NASA Ames Research Center
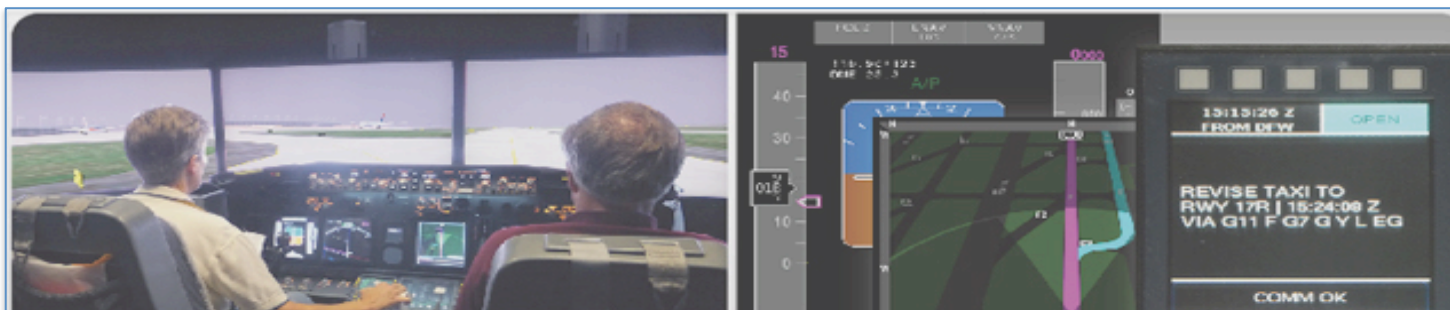
HUMAN CENTERED SYSTEMS LAB
Airport and Terminal Area Simulator (ATAS)

Towards Autonomous Airport Surface Operations:
NextGen Flight Deck Implications

David C. Foyle, Becky L. Hooey, NASA Ames Research Center
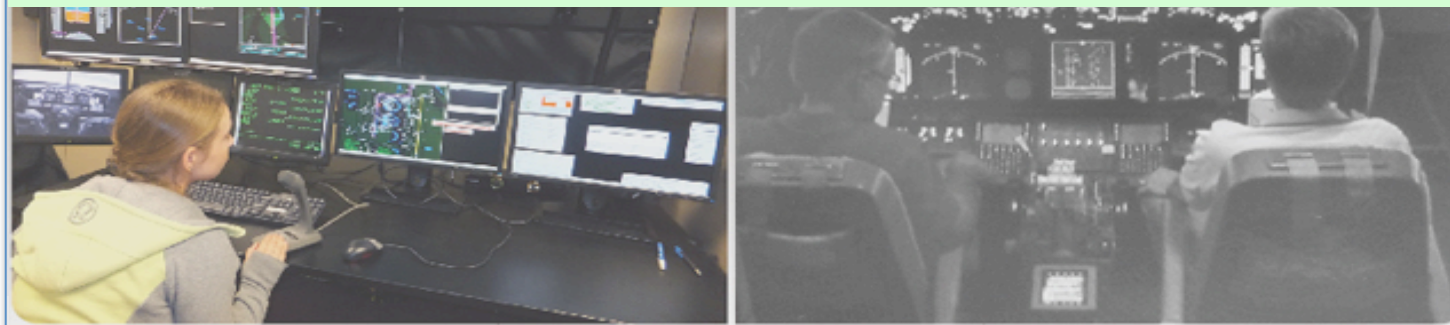**Deborah L. Bakowski, San Jose State University / NASA Ames**

