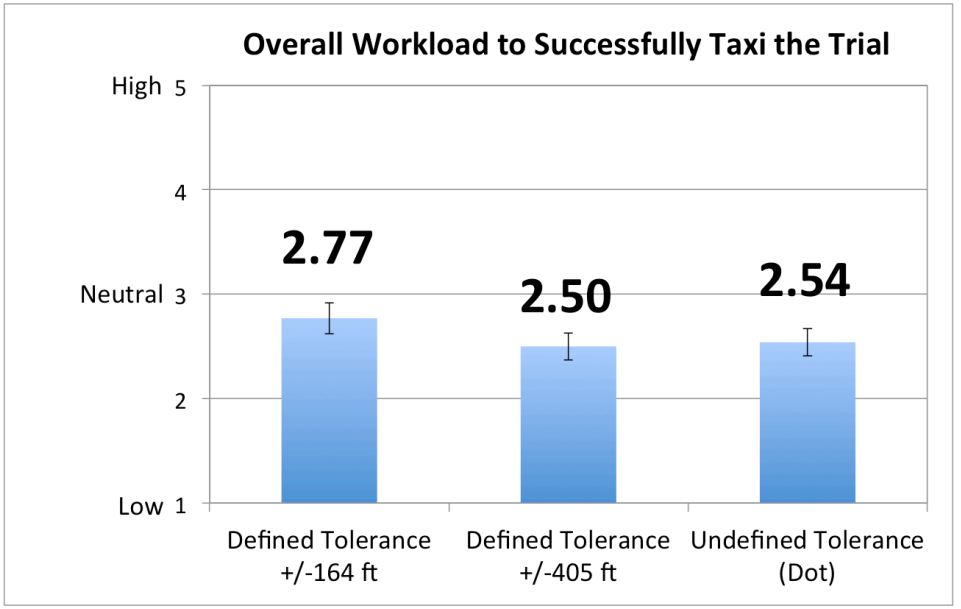
## Workload

Overall workload required to successfully taxi each trial.

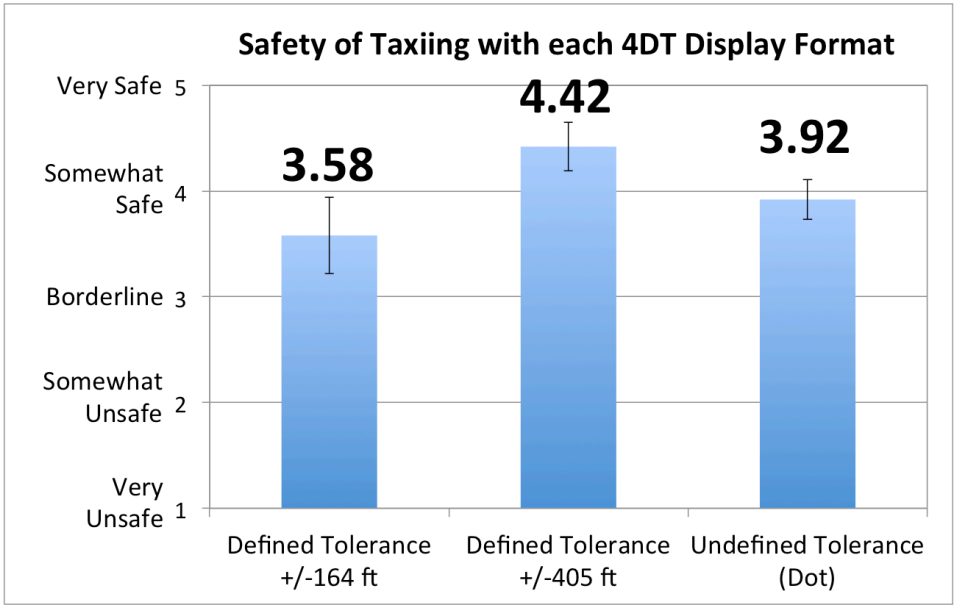
*Pilots perceived workload to be higher with the +/- 164 ft band than with the +/- 405 ft band or the dot.




## Safety

Rate the safety of taxiing with each of the 4DT display formats.

