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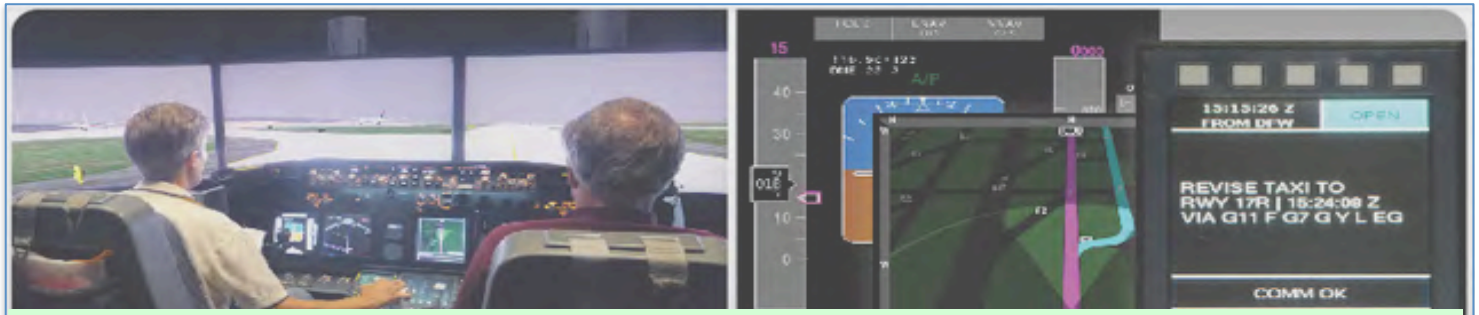

Towards Autonomous Airport Surface Operations: NextGen Flight Deck Implications

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Human Systems integration division

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

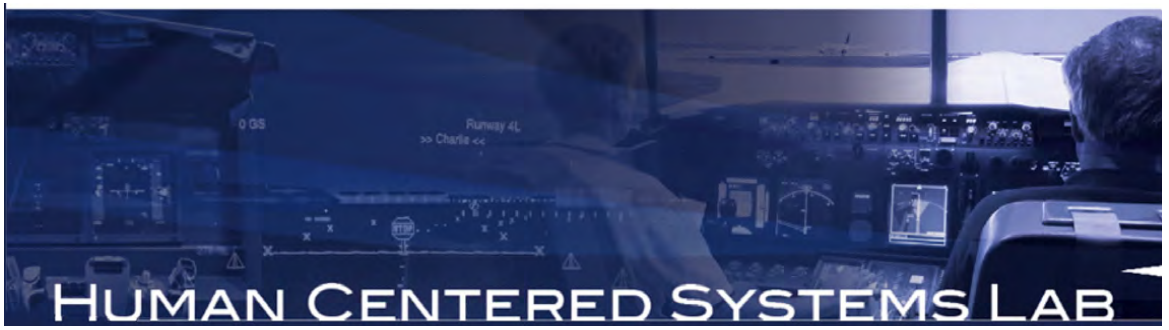
Mission:

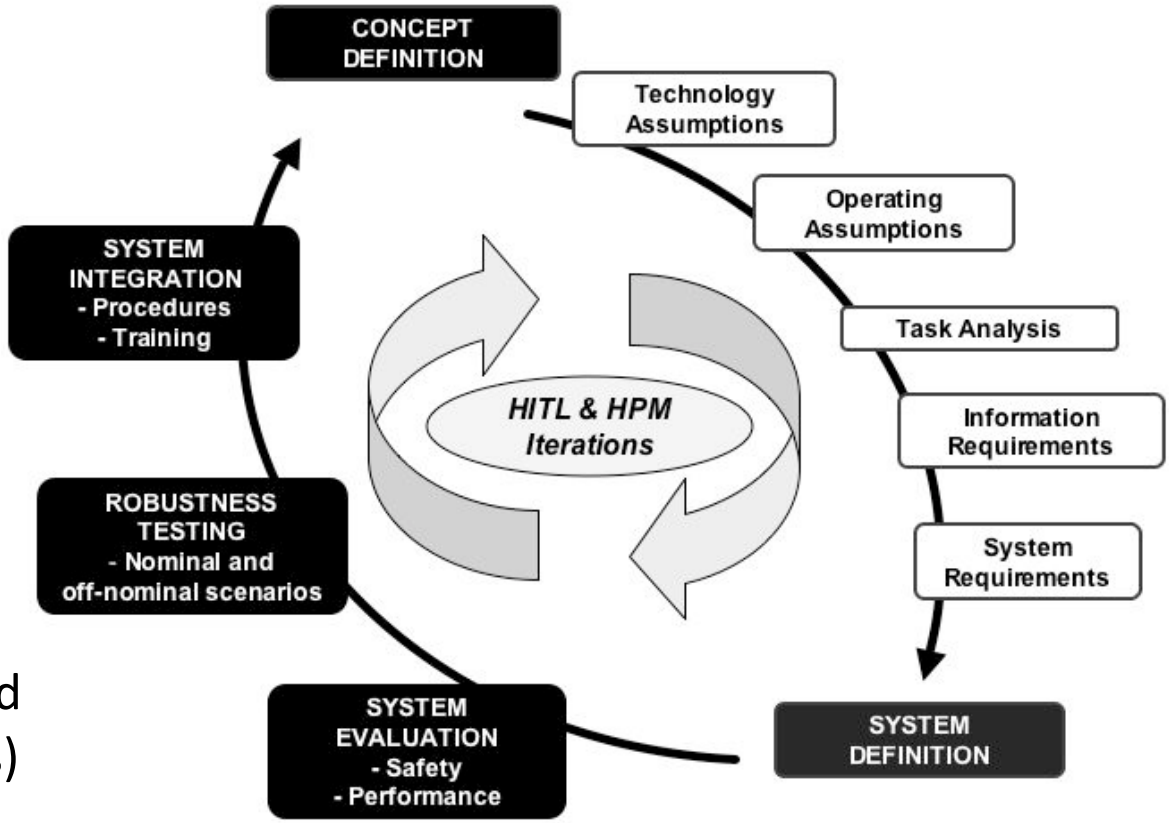
- Develop **principled and robust procedures** and **user interfaces** with appropriate **human-automation function allocation**

- 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





Human Systems integration division

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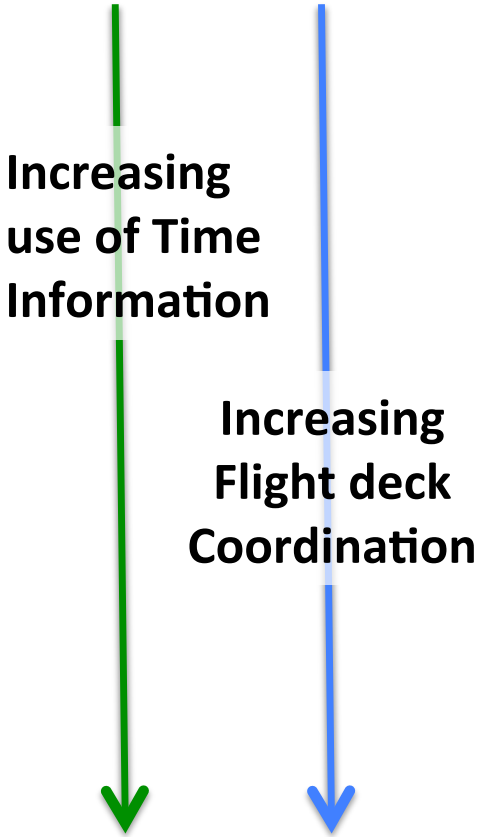
OVERVIEW

- 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)

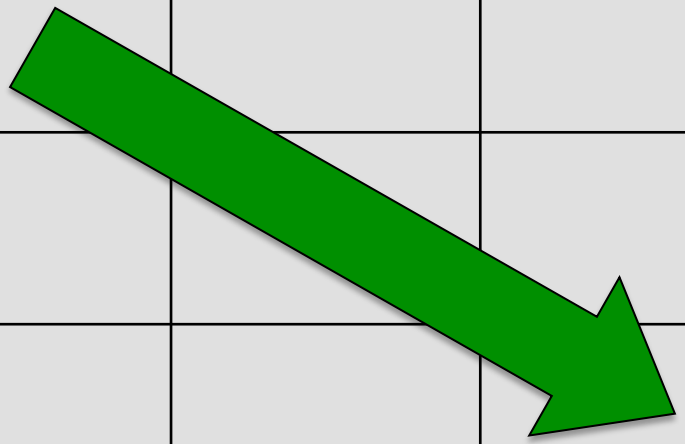
STBO = Adding time component to Surface Operations (taxi/departure)



- 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

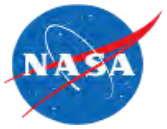
Continuum of Surface Operations Manual → Autonomy