POCs:
David.Foyle@nasa.gov
650-604-3053
Becky.L.Hooey@nasa.gov
650-604-2399

Human Systems integration division
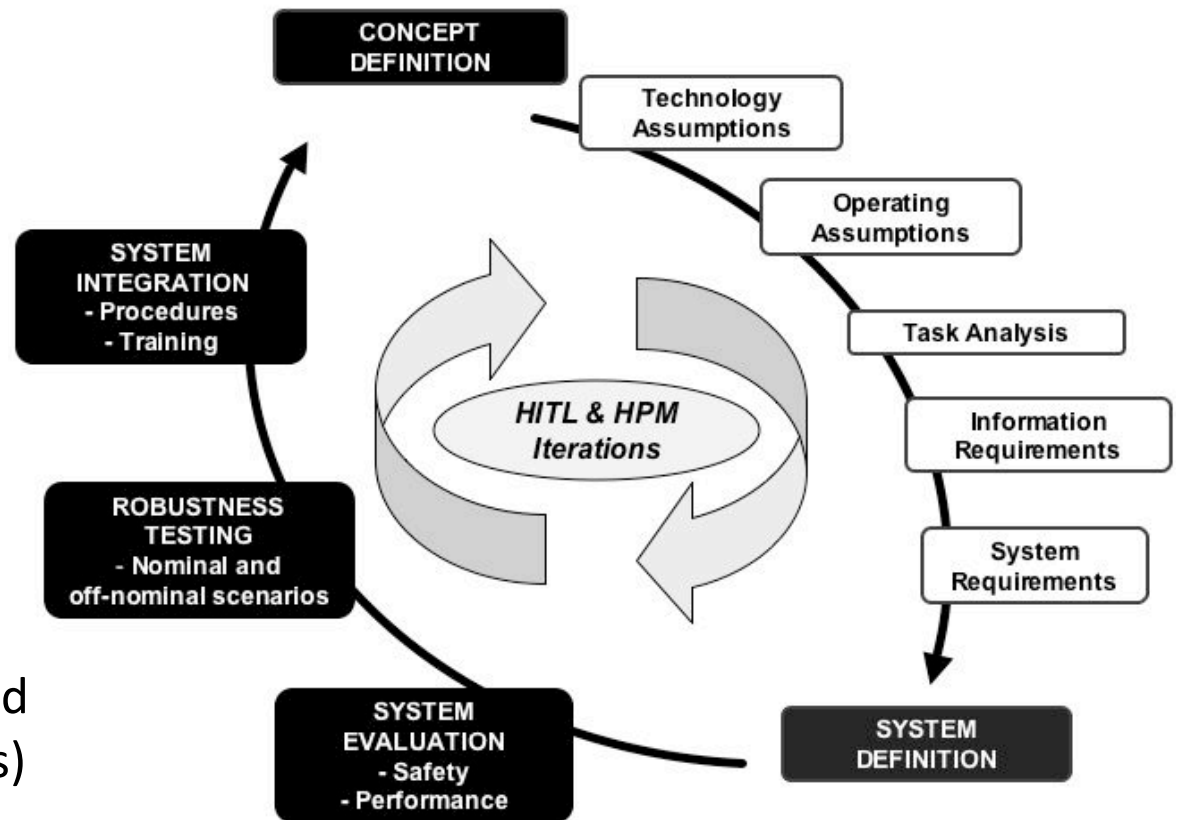
URL: http://humansystems.arc.nasa.gov/groups/HCSL

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 CENTERED SYSTEMS LAB

CONCEPT DEFINITION

Technology Assumptions

Operating Assumptions

SYSTEM INTEGRATION
- Procedures
- Training

Task Analysis

HITL & HPM Iterations

Information Requirements

ROBUSTNESS TESTING
- Nominal and off-nominal scenarios

System Requirements

SYSTEM EVALUATION
- Safety
- Performance

SYSTEM DEFINITION

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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
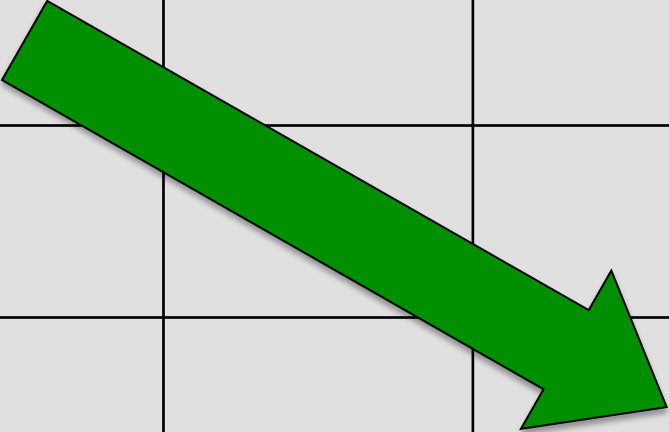# Surface Trajectory-Based Operations (STBO)

