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NEXTGEN SURFACE TRAJECTORY-BASED OPERATIONS: CONTINGENCY-HOLD CLEARANCES

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Abstract

The purpose of this pilot-in-the-loop taxi simulation was to investigate a NextGen Surface Trajectory-Based Operations (STBO) concept called "contingency holds." The contingency-hold concept parses a taxi route into segments, allowing an air traffic control (ATC) surface traffic management (STM) system to hold an aircraft when necessary for safety. Under nominal conditions, if the intersection or active runway crossing is clear, the hold is removed, allowing the aircraft to continue taxiing without slowing, thus improving taxi efficiency, while minimizing the excessive brake use, fuel burn, and emissions associated with stop-and-go taxi. However, when a potential traffic conflict exists, the hold remains in place as a fail-safe mechanism.

In this departure operations simulation, the taxi clearance included a required time of arrival (RTA) to a specified intersection. The flight deck was equipped with speed-guidance avionics to aid the pilot in safely meeting the RTA. On two trials, the contingency hold was not released, and pilots were required to stop. On two trials the contingency hold was released 15 sec prior to the RTA, and on two trials the contingency hold was released 30 sec prior to the RTA. When the hold remained in place, all pilots complied with the hold. Results also showed that when the hold was released at 15-sec or 30-sec prior to the RTA, the 30-sec release allowed pilots to maintain nominal taxi speed, thus supporting continuous traffic flow; whereas, the 15-sec release did not. The contingency-hold concept, with at least a 30-sec release, allows pilots to improve taxiing efficiency by reducing braking, slowing, and stopping, but still maintains safety in that no pilots "busted" the clearance holds. Overall, the evidence suggests that the contingency-hold concept is a viable concept for optimizing efficiency while maintaining safety.

Surface Trajectory-Based Operations

The next generation (NextGen) of the National Airspace System aims to improve the throughput and efficiency of aircraft operations [1]. Realizing these goals will require increased timing precision and reduced aircraft spacing in all phases of flight, including surface operations. In one far-term vision of the Surface Trajectory-Based Operations (STBO) concept, an air traffic control (ATC) surface traffic management (STM) system will issue conflict-free taxi clearances that contain a required time of arrival (RTA) to points on the surface, such as the departure runway, an active runway crossing, or a traffic-merge intersection [2]. Aircraft will be required to reach these specified locations on the airport surface with relatively precise timing.

Following these time-based taxi clearances issued by an ATC/STM system will allow aircraft to: 1) arrive at the departure runway in time for immediate take-off; and, 2) arrive at active runways in time to cross the runway (after receiving crossing clearance) during planned or expected landing/take-off "gaps." These departure STBO capabilities also support future NextGen en route and arrival time-based operations (TBO) concepts.

Contingency Holds

While past simulations [2] have focused primarily on the development of flight deck avionics to enable pilots to safely comply with these RTAs, the present pilot-in-the-loop taxi simulation investigated an STBO concept for contingency holds [3, 4].

As first described by Cheng et al. [3, 4], the contingency-hold concept parses a taxi route into segments with a separate clearance for each portion of the route, giving the ATC/STM system the ability to hold an aircraft when necessary for safety.

Conceptually, a contingency hold would be removed only if the intersection or runway was clear and the aircraft could occupy and clear it within a proximate time window, allowing other aircraft to then use the intersection as scheduled. Nominally, the hold would be released prior to the aircraft reaching the intersection or active runway, allowing for continuous and efficient traffic flow.

However, if the intersection or active runway is not clear, or the aircraft is out of compliance, or because of ATC/STM system route changes, the hold remains in effect, serving as a fail-safe mechanism. This taxi simulation explored the timing and conformance, and thus the efficiency and safety, of a contingency hold at a traffic-merge intersection from the perspective of the flight deck. While this simulation investigates the use of a contingency hold at a taxiway intersection, the concept can also be applied to active runway crossings.

The primary objectives of the present simulation were to evaluate the efficacy of the STBO contingency-hold clearance concept, and to determine appropriate timing parameters for the removal of the contingency hold as an aircraft approaches the contingency-hold point. Two contingency-hold release timing values were tested: 15 sec and 30 sec prior to the RTA. These two contingency-hold timing values were evaluated to determine if the aircraft slowed or braked as it approached the RTA point, which would contradict the intended goal of efficient, continuous aircraft movement. The value of 15-sec prior to the RTA was chosen because it represents the *minimum* time to effect a deceleration rate of 1 kt/sec for the nominal taxi speed of 15 kts (i.e., it takes 15 sec to stop at a deceleration rate of 1 kt/sec). It should be noted that 1 kt/sec is approximately half of the *maximum* deceleration rate cited by researchers for taxi operations and represents a level that would be comfortable for passengers (see for example [5]). The 30-sec value was tested as the longer time value because a previous analysis suggested a value of approximately that magnitude [3]. Although other values could have been tested, simulation resources required that testing be limited to these two timing parameters.

