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Flight Deck Robustness/Conformance Testing with a Surface Management System: An Integrated Pilot-Controller Human-in-the-Loop Surface Operations Simulation

David C. Foyle
NASA Ames Research Center
Human-Systems Integration Division
Moffett Field, CA 94035 USA
David.C.Foyle@nasa.gov

Deborah L. Bakowski, Becky L. Hooey, Lara W. S. Cheng, and Cynthia A. Wolter
San Jose State University
at NASA Ames Research Center
Human-Systems Integration Division
Moffett Field, CA 94035 USA

ABSTRACT

An integrated flight deck and controller human-in-the-loop taxi-out operations simulation was conducted in the Dallas/Fort Worth (DFW) environment. In this first integrated Pilot-Controller Spot and Runway Departure Advisor (SARDA) simulation, ATC Ground and Local Controllers used the SARDA decision support tool to plan and issue spot-release clearances and departure clearances. The Airport and Terminal Area Simulator (ATAS), a simulated B737NG, was integrated into the realistic simulation traffic environment. In the simulation, controllers used SARDA advisories to issue spot release, taxi route, and runway/departure radio voice clearances to all aircraft on the airport surface. Ten commercial transport pilots piloted the ATAS and taxied from gate to runway following ATC clearances. Simulation results indicated that under a variety of observed pilot/aircraft performance variations, SARDA yielded controller advisories that were: Supportive of current-day, time-based operations; Compatible with controllers' expectations; Predictive of actual takeoff times; and, Adaptable to off-nominal events. An Information Sharing Display (ISD) that presented SARDA sequence and timing information on the flight deck, was considered useful for both NextGen operations and current-day, time-based Traffic Management Initiative (TMI) operations.

Keywords

Surface operations, NextGen, departure, time-based operations

INTRODUCTION

On a global basis, research is underway to design the next-generation airspace systems of the world. The SESAR [1] and EMMA2 [2] efforts in Europe and the NextGen [3] efforts in the United States are core programs of these new technology efforts. Under these programs, all phases of flight are being investigated: Pre-flight, taxi, takeoff; Departure, Climb; En route cruise; Descent, approach; and, Landing, taxi, arrival. The present simulation investigated the taxi-out departure environment (from the ramp area to the runway) in both current-day and NextGen environments.

One research effort is aimed at the development of surface traffic management (STM) systems for ATC to provide optimized taxi clearances enabling efficient airport traffic operations and improving throughput. One such example is Spot and Runway Departure Advisor, or SARDA [4, 5]. The National Aeronautics and Space Administration's (NASA) SARDA prototype tool is a surface management system decision support tool that helps tower controllers manage airport flow to improve taxi operations efficiency through the integration of spot release and runway scheduling functions.

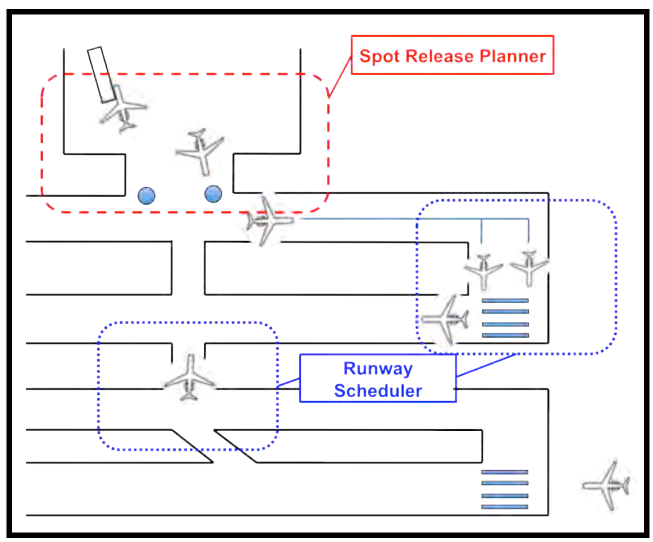

Figure 1. Operational domain areas of SARDA's Spot Release Planner and Runway Scheduler (after [4]).

SARDA's Spot Release Planner component provides the ground controller sequence and timing advisories for releasing departure aircraft from the ramp into the aircraft movement area to minimize delay in the departure queue. Specifically, SARDA algorithms estimate how much time aircraft take to taxi from each spot to the departure runway.

These taxi time estimates are shown to the Ground Controller as a “spot release schedule” advising the controller as to the time to release the departure aircraft from the ramp spot so that the aircraft can make the planned runway departure time. SARDA’s Runway Scheduler component provides the local controller with aircraft takeoff sequence and arrival runway crossing sequence in order to maximize runway usage.

In the near- to mid-term time frame, STM development efforts such as SARDA are aimed at decision support tools to help controllers manage spot release, departures, and arrival runway crossings. Such systems could be expanded to allow for surface trajectory-based operations (STBO), in which taxi clearances would include a time component to reach the runway queue, the runway hold line, or other intermediate intersections. STM systems that support STBO would enable coordinated aircraft movement on the airport surface and on departure and arrival runways leading to efficient operations [6, 7]. It is expected that in order to enable STBO fully, there would be a flight deck component, including DataComm and other advanced avionics [8].