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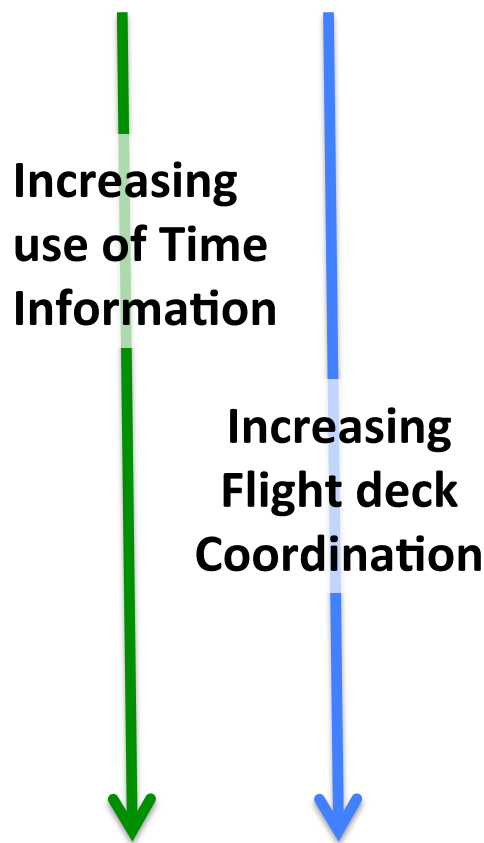
• Current Day Surface Operations

• 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

Increasing use of Time Information

Increasing Flight deck Coordination

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			
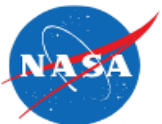
Current Day Surface Operations