Method

Nine commercial Captains, eight male and one female, with a mean age of 56 years (range of 52 – 59 years) participated in the study. The mean number of flight hours logged as Captain was 10,189 hours (range of 3,700 – 15,000 hours). Pilots' type-ratings included A320 (3 pilots), B767/757 (4 pilots), and B747-400 (2 pilots). Captains were paired with an experimenter who acted as First Officer.

Flight Deck Simulator

The study was conducted in the Airport and Terminal Area Simulator (ATAS), in the Human-Centered Systems Laboratory at the NASA Ames Research Center. The airport environment was the Dallas-Fort Worth International Airport (DFW), with high visibility and distant fog/haze conditions. The forward, out-the-window scene was depicted on four LCD displays, with a total horizontal viewing angle of 140 deg. The modified-B737NG cockpit included a Primary Flight Display (PFD), Navigation Display (ND), and Flight Management System (FMS) Control Display Unit (CDU) on both crew members' sides, and a shared Taxi Navigation Display (TND) and DataComm display with a touchscreen interface. Aircraft controls included a tiller on the Captain's side, toe brakes, throttles, and parking brake. The physical and taxi handling characteristics of the aircraft were that of a mid-size, narrow-body aircraft.

Error-Nulling Speed Algorithm

Each departure taxi clearance included a required time of arrival (RTA) at the contingency-hold intersection. To aid the pilots in arriving at the intersection on time, the flight deck was equipped with an error-nulling speed algorithm that computed the straightaway speed required to precisely meet the RTA [2]. The RTA algorithm dynamically computed the advised speed by accounting for remaining distance, remaining time to RTA, and number of turns, with an assumed acceleration/deceleration rate of 1 kt/sec and turn speed of 10 kts (per standard operating procedures, SOPs). Taxi clearance RTAs were calculated such that the initial advised straightaway speed was 15 kts. The algorithm was dynamic and compensated for the pilot slowing down or speeding up by appropriately increasing or decreasing the advised straightaway speed.

STBO Flight Deck Displays

Taxi clearances were issued via DataComm. The

DataComm touchscreen interface was located aft of the throttles between the two pilots. At the start of the trial, the flight deck received a DataComm with an initial taxi clearance (Figure 1). The "proceed clearance," which provided clearance to taxi through the intersection, was also delivered via the DataComm as the ownship approached the contingency-hold intersection. The DataComm clearance followed a format similar to the European Airport Movement Management by Advanced Surface Movement Guidance and Control System, Part 2 project [6]. When a clearance was delivered via DataComm, three touchscreen response buttons were available to the pilot to respond to ATC: Unable, Standby, and Wilco. The DataComm display included the message sent time in the upper left corner, an indicator of message status in the upper right corner (i.e., "OPEN" while ATC was awaiting a response from the flight deck, or "WILCO", "STBY", or "UNABLE" after a response was selected and sent to ATC), and status of the connection (i.e., "COMM OK" or "RECEIVED BY ATC" when ATC received the crew's response). After the crew responded "WILCO" to a clearance, the DataComm text turned magenta, as an indication of acceptance. All incoming DataComm messages were associated with an auditory chime.

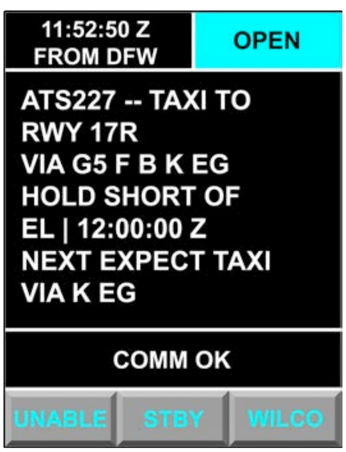

Figure 1. Taxi Clearance DataComm

A Taxi Navigation Display (TND) depicted the airport layout to aid the pilots in airport navigation. The taxi clearance, sent via DataComm, was accompanied by graphic and text preview information displayed in cyan on the TND (Figure 2).

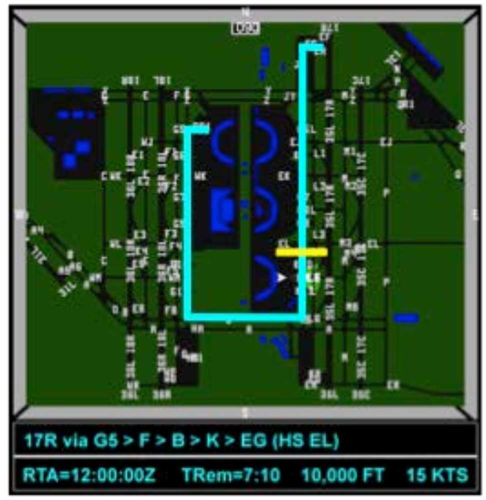

Figure 2. TND with Taxi Clearance Preview

Once accepted by the flight deck, the TND updated with the taxi clearance displayed as a magenta route, in track-up perspective, with text of the accepted clearance (Figure 3). The ownship aircraft's position, shown as a white chevron, and other aircraft traffic within the ownship's 1,250 ft declutter circle were updated in real-time. In all trials, the hold-short intersection was shown in text below the map ("HS EL" in Figure 3). On half of the trials, the hold location was also displayed as a yellow bar (see Figure 3). On the remaining half of the trials, the hold was not graphically displayed on the TND (i.e., there was no yellow hold bar; the hold was represented only in the DataComm text and the clearance text below the TND).

