Towards Autonomous Airport Surface Operations: NextGen Flight Deck Implications

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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
OVERVIEW

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

• Continuum of Surface Operations: Manual \(\rightarrow\) Aided \(\rightarrow\) 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 Manual → Autonomy

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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
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
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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
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<td>NASA Flight Deck / SARDA STM</td>
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<td>Autonomous A/C Operations</td>
<td>NASA Flight Deck / DLR STM</td>
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**Controller**:
- Manual/voice ops, manual sequencing/scheduling aids, manual deconfliction
- Auto-routing, auto-deconfliction, auto-sequencing/scheduling, position timing

**Pilot**:
- Controls manually, info/displays for 4DT STBO
- Controls manually, info/displays for 4DT STBO
Future 4DT Surface Trajectory-based Operations (STBO) Vision (NASA/DLR) - with flight deck component


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

Hold at gates until taxi with minimal interruption is possible

Apron / Ramp

Co1 Co2 Co3 Co4 Co5 Co6 Co7 Co8

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

Maintain a very small runway queue

- 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
Future 4DT Surface Trajectory-based Operations (STBO) Vision (NASA/DLR) - with flight deck component

- 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 APREQ/CFRs)
<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>
</tr>
<tr>
<td>• Specified acceleration/deceleration profile (1kt/sec)</td>
<td>Good RTA performance</td>
<td>• Increased workload and visual demand</td>
</tr>
<tr>
<td>• Speed-conformance bound (+/- 1.5 kts) (n = 18 pilots)</td>
<td></td>
<td>• 14/18 pilots rated “unsafe”</td>
</tr>
</tbody>
</table>

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

**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


“NASA 227, Taxi to RWY 17L via A, B, C at 14 kts”
• **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”)
Two allowable conformance deviation sizes were used:

+/- 164 ft and +/- 405 ft
4DT Surface Trajectory-Based Operations (STBO)

HITL Sim: Bakowski, Hooey, & Foyle, 2017 (Preliminary Analysis)

- Emulated DLR TRACC 4DT STM system
  - Taxi Routes for Aircraft: Creation and Controlling” Surface Management System
  - 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

- Flight Deck/Pilot Manual Control:
  Steering (tiller/rudder), Navigation, speed (thrust/brakes), other flight deck tasks (checklists, callouts, 2\textsuperscript{nd} engine start)

- Map Display with Route and Allowable Deviation

- Position/time ($x_t$, $y_t$) Conformance >90% but decrease with smaller allowable deviation (+/- 164 ft)

- “Eyes-in” time higher, but rated “safe” and “acceptable”

- Safety rating: 4.7 (out of 5) for +/- 164 ft
  4.9 (out of 5) for +/- 405 ft

- Acceptability rating: 4.2 (out of 5) for +/- 164 ft
  4.3 (out of 5) for +/- 405 ft

\textbf{4DT Allowable Deviation}

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<table>
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<th>Deviation</th>
<th>Safety Rating</th>
<th>Acceptability Rating</th>
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<td>+/- 164 ft</td>
<td>4.7</td>
<td>4.2</td>
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<td>4.3</td>
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*p < .05*
4DT Surface Trajectory-Based Operations (STBO)

HITL Sim: Bakowski, Hooey, & Foyle, 2017
(Preliminary Analysis)

Robustness:
- Flight deck interruptions, off-nominals, FMS/equipment problems, etc
- System/integration implications -- speed changes, dynamic updates
- Candidate for automation/autonomous aircraft control during taxi operations

% Time in Conformance

- “Eyes-in” time: 37% for +/- 164 ft
  35% for +/- 405 ft
  29%* for Speed Clearances & Map
  19%* with Map

*HITL Sim: Bakowski, Hooey, Foyle, & Wolter, AHFE, 2015

- Safety rating: 4.7 (out of 5) for +/- 164 ft
  4.9 (out of 5) for +/- 405 ft

- Acceptability rating: 4.2 (out of 5) for +/- 164 ft
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Robustness:
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4DT Allowable Deviation

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<td>Future</td>
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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)

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**TRACC:** “Taxi Routes for Aircraft: Creation and Controlling” Surface Management System – Germany’s DLR
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<th>Function</th>
<th>ATC</th>
<th>Aircraft</th>
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<tbody>
<tr>
<td>Scheduling</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Routing</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Deconfliction</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Execution</td>
<td></td>
<td>X</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

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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

Current route with Other Traffic HOLD
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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Additional Slides
4DT Flight-Deck Display

Cleared-to-Taxi Route

4DT with allowable deviation

Ownship

Taxi Route

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>
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<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>1</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>2</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>
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ATC-Pilot HITL Sim: Foyle, Bakowski, Hooey, Cheng & Wolter, HCI-Aero, 2014)
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