		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

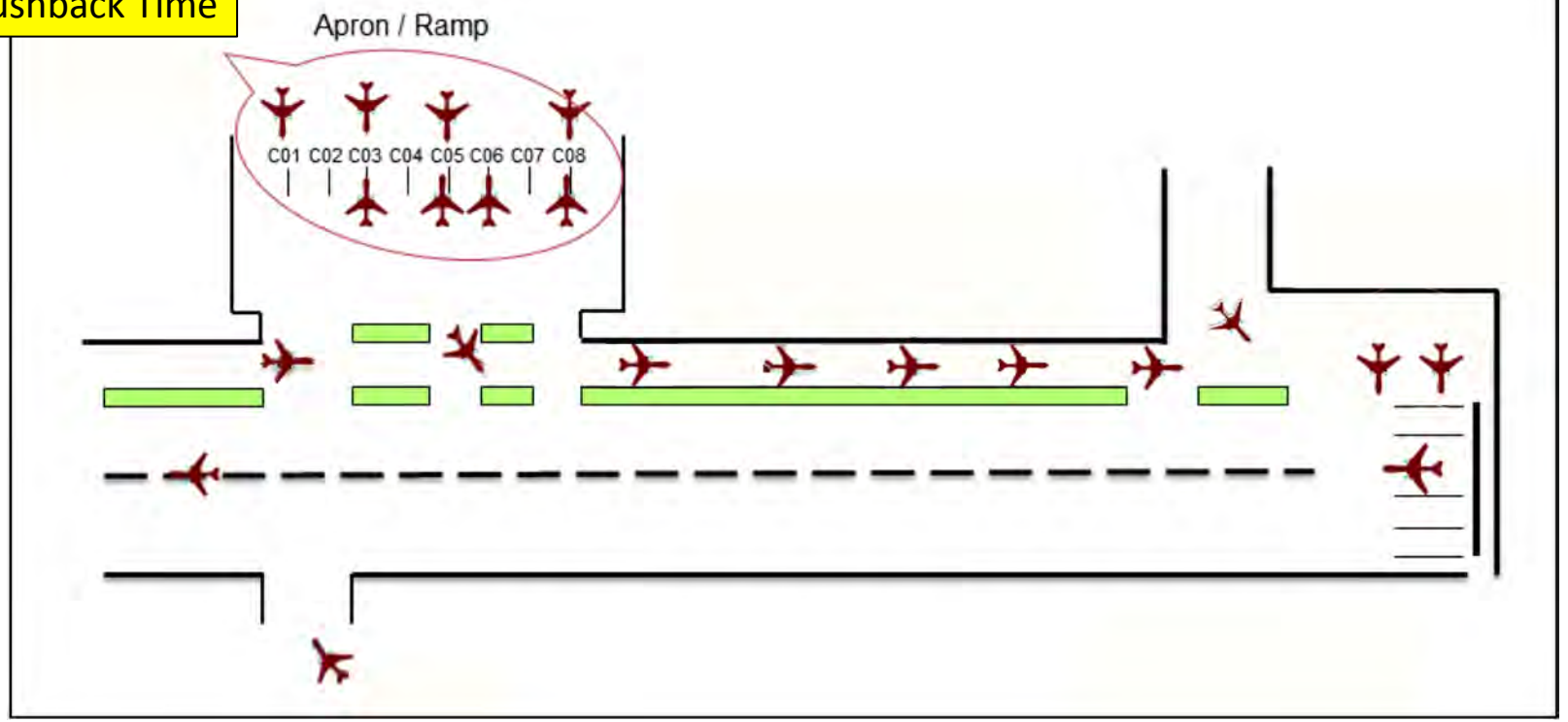
		ATC / Surface Traffic Manager (STM)		
		Manual (Voice)	Manual (Voice) w/ Decision Aids	Autonomous STM
Pilot(s) / Flight Deck	Manual A/C Control	Current Day		
	Manual A/C Control w/ Display Aids			
	Autonomous A/C Operations			



