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

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Human-Centered Systems Lab
https://hsi.arc.nasa.gov/groups/HCSL
Flight Deck 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
Increasing Use of Time Information in Surface Trajectory-Based Operations (STBO)
Surface Trajectory-Based Operations

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

Increasing Use of Time Information in STBO

Current-Day Surface Operations

Near-Term w/ Target Times

*Wheels-Up Time*

Far-Term with Flight Deck Component

Far-Term Full 4DT Operations

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

Flight Deck:
1. Pushback Time
2. Wheels-up Time

No information about:
- taxi duration
- queue size

Image: Okuniak et al. (2016)
Surface Trajectory-Based Operations

Increasing Use of Time Information in STBO

Current-Day Surface Operations

Near-Term with Target Times

Far-Term with Flight Deck Component

Far-Term Full 4DT Operations

Flight Deck:
1. Pushback Time

No information about:
- taxi schedule

ATC/Ramp manages with Scheduling/Decision Support Tools (DSTs):
- Pushback Time (TOBT)
- Airport Movement Area Time (TMAT)
- Target Take-Off Time (TTOT)

Example: ATD2 IADS system to be deployed Charlotte Fall 2017.

Image: Okuniak et al. (2016)
Surface Trajectory-Based Operations

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

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

4DT Operations: \( \infty \) # of time points

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

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

- Expected 4DT Location

Image: Okuniak et al. (2016)

Expected 4DT Location

Allowable 4DT Tolerance
Surface Trajectory-Based Operations

Increasing Use of Time Information in STBO

Current-Day Surface Operations

Near-Term w/ Target Times

Far-Term with Flight Deck Component

Flight Deck / ATC Coordination

Times included in Taxi Clr

4DT Operations: # of time points

4DT Operations: ∞ of time points

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

Flight Deck: Avionics Display/Algorithm to support 4D Taxi conformance.

Expected 4DT Location

允许4DT Tolerance

Expected 4DT Location

Image: Okuniak et al. (2016)
### 4DT Surface Trajectory-Based Ops

**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

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**Allowable Tolerance around 4DT Speed Profile**

**Expected 4DT Location**

\((x, y) \text{ at all times along the taxi route}\)

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Hooey, Cheng, & Foyle (2014)
Four-Dimensional Trajectory (4DT) Concept:

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

Allowable Tolerance around 4DT Speed Profile

Expected 4DT Location

4DT Speed Profile

\((x, y \text{ at time } t)\)

Surface Management System

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

Gerdes & Temme (2012)
4DT Surface Trajectory-Based Ops

4DT Concepts of Operations (ConOps)

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

Hooey, Cheng, & Foyle (2014)

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

Previous Flight Deck 4DT Study

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.


4DT Speed Profile and Taxi Routing Information

Allowable Deviation around Speed Profile

Expected 4DT Location \((x, y\text{ at all times})\)

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

Flight Deck Display: Airport Moving Map (AMM)

- Ownship Speed
- Airport Layout to aid with Navigation
- Traffic displayed within de-clutter circle
Airport Moving Map (AMM)

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

<table>
<thead>
<tr>
<th>4DT Clearance Speed</th>
<th>4DT Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 KTS</td>
<td>15 KTS</td>
</tr>
</tbody>
</table>

Start 18:26:51
Queue 18:35:44
Previous Flight Deck 4DT Study

Previous Pilot-in-the-Loop 4DT Simulation:
  – Along-Route Conformance: % Time in Allowable Tolerance

Speed-Advisory
(No 4DT on AMM)

4DT +/- 30 sec

4DT Info on AMM

Verbal Clearance:
"Taxi at 14 kts"


4DT +/- 30 sec

4DT Info on AMM

4DT +/- 15 sec

4DT Info on AMM
Previous Pilot-in-the-Loop 4DT Simulation:

- Along-Route Conformance: % Time in Allowable Tolerance

Speed-Advisory (No 4DT on AMM)