*Pilots perceived safety to be higher with the +/- 405 ft band than with the +/- 164 ft band or the dot.



# Results

## Summary:

- The **larger +/- 405 ft Defined-Tolerance display** afforded several positive findings:
  - 4DT Conformance was higher than the smaller band.
  - More "**eyes out-the-window**" time than the smaller +/- 164 ft Defined-Tolerance band.
  - The "eyes-in" time associated with the larger Defined-Tolerance band was rated as **more acceptable** than the smaller Defined-Tolerance band.
  - Pilots also rated taxiing with the larger Defined-Tolerance band as **safer** than the smaller Defined-Tolerance Band.

## Summary:

- Considerations for Pilots / Aircraft in 4DT Operations:
  - Frequency and magnitude of 4DT speed changes.
  - Pilots indicated that it may be challenging to maintain **slower speeds** (e.g., 8 or 9 kts) in an actual aircraft, and may require more control inputs (e.g., braking) to do so.
  - Pilots reported that they would be unlikely to maintain **faster taxi speeds** (e.g., 21–25 kts) while approaching a turn or the departure queue area, and therefore would increase brake use.
  - Might managing **safety concerns** on the flight deck (e.g., hot brakes) make pilots less responsive to 4DT speed changes (braking / throttling)?

# Future Research

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## Flight Deck / ATC Communications

- Rejecting a 4DT clearance (before, or during, taxi)
- Renegotiating a 4DT clearance with ATC
- DataComm vs. voice communication

## Mixed-Equipage

## Weather, Low-Visibility

## Traffic

- How to communicate an aircraft's intent? "Is that guy going to stop?"
- How to display another aircraft's 4DT?

## Contaminated Taxiways

## 4DT Conformance

- How is non-conformance defined?
- What will the system do in the event of non-conformance?

## 4DT Revisions

- How much notice does the Flight Deck need for speed or taxi route revisions?
- How long does it take for the Flight Deck to make a speed or taxi route change?

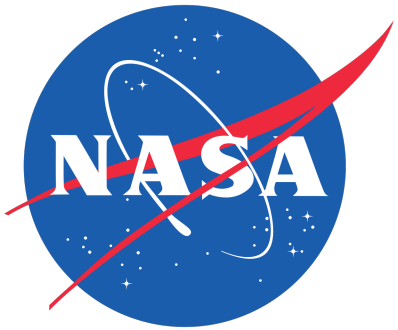
## Aircraft Safety Considerations (e.g., hot brakes)

- Slower / fast taxi speeds
- Airport geometry

## Flight Deck Off Nominals

- Mechanical issue
- Passenger stands-up during taxi
- Final weights are late; fix changes

# Flight Deck Surface Trajectory-Based Operations (STBO): A Four-Dimensional Trajectory (4DT) Simulation




SJSU SAN JOSÉ STATE UNIVERSITY

**Deborah L. Bakowski, M.A.**
*San José State University*
*NASA Ames Research Center*

**Becky L. Hooey, Ph.D.**
*NASA Ames Research Center*

**David C. Foyle, Ph.D.**
*NASA Ames Research Center*

**Human-Centered Systems Lab**
**https://hsi.arc.nasa.gov/groups/HCSL**

# Future Research


Bakowski, D. L., Hooey, B. L., Foyle, D. C., & Wolter, C. A. (2015). NextGen Surface Trajectory-Based Operations (STBO): Evaluating Conformance to 4-Dimensional Trajectories (4DT). In T. Ahram et al. (Eds.), *6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, Procedia Manufacturing Vol. 3,* (pp. 2458–2565). Elsevier Procedia.
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Gerdes, I. & Temme, A. (2012). Taxi routing for aircraft: Creation and Controlling – Ground movements with time constraints. *Second SESAR Innovation Days, November 27–29, 2012.*
https://www.sesarju.eu/sites/default/files/SID_2012-05.pdf

Hooey, B. L., Cheng, V. H. L., Foyle, D. C. (2014). *A concept of operations for far-term Surface Trajectory-Based Operations (STBO).* (NASA TM–2014–218354). Moffett Field, CA: NASA ARC.
https://hsi.arc.nasa.gov/groups/HCSL/publications/STBO%20ConOps_TM_2014_218354.pdf

