Flight Deck Surface Trajectory-Based Operations
David C. Foyle, Becky L. Hooey, NASA Ames Research Center
Deborah L. Bakowski, San Jose State University / NASA Ames

POCs:
David.Foyle@nasa.gov
Becky.L.Hooey@nasa.gov
Debi.Bakowski@nasa.gov

URL: http://humansystems.arc.nasa.gov/groups/HCSL
Mission:
• Develop *principled and robust procedures* and *user interfaces* with appropriate human-automation function allocation

• Develop *safe and efficient systems* that minimize pilots’ cognitive/visual workload and increase *situation awareness*

Research Focus Areas:
• Flight Deck Human Factors
• NextGen surface operations and departure concepts (25+ years)
• KCLT ATD-2 Integrated Arrival, Departure & Surface (IADS) demonstration project

NASA Ames Research Center
OVERVIEW

• Airport Surface Operations: Taxi-out/Departures and **Surface Trajectory-Based Operations** (STBO: taxi with time requirements)

• Continuum of Surface Operations:
  Manual $\rightarrow$ Automated $\rightarrow$ Autonomy

• Current-day; near-term and far-term STBO

• Research on Pilot/Flight deck STBO

• 4DT STBO: A candidate for autonomous operations
  - Research Issues
OVERVIEW
Surface Trajectory-Based Operations (STBO)

STBO = Adding time component to Surface Operations (taxi/departure)

- Current Day Surface Operations
- Current Day (EDCT – APREQ/CFR)
- Near-term (e.g., FAA STBO/NASA ATD2) - without flight deck component
- Future 4DT Surface Trajectory-based Operations (STBO) Vision (NASA/DLR) - with flight deck component

Increasing use of Time Information
Increasing Flight deck Coordination
Continuum of Surface Operations Technologies

Manual → Increased Automation → Autonomy

<table>
<thead>
<tr>
<th>Pilot(s) / Flight Deck</th>
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<tbody>
<tr>
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<td>Manual (Voice) w/ Decision Aids</td>
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<tr>
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<td>Autonomous STM</td>
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Continuum of Surface Operations Technologies
Manual $\rightarrow$ Increased Automation $\rightarrow$ Autonomy

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</table>
Current Day Surface Operations

**Flight Deck:**
1. Pushback Time

**ATC:**
1. Manage departure sequence

- Pilots manage pushback time to meet:
  - Scheduled departure/take-off time
Current Day (EDCT – APREQ/CFR)

**Flight Deck:**
1. Pushback Time

**ATC:**
1. Manage “wheels-up” time (EDCT - APREQ/CFR)

- Flight deck/pilots manage pushback time to meet:
  - “Wheels-up time”
- Flight deck/pilots have no information about:
  - Expected taxi time
  - Surface congestion
  - Departure queue size
## Continuum of Surface Operations Technologies

Manual → Increased Automation → Autonomy

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<td>FAA STBO / NASA ATD2</td>
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<td>Manual A/C Control w/ Display Aids</td>
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<td>Autonomous A/C Operations</td>
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</table>
Near-term (e.g., FAA STBO/NASA ATD2) - without flight deck component

**Flight Deck:**
1. Pushback

ATC/Ramp manages (with Decision Support Tools, DSTs):
1. Pushback (re: gate holds) – Target Off-Block Time (TOBT)
2. Target Airport Movement Area entry time (TMAT)
3. Target/Calculated Take-Off Time (TTOT/CTOT) re: Departure time or “wheels-up” time, EDCT - APREQ/CFR)

- Pilots manage pushback time to meet:
  - “Wheels-up time” (at KCLT, about 10% of flights)
- Pilots have no information about:
  - Expected taxi time
  - Surface congestion
  - Departure queue size
## Continuum of Surface Operations Technologies

Manual → Increased Automation → Autonomy

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### Controller: Manual/voice ops, manual sequencing/scheduling aids, manual deconfliction

### Pilot: Controls manually, infoDisplays for 4DT STBO

### Controller: Auto-routing, auto-deconfliction, auto-sequencing/scheduling, position timing

### Pilot: Controls manually, infoDisplays for 4DT STBO

**Note:** The table shows the progression from manual operations to autonomous operations, with decision aids and display aids becoming more automated. The NASA Flight Deck and SARDA STM are highlighted as examples of autonomous systems.
Future 4DT Surface Trajectory-based Operations (STBO) Vision (NASA/DLR) - with flight deck component

