NASA Ames Research Center



# Towards Autonomous Airport Surface Operations: NextGen Flight Deck Implications

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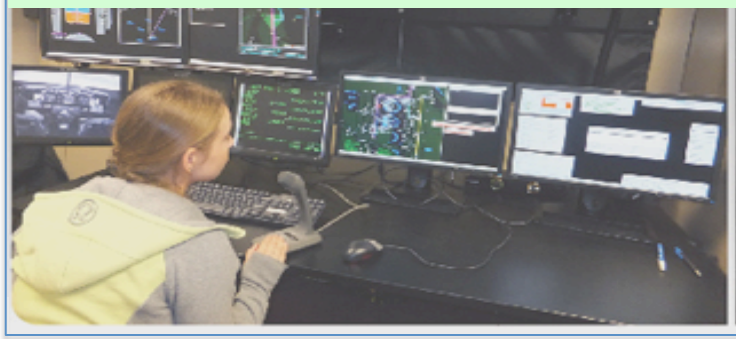

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Human Systems integration division

**URL: http://humansystems.arc.nasa.gov/groups/HCSL**

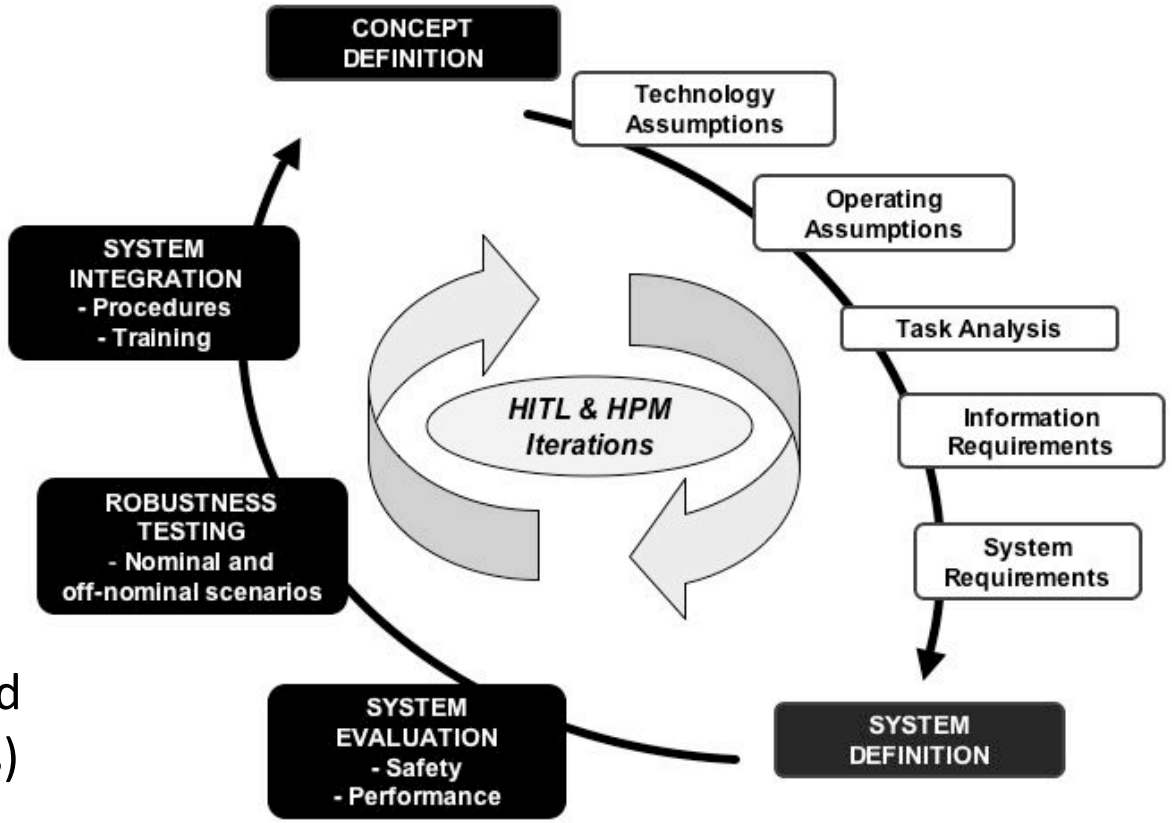
## Mission:

- 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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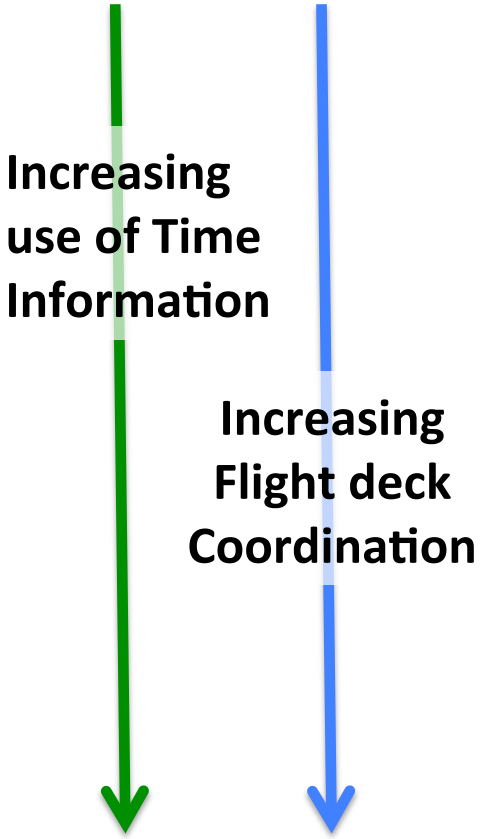
# OVERVIEW

- Airport Surface Operations: Taxi-out/Departures and **Surface Trajectory-Based Operations** (STBO: taxi with time requirements)
- Continuum of Surface Operations:
  Manual → Aided → 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)