It should be noted that pilots, in some current-day operations, already do conduct taxi-out operations with a departure time component. Under current-day Traffic Management Initiative (TMI) programs, Expect Departure Clearance Times (EDCT) or Call For Release (CFR) times are imposed on departing aircraft in order to meter and control the flow of aircraft at the destination airport. In current-day operations, the flight crew does not have any on-board tools to help them meet these departure times, and have to rely on rough estimates of traffic flow and the air traffic controllers to meet these times.

SIMULATION OVERVIEW

Study Goals

The first objective of this simulation was to evaluate SARDA’s taxi conformance monitoring capabilities and robustness with actual pilot/aircraft performance. Specifically, the objective was to assess the effect of pilot/aircraft performance variability on SARDA’s ability to produce stable and usable traffic sequencing and scheduling advisories for controllers -- a necessary condition for successful future field deployment. Pilot/aircraft taxi performance varies widely under actual operations; and, these variations were also observed during the course of this simulation. Specific parameters associated with these pilot/aircraft performance variations will be used to inform the future development and “tuning” of the SARDA system and other traffic sequencing and scheduling ATC decision support tools.

In order to understand and observe interactions between the piloted aircraft and the SARDA decision support tool, the following experimental conditions were tested factorially: 1) Current-day vs. NextGen operations (with associated displays); and, 2) TMI departure operations vs. non-TMI departure operations.

A second objective of this simulation was to evaluate the usefulness of incorporating certain NextGen flight deck information during the taxi-out/departure phase of flight. In a NextGen environment in which a surface management advisory system is operating such as SARDA, the information that SARDA provides the Controllers could prove useful to the flight deck. Understanding what the Controllers are attempting to do could lead to better aircraft conformance and thus lead to better system performance. Specifically, in the NextGen flight deck condition, pilots evaluated the usefulness of an "Information Sharing Display" which shared SARDA Controller information with the flight deck, as well as a Primary Flight Display (PFD) speed advisory which has previously been shown to enable pilots to accurately meet taxi required times of arrival [8].

METHOD

Participants

Ten commercial transport Captains, all male, with a mean age of 54.2 years (range of 38 - 66 years) participated in the study, acting as Captains in the flight deck simulator. The mean number of flight hours logged as Captain was 9,470 (range of 2,300 - 20,000 hrs). The pilots’ current type-ratings included: B737 (1 pilot), B757 (1 pilot), and B747 (8 pilots). Captains were paired with an experimenter who acted as First Officer. Two Air Traffic Controller subject matter experts participated in this study. The Local Controller retired from SFO Tower in 2004. The Ground Controller was also retired from SFO tower with over 20 years of experience in ATC operations at SFO and OAK.

Flight Deck Simulator

The study was conducted in the Airport and Terminal Area Simulator (ATAS) of the Human-Centered Systems Laboratory (HCSL) at NASA Ames Research Center (see Figure 2). 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.

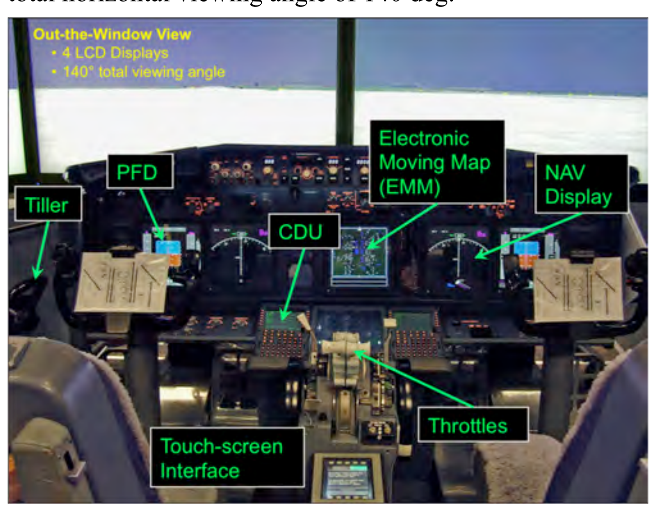

Figure 2. Airport and Terminal Area Simulator (ATAS)

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, a shared Electronic Moving Map (EMM) with updating ownship position, a digital clock showing simulation time, and a touch-screen interface for loading taxi clearances and takeoff times into the avionics. 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.

Each participant Captain sat in the left seat of the ATAS flight deck. The Captain operated the ATAS aircraft with the nose wheel tiller (with left hand) and the throttles (with right hand). An experimenter sat in the right seat and acted as First Officer. Both pilots could hear all tower and flight deck voice communication, but the First Officer operated the digital radios and handled all communications, coordinating with the Captain as appropriate.

Simulation Test Conditions

Table 1. Simulation Test Conditions

Scenario	ATAS Trial	Flight Deck Condition
ATAS flight deck conditions/displays briefing		
1	Training 1	Current Day / TMI
	Off-nominal 1	Current Day / 60 s taxi stop (off-nominal)
2	Experimental 1	Current Day
	Experimental 2	Current Day / TMI
3	Experimental 3	Current Day / TMI
	Experimental 4	Current Day
ATAS flight deck conditions/displays briefing		
4	Training 2	NextGen / TMI
	Off-nominal 2	NextGen / 60 s taxi stop (off-nominal)
5	Experimental 5	NextGen
	Experimental 6	NextGen / TMI
6	Experimental 7	NextGen / TMI
	Experimental 8	NextGen

Note: All trials conducted with SARDA controller advisories.