Along-Route Conformance

- +/-30 sec: 72%
- +/-15 sec: 20%
- 4DT +/-30 sec: 99%
- 4DT +/-15 sec: 99%
Present Flight Deck 4DT Study

**Previous Simulation**

- **One 4DT Display Format**
- **4DT Straightaway Speed** held constant in each trial
- **4DT Speeds**: 14, 15, or 16 kts
- **4DT Route Start**: Spot
- **Time-based Tolerance**
- **Dallas/Fort-Worth Airport**

**Present Simulation**

- **4DT Format Comparison**
- **4DT Speed Changes Mid-Taxi**
- **Range of Realistic Taxi Speeds**: 8 kts – 25 kts
- **4DT Route Start**: at Gate
- **Distance-based Tolerance**
- **Charlotte Douglas Airport**

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

*Bakowski, Hooey, & Foyle (2017)*
Airport and Terminal Area Simulator

Out-the-Window View
- 4 LCD Displays
- 140° viewing angle

Tiller

PFD (Inactive)

Airport Moving Map (AMM)

EICAS

CDU

DataComm Interface

Eyetracker Cameras

B737NG Flight Deck

Human-Centered Systems Lab (HCSL)
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

**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

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

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

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.

<table>
<thead>
<tr>
<th>Speed (kts)</th>
<th>Ramp  'Slow' Avg. Speed</th>
<th>Airport Movement Area (AMA) 'Fast' Avg. Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>13</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>14</td>
<td>20</td>
<td>22</td>
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<tr>
<td>15</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
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<tr>
<td>19</td>
<td></td>
<td></td>
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<tr>
<td>20</td>
<td></td>
<td></td>
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<tr>
<td>21</td>
<td></td>
<td></td>
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<tr>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

**4DT Taxi Clearance**

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

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**4DT Taxi Clr. DataComm**

- Taxi Route/RWY
- 4DT Schedule Info

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**12:01:30 Z FROM KCLT**

ATS227
RWY 18L
VIA M C
TOBT 12:03:15
FWD TAXI 12:05:30
TTOT 12:12:00

**COMM OK**

UNABLE | STBY | WILCO

---

**Clear-to-Taxi Route**

**4DT Clearance Information**

18L via M > C
FWD TAXI 12:05:30  00 KTS  TTOT 12:12:00
4DT Clearance Info on the Flight Deck

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

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)
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

### Two 4DT Speed Changes

![Graph showing distance (absolute value) between ownship and expected 4DT location for two 4DT speed changes with defined and undefined tolerances and slow and fast speeds.]

<table>
<thead>
<tr>
<th>Condition</th>
<th>Defined +/- 164 ft</th>
<th>Defined +/- 405 ft</th>
<th>Undefined Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow Speed</td>
<td>80</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Fast Speed</td>
<td>90</td>
<td>110</td>
<td>70</td>
</tr>
</tbody>
</table>

### Five 4DT Speed Changes

![Graph showing distance (absolute value) between ownship and expected 4DT location for five 4DT speed changes with defined and undefined tolerances and slow and fast speeds.]

<table>
<thead>
<tr>
<th>Condition</th>
<th>Defined +/- 164 ft</th>
<th>Defined +/- 405 ft</th>
<th>Undefined Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow Speed</td>
<td>90</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Fast Speed</td>
<td>100</td>
<td>140</td>
<td>100</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Two 4DT Speed Changes</th>
<th>Five 4DT Speed Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance (Absolute Value)</strong> (ft)</td>
<td><strong>Distance (Absolute Value)</strong> (ft)</td>
</tr>
<tr>
<td>Defined +/- 164 ft</td>
<td>Defined +/- 405 ft</td>
</tr>
<tr>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

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.*
Results

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

e.g.,
+ 300 ft

e.g.,
− 300 ft

+/- 405 ft
Defined-Tolerance
Results

Percent Time the Ownship was in a given Distance Range

Percent Time Ownship within each +/- Distance Range (ft)