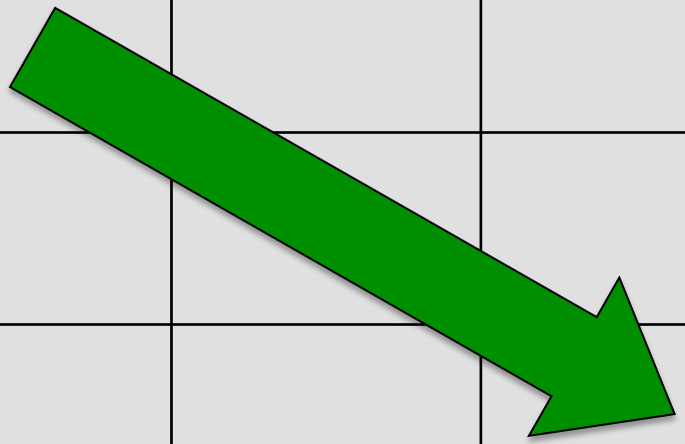
**STBO = Adding time component to Surface Operations (taxi/departure)**




- 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

# Continuum of Surface Operations Manual → Autonomy

| | | ATC / Surface Traffic Manager (STM) | | |
|---|---|---|---|---|
| | | Manual (Voice) | Manual (Voice) w/ Decision Aids | Autonomous STM |
| Pilot(s) / Flight Deck | Manual A/C Control | | | |
| | Manual A/C Control w/ Display Aids | | | |
| | Autonomous A/C Operations | | | |



# Continuum of Surface Operations Manual → Autonomy

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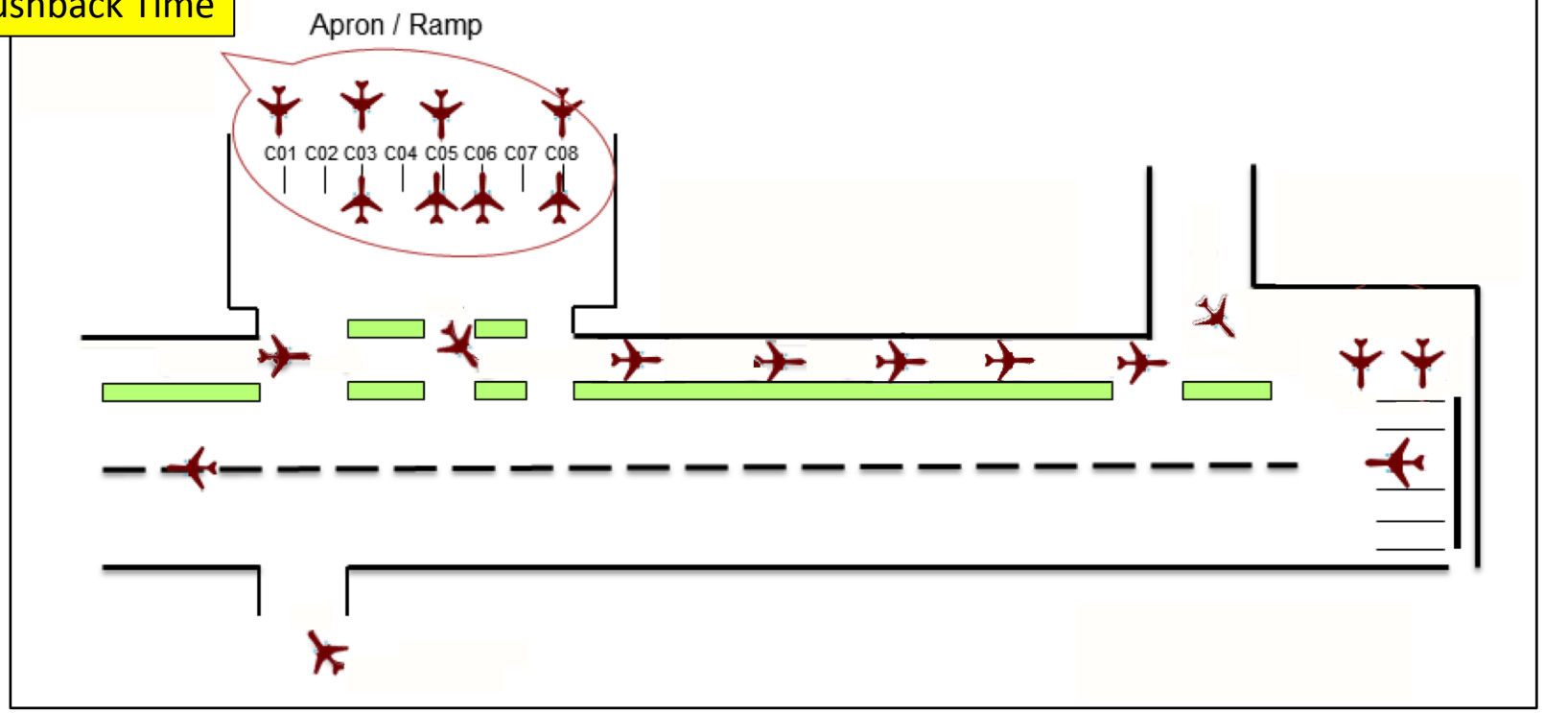
|---|---|---|---|---|
| | | Manual (Voice) | Manual (Voice) w/ Decision Aids | Autonomous STM |
| Pilot(s) / Flight Deck | Manual A/C Control | Current Day | | |
| | Manual A/C Control w/ Display Aids | | | |
| | Autonomous A/C Operations | | | |