Simulation test conditions are listed in Table 1. All trials were conducted with Ground and Local Controllers using the SARDA advisories for spot release and takeoff sequence. Traffic scenarios were approximately 45-min long with continuous departure, arrival, and taxi traffic flows. At about the 5-min point of each scenario, the ATAS simulator appeared as an aircraft in the scenario. The ATAS flight crew pushed-back from the gate and taxied to the spot, and then received the taxi and takeoff clearances via voice from the Ground and Local Controllers who were aided by the SARDA advisories. The ATAS trial ended after initiating the takeoff roll, and the Captain filled out a short post-trial questionnaire. In a similar manner, at about the 25-min point, the ATAS aircraft again appeared in the second half of the scenario.

As shown in Table 1, the day was split into two halves – Current-day operations and equipage, followed by NextGen flight deck operations and displays. The Current-day operations condition was tested first so as to obtain performance as close as possible to that of typical current-day operations, and not be impacted by NextGen concepts. Prior to each half, the ATAS Captain received a briefing on all procedures and displays that they would experience. Also, the first ATAS trial was considered a training trial for "sim familiarization" for hands-on control and procedure familiarization. During the second trial of each half, the experimenter asked the pilot to request a short hold on the taxiway, at which time the ATAS aircraft stopped during taxi out. The ATAS aircraft stopped on the taxiway during taxi out for approximately 60 s, although the associated clearance communications added an additional 10-20 s.

Flight Deck NextGen Displays

In the NextGen condition the flight deck displays included:

• A modification to the PFD speed tape display to enable pilots to safely meet the scheduled departure queue and takeoff times in the STBO environment

• An Information Sharing Display (ISD) that displayed departure sequence and estimated timing information received from the SARDA controller system

These two NextGen displays were not available in the current-day conditions.

STBO PFD modifications

In the NextGen condition, pilots were given a scheduled takeoff time, provided either by the TMI-scheduled takeoff time, or by SARDA's prediction of takeoff time. To aid them in arriving at the runway at the SARDA- or TMI-scheduled takeoff time, the flight deck was equipped with an error-nulling speed algorithm that computed the straightaway speed required to precisely meet the scheduled takeoff time. The algorithm dynamically computed the recommended straightaway speed by accounting for remaining distance to the runway, remaining time to the scheduled takeoff time, and number of turns, with an assumed acceleration/deceleration rate of 1 kt/s and turn speed of 10 kts (per standard aircraft operating guidelines). The algorithm was dynamic and compensated for the pilot slowing down or speeding up by appropriately increasing or decreasing the recommended straightaway speed. For more information, the reader is referred to a more detailed description [8].

The PFD was modified for taxi operations by expanding (doubling) the speed scale from 0-60 kts. Once the scheduled takeoff time was loaded into the flight deck avionics by the pilots, the PFD populated with speed and time information, as shown in Figure 3 (left panel). Recommended speed, as calculated by the error-nulling algorithm, was displayed as a magenta analog pointer ("speed bug") on the speed tape and digitally in magenta directly above the speed tape (e.g., 15 kts in Figure 3). Scheduled Takeoff time (e.g., 15:24:08 Z) and time remaining to the Scheduled Takeoff time (e.g, 4 min 28 s) were displayed below the speed tape.

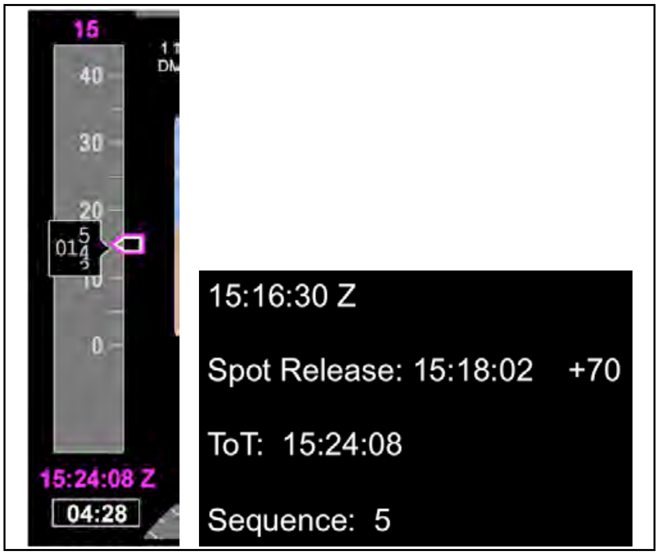

Figure 3. Modified PFD speed tape for STBO (left panel) and Information Sharing Display (right panel)

The PFD also included current ground speed, shown as a sliding indicator with digital value inside (e.g., 14 kts). Upon entering a turn, the magenta speed bug dropped to 10 kts (per typical aircraft operating guidelines), while the white, inner speed bug continued to dynamically indicate the recommended straightaway speed required to meet the Scheduled Takeoff time. The error-nulling algorithm used route information, such as distance and number of turns, as well as scheduled (or revised) takeoff time to calculate the recommended straightaway speed to meet that takeoff time.