Figure 3. TND with Accepted Taxi Clearance

The PFD was modified for taxi operations by expanding (doubling) the speed scale from 0-60 kts. Once accepted by the flight deck, the PFD populated with advised speed and RTA information. Advised straightaway speed, as calculated by the RTA algorithm, was displayed as a magenta analog pointer ("speed bug") on the speed tape and digitally in magenta directly above the speed tape (15 kts in Figure 4). Upon entering a turn, the magenta speed bug dropped to 10 kts (per taxi SOPs), while the white, inner speed bug continued to dynamically indicate the straightaway speed required to meet the RTA. The PFD also included: the current ground speed, shown as a sliding indicator with digital value inside (0 kts, in Figure 4); RTA time (Zulu) in magenta (12:00:00Z); and time remaining to the RTA (7 min 10 sec in Figure 4) in the white box.

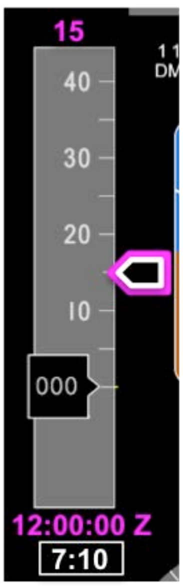

Figure 4. Primary Flight Display (PFD)

Experimental Design

Each crew completed six experimental trials. The three contingency-hold release conditions (hold was not released; hold was released 15 sec prior to RTA; hold was released 30 sec prior to RTA) were factorially crossed with the two TND contingency-hold graphic display conditions (hold location displayed on TND, hold location not displayed on TND). The two graphic display conditions were blocked and the order was counterbalanced; a latin square was used to assign the order of the three contingency-hold release condition trials within each display-condition block. Each trial started at a ramp departure spot and ended just after crossing the contingency-hold intersection. Routes were an average distance of 11,410 ft and an average duration of 11 min and 15 sec.

Procedure

Pilots were instructed to taxi as they would in a B757 aircraft, and never to taxi faster than would be safe in the real world. Crews were informed that the advised straightaway speed was provided as an aid to help them reach the RTA point on time. They were instructed that they were not required to "track" the advised-speed indicator on a moment-by-moment basis, but rather to use it strategically to make speed adjustments when safe taxiing allowed. They were also told that the algorithm was dynamic, and that it assumed a 10-kt turn speed and 1-kt/sec acceleration/deceleration rate.

Each trial began with an expected taxi clearance that included the expected taxi route, departure runway, and departure clearance. Crews used this time to thoroughly review and discuss the taxi clearance and carefully plan their taxi route. The confederate First Officer was responsible for managing the DataComm and programming the Flight Management System (FMS) for the initial departure clearance.

After completing taxi-route planning and FMS entry, the crew received a taxi clearance via DataComm (see Figure 1 for noted examples) that included:

- Departure runway (TAXI TO RWY 17R).
- Taxi clearance from Spot to the Runway (VIA G5 F B K EG).
- Instructions to hold short of the contingency-hold intersection (HOLD SHORT OF EL).
- RTA at the contingency-hold intersection (12:00:00 Z).
- Expected proceed clearance for the remainder of the route following the hold (NEXT EXPECT TAXI VIA K, EG).

As shown in Figure 2, the taxi clearance DataComm was accompanied by preview information in cyan on the TND overview map, including: a graphical taxi route, route and hold short text, time/distance information, and advised speed. In the three TND graphic trials, the graphical route preview also included a yellow hold line at the contingency-hold intersection (as shown in Figure 2).

Upon acceptance of the clearance, the RTA, time remaining, and advised speed were loaded into the aircraft avionics and displayed on the PFD (see Figure 4), while the magenta taxi route was displayed on the TND (Figure 3). In the three TND Graphic condition trials, the yellow hold bar was displayed across the magenta taxi route and came into view on the TND as the ownship neared the intersection (Figure 3). The hold bar depicted on the TND was located prior to the intersection, allowing pilots to stop their aircraft at a safe distance from the intersection in the event that the hold did not release. This distance was based on pre-testing with a pilot subject matter expert.

Pilots were told to expect, in nominal operations, that if they were on track to meet the RTA at the intersection then the contingency hold would release and the flight deck would receive a proceed taxi clearance for the subsequent route segment as the aircraft approached the intersection. However, if they were late and outside of the RTA window or if the ATC/STM system determined that the intersection had become unsafe to cross (e.g., the ownship was early or late, other traffic were out of conformance, or there had been rerouting), the hold would remain in place. No indication of release condition (i.e., no release, 15-sec release, or 30-sec release) was given before the trial. Pilots were told that they were not cleared to taxi through the intersection until receiving the proceed clearance.