# Current Day Surface Operations

**Flight Deck:**
1. Pushback Time

**ATC:**
1. Manage departure sequence

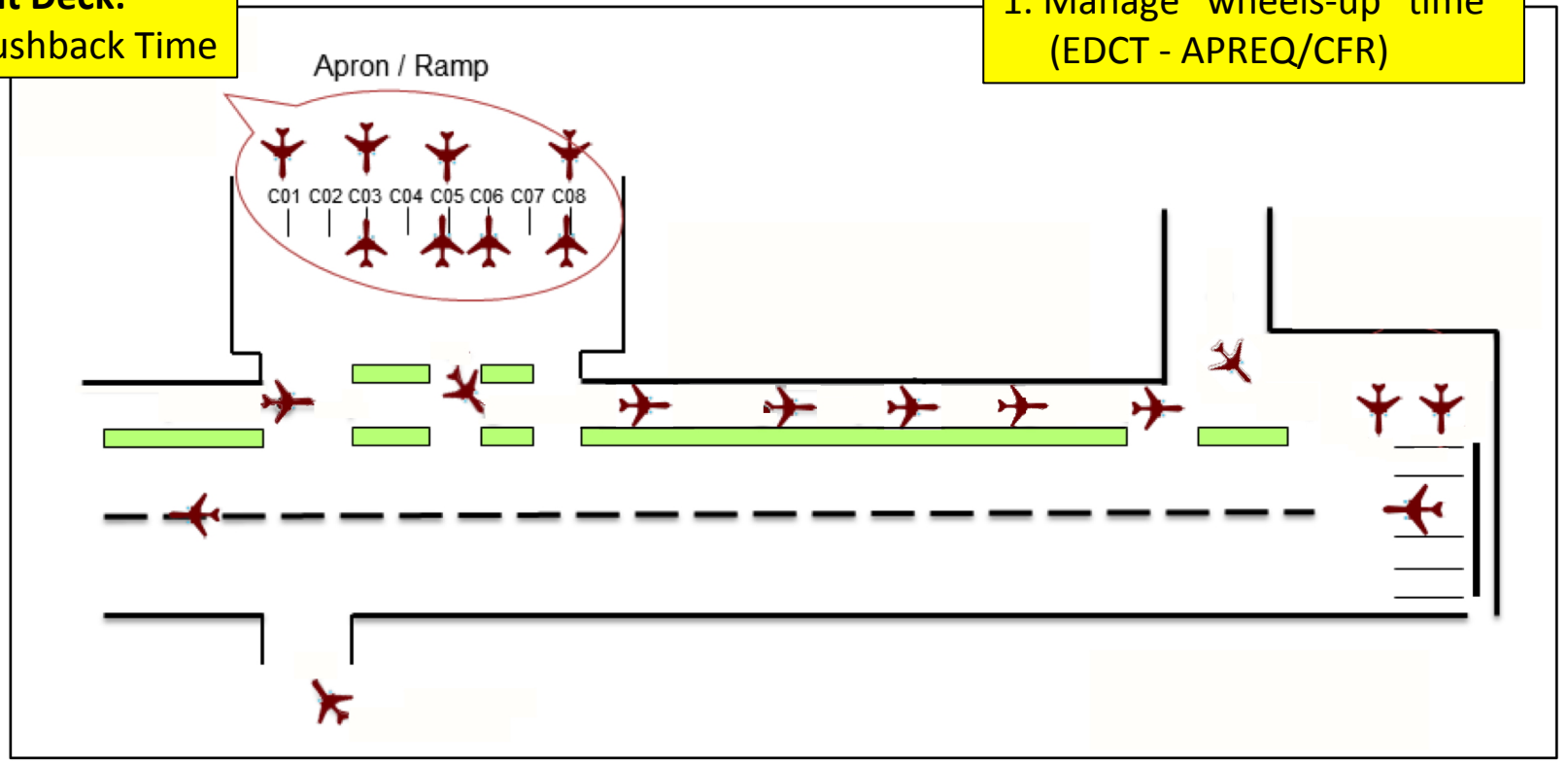



- Pilots manage pushback time to meet:
  - Scheduled departure/take-off time

# 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

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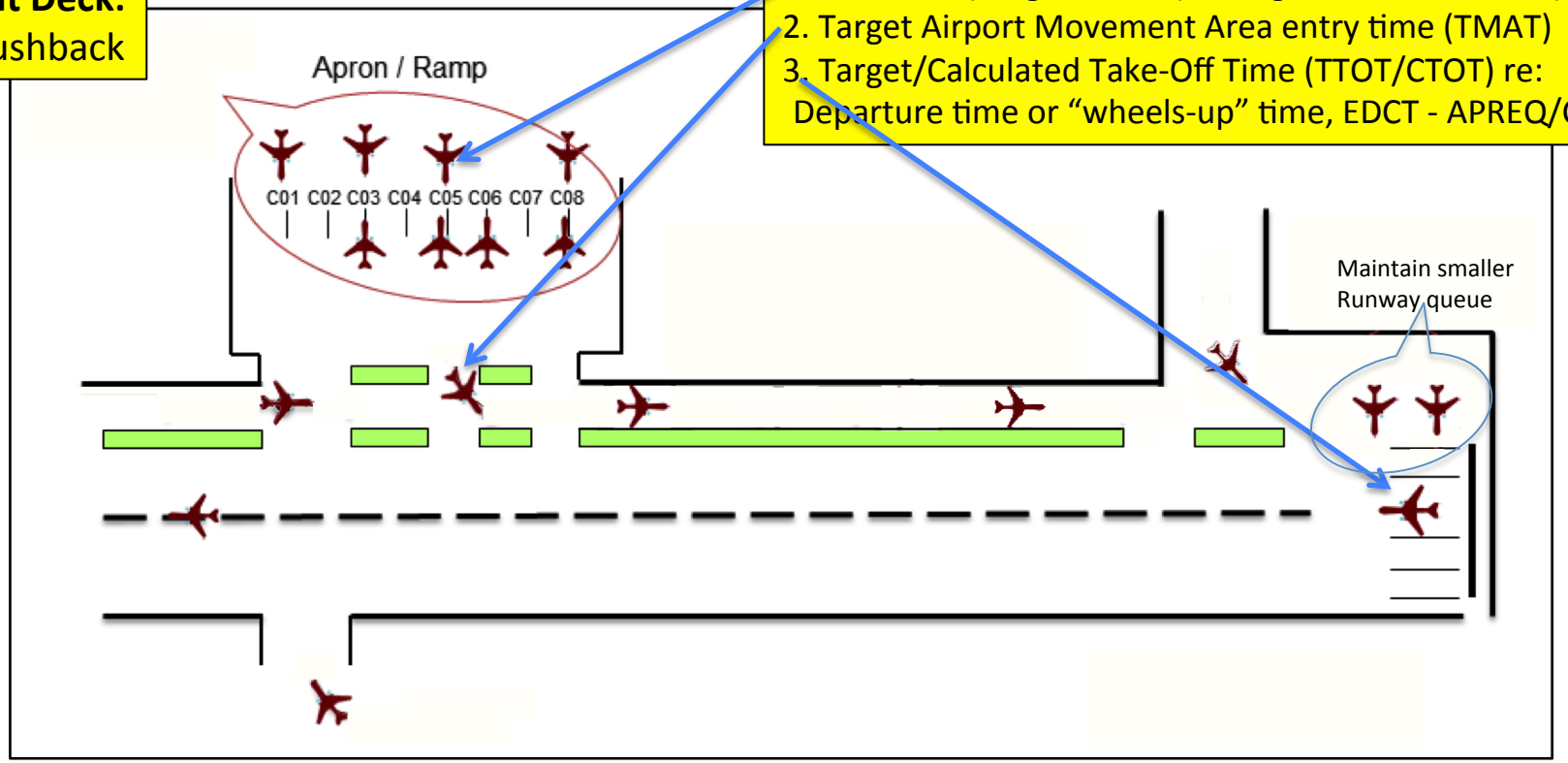
| | | Manual (Voice) | Manual (Voice) w/ Decision Aids | Autonomous STM |
| Pilot(s) / Flight Deck | Manual A/C Control | | FAA STBO / NASA ATD2 | |
| | Manual A/C Control w/ Display Aids | | | |
| | Autonomous A/C Operations | | | |