Information Sharing Display (ISD)

The Current-day condition included only a digital clock that displayed UTC standard time. In the NextGen condition, the flight deck also included an Information Sharing Display (ISD) that displayed information from SARDA (see Figure 3 right panel for examples): Scheduled spot-release time (e.g., "15:18:02"); Scheduled takeoff time (e.g., "15:24:08"); and, Departure sequence number (e.g., "5").

Every 10 s, SARDA recalculated predicted spot-release time and takeoff times. When this new SARDA-recalculated value varied more than 60 s from the currently displayed ISD value, the ISD updated and showed how much it had changed. For example, in Figure 3, the ISD shows that the spot-release time has increased by 70 s from what had been previously displayed.

A touch-screen interface was used by the crew to load the standardized taxi route and scheduled takeoff time into the flight deck avionics. Upon receiving the taxi clearance from the Ground Controller, the crew loaded the taxi route. After receiving the scheduled takeoff time and after receiving any subsequent changes to that time, the crew used the touch-screen interface to load the newly revised takeoff time.

Spot and Runway Departure Advisor (SARDA)

The SARDA software, displays, tower controllers and pseudo-pilots were located in NASA Ames Research Center's Future Flight Central (FFC) during the simulation. The ATAS flight deck was integrated with the Spot and Runway Departure Advisor (SARDA) tool via the HLA communication protocol. Thus, the ATAS aircraft was scheduled for spot release and departure by the SARDA software and appeared as a scenario aircraft on the SARDA controller displays. Similarly, all other scenario aircraft were visible out-the-window in the ATAS. The SARDA advisories were used by the Ground and Local Controllers on all trials.

Aircraft other than the ATAS aircraft were controlled by two pseudo-pilots: One pseudo-pilot handled arrival, departure, and runway crossing aircraft, and the other handled taxiing aircraft. Another team member monitored traffic alongside the pseudo-pilots to ensure the other aircraft maintained safe separation from the ATAS aircraft at all times. Clearances and readbacks among the tower controllers, the ATAS Captain and First Officer, and the aircraft pseudo-pilots were given via voice using a digital radio application, with a ground frequency and a local frequency.

Figure 4. Ground Controller SARDA spot release electronic flight strips display

The Ground Controller used the SARDA spot-release scheduler to deliver taxi clearances to aircraft at the SARDA-suggested time. The Ground Controller also had an updating ground surveillance display with datatags (not shown). Figure 4 shows the SARDA Ground Controller touchscreen "electronic flight strips" display. Columns (from left to right) show: Flight identifier; Aircraft type; Spot Release sequence number; Spot-release time (min:s to go); Spot/taxi route; Departure runway/Fix/Destination; Traffic Management Initiative (TMI) takeoff roll time (if appropriate); and, a Taxi-Departure button.

The Local Controller used the SARDA runway departure sequencer for Line Up and Wait Clearances, Takeoff Clearances, and for crossing arrivals on an active runway. Figure 5 shows the SARDA Local Controller "electronic flight strips" display. Columns from left to right show: Flight identifier; Aircraft type; Sequence number for controller clearance; Destination (Taxi route in the departure queue); Departure fix/Destination; TMI time (if appropriate); and, Line up and Wait (LUAW) and Cleared for Takeoff (CFTO) buttons. The format is slightly different for arrival/crossing aircraft: The third row in Figure 5 (e.g., "AAL974") shows an arrival aircraft that is to be crossed as the fifth action (e.g., "5") heading to Spot 36 (e.g., "S36") and then handed off to the East Ground Controller (e.g., "E GND"), as shown in columns 3 to 5 respectively.

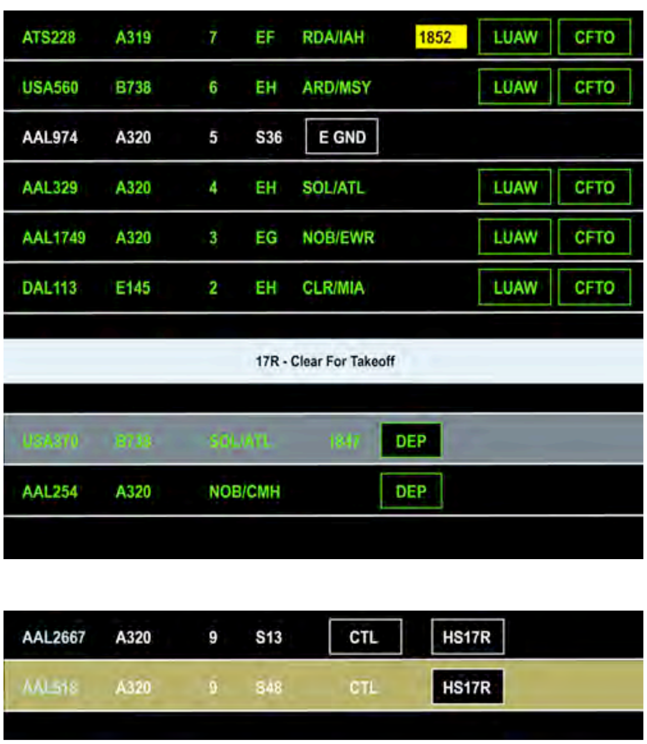

Figure 5. Local Controller SARDA departure queue (top) and runway crossing (bottom) electronic flight strip sections

SARDA used standardized taxi routes from the spot to the runway depending on departure fix. All departures for the ATAS aircraft were from Terminal E to Runway 17R. Non-ATAS aircraft departed from Terminals A, C, or E to Runway 17R. Arrival aircraft landed on Runway 17C, crossed Runway 17R, and proceeded to the gate. Controllers were instructed to follow the SARDA suggested timing and sequence in issuing clearances.