Flight Deck:
1. Pushback Time

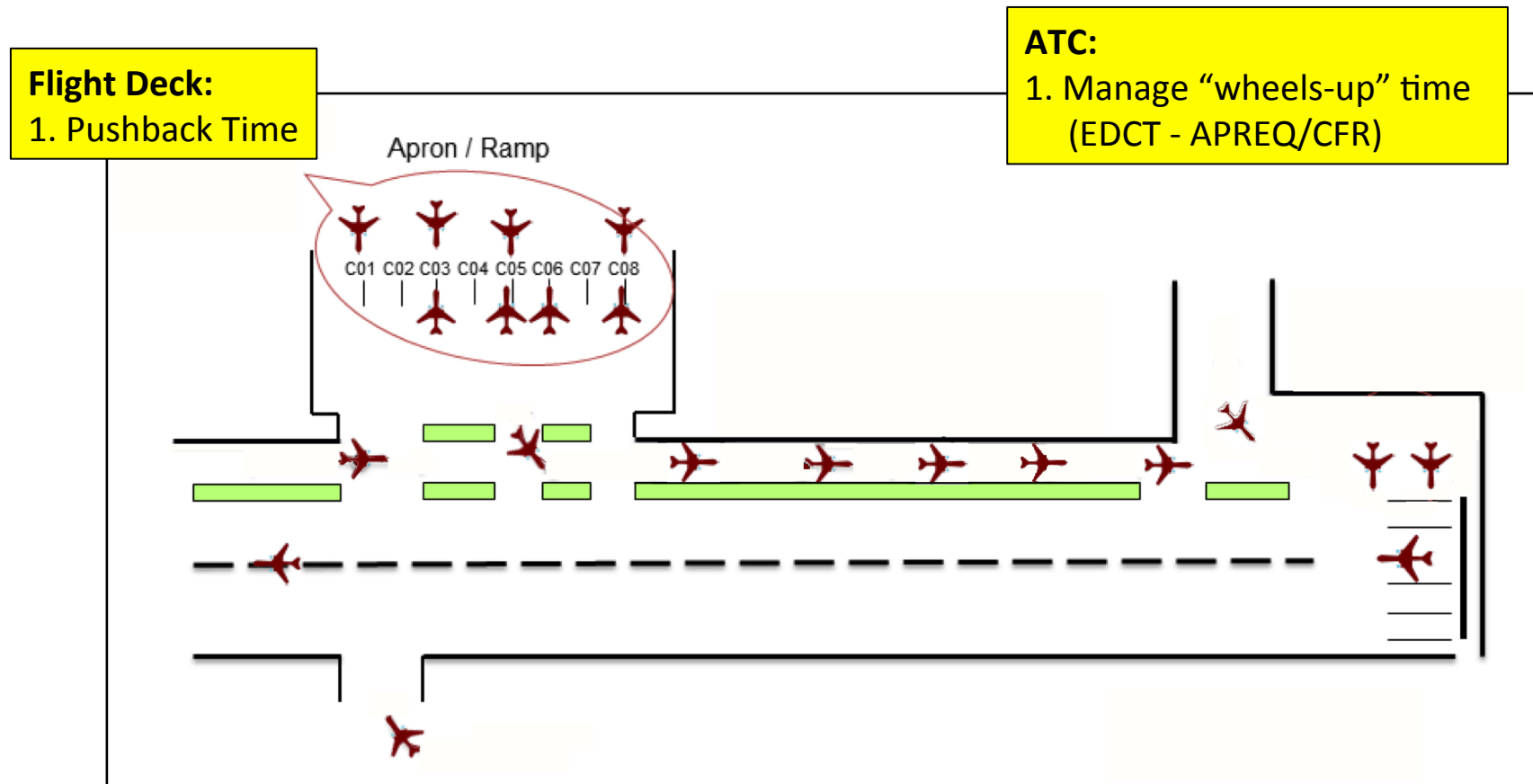**ATC:**
1. Manage departure sequence

Apron / Ramp

C01 C02 C03 C04 C05 C06 C07 C08
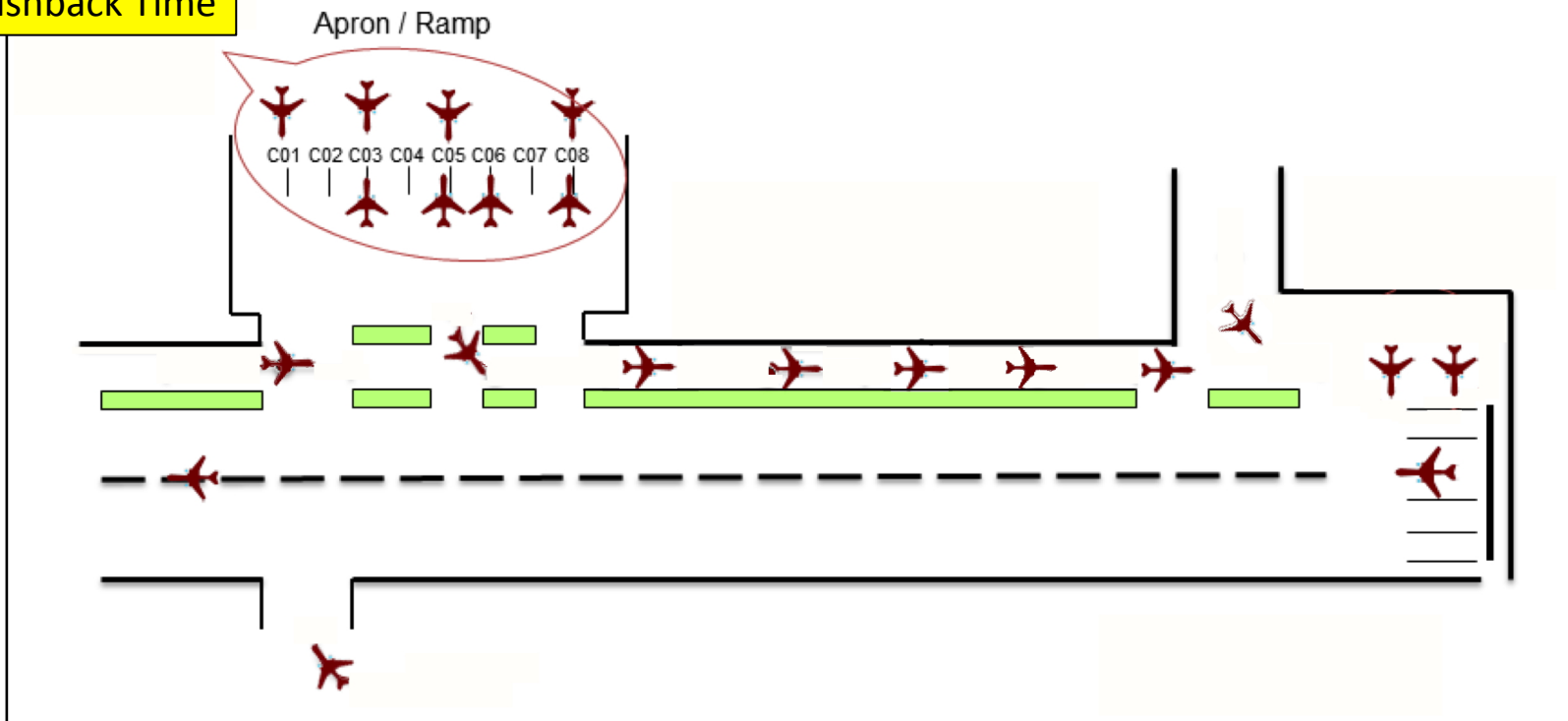
- Pilots manage pushback time to meet:
  - Scheduled departure/take-off time

Current Day (EDCT – APREQ/CFR)

Flight Deck:
1. Pushback Time

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

Apron / Ramp

C01 C02 C03 C04 C05 C06 C07 C08

- Flight deck/pilots manage pushback time to meet:
  - "Wheels-up time"
- Flight deck/pilots have <u>no information</u> 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