# 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 Manual → Autonomy

| | | ATC / Surface Traffic Manager (STM) | | |
|---|---|---|---|---|
| | | **Manual (Voice)** | **Manual (Voice) w/ Decision Aids** | **Autonomous STM** |
| **Pilot(s) / Flight Deck** | **Manual A/C Control** | | | |
| | **Manual A/C Control w/ Display Aids** | | NASA Flight Deck / SARDA STM | NASA Flight Deck / DLR STM |
| | **Autonomous A/C Operations** | | | |

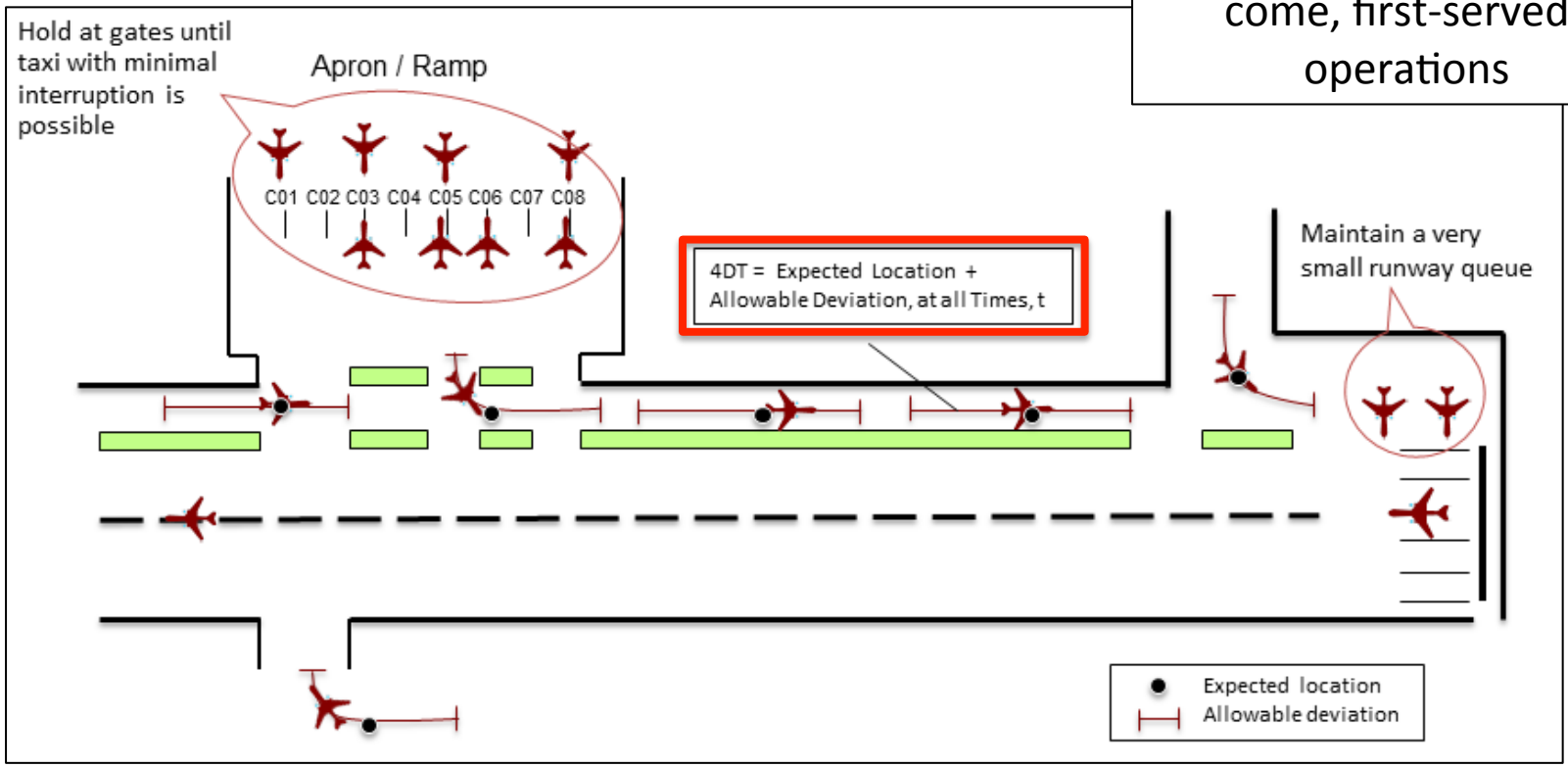
- Controller: Manual/voice ops, manual sequencing/ scheduling aids, manual deconfliction
- Pilot: Controls manually, info/displays for 4DT STBO