In addition to the displays above, the controllers also had an updating ground surveillance display with datatags (not shown). More detail on SARDA and the controller displays can be found in [5].

Experimental Design

Background

Prior to the 10 experimental test days with participant pilots, a full day of training with procedures and scenarios was conducted for the experimenters, confederate First Officer, Local Controller, Ground Controller, two pseudo-pilots and traffic monitor. All parties, with the exception of the Ground Controller, had previous simulation experience with the facility, displays and systems.

Design

As shown previously in Table 1, each flight crew completed a total of 12 taxi out/departures, comprised of a training trial, an off-nominal (taxi stop) trial, and four experimental trials in each of two flight deck conditions, current-day and NextGen. In the Current-day flight deck condition, the flight deck was not provided with SARDA scheduling information or recommended speed. In the NextGen flight deck condition, Scheduled Spot-release time, Scheduled Takeoff time, and Departure Sequence number, as well as, the error-nulling speed display, were presented on the flight deck. During the second trial in each condition, an off-nominal event was created when the crew was required to request a stop for 60 s on the taxiway. In half of the experimental trials, a Traffic Management Initiative (TMI) departure time was implemented in SARDA. Each trial started at the gate, prior to pushback and ended after the aircraft reached 120 kts on the runway. Order of testing of the experimental scenarios was counterbalanced within each block of Current-day/NextGen flight deck trials, however, the Current-day operations condition was tested first for all participants.

Procedure

Each trial began with the ownship parked at the gate. The crew was provided with pre-departure information approximately 5 min prior to pushback (spot, expected taxi route, and departure clearance). The experimenter First Officer was responsible for programming the FMS and for managing the radio, switching between the ground and local frequencies, as needed. Pilots were told that the Controllers would be using a new automation tool (i.e., SARDA) that meters aircraft from the spot, to improve efficiency of surface operations and reduce delay.

The trial began with an indication that the ATAS aircraft was about to pushback. The Captain initiated pushback by releasing the parking brake. The aircraft then began an automated pushback procedure. When complete, the crew received an audio notification that pushback was complete, instructing them to begin taxiing to the spot.

Pilots held at the spot until the Ground Controller delivered the Taxi Clearance, by voice (e.g., "ATS227, taxi to Runway 17R, via K, EG."). After entering the queue area, the Local Controller delivered the Line Up and Wait and Takeoff Clearances, by voice.

Traffic Management Initiative (TMI) Departure Times

While half of the trials in each condition (current-day and NextGen) included a SARDA TMI, the takeoff time requirement was presented to the pilot participants differently, depending on the context of the condition.

In current-day trials that included a SARDA TMI, pilots were told they had an Expect Departure Clearance Time (EDCT) with a +/- 5 min window, which is consistent with current-day operations. The EDCT was provided to flight deck, by voice, before crossing the spot.

In all NextGen trials, pilots were presented with a scheduled takeoff time with a +/- 1 min window. The scheduled takeoff time represented SARDA's prediction of takeoff time as computed at spot release. In trials that did *not* include a SARDA TMI, the flight crew was notified any time the Scheduled Takeoff time changed by more than +/- 60 s. In trials that included a SARDA TMI, however, the flight deck did not receive any changes to Scheduled Takeoff time.

Upon receiving the Pushback Clearance in the NextGen condition, the Information Sharing Display (ISD) populated with the SARDA Scheduled Spot Release and Scheduled Takeoff times. Pilots were told that this information was intended to give them an awareness of the scheduled times that ATC was working toward, and to be an aid to help them meet the smaller takeoff time window of +/- 1 min in NextGen. If the Scheduled Spot Time changed by more than +/- 60 s, prior to reaching the spot, the ISD updated with the new time and the magnitude of the change.

As the ATAS aircraft crossed the spot, the ISD blanked the Scheduled Spot-release time, updated the Scheduled Takeoff time, and populated the Departure Sequence Number, which continued to update in real time as the aircraft neared the runway. The pilots then loaded the Scheduled Takeoff time into the flight deck avionics, for the purpose of calculating the recommended straightaway speed. The error-nulling speed algorithm displayed the recommended speed on the PFD to aid the pilot in meeting the +/- 1 min takeoff window.

RESULTS AND DISCUSSION: EFFECTS OF PILOT/AIRCRAFT VARIATION ON SARDA

Pilot-based Sources of Uncertainty

The first goal of this simulation was to observe pilot/aircraft performance variation in the SARDA environment, and to observe the effects of that variation on SARDA scheduling. Some of the pilot/aircraft-based sources of uncertainty observed included: Taxi speed variation; Taxi navigation errors (one missed turn due to verifying that a crossing aircraft was stopping); Communication errors requiring repeated clearances; Taxi stops on the taxiway; and, Variable time to initiate aircraft movement after: 1) Pushback; 2) Spot-release clearances; 3) Line-up-and-wait runway clearances; and, 4) Takeoff clearances.