In the 15-sec and 30-sec release-conditions, the flight deck received the proceed clearance DataComm (e.g., CONTINUE TAXI TO RWY 17R, VIA K EG, EXPECT NEW RTA) at 15 or 30 sec prior to the RTA. Upon receiving the DataComm, the First Officer read the proceed clearance out loud. The crew then accepted the clearance and taxied through the intersection. In the TND Graphic condition trials, the yellow hold bar was removed from the TND when the proceed DataComm was sent to the flight deck. Upon reaching the hold point, the PFD no longer displayed advised speed and time remaining.

As the proceed clearance was a time-based event (i.e., 15 or 30 sec before the RTA), ownship position along the taxi route at the time the hold released varied. If the ownship was determined to be too far from the intersection at the scheduled release time, that is, unable to meet its proximate time window, the hold did not release.

Specifically, at 15 or 30 sec before the RTA, the ownship was deemed "late" if the speed necessary to reach the hold point by the RTA time exceeded 25 kts, which is outside the bounds of taxi speed SOPs. It follows then, that in distance terms, for the 15-sec release condition the ownship had to be within 633 ft of the hold point at 15 sec prior to the RTA time, and for the 30-sec release condition the ownship had to be within 1,266 ft at 30 sec prior to the RTA time. Likewise, if the ownship arrived at the hold point early, the hold did not release until the scheduled clearance time of 15 or 30 sec prior to the RTA, because conceptually, another aircraft may be scheduled to occupy the intersection. See Figure 5 for a schematic representation of the 30-sec release condition. Figure 5 depicts the participant pilot's (ownship) aircraft, times and traffic positions when the ownship was "on-time" (top panel) or "late" (bottom panel) to meet the RTA at the K/EL intersection for the 30-sec contingency-hold release condition. The 15-sec release condition is similar, except that the middle panel is at time 11:59:45Z (15 sec prior to the RTA time) and the early/late evaluation distance is 633 ft. The noted distances (i.e., 1,266 ft for 30-sec release, and 633 ft for 15-sec release) are the distances that would require a speed of 25 kts or greater to exactly meet the RTA. Thus, if an aircraft was more than that distance from the RTA point, the aircraft would require a speed greater than 25 kts to meet the RTA, and hence it was deemed "late."

In the no-release condition, the flight deck did not receive the proceed clearance and the hold remained in place, requiring pilots to come to a complete stop prior to entering the intersection. Pilots were told this could happen due to ATC/STM system rerouting. In the Graphic condition trials, the yellow hold bar remained visible on the TND. While being held, the intersection was used by a crossing aircraft. Once that aircraft was clear of the intersection, a proceed clearance was sent to the flight deck.

In all conditions, the experimental trial ended as soon as the pilot's aircraft passed the intersection. In actual operations, the proceed clearance would include an RTA to the next hold location (i.e., traffic-merge intersection or active runway crossing) or departure runway.

Results

Several measures in the no-release and release conditions were examined to characterize pilot performance, efficiency, and safety at the contingency hold.

No-Release Condition

In the no-release condition, all pilots (18 observations; 9 pilots x 2 repetitions) complied with the hold and braked in a safe (non-emergency) manner, a finding that is consistent with the intent of the fail-safe aspect of the contingency-hold concept.