- Controller: Auto-routing, auto-deconfliction, auto-sequencing/scheduling, position timing
- Pilot: Controls manually, info/displays for 4DT STBO

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

*Okuniak, Gerdes, Jakobi, Ludwig, Hooey, Foyle, Jung, & Zhu, AIAA/ATIO 2016 Conference, DLR/NASA Concept of Operations for Trajectory-based Taxi Operations*

Transition from "first-come, first-served" operations




- 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

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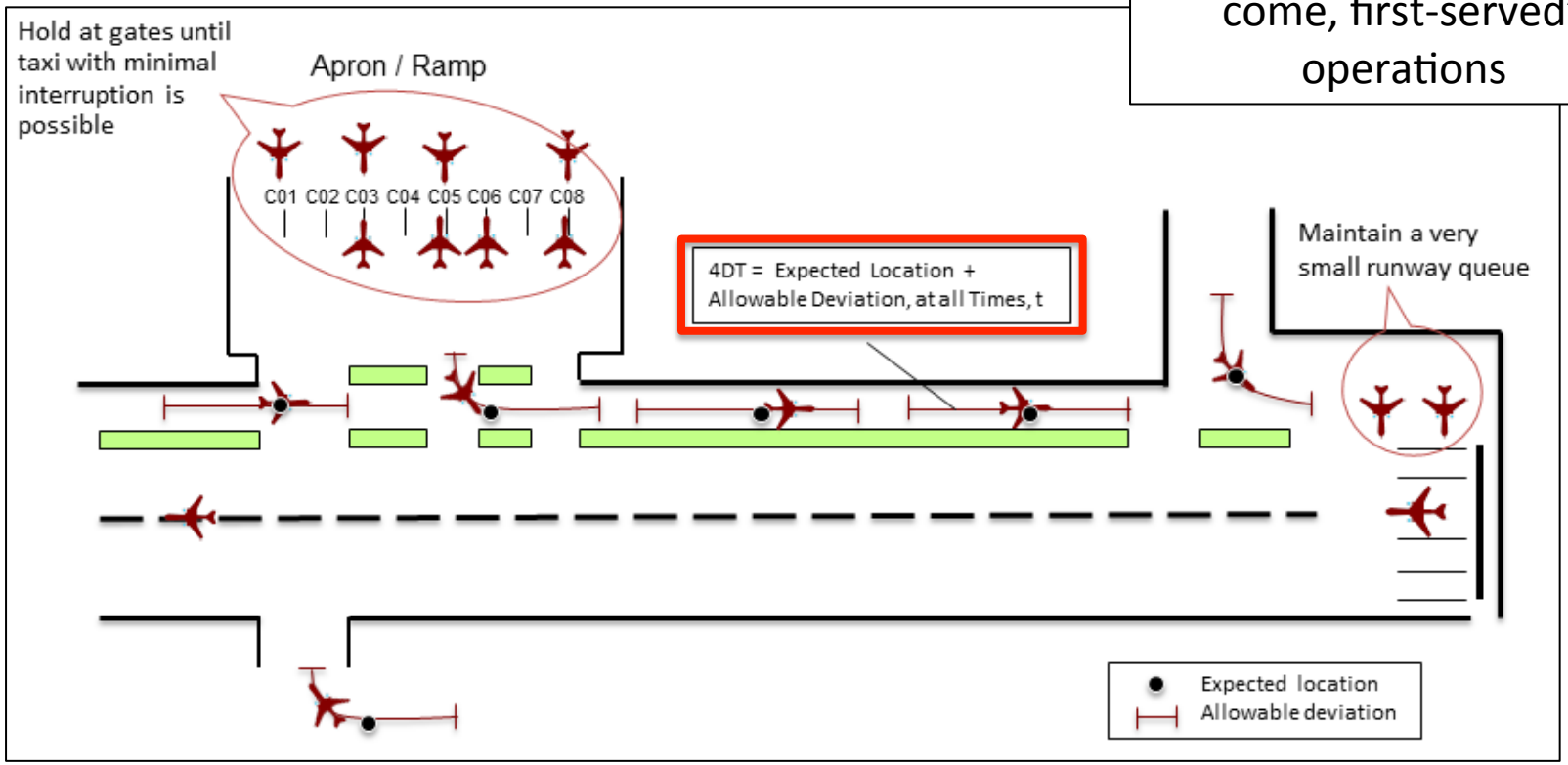
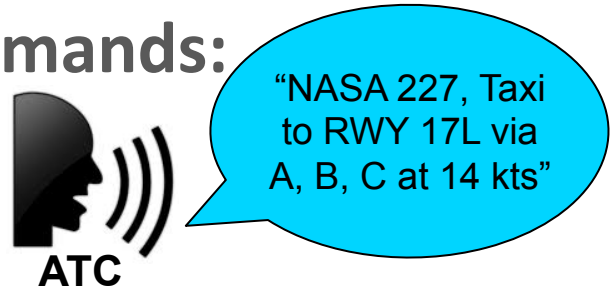