Hold at gates until taxi with minimal interruption is possible

4DT = Expected location + Allowable Deviation, at all Times, t

- Requirement to be at locations at specific time; defined \((x_t, y_t)\) with certain tolerance
- DLR TRACC Surface Management System dynamically creates conflict-free routes
- Coordination between Flight Deck – ATC/Ramp re: location and times

Transition from “first-come, first-served” operations

Maintain a very small runway queue

Transition from “first-come, first-served” operations

- Enables dynamic surface flow re-planning
- Enables increasingly precise taxi routing plans for improved surface traffic flow efficiency
- Flight deck component allows for coordination with ATC re: schedule issues (e.g., maintenance, FMS, weights/balances, RWY changes, etc.)
- Extension of FAA/NASA STBO concept
- Would enable aircraft traffic to continue rolling through Active RWY Crossings, instead of stopping aircraft and requiring ATC to do “batch” crossings of arrivals
- Facilitate timed runway take-off window conformance (+/- 5 min EDCTs, -2/+1 min AREQ/CFRs)
### 4DT STBO: Taxi Clearances w/ Speed Commands: Taxi Time-based Conformance

Summary HITL sim data from: *Foyle, Hooey, Bakowski & Kunkle, Int'l Journal of Aviation Psychology, 2015*

<table>
<thead>
<tr>
<th>Taxi Clearance</th>
<th>Required time of Arrival (RTA) Performance</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Non-specified acceleration/deceleration speed profile (n = 8 pilots)</td>
<td>Not able to achieve accurate RTAs</td>
<td>Slightly increased visual demand, as compared to baseline</td>
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| • Specified acceleration/deceleration profile (1kt/sec) | Good RTA performance | • Increased workload and visual demand  
  • 14/18 pilots rated “unsafe” |
| • Speed-conformance bound (+/- 1.5 kts) (n = 18 pilots) |                        |        |

- Taxiing Captain cannot “tightly control/track” speed, navigate, and maintain separation.
- “Open-loop” control compounds error

**ConOps Implications:**
- Incorporating speed into the taxi clearance alone is not sufficient for the performance/safety balance
- There is a requirement for human-centered flight deck display algorithms

**ATC**

“NASA 227, Taxi to RWY 17L via A, B, C at 14 kts”
“Closed-loop” speed control to specific airport locations

Taxi Clearance | Required time of Arrival (RTA) Performance | Safety
--- | --- | ---
Non-specified acceleration/deceleration speed profile (n = 8 pilots) | Not able to achieve accurate RTAs | Slightly increased visual demand, as compared to baseline
Specified acceleration/deceleration profile (1kt/sec) | Good RTA performance | Increased workload and visual demand • 14/18 pilots rated “unsafe”
Speed-conformance bound (+/- 1.5 kts) (n = 18 pilots) | Good RTA performance | Low visual demand

“3.5-DT” Speed Display (n = 8 pilots)
4DT STBO: Flight Deck Display Design/Philosophy

“3.5-DT” / 4DT Speed-based Flight Deck Display

• “Closed-loop” speed control to specific airport locations

s_t = d_{rem} / t_{rem}

Full 4DT Location-based Flight Deck Display
Bakowski, Hooey, Foyle, & Wolter, 2015, AHFE
Bakowski, Hooey, & Foyle, 2017, DASC

• Status-at-a-glance display to maximize ‘eyes-out’ time

• Enable strategic use – pilots do not need to track speed continuously (anywhere in pink band is ‘in conformance’)

• Display expected position with tolerance and allow pilots to use expertise to control aircraft (e.g., “human/pilot-centered”)
Continuum of Surface Operations Technologies
Manual → Increased Automation → Autonomy

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<td>Autonomous A/C Operations</td>
<td>Future</td>
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**TRACC**: “Taxi Routes for Aircraft: Creation and Controlling” Surface Management System – Germany’s DLR

- Creates conflict free routes/re-routes
- Non-Conformance within 50 m (164 ft) of deviation from expected x, y position
- Dynamic, multiple speed changes (up to 5) along taxi route