Table 2 shows the variation observed in the ATAS pilot/aircraft performance across the simulation. Future surface management systems or advisory systems must work with these typical (even the "off-nominal" taxi stopping is not atypical) aircraft taxi performance variations.

Table 2. Observed Sources of Pilot/Aircraft Uncertainty

Source	Mean	Range
Time to initiate movement (s) after receiving taxi clearance	12.5	0.2 - 32.5
Taxi Speed Straightaway	15.4	11.6 - 19.5*
Time to initiate movement after receiving line-up and wait clearance (s)	7.1	0.1 - 16.5
Time to initiate takeoff (s)	9.2	0.0 - 37.0
Off-nominal Event (unplanned): 1 pilot missed a taxi turn (due to traffic distraction)		
Off-nominal Event (planned): 1-min delay imposed during taxi out (2 per pilot)		

* Range of *average* taxi speeds observed during taxi out.

In order for successful adoption in the field, SARDA advisories for traffic sequencing and scheduling must be robust to the pilot/aircraft performance variations delineated in Table 2. Simulation results indicated that with these observed pilot/aircraft performance variations, SARDA yielded controller advisories that were: Supportive of current-day, time-based operations; Compatible with controllers' expectations; Predictive of actual takeoff times; and, Adaptable to off-nominal events. These are addressed, in turn, in the following sections.

SARDA Estimates Supported Current-day Flight Deck Time-based Operations (TMI)

During trials with TMI scheduled takeoff times (half of all trials), 100% of the pilots met their required takeoff times within 1 min.

SARDA Sequences were Compatible with Controllers' Expectations

For the ATAS aircraft, the Ground Controller concurred with SARDA's recommendations of the spot release sequence on 94% of trials, and the Local Controller concurred with the takeoff sequence on 96% of the trials (see Figure 6). The Local Controller considered that the piloted aircraft arrived "just in time" (i.e., not early or late) at the runway hold line on 93% of the trials.

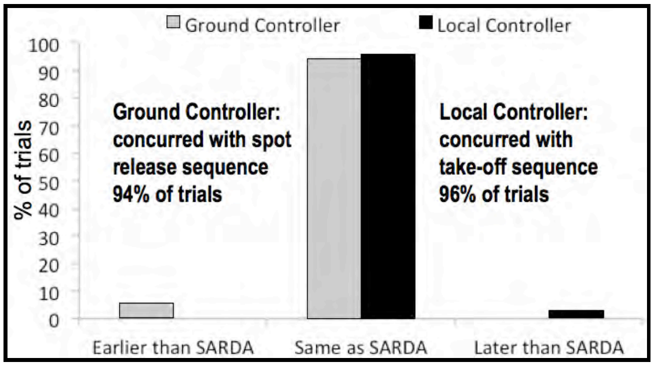

Figure 6. Controller concurrence with SARDA sequence recommendations

SARDA Estimates were Predictive of Actual Takeoff Times

On average, the ATAS aircraft took approximately 8 min to taxi from the Terminal E spot to Runway 17R. As aircraft taxied, every 10 s, the SARDA algorithms internally (not presented to the pilot or controller) re-calculated takeoff times, which are then used as the basis to determine the takeoff sequence.

Figure 7 shows the mean absolute value error of SARDA's predicted takeoff time from that actually observed for the ATAS aircraft. As can be seen, stable and accurate SARDA predictions of takeoff times are seen throughout the departure taxi profile with average prediction errors of less than 45 s error, which converge to about 10 s at the time of the actual takeoff clearance.

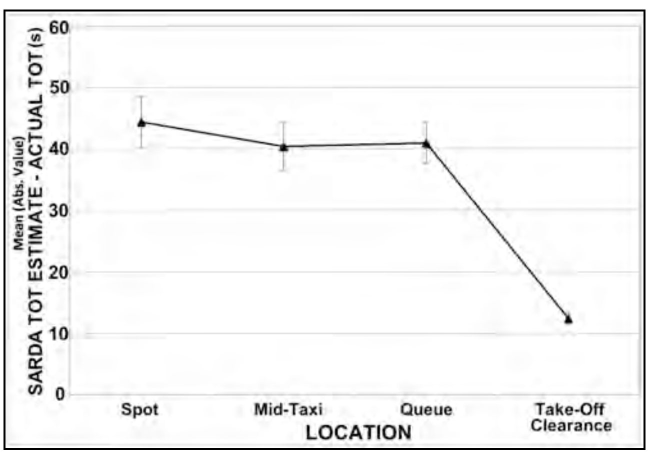

Figure 7. Mean absolute value error (s) of SARDA's takeoff time (TOT) prediction at various taxi locations (error bars indicate +/- 1 standard error)

SARDA Estimates were Adaptable to Off-nominal Events

At the mid-point of two taxi-out operation trials, the experimenter asked the crew to contact the Ground Controller and request a 60-s stop. This 60-s stop simulated an off-nominal event in which the aircraft needed to stop because there was a standing passenger.