Apron / Ramp

C01 C02 C03 C04 C05 C06 C07 C08

Maintain smaller
Runway queue

- 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			

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

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

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

- 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

Okuniak, Gerdes, Jakobi, Ludwig, Hooey, Foyle, Jung, & Zhu, AIAA/ATIO 2016 Conference, DLR/NASA Concept of Operations for Trajectory-based Taxi Operations
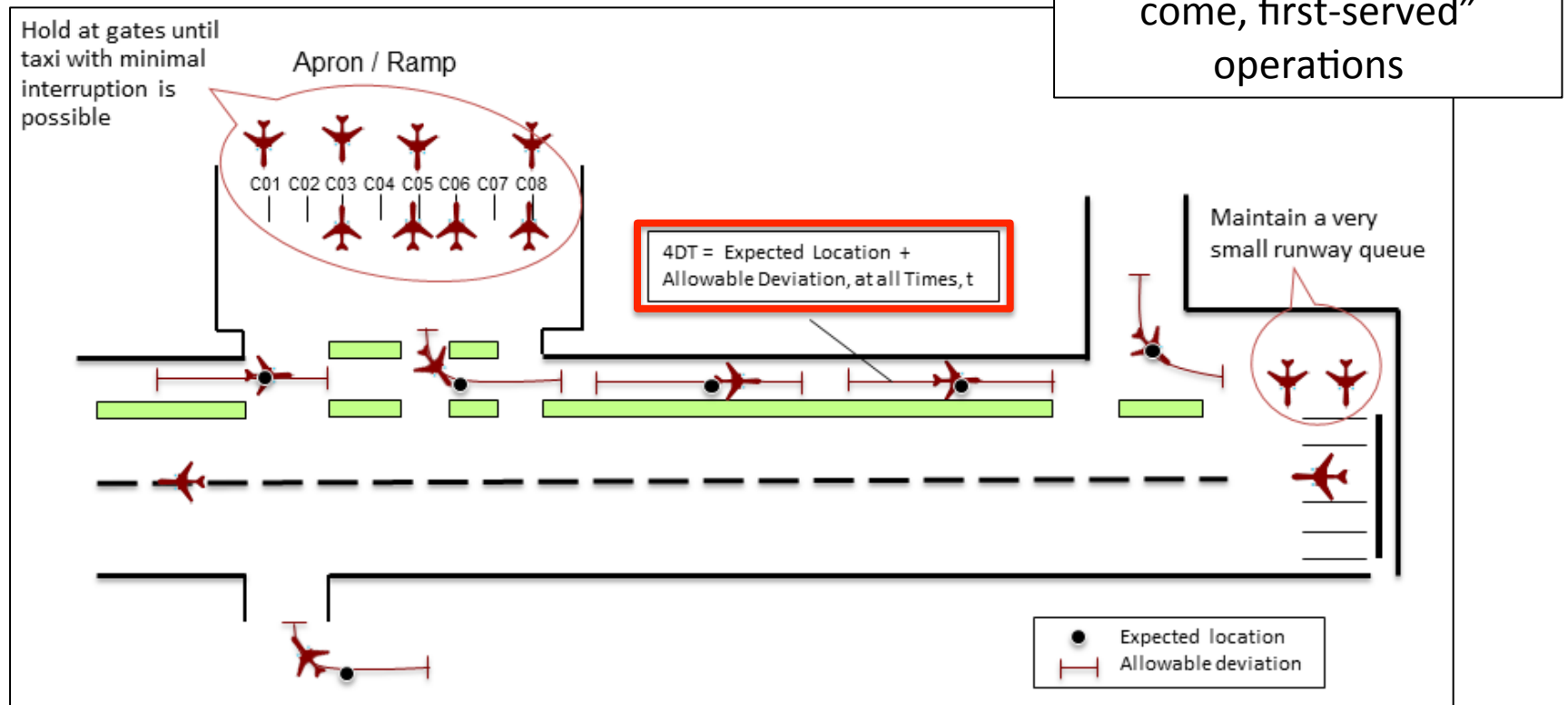
Transition from "first-come, first-served" operations

Hold at gates until taxi with minimal interruption is possible

Apron / Ramp

C01 C02 C03 C04 C05 C06 C07 C08

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

Maintain a very small runway queue

Expected location
Allowable deviation

- 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*

ATC

"NASA 227, Taxi to RWY 17L via A, B, C at 14 kts"