**Autonomous Surface Operations:**

- Enables 4DT STBO efficiencies
- Distributed architecture (Airport/Tower/Aircraft)
- Surface traffic manager
  - 4DT STBO operations (i.e., times at AMA entry, taxi merge points, rolling runway crossings, runway departure queue)
  - Routing/re-routing
  - Traffic de-confliction
- Candidate Auto-taxi propulsion
  - Wheel-bots
  - Electric tugs
  - Auto-taxi aircraft
**TRACC**: “Taxi Routes for Aircraft: Creation and Controlling” Surface Management System – Germany’s DLR
- Creates conflict free routes/re-routes
- Non-Conformance within 50 m (164 ft) of deviation from expected x, y position
- Dynamic, multiple speed changes (up to 5) along taxi route

**Autonomous Surface Operations:**
Candidate initial architecture (NASA/DLR Concept):
- **Ground/Tower**: Surface Traffic Management
  - Issue STBO Clearances (Routes w/ times)
  - Re-routing for efficiency or non-conformance
  - Traffic deconfliction
- **Aircraft**:
  - Aircraft navigation
  - Aircraft movement (steering, speeds, turns)
  - Additional On-board Conflict Detection and Resolution (CD&R)

<table>
<thead>
<tr>
<th>Function</th>
<th>ATC</th>
<th>Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduling</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Routing</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Deconfliction</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Execution</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
STBO with Autonomous flight deck component
Pilot(s) responsible for aircraft/crew & passenger safety

Enabling Pilots/Flight deck Situation Awareness
Need for “status-at-a-glance” awareness and intent displays

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</tr>
<tr>
<td></td>
<td>Manual</td>
</tr>
<tr>
<td>Manual / Aided</td>
<td>Manual / Aided</td>
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STBO with Autonomous flight deck component
Pilot(s) responsible for aircraft/crew & passenger safety
Enabling Pilots/Flight deck Situation Awareness
Need for “status-at-a-glance” awareness and intent displays

Re-routing Pending
Bakowski, Foyle, Hooey, Meyer & Wolter, AHFE 2012

Current route with Other Traffic HOLD
Bakowski, Hooey, Foyle, Wolter & Cheng, DASC 2013
STBO with Autonomous flight deck component
Pilot(s) responsible for aircraft/crew & passenger safety
Enabling Pilots/Flight deck Situation Awareness and Flight Deck workflow/procedure integration

Research issues, re: Pilot roles:
- Taxi clearance (how to load? pilot approve if auto-load?)
- 4DT STBO – speed/time updates (approve? Auto-load?)
- Departing Runway (changes, FMS, weights, temps, etc)
- Runway crossings, “wheels-up” times
- Braking – hot brakes (take-off abort)
  - Airports are not flat; KCLT, DFW varies 50ft
    - 747-8 *[1 Million lbs]* fully loaded
- Monitoring:  - Traffic (aircraft, pedestrian, vehicle) – Separation assurance
  - Ownship aircraft intent (stopping, turning, waiting to cross active runway)
- (Non) Conformance:  - Mid-taxi stopping / abort – FMS, passengers, weights
  - For 4DT STBO – interactions re: dynamic STM system; # updates
- Pilot Intervention? Revert to manual or abort taxi, or unable to make time b/c of flight deck, equipment, passenger, baggage, etc. issues
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URL:  http://humansystems.arc.nasa.gov/groups/HCSL
Additional Slides
4DT Flight-Deck Display

- Cleared-to-Taxi Route
- 4DT with allowable deviation
- Ownship
- Taxi Route

**Diagram Details:**
- GS 19
- DAL132
- AAL154
- K > EK > L > EH
- Start 23:08:06
- 14 KTS
- Queue 23:13:36
STBO with flight deck component and Information Sharing Displays
Enables better flight deck workflow prior to departure

“For NextGen time-based operations, how useful were the following pieces of information in supporting time-based taxi (your ability to meet your takeoff time?)”