- Enables dynamic surface flow re-planning
- Enables increasingly precise taxi routing plans for improved surface traffic flow efficiency
- Flight deck component allows for coordination with ATC re: schedule issues (e.g., maintenance, FMS, weights/balances, RWY changes, etc.)
- Extension of FAA/NASA 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)

# 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*




| 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)<br>• Speed-conformance bound (+/- 1.5 kts) (n = 18 pilots) | **Good RTA performance** | **• Increased workload and visual demand**<br>**• 14/18 pilots rated "unsafe"** |

- 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

# 4DT STBO: Flight Deck Display Design/Philosophy

*Bakowski, Hooey, Foyle, & Wolter, 2015, AHFE*
*Bakowski, Hooey, & Foyle, 2017*

- **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")

# 4DT STBO: Flight Deck Display Design/Philosophy

*HITL Simulation: Bakowski, Hooey, & Foyle, 2017*

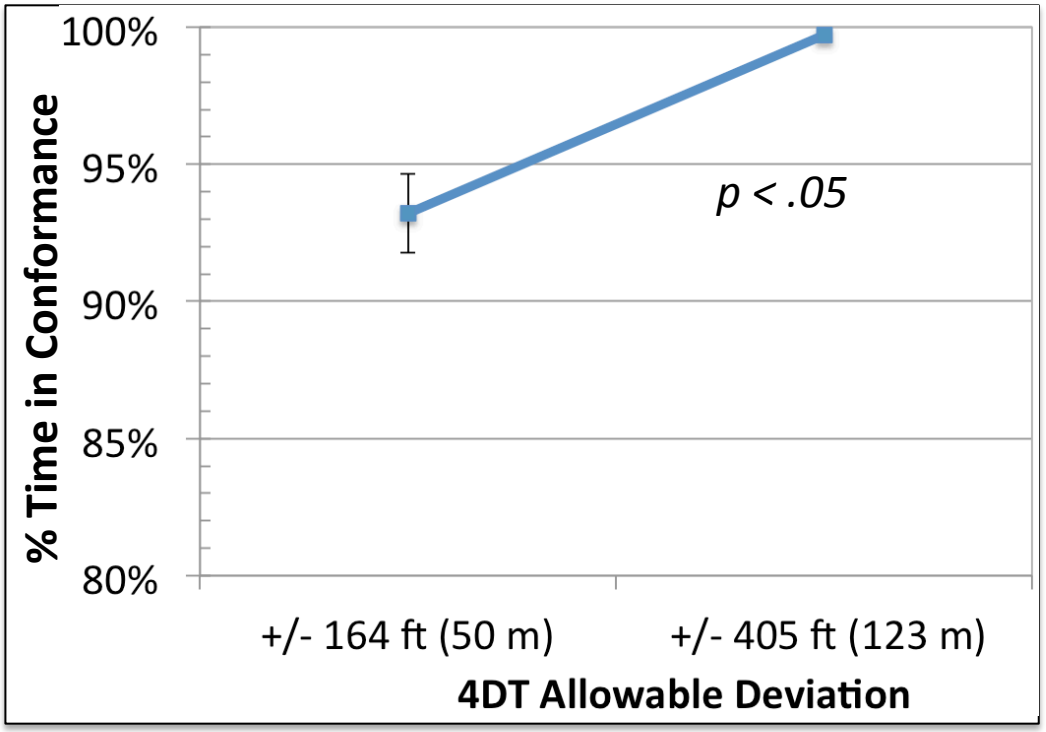
- Two allowable conformance deviation sizes were used:

  +/- 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, 2nd 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"




- "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*

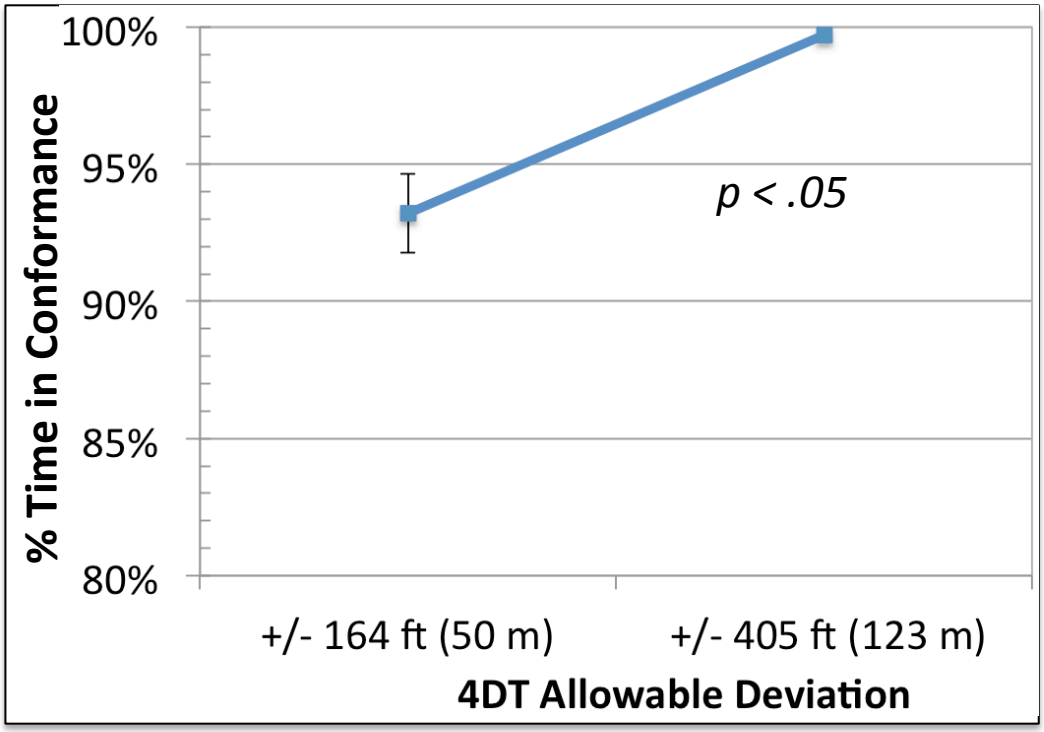
- Safety rating: 4.7 (out of 5) for +/- 164 ft
  4.9 (out of 5) for +/- 405 ft
- Acceptability rating: 4.2 (out of 5) for +/- 164 ft
  4.3 (out of 5) for +/- 405 ft