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

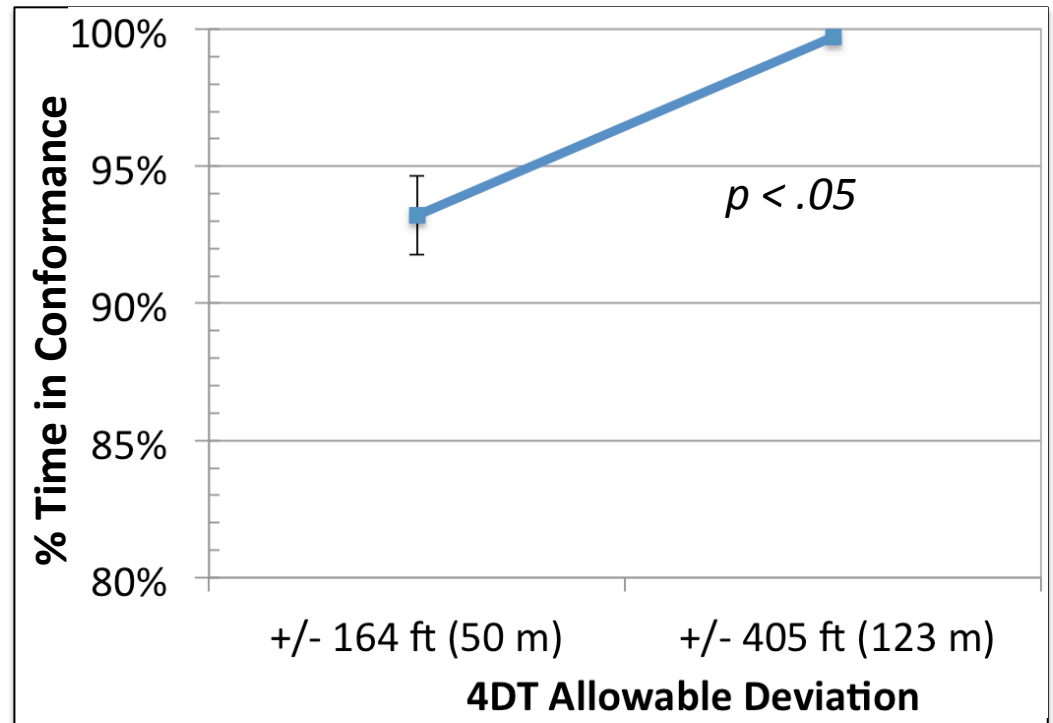*HITL Simulation: Bakowski, Hooey, & Foyle, 2017*

- 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"

% Time in Conformance (y-axis: 80%, 85%, 90%, 95%, 100%)

$p < .05$

4DT Allowable Deviation (x-axis: +/- 164 ft (50 m), +/- 405 ft (123 m))

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

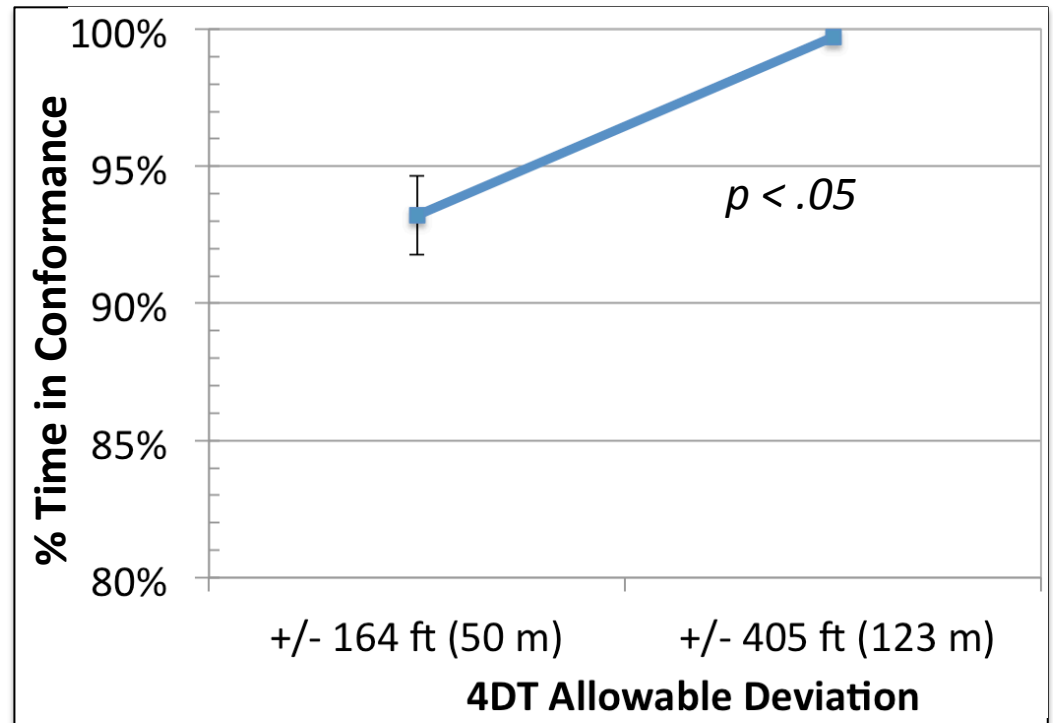 *HITL Sim: *Bakowski, Hooey, Foyle, & Wolter, AHFE, 2015*