<table>
<thead>
<tr>
<th>Information Source</th>
<th>Not at all</th>
<th>Border-line</th>
<th>Very much</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assigned Pushback time</td>
<td>-</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Spot-release time</td>
<td>1</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Takeoff Time</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Departure Sequence</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Speed Advisory on PFD</td>
<td>-</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Time Remaining to Takeoff Time</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
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</table>

ATC-Pilot HITL Sim: Foyle, Bakowski, Hooey, Cheng & Wolter, HCI-Aero, 2014)
David Foyle, PhD, NASA
Becky Hooey, PhD, NASA
Debi Bakowski, MS SJSU
Glenn Meyer, MA Dell
Capt. Rob Koteskey, MA

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David.Foyle@nasa.gov
650-604-3053
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650-604-2399

URL: http://humansystems.arc.nasa.gov/groups/HCSL
Flight Deck Pilot-in-the-Loop 4DT Studies
Human-Centered Systems Lab (HCSL)

Proof-of-Concept Study (2014)

- Proof-of-concept simulation.
- Demonstrated the feasibility of the 4DT concept, from the pilot's perspective.

4DT Display Comparison Study (2016)

- Compared 4DT display formats.
- More robust operating conditions than 2014 study.
  - 4DT speed updates
  - Range of taxi speeds
- Several parameters based on the TRACC system.

Bakowski, Hooey, Foyle, & Wolter
Applied Human Factors and Ergonomics (AHFE 2015)

Bakowski, Hooey, & Foyle
Digital Avionics Systems Conference (DASC 2017)
Out-the-Window View
- 4 LCD Displays
- 140° viewing angle

Airport Moving Map (AMM)

EICAS

PFD (Inactive)

Clock

EICAS

CDU

DataComm Interface

Airport and Terminal Area Simulator (ATAS)
Human-Centered Systems Lab (HCSL)

Eyetracker Cameras (4) (Smart Eye Pro)

Tiller

B737NG aircraft
Flight Deck 4DT Proof-of-Concept Study (2014)

Airport Moving Map (AMM)

Ownship's Ground Speed

Traffic displayed within de-clutter circle
Flight Deck 4DT Proof-of-Concept Study (2014)

Airport Moving Map (AMM) Augmented with 4DT Clearance Information

- Ownship's Ground Speed
- 4DT Reference Markers (expected 4DT location)
- Ownship
- Cleared-to-Taxi Route (spot to runway)
- Allowable 4DT Tolerance (ownship's "real estate")
- Traffic displayed within de-clutter circle
- 4DT Clearance Text

K > K8 > L > B > F > WP
Start 18:46:43  16 KTS  Queue 18:55:10
# Flight Deck 4DT Proof-of-Concept Study (2014)

<table>
<thead>
<tr>
<th>Condition</th>
<th>ATC Schedule Information</th>
<th>Required Speed</th>
<th>Allowable Deviation</th>
<th>Flight Deck Display</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition 1</strong>&lt;br&gt;Current-Day Flight Deck Equipage</td>
<td>Pushback Begin Taxi</td>
<td>Not Specified</td>
<td>Not Specified</td>
<td>![Image]</td>
</tr>
<tr>
<td><strong>Condition 2</strong>&lt;br&gt;Speed Advisory</td>
<td>Pushback Begin Taxi</td>
<td>ATC-issued Speed</td>
<td>Not Specified</td>
<td>![Image]</td>
</tr>
<tr>
<td><strong>Condition 3</strong>&lt;br&gt;4DT +/- 15 sec</td>
<td>4DT Speed Profile</td>
<td>4DT Speed Profile</td>
<td>+/- 15 sec</td>
<td>![Image]</td>
</tr>
<tr>
<td><strong>Condition 4</strong>&lt;br&gt;4DT +/- 30 sec</td>
<td>4DT Speed Profile</td>
<td>4DT Speed Profile</td>
<td>+/- 30 sec</td>
<td>![Image]</td>
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Flight Deck 4DT Proof-of-Concept Study (2014)

14 kts \times \text{ +/- 30 sec} = \text{ +/- 216 m
Distance (Length) of Allowable 4DT Tolerance Band

Time-based allowable tolerance band (speed $\times$ time = distance)
Flight Deck 4DT Proof-of-Concept Study (2014)

- Dallas/Fort Worth Airport (DFW)
- 13 Captains
- Experimenter First Officer
  - assisted with navigation, DataComm
- 12 experimental trials
  - 4 experimental conditions
  - 3 speed/route combinations
  - practice trials before each block
  - 2 4DT conditions always last
- Spot and Runway Departure Advisor (SARDA):
  - surface management system
  - ran in closed-loop mode
  - triggered Pushback and Taxi
  - queue-entry derived from ToT
  - SARDA traffic appeared OTW