Okuniek, N., Gerdes, I., Jakobi, J., Ludwig, T., Hooey, B. L., Foyle, D. C., Jung, Y. C., & Zhu, Z. (2016). A concept of operations for trajectory-based taxi operations. *Proceedings of the 16th AIAA Aviation Technology, Integration, and Operations Conference, Paper AIAA-2016-3753, Washington, DC, June 13–17, 2016.*
https://hsi.arc.nasa.gov/groups/HCSL/publications/AIAA_ATIO_2016_NASA_DLR_4DT_ConOps.pdf


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# Additional Slides

# Conformance to the 4DT

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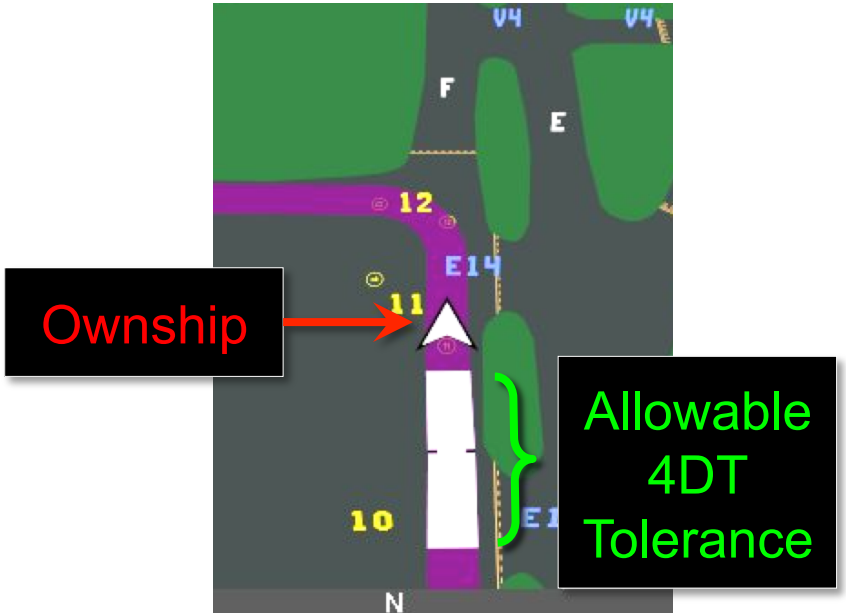
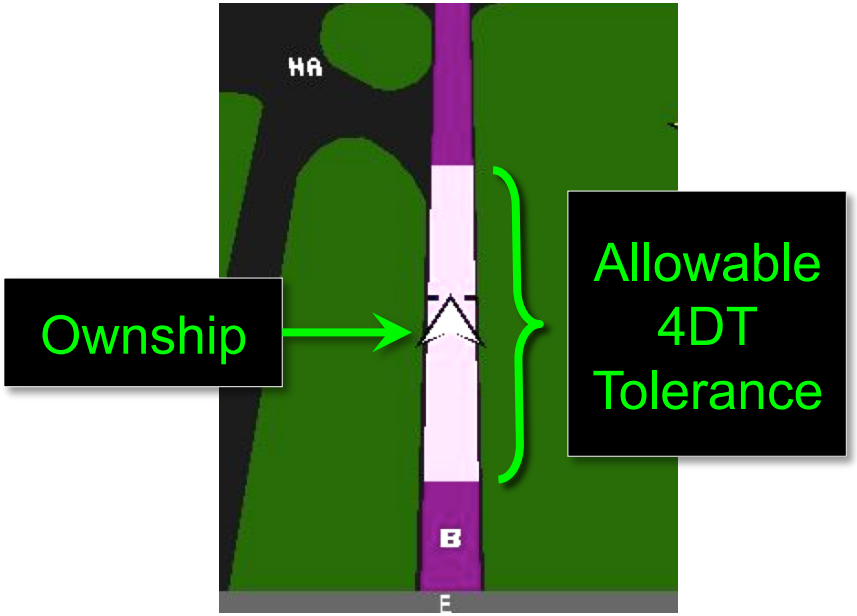
## Definition of Conformance to the 4DT:

– Ownship icon is within the Allowable Tolerance Band

### Ownship Out of Conformance with 4DT




### Ownship In Conformance with 4DT



# Previous Flight Deck 4DT Study

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## Previous Pilot-in-the-Loop 4DT Simulation:

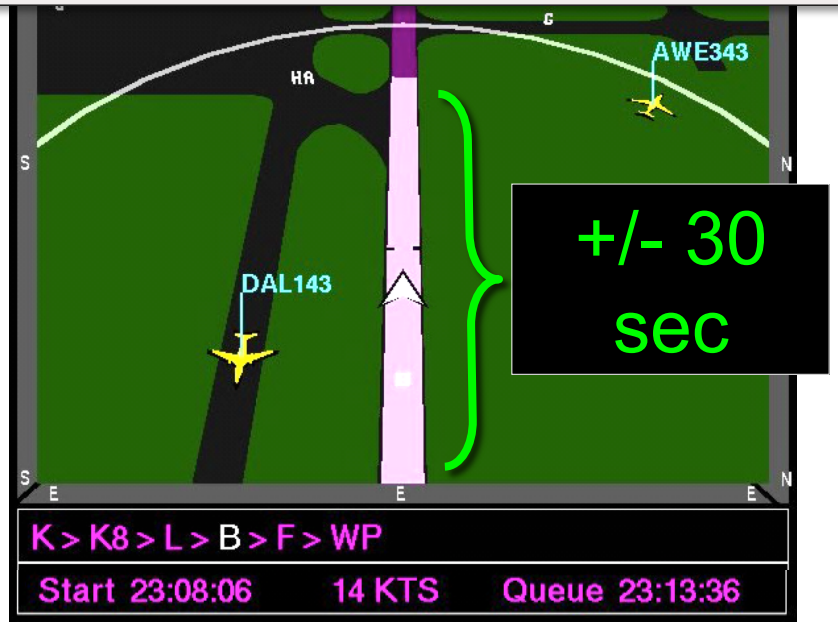
- Taxied on the surface of Dallas/Fort Worth (DFW) Airport
- 4DT Speeds: 14, 15, 16 kts *Bakowski, Hooey, Foyle, & Wolter (2015)*

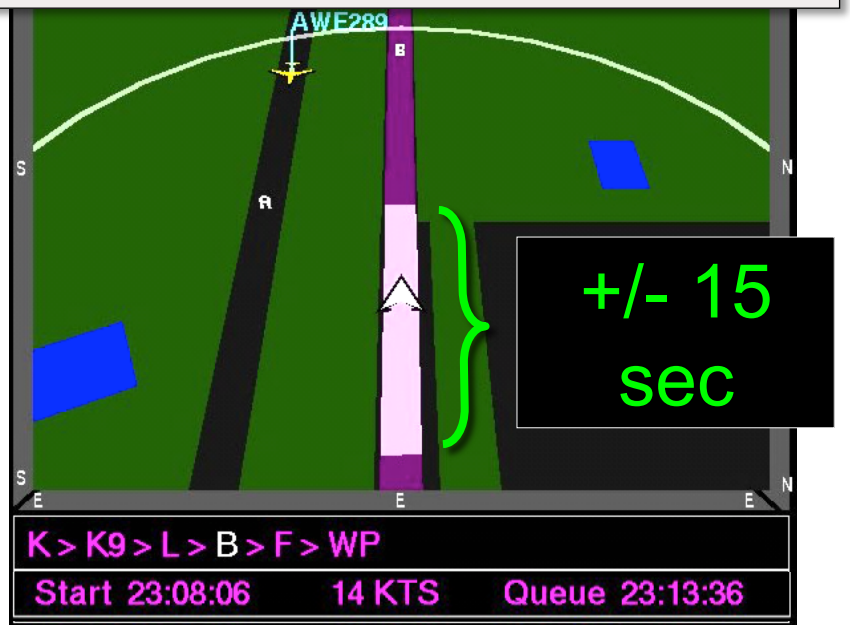
**15 kts** × **+/- 30 sec** = **+/- 760 ft (+/- 232 m)**

4DT Straightaway Speed (kts --> ft per sec)