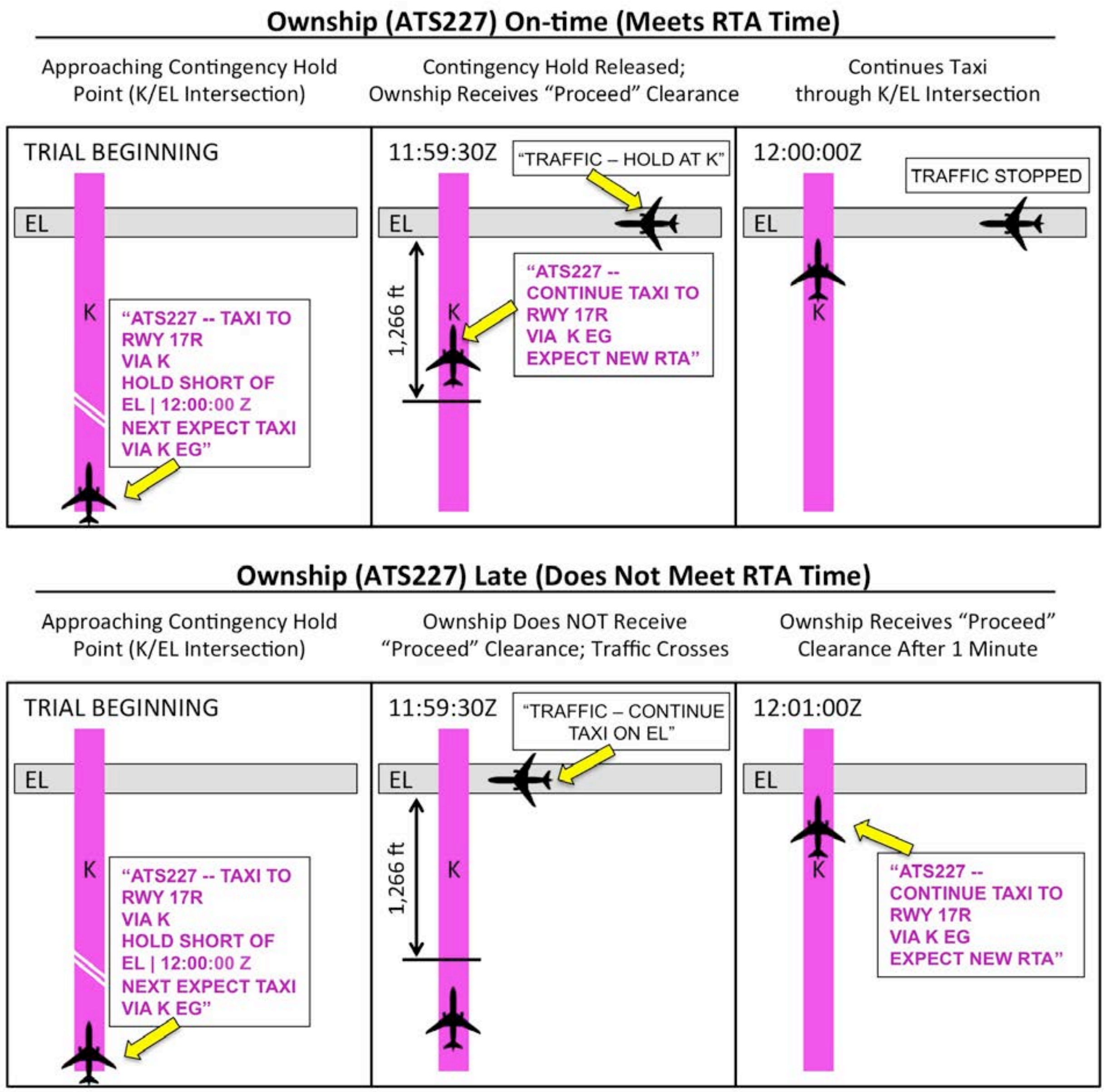

Figure 5. Contingency-Hold Release Schematic

An analysis of braking in the no-release condition examined how many seconds prior to the contingency-hold point pilots initiated braking. Time was calculated as a function of distance between the first brake application and the contingency-hold point, and their instantaneous speed at brake onset. On average, pilots initiated braking 15.3 sec prior to the hold (Figure 6). In actual aircraft operations, braking response varies as a function of aircraft type, weight (e.g., fuel, passenger, and baggage loads), and airport surface conditions. It was beyond the scope of this simulator study to manipulate these factors, but it is reasonable to expect that pilots adopted a "typical" distance to initiate braking based on their many years of experience. Further, results showed no significant difference in brake initiation time in the TND Graphic condition (*M* = 18.0 sec, *S.E.* = 4.5) as compared to the no-graphic condition (*M* = 12.6 sec, *S.E.* = 1.4), $t(8) = 1.27$, $p = 0.24$.[1] One data point was removed from this analysis because one pilot came to a stop prior to the hold point by reducing throttle instead of braking.

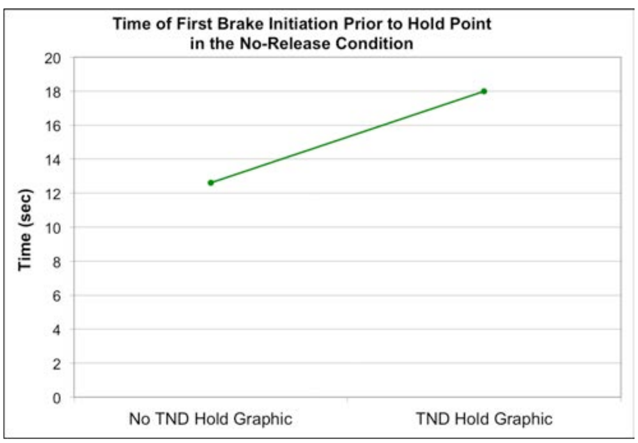

Figure 6. Time of First Brake Initiation

Release Conditions

In the 15-sec and 30-sec release-condition trials, the contingency hold was released if the aircraft arrived at the hold point within the allowable time-conformance window.

For those trials in which the ownship did arrive within the time-conformance window and the contingency hold released, an analysis was conducted to assess whether there was any indication that pilots initiated slowing before the hold was released. Recall that the goal of the concept was to release the hold *before* pilots initiated slowing in order to optimize efficiency, reduce brake wear, and reduce need to increase throttles after the hold is released. Three measures were examined: 1) brake activity; 2) throttle behavior; and, 3) reduction in speed from the nominal speed.