<table>
<thead>
<tr>
<th>Route 1</th>
<th>Route 2</th>
<th>Route 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4DT Speed 14 kts</td>
<td>4DT Speed 15 kts</td>
<td>4DT Speed 16 kts</td>
</tr>
</tbody>
</table>

- Spot and Runway Departure Advisor (SARDA):
Flight Deck 4DT Proof-of-Concept Study (2014)

4DT Straightaway Speed was held constant in each trial
e.g., 14 kts

4DT Acceleration /Deceleration Rate
1 kt per sec

Beginning of 4DT Taxi
Entering/Exiting Turns

4DT Start
Ramp Spot
Transition from Ramp to AMA

4DT End
Queue-Entry

Runway 17R

Dallas/Fort Worth Airport

4DT Turn Speed
10 kts

*Time-based tolerance band
Example Trial
"ATS227, Pushback and Taxi to Spot 47."

Terminal E at DFW

Ownship

Ramp Departure Spots

Ramp Area

Queue Area

Queue Entry

4DT Start Time

Taxi Clr

Pushback

Ownship

Terminal E at DFW

Ramp Departure Spots

Ramp Area
Flight Deck 4DT Proof-of-Concept Study (2014)
Flight Deck 4DT Proof-of-Concept Study (2014)

4DT Clearance Information (cyan until 4DT Start Time)

Queue Area

Queue Entry

4DT Start Time

TaxiClr

Cleared-to-Taxi Route

4DT Info

4DT Tolerance Band

Pushback

Joint Workshop for DLR – NASA ATM Research Collaboration August 22 – 24, 2017
Flight Deck 4DT Proof-of-Concept Study (2014)

• 4DT Start Time: 30 sec after Taxi Clearance.
• Defined by the 4DT speed profile.
• Auditory Chime and 4DT information turns magenta.
• Pilot enters the AMA and begins to taxi.
Flight Deck 4DT Proof-of-Concept Study (2014)

- 4DT Tolerance Band accelerates from 0 kts to 14 kts at 1 kt per sec.

- Pilot Instructions:
  - In compliance with the 4DT clearance when the ownship icon is within the tolerance band.
  - No need to track the 4DT reference markers precisely.
Flight Deck 4DT Proof-of-Concept Study (2014)

• 4DT straightaway speed held constant during each trial.
Flight Deck 4DT Proof-of-Concept Study (2014)

- 4DT speed in turns was 10 kts.
- Distance-based tolerance band.

Decelerate
14 kts → 10 kts
@ 1 kt per sec

Turn
10 kts

Accelerate
10 kts → 14 kts
@ 1 kt per sec
Flight Deck 4DT Proof-of-Concept Study (2014)

- End of 4DT taxi route at the queue-entry point.
- Upon reaching the queue entry, the tolerance band disappeared.
- Pilot enters the queue area at a safe speed and lines up behind any aircraft at the runway hold line.
Flight Deck 4DT Proof-of-Concept Study (2014)

- A verbal speed command, alone, may not support adequate 4DT conformance along the taxi route.
- Flight deck display required to aid pilots in conforming to the 4DT.
Flight Deck 4DT Proof-of-Concept Study (2014)

- A verbal speed command, alone, may not support adequate 4DT conformance along the taxi route.
- Flight deck display required to aid pilots in conforming to the 4DT.

+/- 15 sec 4DT Tolerance Condition

AMM augmented with graphical representation of allowable 4DT deviation

Based Deviations from Expected Position (sec)
Flight Deck 4DT Proof-of-Concept Study (2014)

- A verbal speed command, alone, may not support adequate 4DT conformance along the taxi route.
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# Flight Deck Pilot-in-the-Loop 4DT Studies