Figure 8 shows that SARDA takeoff time prediction error for these delayed aircraft (labeled "off-nominal" in Figure 8) closely matched that of aircraft that did not have an induced delay (labeled "nominal" in Figure 8).

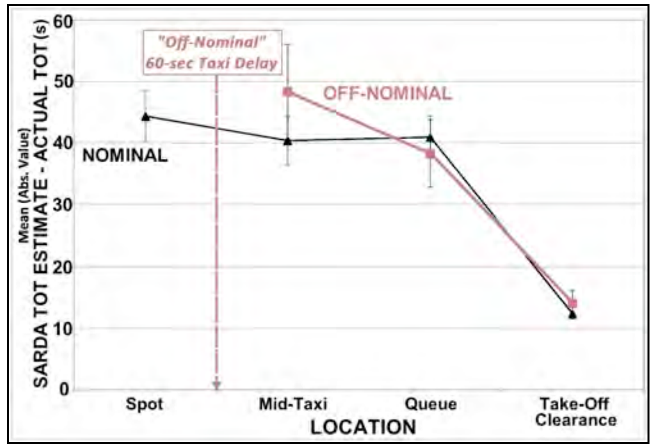

Figure 8. Effect of 60-s off-nominal taxi delay on mean absolute value error (s) of SARDA's takeoff time (TOT) prediction (error bars indicate +/- 1 standard error)

A 2 (Nominal vs. Off-nominal 60-s delay) by 3 (Taxi Location) within-participants ANOVA revealed only a significant main effect of taxi location, $F(2,18)=33.2$, $p<.05$. The interaction was not significant, suggesting the same pattern of takeoff time prediction error for both nominal and off-nominal (60-s delay) conditions. Thus, SARDA detected the pilot non-conformance (i.e., the 60-s delay), adapted and successfully updated its internally computed predicted takeoff time in response to the 60-s taxi delay. In this manner, SARDA detected aircraft non-conformance and was able to adapt and reschedule takeoff times accurately.

RESULTS AND DISCUSSION: NEXTGEN FLIGHT DECK USEFULNESS EVALUATIONS

The second goal of this simulation was to evaluate the usefulness of incorporating certain NextGen flight deck information during the taxi-out/departure phase of flight. Specifically, the usefulness of sharing SARDA information with the flight deck, and the usefulness of a flight deck speed advisory for meeting takeoff times in the SARDA NextGen environment were assessed.

Information Sharing Display Usefulness

At the end of the experiment, each of the 10 Captains completed a questionnaire regarding the usefulness of the Information Sharing Display. For all questions, Captains used the following ratings: 1="Not at all"; 3= "Borderline"; 5="Very Much"

NextGen Operations

Pilots were asked which pieces of information would be useful to support Next-Gen time-based taxi operations. Table 3 shows the response frequency distribution. Assigned Pushback Time, Takeoff Time, and Departure

Sequence were selected as being the most useful with greatest frequency.

Table 3. Response frequency (n=10) of usefulness ratings for question, "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?)"

Information Source	Usefulness Rating				
	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

Note: 1="Not at all"; 3= "Borderline"; 5="Very Much"

During taxi out operations, pilots are preparing the aircraft for departure, communicating with company flight operations, completing checklists, and programming the Flight Management System (FMS) for departure. As shown in Table 4, when asked which pieces of information were useful for supporting these flight deck procedures and the taxi work flow, pilots rated all types of information as useful, but rated Assigned Pushback, and Takeoff Time with higher usefulness ratings. Additionally, as can be seen in Table 5, most pilots would use those information sources to optimize the timing of their pre-departure taxi tasks.

Table 4. Response frequency (n=10) of usefulness ratings for question, "How useful were the following pieces of information in supporting taxi flow and procedures?"

Information Source	Usefulness Rating				
	1	2	3	4	5
Assigned Pushback time	-	-	1	4	5
Spot-release time	1	1	1	6	1
Takeoff Time	-	-	-	2	8
Departure Sequence	-	2	-	3	5
Speed Advisory on PFD	-	1	2	3	4
Time Remaining to Takeoff Time	-	2	3	4	1

Note: 1="Not at all"; 3= "Borderline"; 5="Very Much"

Table 5. Response frequency (n=10) of ratings for question "Please rate the degree to which the Schedule Display information (spot release, takeoff time, departure sequence) might change the time at which you perform cockpit tasks such as checklists, taxi flow items, etc."

Information Source	Rating				
	1	2	3	4	5
All Information	-	1	2	3	4

Note: 1="Very Low"; 2="Low"; 3= "Neutral"; 4="High"; 5="Very High"

TMI/EDCT Operations

Current-Day TMI/EDCT Operations (+/- 5 minute window)

Today, pilots do not have much information available on the flight deck to allow them to meet their specific takeoff times during current-day TMI/EDCT operations. Currently pilots are provided only their required takeoff time, and have to make their best guess estimate of the distance and duration (factoring in the taxi traffic flow) that their taxi out will be when requesting pushback. Table 6 shows pilots' estimates of the usefulness of the shared information sources toward meeting a specific takeoff time under TMI/EDCT operations. Most useful sources included: Assigned Pushback Time, Departure Sequence, and having a Speed Advisory on the PFD, which allows the pilots to know what speed they have to taxi in order to meet the takeoff time (although the Speed Advisory produced a bi-modal response distribution).