Defined +/- 164 ft
Defined +/- 405 ft
Undefined Tolerance

[Graph showing the percentage of time spent within different distance ranges]
Results

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

Percent Time Ownership within each +/- Distance Range (ft)

95% Conformance

+/- 164 ft
Defined-Tolerance Display

+/- 175 ft

+/- 405 ft
Defined-Tolerance Display

+/- 250 ft

+/- 300 ft
Undefined-Tolerance (dot) Display
Results

Conformance in the Defined-Tolerance Band Conditions

Percent Time Ownership within each +/- Distance Range (ft)

<table>
<thead>
<tr>
<th>Distance Range</th>
<th>Conformance</th>
</tr>
</thead>
<tbody>
<tr>
<td>+/- 164 ft</td>
<td>93.4%</td>
</tr>
<tr>
<td>+/- 405 ft</td>
<td>99.7%</td>
</tr>
</tbody>
</table>
Eyes-Out Time

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

Percent Time Eyes-Out

<table>
<thead>
<tr>
<th>Condition</th>
<th>Eyes-Out 61.84%</th>
<th>Eyes-Out 65.53%</th>
<th>Eyes-Out 65.23%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defined Tolerance +/-164 ft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defined Tolerance +/-405 ft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undefined Tolerance (Dot)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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%).

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 $F(1,8) = 5.24$, $p = .051$
Pilot Assessment of Eyes-In Time

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?

<table>
<thead>
<tr>
<th>Acceptability</th>
<th>Most of the Time</th>
<th>Frequently</th>
<th>Sometime</th>
<th>Seldom</th>
<th>Rarely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defined Tolerance</td>
<td>2.63</td>
<td>2.02</td>
<td>2.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+/-164 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+/-405 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undefined Tolerance (Dot)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Acceptability</th>
<th>Very Acceptable</th>
<th>Acceptable</th>
<th>Borderline</th>
<th>Unacceptable</th>
<th>Very Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defined Tolerance</td>
<td>3.33</td>
<td>4.25</td>
<td>3.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+/-164 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+/-405 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undefined Tolerance (Dot)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Pilots rated the +/- 405 ft band as more acceptable than +/- 164 ft band.
Workload / Safety (Subjective Ratings)

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

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

Mixed-Equipage

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

Weather, Low-Visibility
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Future Research


Additional Slides
Conformance to the 4DT

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 Pilot-in-the-Loop 4DT Simulation:

- Taxied on the surface of Dallas/Fort Worth (DFW) Airport
- 4DT Speeds: 14, 15, 16 kts


<table>
<thead>
<tr>
<th>15 kts</th>
<th>+/- 30 sec</th>
<th>=</th>
<th>+/- 760 ft (+/- 232 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4DT Straightaway Speed (kts --&gt; ft per sec)</td>
<td>Allowable Time Deviation</td>
<td>Distance (Length) of Allowable Tolerance Band</td>
<td></td>
</tr>
</tbody>
</table>

K > K8 > L > B > F > WP
Start 23:08:06  14 KTS  Queue 23:13:36

K > K9 > L > B > F > WP
Start 23:08:06  14 KTS  Queue 23:13:36
Experimental Taxi Scenario

4DT Start Time

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

4DT Indicator

+/- 164 ft
Defined-Tolerance Band

Cleared-to-Taxi Route
(Gate to RWY)

Concourse A

18L via M > C
FWD TAXI 12:05:30 11 KTS TTOT 12:12:00
Experimental Taxi Scenario

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

Percent Time the Ownship was in a given Distance Range

Example

72%
Results

Percent Time the Ownship was in a given Distance Range

Percent Time Ownship within each +/- Distance Range (ft)

+/- 164 ft Defined-Tolerance Display Format:
More time taxiing closer to the expected 4DT location

Defined +/- 164 ft
Defined +/- 405 ft
Undefined Tolerance
Results

Percent Time the Ownship was in a given Distance Range

Percent Time Ownship within each +/- Distance Range (ft)

 +/- 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.