**Human-Centered Systems Lab (HCSL)**

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<th>4DT Display Comparison Study (2016)</th>
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<td>Allowable 4DT Deviation Band</td>
<td>Time-Based Band</td>
<td>Distance-Based Band</td>
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<tr>
<td>4DT Straightaway Speed</td>
<td>Held constant within each trial</td>
<td>4DT Speed Changes Mid-Taxi</td>
</tr>
<tr>
<td>4DT Speeds</td>
<td>14, 15, or 16 kts</td>
<td>Range of Realistic Taxi Speeds 8 kts – 25 kts</td>
</tr>
<tr>
<td>Start of 4DT Taxi Route</td>
<td>Ramp Spot</td>
<td>Near the Terminal</td>
</tr>
<tr>
<td>Airport</td>
<td>Dallas/Fort Worth Airport (DFW)</td>
<td>Charlotte Douglas Airport (KCLT)</td>
</tr>
<tr>
<td>Condition</td>
<td>4DT Conformance</td>
<td>Allowable Deviation</td>
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<tr>
<td>-----------</td>
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</tr>
<tr>
<td>Condition 1</td>
<td>Defined Conformance</td>
<td>+/- 50 m</td>
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<tr>
<td>4DT +/- 50 m</td>
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<td></td>
</tr>
<tr>
<td>Condition 2</td>
<td>Defined Conformance</td>
<td>+/- 123 m</td>
</tr>
<tr>
<td>4DT +/- 123 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition 3</td>
<td>Undefined Conformance</td>
<td>Undefined</td>
</tr>
<tr>
<td>4DT Undefined Conformance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Flight Deck 4DT Display Comparison Study (2016)**

**Defined-Tolerance Display Format (Distance-Based Band)**

- Defined Tolerance Instructions:
  - 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.

---

18L via M > C

<table>
<thead>
<tr>
<th>FWD TAXI</th>
<th>12:05:30</th>
<th>10 KTS</th>
<th>TTOT 12:12:00</th>
</tr>
</thead>
</table>

18L via M > C

<table>
<thead>
<tr>
<th>START</th>
<th>12:05:30</th>
<th>15 KTS</th>
<th>TTOT 12:11:00</th>
</tr>
</thead>
</table>
**Undefined-Tolerance Display Format**

- 4DT indicator: Light pink dot.
- Allowable tolerance was undefined.
- Undefined tolerance display format instructions:
  - "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.
- No need to track the 4DT indicator (dot) precisely.
Flight Deck 4DT Display Comparison Study (2016)

4DT Acceleration/Deceleration Rate
1 kt per sec

Beginning of 4DT Taxi
4DT Speed Changes
14 kt turn in the AMA

Turn Speed = 14 kts in the AMA

Charlotte Douglas Airport

4DT Start
Ramp, Near Terminal

AMA Entrance
(one, continuous, clearance Ramp to RWY Queue)

Queue-Entry

4DT End

RWY 18L

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**Flight Deck 4DT Display Comparison Study (2016)**

### 4DT Speed Changes

- 2 or 5 per Trial

### 4DT Speeds

- 8 kts – 25 kts
- 'Slow' or 'Fast' Average Speed

<table>
<thead>
<tr>
<th>Ramp</th>
<th>AMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow</td>
<td>10 kts</td>
</tr>
<tr>
<td>Fast</td>
<td>13 kts</td>
</tr>
</tbody>
</table>

**Example Trial:**

- 5 4DT Speed Changes
- 'Fast' Speed

![Queue-Entry](image)
Flight Deck 4DT Display Comparison Study (2016)

- Charlotte Douglas Airport (KCLT)
- 12 Pilots
- Experimenter First Officer
  - assisted with navigation, DataComm
- 12 experimental trials
  - 3 4DT Display Formats:
    - blocked and counterbalanced
    - practice trial before each block
- Taxi Routing for Aircraft: Creation and Controlling (TRACC) (DLR)
  - prototype surface management system
  - parameters from simulation analysis
  - two or five speed changes
  - +/- 50 m (smaller tolerance band)

- These four trials repeated in each of the three 4DT Display Format conditions.
Example Trial
Flight Deck 4DT Display Comparison Study (2016)
Flight Deck 4DT Display Comparison Study (2016)

Queue Area

Ownship at Concourse A

Cleared-to-Taxi Route (Ramp to Queue)

4DT Clearance Information (cyan until 4DT Start Time)

4DT Info

4DT Start Time

Queue Entry

Taxi Clr

Speed Changes

Pushback (TOBT)

4DT Start Time

4DT Info
Flight Deck 4DT Display Comparison Study (2016)

- At Target Off-Block Time (TOBT)
Flight Deck 4DT Display Comparison Study (2016)

Queue Entry

Queue Area

Taxi Clr

Speed Changes

Pushback (TOBT)

4DT Start Time

4DT Tolerance Band (or dot)

