Flight Deck Surface Trajectory-based Operations (STBO): Results of Piloted Simulations and Implications for Concepts of Operation (ConOps)

David C. Foyle, NASA Ames Research Center
Becky L. Hooey and Deborah L. Bakowski, San Jose State University
## Problem

1. Current-day flight deck operations are not able to support:
   - NextGen Arrival - Anticipated throughput generated by NextGen concepts such as M&S, VCSPA, etc.
   - NextGen Departure - Predictability required for NextGen concepts.
     (re: IADS RTT ConOps 4-12-10)

2. Must work ATC concepts in parallel with flight deck concepts or be vulnerable to risk of developing concepts to which pilots cannot comply.
   (i.e., IADS RTT Doc: “OV-6c NEXTGEN 2018 Scenario 07 - Peak Departures v0.1 4-13-2009”)

## Research Needs

- Develop/assess Surface Traffic Mgmt. Systems / Flight Deck ConOps variants
- Determine technologies/procedures for pilots to conduct NextGen taxi operations
- Assess compliance and pilot workload under NextGen IADS operations
- Define and conduct RTT IADS RTP efforts

## Approach

**Iterative Pilot-in-the-loop Simulations**
- ConOps Definition / refinement
- Pilot compliance
- Pilot info. requirements
- Pilot acceptance

**Impact**
- ConOps Development
- SMS Algorithm/Parameters Development
- Flight Deck System Requirements
- Robust systems (e.g., off-nominals)

## Progress

- Multiple simulations
- Defined ConOps options
- Eliminated specific candidate ConOps options
Pilot requirements for Surface Trajectory Based Operations (STBO) clearances

- Speed conformance
- Route and time conformance
- Conceptual (ConOps) development
- Pilot workload, Situation awareness (SA)
- Safety impacts due to time pressure

Human Factors Pilot-in-the-loop Studies to Determine Pilot Operating Requirements
- Speed conformance
- Route and time conformance
- Conceptual (ConOps) development
- Pilot workload, Situation awareness (SA)
- Safety impacts due to time pressure

Advanced Surface Management Optimization (SMO) Systems and ConOps Must Incorporate Pilot Operating Requirements
- Ability to comply with speed requests
- Variance of route and time conformance
- Conceptual development (e.g., form of taxi clearances - continuous, updates, etc.)
- Pilot/Aircraft non-conformance
- Rerouting

STBO Flight Deck Issues

STBO Concepts
- Progressive taxi/route updates
- Continuous-coupled STBO clearances
- Endpoint-only STBO Clearances (push-back, departure queue)

STBO Taxi Clearance Formats
- Flight Deck speed & time displays
- Bandwidth of error-nulling (i.e., continuous vs. non-continuous checkpoint error)
- ATC STBO Clearance: Speed, Time

Pilot Performance Metrics
- Variance of speed, time-of-arrival error
- SA, workload, safety impacts

Problem: Integrating Surface Management Optimization (SMO) STBO clearances with flight deck information requirements
NextGen Taxi / Surface Trajectory-Based Operations (STBO)

Surface Trajectory-Based Operations (STBO) inherently different than In-Air TBO

- **In-Air**: More constrained – due to aircraft inertia, min/max speeds, in-trail separations.
  - More predictable, much more likely to have fully defined trajectories: $X(t)$, $Y(t)$
- **Taxi**: Not constrained – aircraft start, stop, wait, merge into queues, no min. separation
  - Less predictable, more variants on defining STBO than in-air TBO

![Diagram of constraint points and operations](image)
NextGen Taxi / Surface Trajectory-Based Operations (STBO)

SARDA: Spot and Runway Departure Advisor

RTT Research Transition Product: "Integrated Surface Management w/Flight Deck"

HCSL

Surface Traffic Management Algorithms

# Constraint Points (X_t, Y_t)

1. Spot
2. Rwy Queue
3. Rwy Queue
4. Rwy Queue
5. Rwy Queue

FULL STBO
Simulation and Results
Pilot requirements for 4-D taxi clearances

**Initial Baseline 4-D Taxi Navigation Study**
*Williams, Hooey & Foyle, 2006, Proc. AIAA*

- **18 Current Captains**
- Minimal display information (baseline study)
- 4-D Taxi Clearance Formats
  - **Speed:** Commanded average route speed + Current speed
  - **Time:** Commanded time to RWY + Elapsed time
  - **Both:** All

