Flight Deck Surface Trajectory Based Operations (STBO):

Results of Piloted Simulations and Implications for Concepts of Operation (ConOps)

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NASA Airspace Systems Program (ASP)
NextGen Concepts and Technology Development (CTD) Project
Safe and Efficient Surface Operations (SESO)
Outline

Objective and Goals

Surface Trajectory Based Operations (STBO)

Flight Deck Simulations and Results

• Expt. 1: Initial Flight Deck simulation (Information, distance, speed)
• Expt. 2: Minimum Flight Deck equipage – RTA via Taxi Clearance with required speed
• Expt. 3: Minimum Flight Deck equipage – RTA via Taxi Clearance with required speed and conformance requirements
• Expt. 4: Flight Deck display – Error-nulling algorithm/display

Cross-Studies: Usage/Safety Implications

Summary / Overall ConOps Implications
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., Departure Timing/Airspace Merging; Active Rwy Crossings; Surface Merge, Flow) (ref: IADS RTT ConOps 4-12-10)

Must work ATC concepts in parallel with flight deck concepts
• Otherwise, vulnerable 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

Prior to these studies, there were no existing studies/data on flight deck STBO
Research Focus: Pilot requirements for Surface Trajectory Based Operations (STBO) clearances

**Objective**
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**Why Flight Deck STBO?**

**Delivery to departing runways at RTAs**
- Reduce/eliminate departure queues (delays, fuel, emissions)
- Enable efficient merging into airspace (fuel, emissions, noise)

**Active runway crossings**
- Crossing runways without wait (delays, fuel, emissions)
- Cross at “operation gaps” created by other NextGen technologies

**Must work ATC concepts in parallel with flight deck concepts**
- Otherwise, vulnerable to risk of developing concepts to which pilots cannot comply (ref: IADS RTT Doc: “OV-6c NEXTGEN 2018 Scenario07 / Peak Departures v0.1”)
NextGen Taxi / Surface Trajectory-Based Operations (STBO)

STBO

"FULL" STBO

# Constraint Points \((X_t, Y_t)\)

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

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

\[ \ldots \]

\[ \ldots \]

\[ \ldots \]

\[ \infty \]

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\[ \ldots \]

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Flight Deck Simulations and Results
**Objective:** Initial Baseline Flight Deck STBO Study
- 18 Current Captains
- Minimal display information (baseline study)
- **Manipulated Required Speed; Taxi Route Length**
  - **STBO Taxi Clearance Formats**
    - Speed: Commanded average route speed + Current speed
    - Time: Commanded time to route end + Elapsed time
  - Speed & Time: All
- **Results**
  - Slower required speeds → early arrival
  - Faster required speeds → late arrival
  - More RTA error with longer routes

**Experiment 1:** Pilot information requirements for STBO taxi clearances

*Williams, Hooey & Foyle, 2006, Proc. AIAA*
Experiment 1: Pilot information requirements for STBO taxi clearances

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  - Speed & Time: All

**Results**
- Less RTA error with “Speed & Time” clearances
- RTA Error compounds over route
  - Estimate “closes loop” (but pilot must estimate)
  - Estimate distance and speed needed to compensate error
  - 20 sec late: +3kts at 3,000ft to go; +7.6kts at 1,500ft to go

*Williams, Hooey & Foyle, 2006, Proc. AIAA*
Experiment 1: Pilot information requirements for STBO taxi clearances

RTA Predictability:
- 95% of normal data lies within +/- 2 Standard Deviations
- For these sample sizes: 95% data within +/- 6x to 8x
  Standard Error (SE) value (see example)
  → 95% Data Range much larger than SE (shown)

ConOps Implications:
- Current-day operations: Up to 40 operations/RWY/hr
  - Every 90 sec on average, and as close as 60 sec apart
    (Cheng, Yeh, Diaz & Foyle, 2004)
- In NextGen, to improve system efficiency (Departure runway queues and active runway crossing):
  → RTA predictability: Likely needed to be less than today’s 60-sec current-day operation window
  → Possibly within a 30-sec window (i.e., RTA +/- 15 sec)