# 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

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| Pilot(s) / Flight Deck | Manual A/C Control | | | |
| | Manual A/C Control w/ Display Aids | | | |
| | Autonomous A/C Operations | Future | Future | Future |

# Automation/Autonomy in 4DT Surface Trajectory-Based Operations (STBO)

***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

# Automation/Autonomy in 4DT Surface Trajectory-Based Operations (STBO)

***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)

| *Function* | ATC | Aircraft |
|---|---|---|
| **Scheduling** | **X** | |
| **Routing** | **X** | |
| **Deconfliction** | **X** | **X** |
| **Execution** | | **X** |

# 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

| | | ATC / Surface Traffic Manager | | |
|---|---|---|---|---|
| | | **Manual** | **Manual / Aided** | **Autonomous** |
| **Pilot / Flight Deck** | **Manual** | Current-day | FAA STBO / NASA ATD2 | |
| | **Manual / Aided** | | NASA / DLR | NASA / DLR |
| | **Autonomous** | Future | Future | Future |

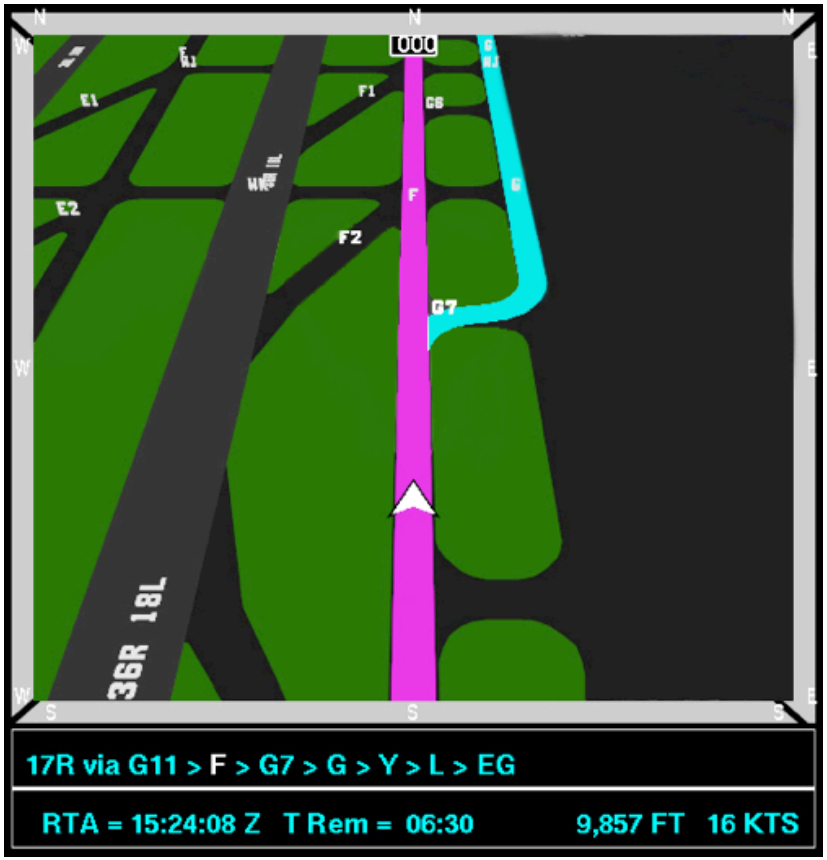
# STBO with Autonomous flight deck component

## 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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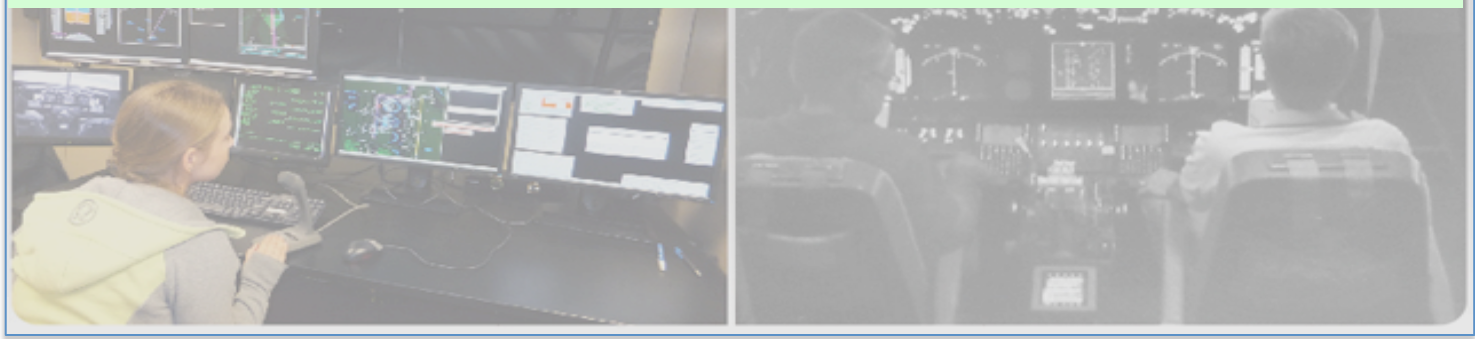