**Speed/Time Format (in green)**
Pilot requirements for 4-D taxi clearances

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- Minimal display information (baseline study)
- 4-D Taxi Clearance Formats
  - Speed: Commanded average route speed + Current speed
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  - Both: All
- Results
  - Less error with Both (Time and Speed together) formatted clearances
  - Eyetracking usage - speed used early in route, then switch to using time information
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Simulation and Results
Pilot requirements for 4-D taxi clearances

Initial Baseline 4-D Taxi Navigation Study (Expt #1) *(Williams, Hooey & Foyle, 2006, Proc. AIAA)*
- Less error with Both (Time and Speed together) formatted clearances
- Eyetracking usage - speed used early in route, then switch to using time information

Baseline 4-D Taxi Navigation - Updating/adjusting 4-D taxi clearances study (Expt #2)
- Scenario: ATC Taxi clearance - Segmented ATC clearances w/ "time checkpoints" due to:
  1) changing conditions; or
  2) imperfect aircraft Time of arrival (TOA) compliance at checkpoints
- 17 Current Commercial Transport Captains
- Minimal display information (follow-on to first baseline study)
- 4-D Taxi Clearance Format:
  - Both: Commanded average **SPEED + TIME** to runway crossing (plus current readout)
- 6 experimental trials: 3 w/checkpoints & 3 no checkpoints
- Time checkpoints on EMM (white bars) & auditory tone 75 ft before checkpoint
Pilot requirements for 4-D taxi clearances

TOA Absolute Error (Left panel).
- For slower commanded taxi speeds, time checkpoints improve Runway (Time of Arrival) TOA accuracy

Eye Dwell Time (Right panel).
- Overall, pilots looked at display information more during checkpoint trials than non-checkpoint trials (24% vs 20% of trial)
- Middle-of-route checkpoints (Segments S2 & S3) --> more visual attention (% Dwell Time) on display
  - Pilots received new updated checkpoint information 4 times as often
  - Visual workload increased
  - Possible traffic awareness issues
## Evaluated

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## Results

- **Taxi information needed:** Speed, time, both?
- **Intermediate checkpoints w/ speed + time**
- **ATC speed commands:** Avionics/EFB need? (16 CA/FOs)
- **ATC speed commands:** Speed with conformance bands and defined A/C handling? (18 CA/FOs)

## Findings

- **Taxi information needed:**
  - Need both Speed (A/C control) and Time (RTA) information to meet RTAs
  - Need FD displays
  - Need RTA in taxi clearance

- **Intermediate checkpoints with speed + time**
  - Intermediate checkpoints (intersections, Rwy crossings) allow SMOs to "null error" for Rwy RTA

- **ATC speed commands:**
  - ATC speed commands only → poor RTA conformance
  - ATC speed commands with defined A/C handling → good RTA conformance **but** with 2-3x “eyes-in” time
  - Viewed as **not safe**

## ConOps Implications

- **Taxi information needed:**
  - Need FD displays
  - Need RTA in taxi clearance
  - Customers: FAA, avionics/EFB mfg.

- **Intermediate checkpoints with speed + time**
  - Intermediate RTAs in taxi clearance help
  - Customers: FAA, RTTs, SMO Develop.

- **ATC speed commands:**
  - Defined SMO algorithm parameters: Speed, Distance, # constraint pts
  - Initial FD display requirements
  - Customers: FAA, avionics/EFB mfg., SMO Developers

- **ATC speed commands with defined A/C handling:**
  - ATC speed clearances will not suffice
  - Customers: FAA, RTT
Simulation and Results
AP.2.S.09 - "NextGen Time-based Taxi Clearances" Pilot-in-the-loop simulation

**Experiment Goal**
Characterize the distribution of pilots’ Time of Arrival (TOA) performance to inform the development of Surface Traffic Management (STM) algorithms.

**Compare three STM system concepts** (# traffic flow points; within-subjects factor):
1) One single traffic flow point to ensure on-time arrival at the destination runway;
2) Occasional (three) traffic flow points to enable traffic sequencing at important intersections and
3) Frequent (five) traffic flow points to enable dynamic system re-optimizations and very close coordination

**Compare two NextGen Time-based Taxi Ops implementations** (Between-subjects factor):
1) Speed Clearances: Current-day Avionics without Speed Error Nulling
2) Speed & Time (Checkpoint) Clearances: Advanced Avionics with Speed Error Nulling

**Experiment Overview**
16 Pilots (Commercial Transport, CA & FO)
32 departure taxi trials (‘spot’ to runway)
Medium-fidelity simulator; DFW airport
Questionnaires; SME debriefs
**Time of Arrival Error**