First, braking activity prior to the release of the hold was investigated. No pilots initiated braking in the 15-sec or 30-sec release conditions.

Next, pilots' throttle activity was evaluated to determine if the pilot began to throttle back in preparation for the hold prior to the contingency hold release. The amount of time (sec) that the throttle positions were fully back (at idle) was recorded. As shown in Figure 7, a 2 (graphic) by 2 (release timing) within-participants ANOVA revealed a main effect of release timing $F(1,8) = 6.5$, $p = .03$. Pilots in the 15-sec release condition (*M* = 4.2 sec, *S.E.* = 1.4) positioned the throttle at idle longer than in the 30-sec release condition (*M* = 0.5 sec , *S.E.* = 0.5). These results suggest that a 30-sec release allows for more efficient traffic flow as pilots are not required to reduce throttle and slow their speed as much as in the 15-sec release condition. Two data points were removed from this analysis because, in two trials, the pilot did not meet the RTA conformance window and the hold did not release.

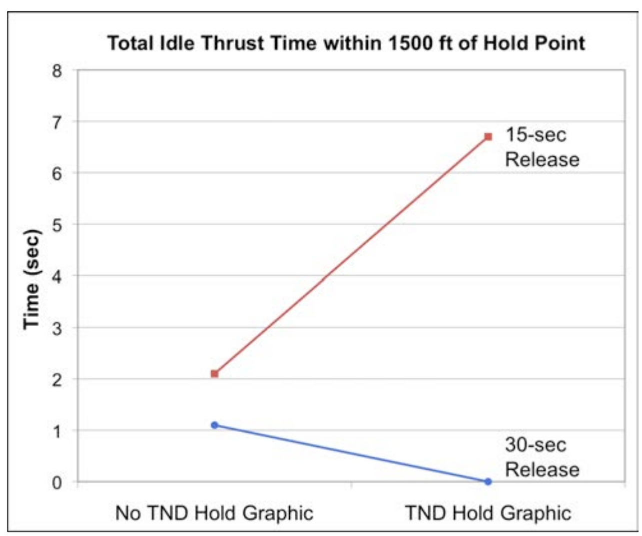

Figure 7. Total Idle Thrust Time

[1] Unless otherwise noted, all statistical tests are two-tailed.

Finally, instantaneous aircraft speed at the time that the proceed clearance was issued was examined to determine if there was any evidence of the reduction of taxi speed. A 2 (graphic) by 2 (release timing) ANOVA showed a significant main effect of release, $F(1,8) = 7.1$, $p = .03$. Pilots' instantaneous speed at the time of the proceed clearance was slower in the 15-sec release condition ($M = 13.5$ kts, $S.E. = 0.8$) than in the 30-sec release condition ($M = 15.3$ kts, $S.E. = 0.5$). However, any aircraft slowing prior to the proceed clearance would be evidenced by a reduction from the nominal taxi speed of 15 kts at the time of the proceed clearance. Results showed that aircraft were slower than the nominal 15 kt speed in the 15-sec release condition, $t(8) = 1.98$, $p = .04$ (one-tail), but no slowing was found in the 30-sec release condition, $t(8) = 0.55$, $p = .30$ (one-tail) (Figure 8). The result of nominal (15 kts) taxi speeds in the 30-sec release and slower taxi speeds with the 15-sec release further suggests that releasing aircraft 30 sec prior to the RTA supports efficient and continuous traffic flow. Two data points were removed from this analysis because, in two trials, the pilot did not meet the RTA conformance window and the hold did not release.

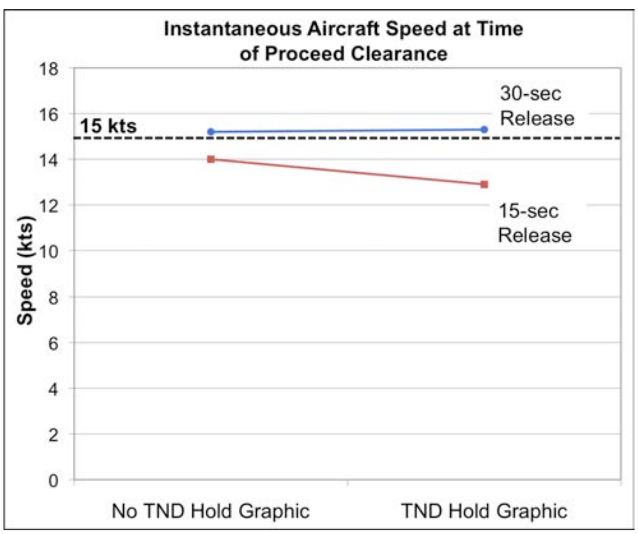

Figure 8. Aircraft Speed at Proceed Clearance

The hold was released as expected in all but two trials (once each in the 15-sec and 30-sec conditions). In these two trials, the pilots were late reaching the RTA time window and as a result, were held while other traffic used the intersection. After holding for approximately 1 min, they received clearance to continue taxi.