- Need fast-time simulation system studies to determine:
  - Level of aircraft RTA precision or predictability for various STBO concepts
  - Interactions with other concepts (e.g., TAPSS, Swenson et al.).
**Objective:** Initial Baseline Flight Deck STBO Study

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**20 sec late:**
- +3kts at 3,000ft to go
- +7.6kts at 1,500ft to go

**Initial Findings**
- Determined value of information:
  - Speed: Provides aircraft control information
  - Time: Provides (some) information to “close loop” on RTA
- RTA error compounds with distance
- Time and/or speed information is insufficient operationally
  - Because of “end of route compensation”
  - Insufficient information for pilots
  - Lack of predictability by ATC/Surface Traffic Management systems
Experiment 2: 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
- Taxi routes: 14,300 ft average length
- 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
**Objective:** “Minimum Flight Deck Equipage”

ConOps Evaluation

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- STBO Taxi Clearances – manipulated:
  - Speed
  - # Intermediate Time Constraint Points

**Findings**

- ATC taxi clearances with only required speed information → Poor RTA conformance

**ConOps Implications**

- Defined STM STBO algorithm parameters: Speed, Distance, # Time constraint points
- Intermediate taxi time constraint points useful (meeting RTAs, traffic flow)
- ATC taxi clearances with speed requirements alone may not suffice
Experiment 3: 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
- Taxi routes: 11,430 ft average length
- 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 3: Commanded Speed – With Speed Profiles/Conformance Range

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ConOps Evaluation
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     - # Intermediate Time Constraint Points
     - Speed Conformance Range:
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Findings

ATC taxi clearances with speed:
• Poor RTA conformance without speed acceleration/deceleration profiles
• Good RTA conformance with speed acceleration/deceleration 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/algorith
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
- Taxi routes: 14,300 ft average length
- 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

\[ s_t = \frac{d_{rem}}{t_{rem}} \]
**Experiment 4: Error-nulling algorithm/display**

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

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2) Flight deck equipage (Avionics or EFB, electronic flight bag)

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  - **TND**: Route; Time constraint point
- STBO Taxi Clearances – manipulated:
  - Speed
  - # Intermediate Time Constraint Points

**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

**Graph**

![Graph showing RTA Error vs. Number of Time Constraint Points](image)
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?”

Rating (1-5)
- 1 Rarely
- 2 Seldom
- 3 Sometimes
- 4 Frequently
- 5 Most of the time

Expt. 2: Speed Commands
Expt. 4: Algorithm / Display
Expt. 3: Undefined Conformance
Expt. 3: Defined Conformance
Expt. 3: Current Day Baseline
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?”
## Summary / Overall ConOps Implications

<table>
<thead>
<tr>
<th>Summary Findings</th>
<th>ConOps Implications</th>
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<tbody>
<tr>
<td>• STBO clearances with speed requirement alone are not viable solution</td>
<td>• Requirement for <em>human-centered</em> flight deck display/algorithm for STBO</td>
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<td>• Taxiing Captain cannot “tightly control/track” speed, navigate, and maintain separation</td>
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<tr>
<td>• Only flight deck algorithm/display condition</td>
<td><em>Human-centered designed systems</em> (Foyle 2009, 2011):</td>
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<tr>
<td>→ Good RTA conformance AND appropriate visual workload / safety</td>
<td>- Are intuitive and “natural”</td>
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<tr>
<td>Caveat: Flight deck algorithm/display -- Needs to allow “strategic operation”, not “tight control/tracking”</td>
<td>- Have readily accessible information</td>
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<td>- Support human capabilities (e.g., perceptual processing)</td>
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<td>- Mitigate human limitations (e.g., memory)</td>
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<td>- Have features supported by “human factors design principles/research results trace”</td>
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<td>- Enable appropriate task usage strategies</td>
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### Next Steps:
- STBO human-centered flight deck displays
- Operational issues:
  - Datalink coordination between STM system and flight deck
  - Integration with NASA’s SARDA (Spot and Runway Departure Advisor)
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Backup Slides
Expt. 1 - RTA Error:
Format x Distance x Route Quartile
Expt. 1 - RTA Error: Format x Distance x Speed