**Speed Effect:**
- Slow speeds (10 kts): A/C early
- Fast speeds (18, 22 kts): A/C late
- 14 kts (negligible error)

**Traffic Flow Point Effect:**
- TOA error larger for 1 traffic flow point than for 3 and 5

**Next-Gen Implementation Effect:**
- TOA Error larger for "no error nulling"
- Reduced spread of TOA Error distribution with "error nulling"

**Workload**
- Error-nulling avionics increased time to verify/accept departure clearance (~ 1 sec for nominal clearance; 12 sec for off-nominal clearance with error)
- 2-3 speed/checkpoint updates recommended by pilots
- 5 updates viewed as too many for:
  - Error nulling: 88%; 7 of 8
  - No Error nulling: 0%; 0 of 6

(p<.001, Performance/workload trade-off)

**Structured Interview Results**

**Safety:** "eyes in" vs "eyes out"

**NextGen Implementation:**
- PFD appropriate and intuitive
- Taxi navigation display should show traffic and taxi hold instructions
- Increased cockpit coordination (i.e., "callouts" for speed & traffic)

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**AP.2.S.09: "NextGen Time-based Taxi Clearances" Pilot-in-the-loop simulation**

**Next-Gen Implementation:**
- Speed Clearance / No Error Nulling
- Speed & Time Clearances / Error Nulling

**Distribution of TOA Errors**

**Average TOA Error = Actual TOA - Commanded TOA**
- Positive Error = Aircraft was late / too slow
- Negative Error = Aircraft was early / too fast

(Plotted with +/- 1 standard error)

Results inform STM Algorithm Development
Departure clearance operations under NextGen surface operations conditions

Compared to “current-day” baseline taxi, Advanced NextGen (error-nulling avionics) had longer latencies to:
- Correctly accept correct clearances
- Correctly reject incorrect clearances

Compared to Limited NextGen (speed commands only), Advanced NextGen (error-nulling avionics) had longer latencies to:
- Correctly reject incorrect clearances

May be indicative of increased workload in Advanced NextGen implementation

Structured Interview Results

- Datalinked direct upload (vs. manual FMS loading): Potential flightdeck workload savings
- "Tailored Departures / Unique Dynamic RNAV/RNP Departures": Clear advantages for system efficiency (re: Wx, winds, traffic) and individual aircraft efficiency (e.g., flight time, fuel savings)
- Need for verification of route (e.g., "NA227-123456), especially vs. SIDs implementations
- Issues:
  - How does flightdeck "back up" tailored departure routes in case of equipment failure, FMS dumping route, etc. (vs. Current SIDs with hard copy, FULL route information)
  - How does crew do pre-departure route briefing? (vs. Current SIDs with heading based turns, speeds, etc.)
# HCSL Completed NextGen Taxi Sims

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*but* with 2-3x “eyes-in” time  
• Viewed as *not safe* | • ATC speed clearances will not suffice  
Customers: FAA, RTT |
Simulation and Results
ConOps: “ATC Voice Taxi Clearances with Speed Commands”

Pilots: 18 commercial transport Captains (current or recent retirees)

Scenario: DFW Taxi out to take off – Ramp parking spot to runway through take-off roll (up to 80 kts)

Concept Scope

Trajectory-Based Surface Operations

Taxi out operations with:
• ATC *voice speed commands*
• Pilots required *speed range compliance* of +/- 1.5 kts
• Pilot *acceleration profile control* requirement
• Pilot crosscheck of dynamic RNAV routes datalinked to cockpit (waypoints/crossing restrictions)

NextGen Paired Departures

• Closely spaced parallel paired departures - (MITRE/ Lunsford; ICNS 2008, 2009)
• Ownship informed of paired departure via datalink, paired aircraft’s route depicted on Navigation Display

A/C dynamics: 2 kts/sec spool up/down; 14 kts turns;
Max. acceleration of: 0.25g long.; 0.15g lateral
(Cheng, Sweriduk, Yeh, Andre & Foyle; AIAA GNC, 2008)
• Time of Arrival (TOA) Error to traffic flow points is improved compared to previous study (40-60 secs TOA error, Foyle et al, 2009) - because of defined aircraft acceleration and speed range requirements …BUT…

• Workload and safety level were unacceptable

• Likely due to increased requirements of taxi task (Acceleration profile, speed range requirement)
  - 14 of 18 pilots responded that speed conformance range restriction would compromise safety \( (p = .018) \)
  - Rated more difficult than current actual taxi operations \( (p = .042) \)
  - Eyes-in time 18-24% compared to 8% baseline
  - Responded that they were “frequently” focused on the PFD speed tape when needed to attend to the taxiway

**IMPACT**
• ConOps of ATC providing taxi clearances with speed (via ATC DST) is not workable
• Need for RTA in taxi clearance; flight deck displays
### HCSL Completed NextGen Taxi Sims

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Conclusion: What do we know re: ConOps?