- 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

$p < .05$

% Time in Conformance (y-axis: 80%, 85%, 90%, 95%, 100%)

4DT Allowable Deviation (x-axis: +/- 164 ft (50 m), +/- 405 ft (123 m))

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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
- 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

17R via G11 > F > G7 > G > Y > L > EG

RTA = 15:24:08 Z   T Rem = 06:30   9,857 FT   16 KTS

Current route with Other Traffic HOLD

K > EK > L > EH

Start 23:08:06   14 KTS   Queue 23:13:36

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
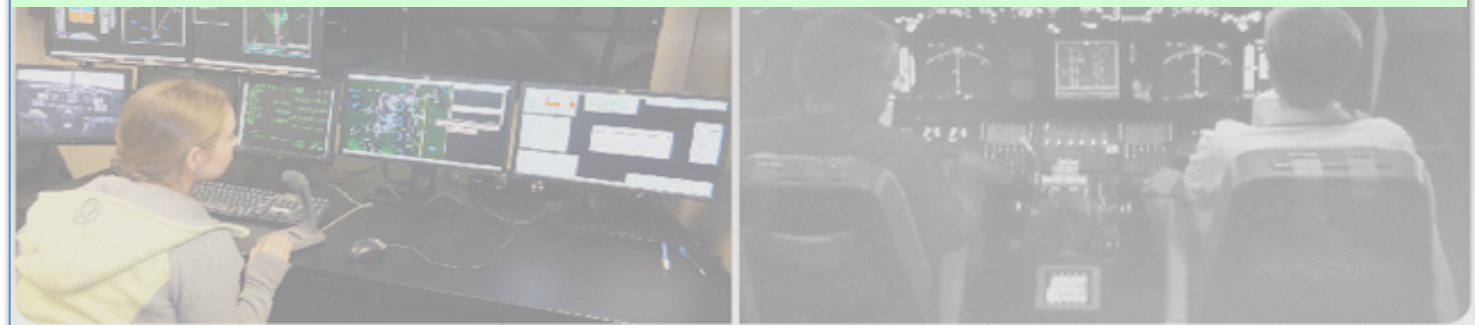
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REVISE TAXI TO
RWY 17R | 15:24:08 Z
VIA G11 F G7 G Y L EG

COMM OK

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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
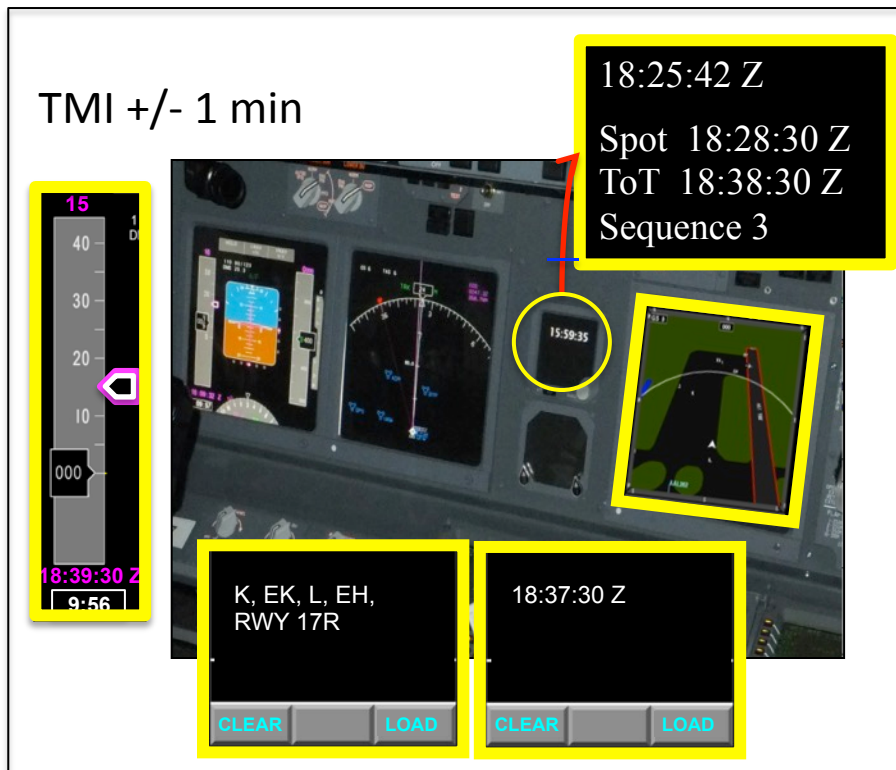
GS 19   000