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# Additional Slides

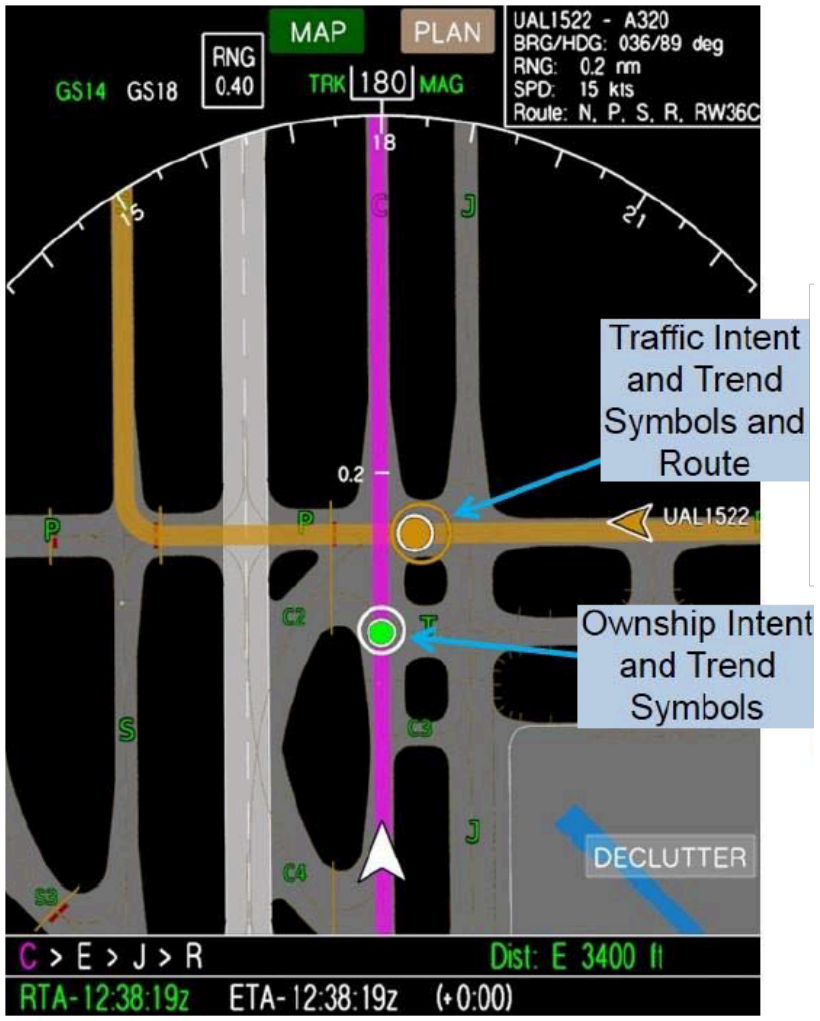
# 4DT Flight-Deck Display


Cleared-to-Taxi Route

Ownship

4DT with allowable deviation

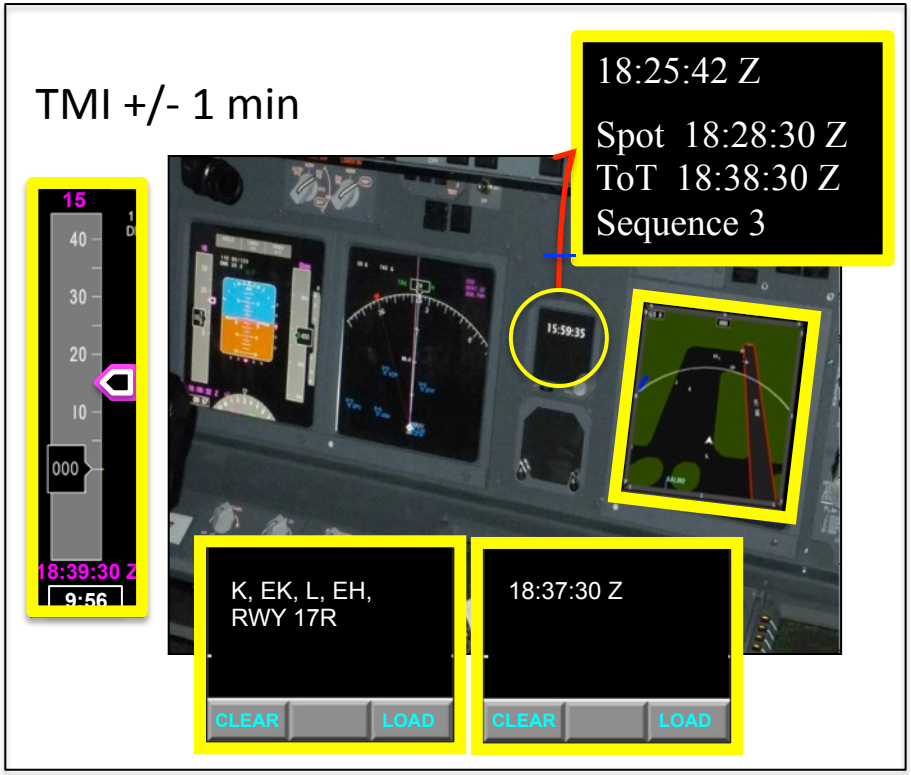
Taxi Route


*Jones et al NASA TP 2016-219172*

# 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?)"**

| Information Source | Response frequency (n=10) of usefulness ratings: Not at all 1 | 2 | Borderline 3 | 4 | Very much 5 |
|---|---|---|---|---|---|
| Assigned Pushback time | - | - | 1 | 4 | 5 |
| Spot-release time | 1 | - | 1 | 5 | 3 |
| Takeoff Time | - | - | - | 7 | 3 |
| Departure Sequence | - | 2 | - | 2 | 6 |
| Speed Advisory on PFD | - | 1 | 4 | 2 | 3 |
| Time Remaining to Takeoff Time | - | - | 4 | 4 | 2 |

ATC-Pilot HITL Sim: *Foyle, Bakowski, Hooey, Cheng & Wolter, HCI-Aero, 2014)*

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# Human Centered Systems Lab

## Airport and Terminal Area Simulator (ATAS)


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