Allowable *Time* Deviation

Distance (Length) of Allowable Tolerance Band



# Experimental Taxi Scenario

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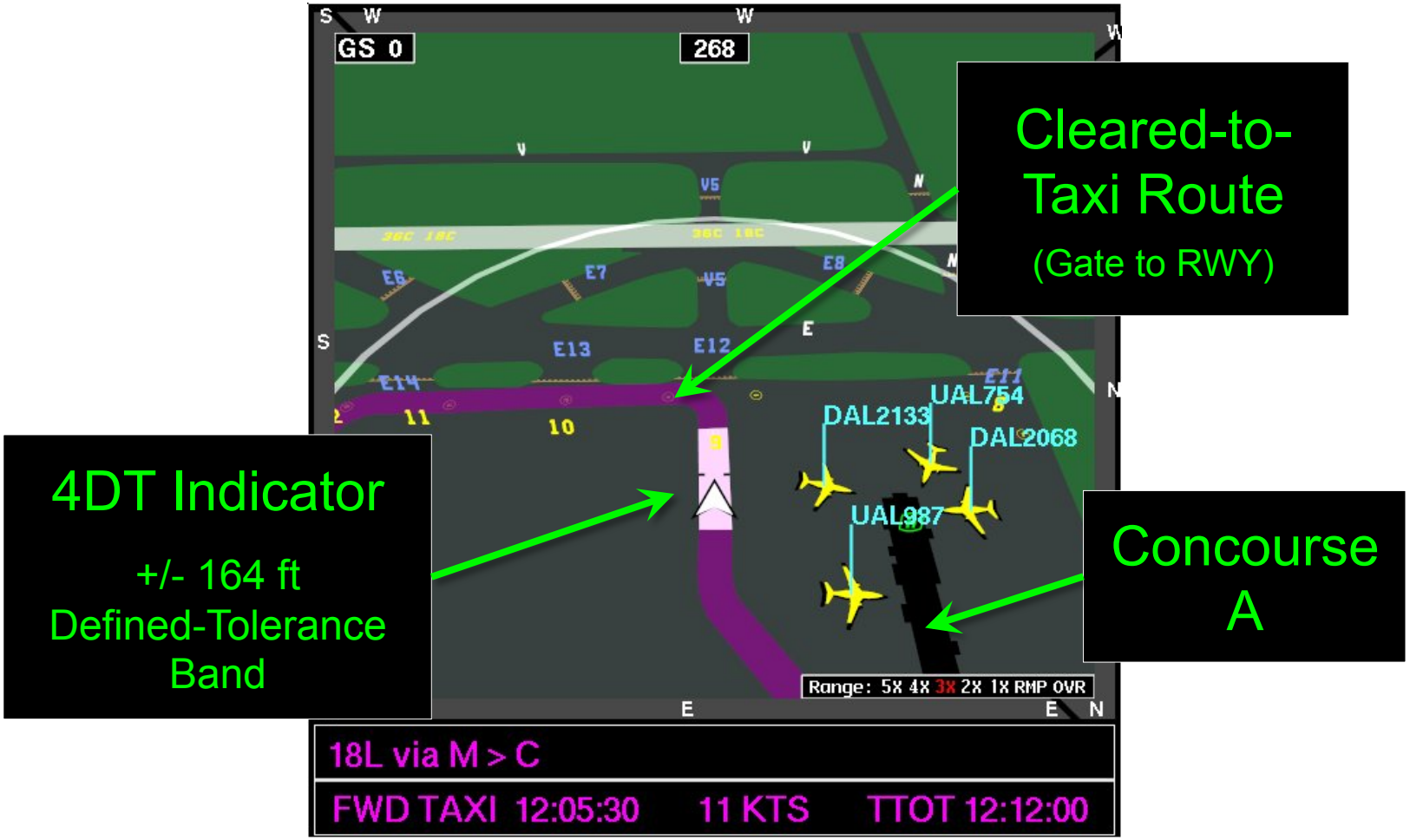
## 4DT Start Time

- Accompanied by an auditory chime on the flight deck
- 4DT Indicator begins to accelerate