1) Surface Traffic Management System ↔ Sim data (TOA error, variability) of taxi speed, route length, # constraint points

2) ATC Clearance: Recommend 1 ≤ # intersection constraint points ≤ 4

3) ATC Clearance: Time (RTAs) necessary but not sufficient

4) ATC Clearance/Flight Deck: Taxi clearances with speed not safe/workable with current-day flight deck

5) Flight Deck: Need flight-deck display (avionics/EFB) capability
Next Steps: HCSL NextGen Taxi Sims

**Conclusion: What do we know re: ConOps?**

1) Surface Traffic Management System $\leftrightarrow$ Sim data (TOA error, variability) of taxi speed, route length, # constraint points
2) ATC Clearance: Recommend $1 \leq \#$ intersection constraint points $\leq 4$
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4) ATC Clearance/Flight Deck: Taxi clearances with speed not safe/workable with current-day flight deck
5) Flight Deck: Need flight-deck display (avionics/EFB) capability

**Overall Research Objectives**

Expand ConOps to address:
- Flight Deck Avionics/EFBs
- Traffic management

**Specific Plan**

- **FY11 Simulations**
  - Sim #1 – Timing/format parameters for Data Comm vs. Voice trades for taxi re-routing
  - Sim #2 - Initial look at RTT RTP “Integrated Surface Management w/ Flight Deck”
    - a) Evaluate Flight Deck Display concepts x Traffic Flow concepts
    - b) Increase scenario complexity (traffic conditions, ATC-revised Rwy RTAs)
- **FY12 sims** – Advanced flight deck concepts to enable SMO re-optimizations
- **FY13 – SMS / Flight Deck Integration sims**
  - a) Evaluate Flight Deck concept elements (# Constraint Points + Flightdeck + Traffic) defined in previous sims with actual SMS algorithms (informed by sims)
- **FY14-15 sims** – Develop RTT RTP “Integrated Surface Management w/ Flight Deck”
Backup Slides
Human-centered design and evaluation process
(from Foyle & Hooey, 2008)

NextGen Pilot Taxi Operations
HITL Research Approach

Off-nominal Methodology Papers:
Flight Deck Surface Trajectory-based Operations (STBO): Results of Piloted Simulations and Implications for Concepts of Operation (ConOps)

David C. Foyle, NASA Ames Research Center
Becky L. Hooey, Deborah L. Bakowski  San Jose State University
Research Focus: Pilot requirements for Surface Trajectory Based Operations (STBO) clearances

Objective
STBO to enable NextGen flight deck operations to support:
• NextGen Arrival - Anticipated throughput generated by NextGen concepts such as M&S, VCSPA, etc.
• NextGen Departure - Predictability required for NextGen concepts (e.g., Rwy; Merge; Flow)  

(ref: IADS RTT ConOps 4-12-10)

Must work ATC concepts in parallel with flight deck concepts
• Otherwise, vulnerability to risk of developing concepts to which pilots cannot comply 
(ref: IADS RTT Doc: “OV-6c NEXTGEN 2018 Scenario07 / Peak Departures v0.1 4-13-2009”)

Goals:
• Integrate Surface Traffic Management (STM) systems’ STBO clearances with flight deck information requirements
• Define parameters for flight deck and STM system
• Determine ConOps for STBO
**NextGen Taxi / Surface Trajectory-Based Operations (STBO)**

1. Spot
2. Rwy Queue
3. Rwy Cross
4. Taxiway Merge
5. Rwy Queue

∞

**SARDA:**
Spot and Runway Departure Advisor

**RTT Research Transition Product:**
“Integrated Surface Management w/Flight Deck”

**HCSL**

**Surface Traffic Management Algorithms**

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**# Constraint Points** $(X_t, Y_t)$

1
2
3
4
5

∞

1. Spot
2. Rwy Cross
3. Rwy Queue

… All intermediate pts…

… All intersections…

… All intermediate pts…

∞. Rwy Queue

**“FULL” STBO**
Flight Deck Simulations and Results
Experiment 1: Commanded Speed – Without Speed Profiles or Conformance