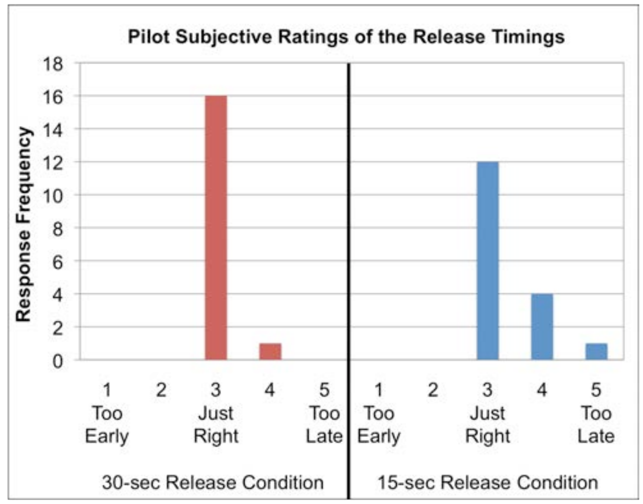

Figure 9. Subjective Ratings of Release Timings

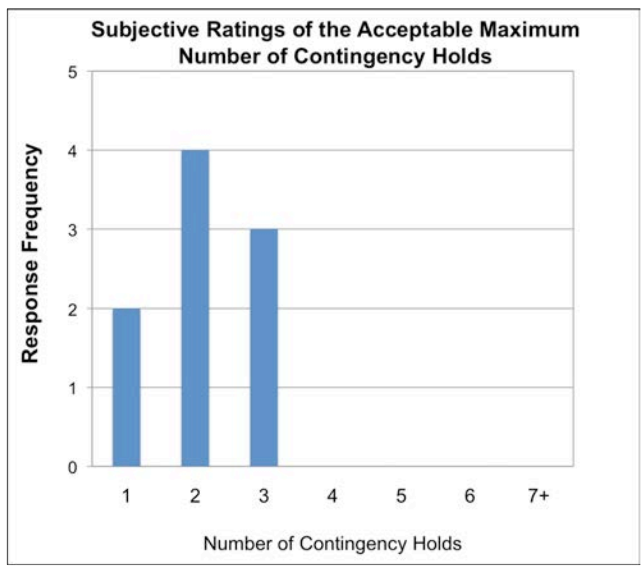

Figure 10. Maximum Number of Holds

On a post-trial questionnaire, pilots were asked to rate the timing of the hold release in the trial they just completed using a 5-point scale, where 1 = Too Early, 3 = Just Right, and 5 = Too Late. As shown in Figure 9, the 15-sec release condition resulted in more ratings closer to, or at, "too late" (indicating that pilots were more comfortable with the 30-sec release). The mean response rating in the 30-sec release condition (M = 3.1, $S.E.$ = 0.1) was closer to "just right" than in the 15-sec release condition (M = 3.4, $S.E.$ = 0.1), although p = .065. Two data points were removed from this analysis because, in two trials, the pilot did not meet the RTA conformance window and the hold did not release.

On a post-study questionnaire, participants were asked to indicate the maximum number of contingency-hold points that would be acceptable in a single taxi route. The mean response (n = 9) was 2.1 contingency-hold points, with a range of 1 – 3 holds; with two pilots responding "1 hold", four pilots responding "2 holds", and three pilots responding "3 holds" (Figure 10).

Discussion

Overview of the Contingency-Hold Concept

In NextGen Surface Trajectory-Based Operations (STBO), it has been proposed that aircraft may receive a required time of arrival (RTA) to an intersection or a runway crossing as part of their taxi clearance [3, 4]. Such time-based operations are being considered to enable efficient taxi operations, so that all aircraft airport movement can be conducted in a coordinated fashion. Exceptions to planned routes with RTAs will certainly occur; either because of the need for the ATC/STM system to re-plan routes, or because of aircraft non-conformance (of the route, the RTA time, or both) to the time-based taxi clearance. In order to maintain safe aircraft separation, aircraft that do not have conflict-free routes (i.e., aircraft that have routes with other aircraft traffic crossing their routes), will need a positive way to maintain separation. The contingency-hold concept has been proposed as a mechanism to enable that positive control of safe separation on the airport surface in the NextGen STBO environment [3, 4].