# Experimental Taxi Scenario

SJSU

## 4DT Speed Changes

- Predetermined locations along the taxi route (speed profile)
- Two or five speed changes per trial

- Accompanied by an auditory tone on the flight deck
- AMM text display updated
- First Officer acknowledged, "Speed Change"
- Accel / Decel Rate = 1 kt/sec

# Results

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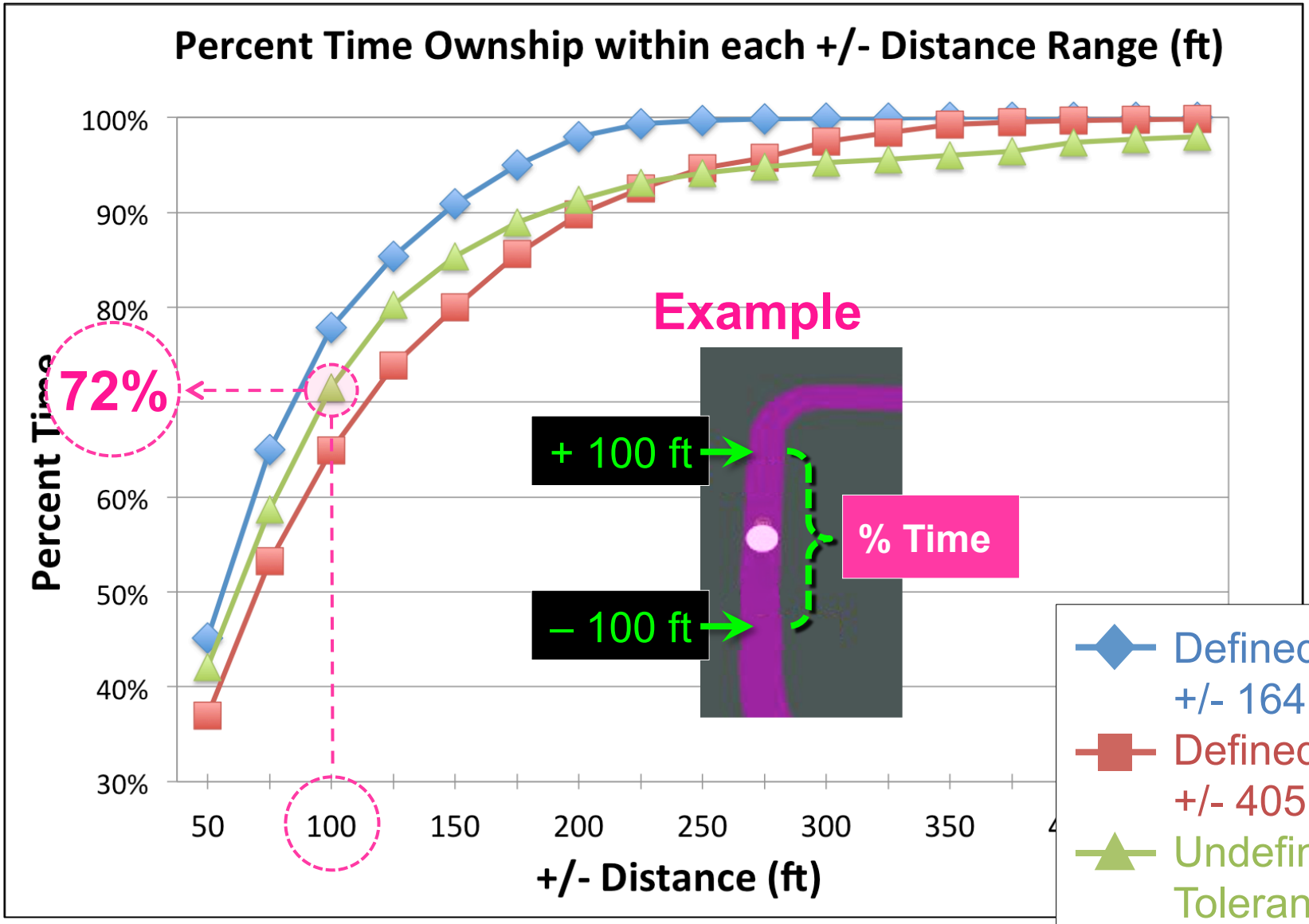
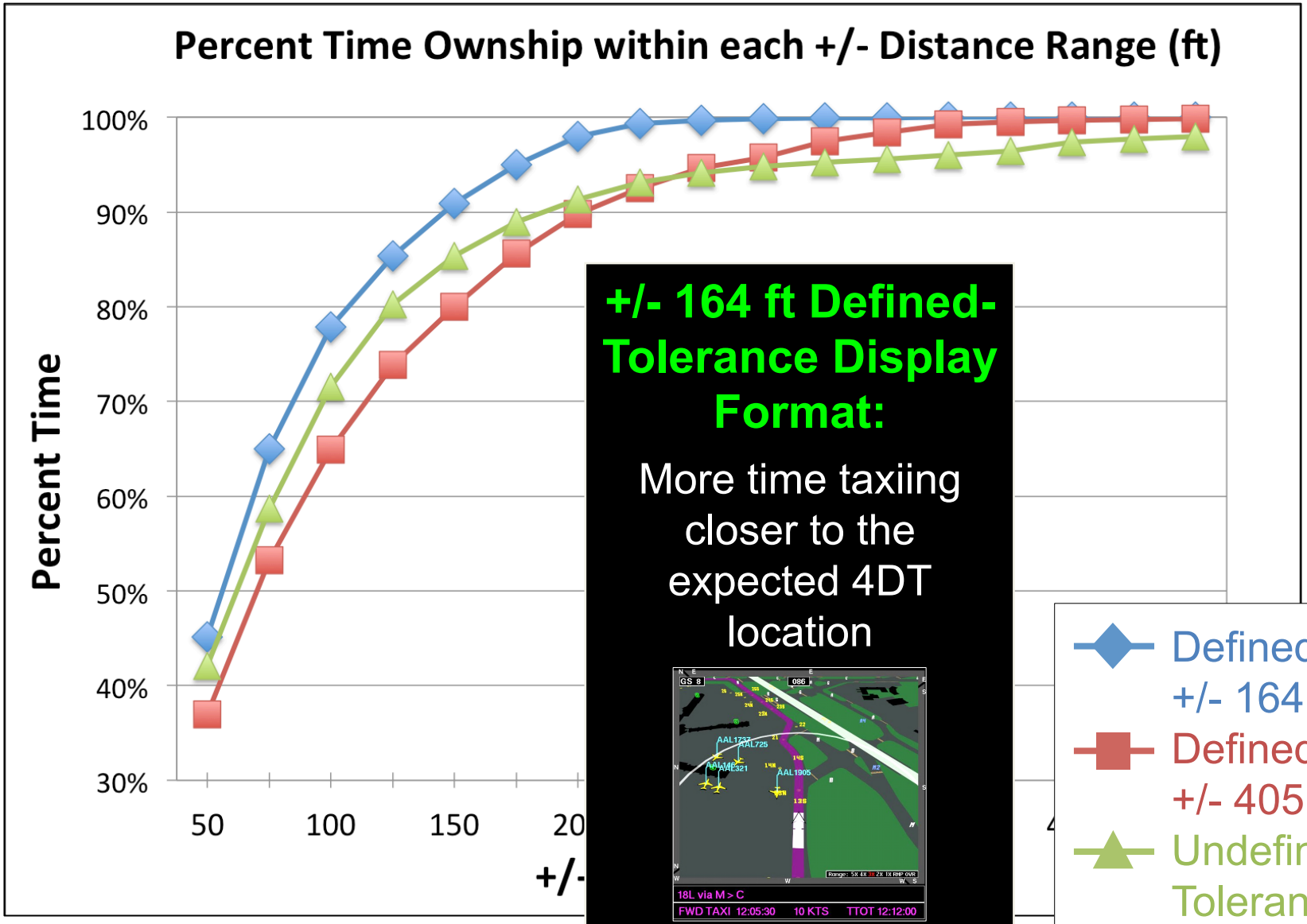
## Percent Time the Ownship was in a given Distance Range