**Objective:** “Minimum Flight Deck Equipage”
ConOps Evaluation
1) ATC provides ‘A/C required speed’ in taxi clearance (either automated or ATC Decision Support Tool)
2) Pilots not required to follow specific acceleration/deceleration speed profiles (only “be aggressive”)

- 8 Current or recently retired pilots: 6 CAs; 2 FOs
- STBO Taxi Clearances – manipulated:
  - **Speed:** Taxi clearance included required speed
  - # **Intermediate Time Constraint Points**

**Results**
- More RTA error with 1 time constraint point
- Less RTA error with 3 or 5 time constraint points
- Slower required speeds → early arrival; Faster required speeds → late arrival

Foyle, Hooey, Kunkle, Schwirzke & Bakowski, 2009, ICNS
# Experiment 1: Commanded Speed – Without Speed Profiles or Conformance

**Objective:** “Minimum Flight Deck Equipage” ConOps Evaluation

1) ATC provides ‘A/C required speed’ in taxi clearance (either automated or ATC Decision Support Tool)
2) Pilots not required to follow specific acceleration/deceleration speed profiles (only “be aggressive”)

- 8 Current or recently retired pilots: 6 CAs; 2 FOs
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Foyle, Hooey, Kunkle, Schwirzke & Bakowski, 2009, ICNS
**Objective:** “Minimum Flight Deck Equipage”

ConOps Evaluation

1) ATC provides ‘A/C required speed’ in taxi clearance (either automated or ATC Decision Support Tool)

2) Pilots required to follow specific acceleration/deceleration speed profiles (2 kts/sec accel./decel.)

3) Investigated speed conformance tolerance

- 18 Current/recently retired pilots: 13 CAs; 5 FOs
- STBO Taxi Clearances – manipulated:
  - **Speed**: Taxi clearance included required speed
  - **# Intermediate Time Constraint Points**
  - **Speed Conformance Range**:
    - Undefined (tested first) / Defined (+/- 1.5 kts); Current-Day Baseline

- Results
  - Improved RTA error (because of defined aircraft acceleration and speed range requirements **BUT**…
  - Visual workload and safety level were **unacceptable**

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*Bakowski, Foyle, Kunkle, Hooey & Jordan, 2011, ISAP*
**Experiment 2: Commanded Speed – With Speed Profiles/Conformance Range**

**Objective:** “Minimum Flight Deck Equipage” ConOps Evaluation

1) ATC provides ‘A/C required speed’ in taxi clearance (either automated or ATC Decision Support Tool)
2) Pilots required to follow specific acceleration/deceleration speed profiles (2 kts/sec accel./decel.)
3) Investigated speed conformance tolerance
   - 18 Current/recently retired pilots: 13 CAs; 5 FOs
   - STBO Taxi Clearances – manipulated:
     - Speed:
       - Taxi clearance included required speed
     - # Intermediate Time Constraint Points
     - Speed Conformance Range:
       - Undefined (tested first) / Defined (+/- 1.5 kts); Current-Day Baseline

**Findings**

ATC taxi clearances with speed:
- Poor RTA conformance without speed accel./decel. profiles
- Good RTA conformance with speed accel./decel. profiles, **but**
  - with 2-3x “eyes-in” time
  - viewed as **not safe**

**ConOps Implications**

- ATC speed clearances alone will not suffice
  → Need for flight deck display/algorithm

**Customers:**
FAA, RTT

**Results**
- Improved RTA error (because of defined aircraft acceleration and speed range requirements **BUT**…
- Visual workload and safety level were **unacceptable**
Objective: “Flight Deck Equipage” ConOps Evaluation
1) ATC provides taxi clearance with RTA
2) Flight deck equipage (Avionics or EFB, electronic flight bag)

- 8 Current or recently retired pilots: 7 CAs; 1 FO
- Displays (PFD; Taxi Nav. Display, TND)
  - PFD: RTA time-to-go; Elapsed time;
    Algorithm: Speed required to meet RTA
    (Enables strategic usage)
  - TND: Route; Time constraint point
- STBO Taxi Clearances – manipulated:
  - Speed
  - # Intermediate Time Constraint Points
- Results
  - Display/algorith with speed recalculation
    → good RTA conformance

Foyle, Hooey, Kunkle, Schwirzke & Bakowski, 2009, ICNS

Experiment 3: Error-nulling algorithm/display
**Objective:** “Flight Deck Equipage” ConOps Evaluation