Current Day Surface Operations

Flight Deck:
1. Pushback Time

ATC:
1. Manage departure sequence

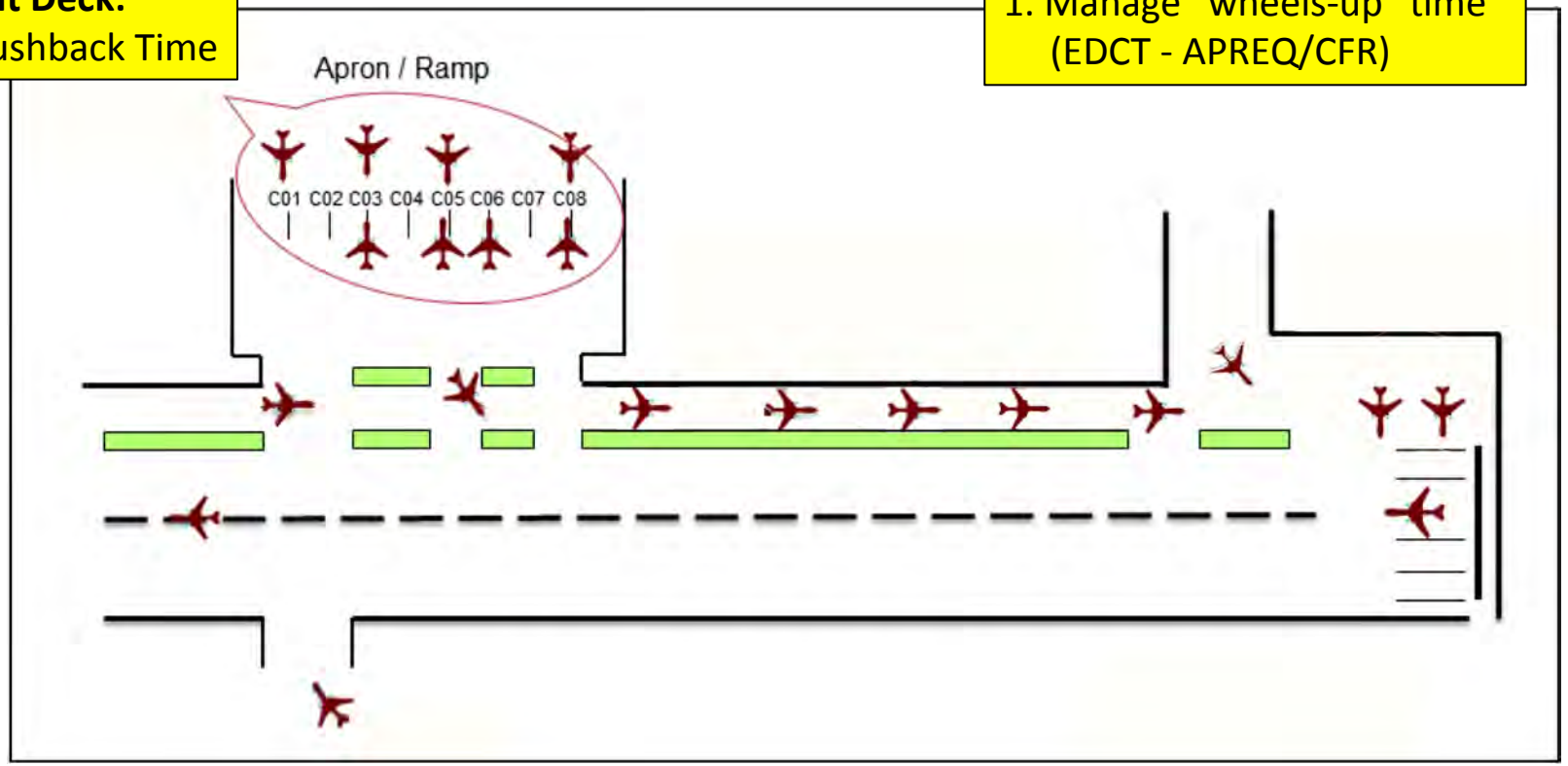


- Pilots manage pushback time to meet:
  - Scheduled departure/take-off time

Current Day (EDCT – APREQ/CFR)

Flight Deck:
1. Pushback Time

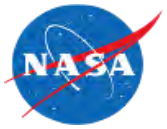
ATC:
1. Manage "wheels-up" time (EDCT - APREQ/CFR)



- 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

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		FAA STBO / NASA ATD2	
	Manual A/C Control w/ Display Aids			
	Autonomous A/C Operations			