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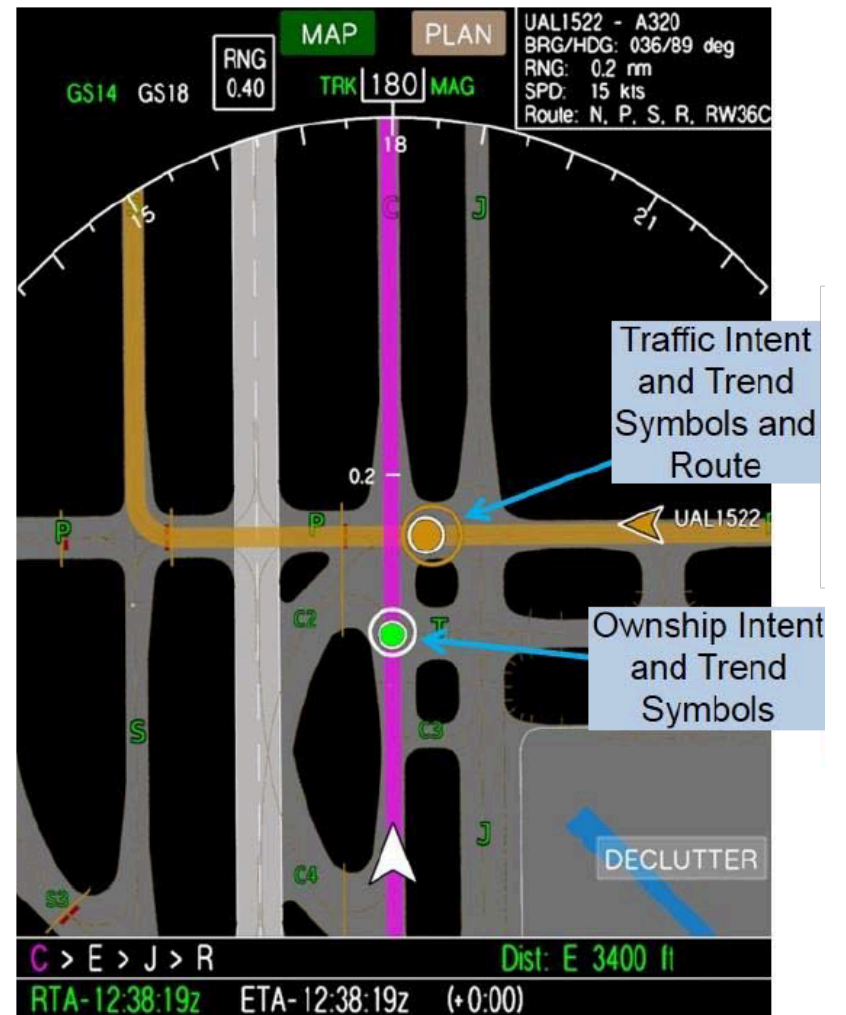
Jones et al NASA TP 2016-219172

STBO with flight deck component and Information Sharing Displays
Enables better flight deck workflow prior to departure

TMI +/- 1 min

18:25:42 Z

Spot 18:28:30 Z
ToT   18:38:30 Z
Sequence 3

15:59:35

K, EK, L, EH,
RWY 17R

18:37:30 Z

CLEAR   LOAD

CLEAR   LOAD

"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?)"

Response frequency (n=10) of usefulness ratings

Information Source	Not at all		Border-line		Very much
	1	2	3	4	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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Glenn Meyer, MA Dell
Capt. Rob Koteskey, MA

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650-604-3053
Becky.L.Hooey@nasa.gov
650-604-2399

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