1) ATC provides taxi clearance with RTA
2) Flight deck equipage (Avionics or EFB, electrical)

- 8 Current or recently retired pilots: 7 CAs; 1 FO
- Displays (PFD; Taxi Nav. Display, TND)
  - PFD: RTA time-to-go; Elapsed time; Algorithm: Speed required to meet RTA (Enables strategic usage)
  - TND: Route; Time constraint point
- STBO Taxi Clearances – manipulated:
  - Speed
  - # Intermediate Time Constraint Points
- Results
  - Display/algorithm with speed recalculation → good RTA conformance

### Findings

- Flight deck algorithm: Speed recalculation → good RTA conformance

### ConOps Implications

- Defined STM STBO algorithm parameters: Speed, Distance, # Time constraint points
- Initial flight deck requirements for STBO ConOps

**Customers:**
- FAA, avionics/EFB mfg., STM STBO Developers

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**Experiment 3: Error-nulling algorithm/display**

Foyle, Hooey, Kunkle, Schwirzke & Bakowski, 2009, ICNS
Cross-Studies: Usage/Safety Implications

“How often did you find yourself focusing on the PFD Speed or Time display, when you should have been paying attention to the external taxiway environment?”

- Exp.1: Speed – No accel./decel. profile
  - Eyetracking: 2.4 – 3.3 times baseline
  - “Unsafe”: 14/18 pilots

- Exp.2: Speed – With accel./decel. profile, Undefined Conformance
  - +/- 1.5 kts Conformance

- Exp.3: Display/Algorithm

Current-Day Baseline

Mean Abs. RTA Error (sec)
(1 Time-Constraint Point)
## Summary / Overall ConOps Implications

<table>
<thead>
<tr>
<th>Summary Findings</th>
<th>ConOps Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• STBO clearances with speed are not viable solution</td>
<td>• Requirement for <em>human-centered</em> flight deck display/algorithm for STBO</td>
</tr>
<tr>
<td>• Taxiing Captain cannot “tightly control/track” speed, navigate, and maintain separation</td>
<td></td>
</tr>
<tr>
<td>• Only flight deck algorithm/display condition → Good RTA conformance AND appropriate visual workload / safety</td>
<td>Customers: FAA, avionics/EFB mfg., STM STBO Developers</td>
</tr>
<tr>
<td><strong>Caveat:</strong> Flight deck algorithm/display -- Needs to allow “strategic operation”, not “tight control/tracking”</td>
<td></td>
</tr>
</tbody>
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*Human-centered designed systems (Foyle, 2009):*
- Are intuitive and “natural”
- Have readily accessible information
- Support human capabilities (e.g., perceptual processing)
- Mitigate human limitations (e.g., memory)
- Have features supported by “human factors design principles trace”
- Enable appropriate task usage strategies

### Next Steps:
- STBO human-centered flight deck displays
- Operational issues: Datalink coordination between STM system and flight deck
  - Integration with SARDA (Spot and Runway Departure Advisor)
Backup Slides
Objective: Initial Baseline 4-D Taxi Navigation Study

- 18 Current Captains
- Minimal display information (baseline study)
- STBO Taxi Clearance Formats
  - **Speed**: Commanded average route speed + Current speed
  - **Time**: Commanded time to RWY + Elapsed time
  - **Both**: All

Results
- Less RTA error with Both Time and Speed clearances
- More RTA error with longer routes
- Slower speeds → early arrival; Faster speeds → late arrival
- Eyetracking usage - speed used early in route, then switch to using time information
**Objective:** Initial Baseline 4-D Taxi Navigation Study
- 18 Current Captains
- Minimal display information (baseline study)
- STBO Taxi Clearance Formats
  - **Speed:** Commanded average route speed + Current speed
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- Eyetracking usage - speed used early in route, then switch to using time

### Findings
To accurately meet RTAs:
- Need both Speed (A/C control) and Time (RTA) information

### ConOps Implications
- Need Flight Deck displays
- Need RTA in ATC taxi clearance

**Customers:**
FAA, avionics/EFB mfg.
Cross-Studies: Usage/Safety Implications

“How often did you find yourself focusing on the PFD Speed or Time display, when you should have been paying attention to the external taxiway environment?”

<table>
<thead>
<tr>
<th>Rating (1 - 5)</th>
<th>No Aircraft Control / Speed Profile</th>
<th>With Aircraft Control / Speed Profile</th>
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