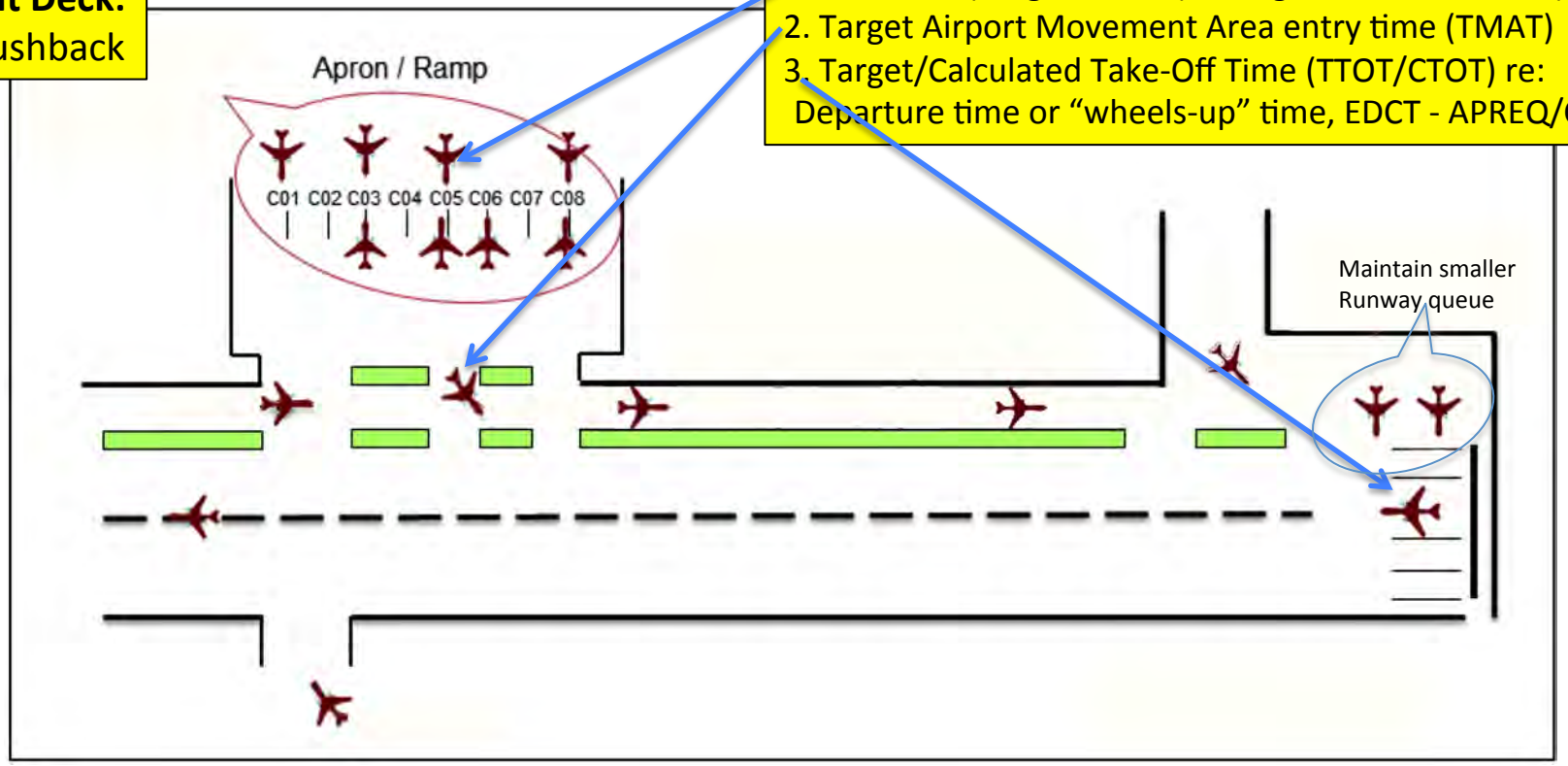


Near-term (e.g., FAA STBO/NASA ATD2)

- 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)



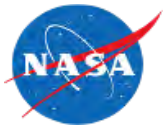
- Pilots manage pushback time to meet:
  - "Wheels-up time" (at KCLT, about 10% of flights)
- Pilots have no information about:
  - Expected taxi time
  - Surface congestion
  - Departure queue size