In the contingency-hold STBO concept, an aircraft not only receives a taxi clearance with an RTA to the end of the route (e.g., the departure runway), but also receives an RTA to one or more intermediate locations. These intermediate locations (e.g., taxiway intersection or runway) each have an assigned RTA that the aircraft is expected to meet. Nominally, the aircraft meets the RTA and passes through the intersection at that assigned time. Thus, other crossing aircraft may occupy the intersection at other times, since each aircraft has a conflict-free assigned time to occupy the intersection. As a fail-safe method to ensure aircraft separation, under the contingency-hold STBO concept aircraft are only cleared to a hold point located immediately before the intersection with the RTA. Under nominal conditions, the ATC/STM system assesses that it is safe to proceed (i.e., the "contingency hold" is removed) and the aircraft is provided with clearance to proceed to the next RTA point with sufficient lead time such that the aircraft would not need to brake or slow, allowing efficient aircraft operations (i.e., improved traffic flow, lower emissions and fuel consumption because aircraft do not need to "stop and go" or wait for crossing traffic). Under these nominal operations, pilots would come to expect that, most of the time, the contingency-hold clearance would be released as they approached the intersection.

In the contingency-hold STBO concept, when performance is nominal and all aircraft meet their intersections' assigned RTA times, there are no efficiency or safety issues. However, when aircraft do not meet the assigned RTA times or go off-route, or when there is a change in taxi routing, the contingency hold may remain in place and not be removed as expected. If the contingency hold is left in place only a small proportion of time, pilots could be induced to "miss" that it was not released, and thus would, at the minimum, produce a pilot deviation error in that they were not cleared to enter the intersection, or at worst, come in contact with another aircraft proceeding through that intersection.

The present simulation evaluated three aspects of the contingency-hold STBO concept, and each will be discussed in turn. The three aspects of the contingency-hold STBO concept were:

- An evaluation of pilot conformance to the contingency-hold clearance when it was not released as expected;
- An assessment of pilot performance to determine the amount of time prior to an intersection's assigned RTA time that the contingency-hold clearance must be removed such that the aircraft can continue through the intersection without slowing or braking; and,

- An evaluation of the need for flight deck graphical aids representing the status and location of the contingency-hold clearance.

Pilot Conformance When the Contingency-Hold Clearances Were Not Removed

All pilots appropriately braked and stopped without "busting the hold" when the contingency-hold clearance remained in effect (i.e., the hold was not removed) as they approached the intersection. This was the result whether or not the contingency-hold clearance was represented graphically on the Taxi Navigation Display (TND) map. Pilots reported that in current operations it is fairly common to be given taxi clearance to proceed to a location, hold, and await further instructions, and that the contingency-hold concept is consistent with those common operations. The finding that no pilots proceeded incorrectly through the contingency-hold clearance when it was not removed suggests that the data are consistent with the "fail-safe" intent of the contingency-hold STBO concept.

Timing Requirements for Removing the Contingency-Hold Clearance

As noted previously, multiple measures suggest that in order to allow for efficient, continuous taxi with no or minimal slowing or braking through an intersection with a contingency-hold clearance, the contingency hold must be released (i.e., the "proceed clearance" must be issued) about 30 sec in advance of reaching the intersection. Specifically, pilots in the 30-sec release condition were able to maintain nominal taxi speed and, on average, spend less time with the throttle reduced to idle, which suggests that sending the proceed clearance 30 sec prior to the RTA supports efficient taxi when implementing contingency-hold clearances. Questionnaire results also showed that pilots believed that a hold release time of 30-sec provided the appropriate lead-time to taxi through the intersection without slowing or braking. That is, when the hold is removed, and the "proceed clearance" is issued 30 sec in advance of the RTA, it provides sufficient time in advance of the intersection such that no (or minimal) braking or slowing is required by the pilot. When the hold is removed and the "proceed clearance" is provided only 15 sec in advance, the pilot has already initiated braking or slowing because of the closer proximity to the intersection.

The present study showed that for efficient aircraft operation under STBO, a 30-sec release suffices, but a 15-sec release does not. As the STBO contingency hold concept matures, further research will be necessary to define precisely what specific hold release timing value should be used.

Graphical Representation of the Contingency-Hold Clearance

Although pilot comments during debrief interviews supported the usefulness and safety implications of the graphical depiction (i.e., yellow bars) of the clearance holds on the TND, the pilot/aircraft performance measures presented were not affected by this factor. As mentioned previously, in current operations pilots commonly are told to hold at airport locations without a TND and without any graphical clearance representation. However, it should be noted that such a graphical representation of the hold clearance provides a redundant, visual record of the current clearance without reliance on memory. Even though it did not improve pilot performance on the measures in this condition, pilots reported that it would likely improve safety and reliability in actual operation since it is a redundant and salient source of information.

Summary

The contingency-hold STBO concept provides a method of time-based taxi clearances that allows for crossing aircraft traffic. In the present experiment, data suggest that removing the hold at least 30-sec in advance provides the pilot sufficient advance notice such that braking or slowing does not need to be initiated. Importantly, when operations under the contingency-hold STBO concept do not unfold nominally as planned and the hold clearance is not removed as expected, the hold remains in effect. The present data indicate that there were no negative effects (i.e., pilots did not "bust the hold") when the contingency hold was not released, and remained in effect. Overall, the evidence suggests that the contingency-hold STBO concept is a viable concept for optimizing efficiency while maintaining safety in the advanced NextGen environment.

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