# Results

SJSU

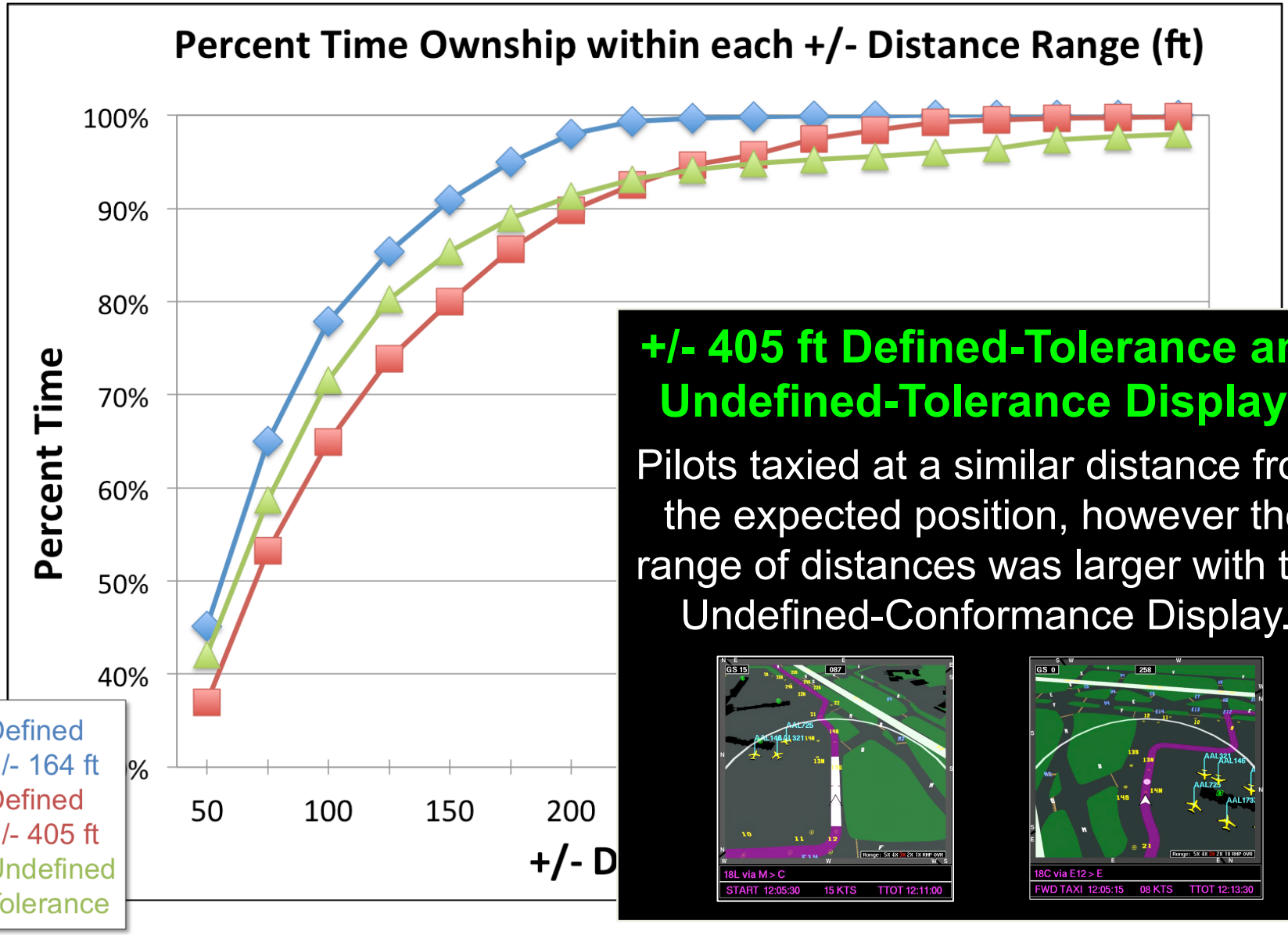
## Percent Time the Ownship was in a given Distance Range



# Results

SJSU

## Percent Time the Ownship was in a given Distance Range




**+/- 405 ft Defined-Tolerance and Undefined-Tolerance Displays**

Pilots taxied at a similar distance from the expected position, however the range of distances was larger with the Undefined-Conformance Display.