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

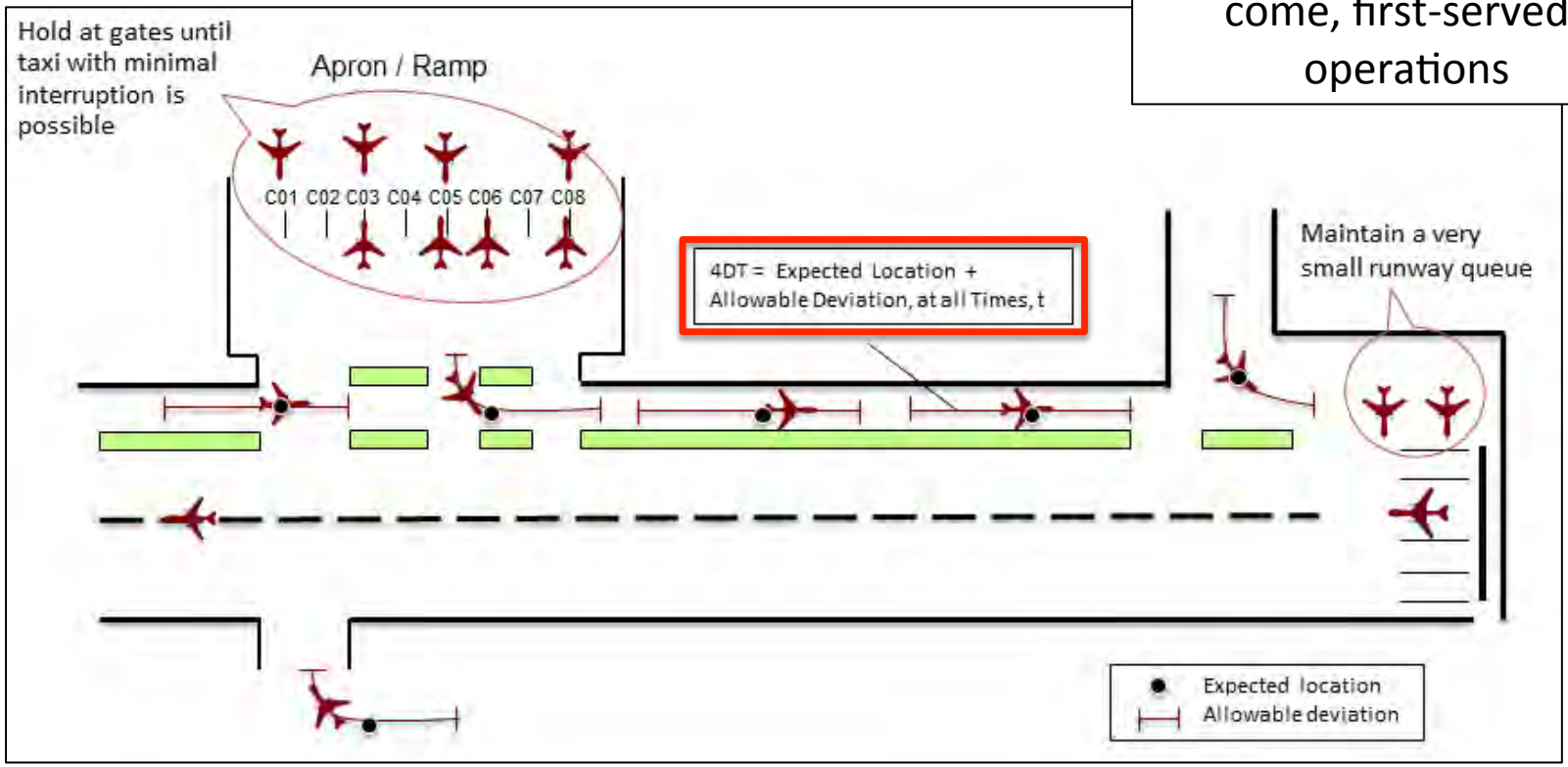
- Controller: Auto-routing, auto-deconfliction, auto-sequencing/scheduling, position timing
- Pilot: Controls manually, info/displays for 4DT STBO