Cleared-to-Taxi Route

Ownship

4DT Start Time

Range: 5X 4X 3X 2X 1X RMP OVR

18L via M > C

FWD TAXI 12:05:30 00 KTS TTOT 12:12:00

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Flight Deck 4DT Display Comparison Study (2016)

- 4DT Start Time (defined by the 4DT speed profile).
- Auditory Chime and 4DT information turns magenta.
- Pilot begins to taxi.
- 4DT tolerance band (or dot) accelerates from 0 kts to 11 kts at 1 kt per sec.
Flight Deck 4DT Display Comparison Study (2016)

- 4DT speed changes were accompanied by an auditory tone.
- AMM text display updated.
- First Officer: "Speed Change".
- Two or five speed changes per trial.
- At predetermined locations.
Flight Deck 4DT Display Comparison Study (2016)

- End of 4DT taxi route at the queue-entry point.
- Upon reaching the queue entry, the tolerance band disappeared.
• Pilot enters the queue area at a safe speed and lines up behind any aircraft at the runway hold line.
Flight Deck 4DT Display Comparison Study (2016)

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

Percent Time

50  100  150  200  250  300  350  400  450
+/- Distance (ft)

+/- 164 ft
Band: 93.37%

+/- 405 ft
(+/- 123 m)
Band: 99.71%
Flight Deck 4DT Display Comparison Study (2016)

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

- +/- 164 ft ( +/- 50 m)
  Band: 93.37%
- +/- 405 ft
  Band: 99.71%

AMM augmented with graphical representation of defined allowable 4DT deviation

 +/- 123 m 4DT Defined Tolerance
Flight Deck 4DT Display Comparison Study (2016)

+/- 50 m 4DT Defined Tolerance
AMM augmented with graphical representation of defined allowable 4DT deviation

+/- 164 ft (+/- 50 m)
Band: 93.37%

+/- 405 ft (+/- 123 m)
Band: 99.71%

+/- 123 m 4DT Defined Tolerance
AMM augmented with graphical representation of defined allowable 4DT deviation
Distance between the ownship and the expected 4DT location.
Pilots spent more time taxiing closer to the expected 4DT location in this condition than in either the larger or undefined-tolerance conditions.
Pilots spent more time taxiing closer to the expected 4DT location in this condition than in either the larger or undefined-tolerance conditions.
Backup Slides
Flight Deck 4DT Proof-of-Concept Study (2014)

DataComm Touchscreen Interface Display

🎵 DataComm Accompanied by Auditory Chime

Call Sign
RWY
Taxi Route

4DT Schedule Information

Touchscreen Response Buttons
(First Officer)

♫

DataComm
Accompanied by
Auditory Chime

23:07:36 Z
FROM DFW

OPEN

ATS227 TAXI TO
RWY 17R
VIA K EK L EH
START 23:08:06
QUEUE 23:13:36

COMM OK

UNABLE STBY WILCO

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Flight Deck 4DT Proof-of-Concept Study (2014)

Out-the-Window (Ramp Departure Spots) at DFW

#’d Ramp Departure Spots
Flight Deck 4DT Proof-of-Concept Study (2014)

Queue Entry
4DT Indicator disappears.

Queue Area
Aircraft continues taxiing to RWY hold line.

4DT Start Time
4DT Indicator begins to move. Pilot enters the AMA and begins taxi.

Taxi Clearance
At the spot, the flight deck receives the Taxi Clearance, via DataComm.

Pushback
Verbal clearance to pushback and taxi to Ramp Spot.
Flight Deck 4DT Proof-of-Concept Study (2014)

- Time of Arrival (TOA) variability at the queue-entry point (seconds).
- The TOA range was reduced by providing pilots a verbal speed in the Speed-Advisory condition, and further reduced in the two 4DT conditions.

<table>
<thead>
<tr>
<th>Route</th>
<th>Current-Day Equipage Mean (sec)</th>
<th>Speed Advisory Mean (sec)</th>
<th>4DT +/-30 sec Mean (sec)</th>
<th>4DT +/-15 sec Mean (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East/14 kts</td>
<td>300 s</td>
<td>349 s</td>
<td>325 s</td>
<td>327 s</td>
</tr>
</tbody>
</table>

Box and Whisker plots for the West1/15kts and West2/16kts routes followed a similar pattern.
Pilots spent more time taxiing closer to the expected 4DT location in this condition than in either the larger or undefined-tolerance conditions.