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

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

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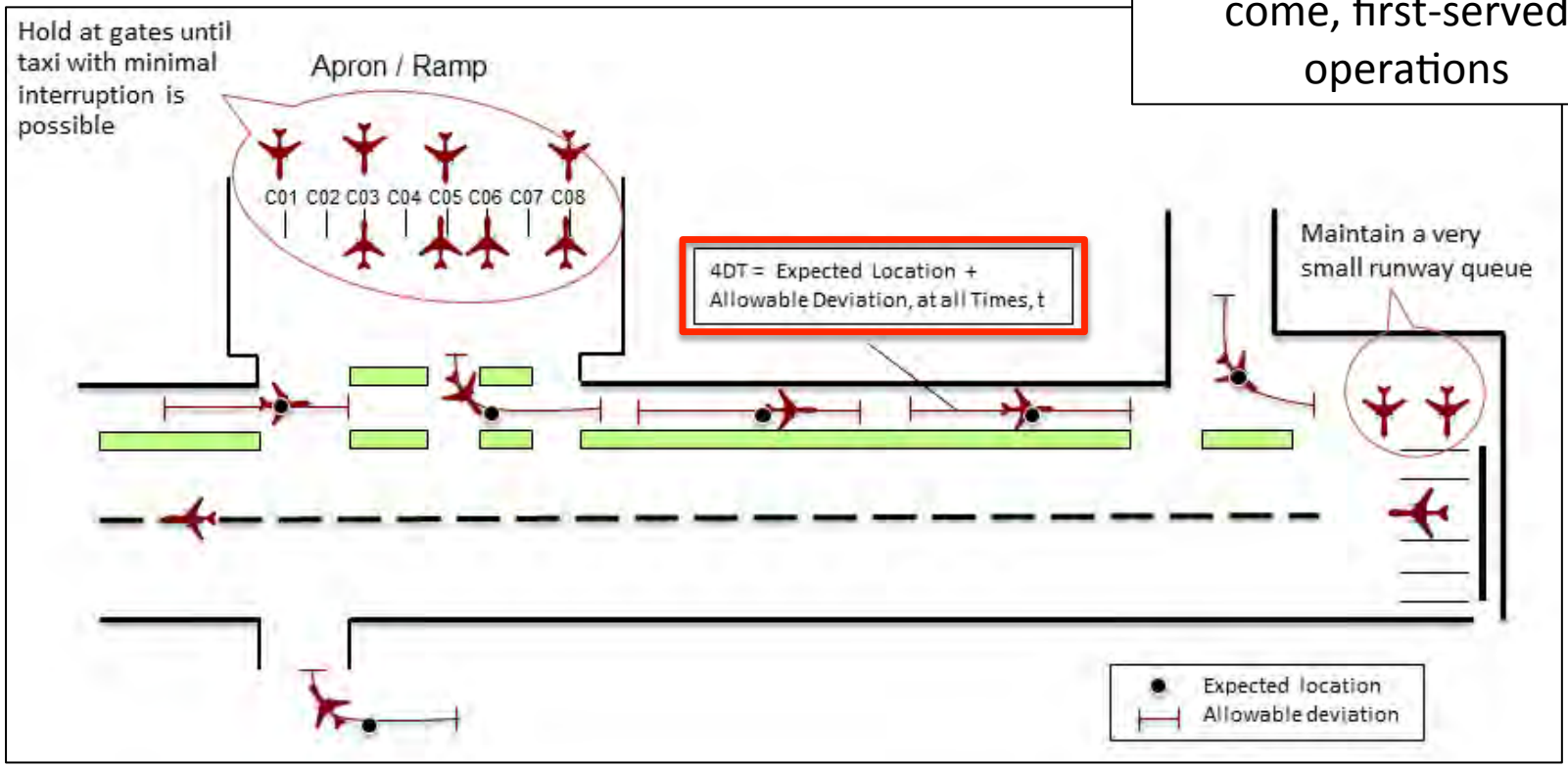
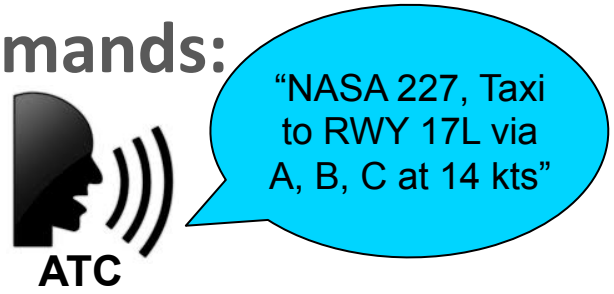


- Enables dynamic surface flow re-planning
- Enables increasingly precise taxi routing plans for improved surface traffic flow efficiency
- Flight deck component allows for coordination with ATC re: schedule issues (e.g., maintenance, FMS, weights/balances, RWY changes, etc.)
- Extension of FAA/NASA 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) • Speed-conformance bound (+/- 1.5 kts) (n = 18 pilots)	**Good RTA performance**	**• Increased workload and visual demand** **• 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

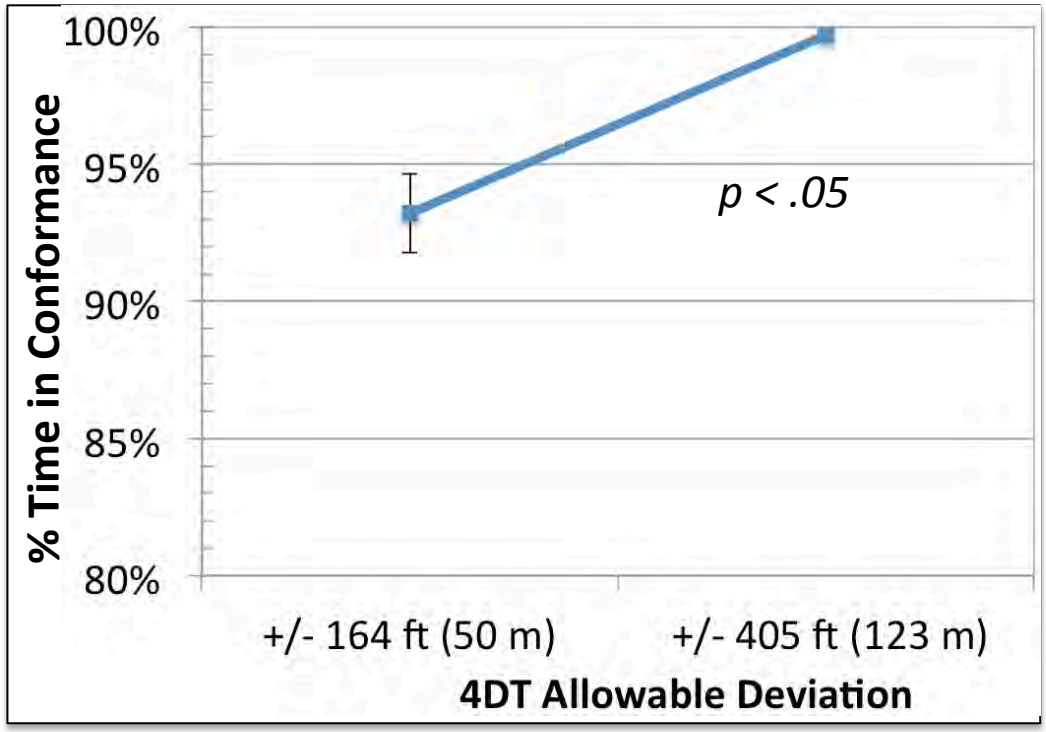
- Two allowable conformance deviation sizes were used:

  +/- 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*

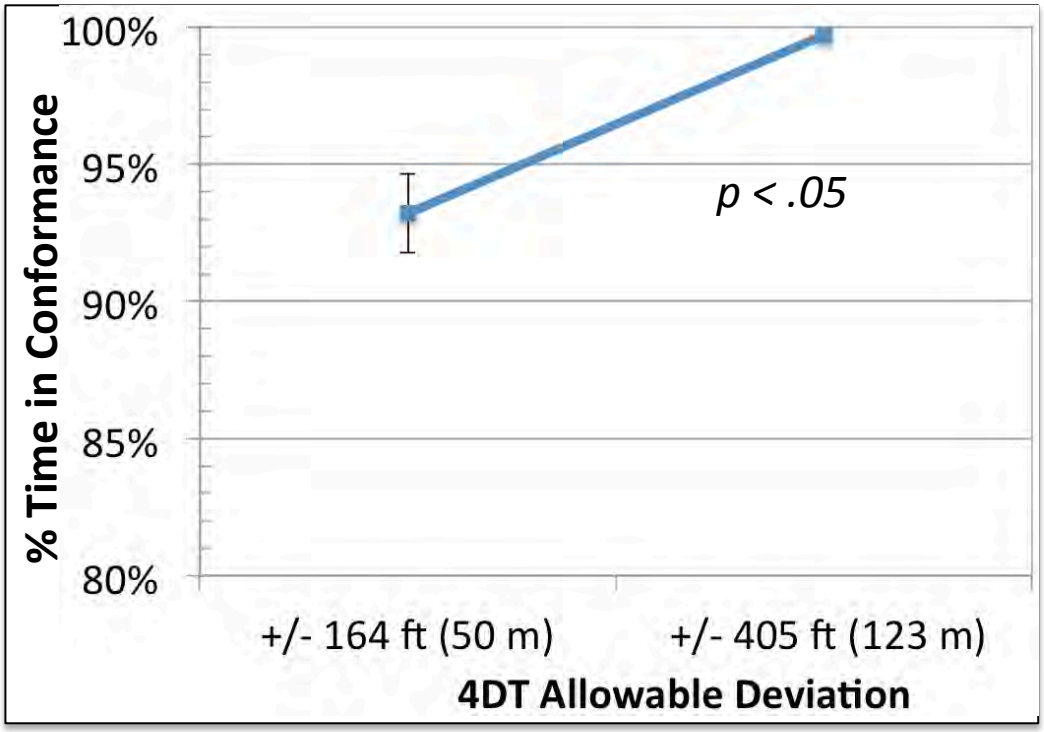
- Safety rating: 4.7 (out of 5) for +/- 164 ft
  4.9 (out of 5) for +/- 405 ft
- Acceptability rating: 4.2 (out of 5) for +/- 164 ft
  4.3 (out of 5) for +/- 405 ft

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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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	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

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- 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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