Table 6. Response frequency (n=10) of usefulness ratings for question, "In current-day operations, when an EDCT is in place, how useful would it be to have the following pieces of information?"

Information Source	Usefulness Rating				
	1	2	3	4	5
Assigned Pushback time	-	3	1	1	5
Spot-release time	1	1	4	2	2
Departure Sequence	-	2	1	2	5
Speed Advisory on PFD	-	4	-	4	2
Time Remaining to Takeoff Time	-	3	2	2	3

Note: 1="Not at all"; 3= "Borderline"; 5="Very Much"

NextGen TMI/EDCT Operations

Additionally, Captains were asked to estimate the window size for EDCT/TMI operations if they had the various information sources available. On average, Captains estimated that the window could be reduced from +/- 5 min to +/- 3.05 min (on average), with standard error of 0.47 min; Median value was +/- 3.0 min. It should be noted that in actuality, as reported earlier, 100% of the pilots were actually able to meet the EDCT/TMI within +/- 1.0 min. In fact, previous studies have demonstrated that the error-nulling algorithm speed advisory on the PFD would allow aircraft to arrive at the runway hold line within a 5-s window [9].

Taken as a whole, these questionnaire data suggest that pilots generally rate positively the usefulness of having the various information sources available on the flight deck in an Information Sharing Display. The data also suggest that having such an Information Sharing Display available could allow for tighter EDCT/TMI time windows (reduced from +/- 5 min to approximately +/- 3 min), which would allow for improved future efficiency.

CONCLUSIONS AND SUMMARY

The results of this integrated Controller- and Pilot-in-the-loop simulation demonstrated that the SARDA algorithms were able to accurately monitor aircraft taxi conformance and adapt to the range of typical pilot/aircraft taxi performance as well as off-nominal taxi operation scenarios.

To be adopted, SARDA advisories for traffic sequencing and scheduling must be robust to the pilot/aircraft performance variations similar to those observed in this simulation (i.e., Variation in taxi speeds; and, variability in initiating taxi, line-up-and-wait movement, and to effect takeoff after receiving clearance). Simulation results indicated that with these observed pilot/aircraft performance variations, the SARDA system yielded controller advisories that were: Supportive of current-day, time-based operations; Compatible with controllers' expectations; Predictive of actual takeoff times; and, Adaptable to off-nominal events.

Having a controller advisory system such as SARDA allows for that scheduling information to be shared with the flight deck. Since one NextGen goal is to expand information sharing among operating partners, displays and concepts similar to the Information Sharing Display on the flight deck will become more likely as we move forward. Questionnaire results indicated that pilots generally had positive attitudes toward the usefulness of such information, and, in fact, that it could be useful for supporting current-day, time-based (i.e., EDCT/TMI) operations.

The results of this integrated ATAS flight deck and SARDA simulation suggest that the SARDA system is in position for expansion to other airport environments and field-testing. It also suggests the value in developing integrated flight deck and air traffic controller STBO solutions in the NextGen environment.

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REFERENCES

1. SESAR Consortium. SESAR Master Plan. April 2008. Available at: www.atmmasterplan.eu.
2. EMMA2 Consortium. A-SMGCS services, procedures, and operational requirements (SPOR), European Commission/DG TREN, Brussels, Belgium, 2008. Available at: www.dlr.de/emma2
3. Joint Planning and Development Office. Concept of Operations for the Next Generation Air Transport System, v3.0. Accessed February 21, 2012, www.jpdo.gov/library/NextGen_ConOps_v3%200.pdf
4. Jung, Y.C., Hoang, T., Montoya, J., Gupta, G., Malik, W. and Tobias, L. A concept and implementation of optimized operations of airport surface traffic. In *10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*, (Fort Worth TX, 2010), AIAA.
5. Hayashi, M., Hoang, T., Jung, Y., Gupta, G., Malik, W. and Dulchinos, V. Usability evaluation of the Spot and Runway Departure Advisor (SARDA) concept in a Dallas/Fort Worth airport tower simulation. In *10th USA/Europe ATM R&D Seminar (ATM2013)*, (Chicago IL, 2013), EUROCONTROL/FAA.
6. Cheng, V.H.L., Yeh, A., Diaz, G.M. and Foyle, D.C. Surface-operation benefits of a collaborative automation concept. In *AIAA Guidance, Navigation, and Control Conference*, (Providence RI, 2004), AIAA, 2004-5409.
7. Rathinam, S., Montoya, J. and Jung, Y. An optimization model for reducing aircraft taxi times at the Dallas Fort Worth International Airport. In *26th International Congress of the Aeronautical Sciences (ICAS)*, (Anchorage AK, 2008), ICAS.
8. Foyle, D.C., Hooey, B.L., Bakowski, D.L. Williams, J.L. and Kunkle, C.L. Flight deck surface trajectory-based operations (STBO): Simulation results and ConOps implications. In *9th USA/Europe Air Traffic Management Research and Development Seminar,* (Berlin, Germany, 2011), EUROCONTROL/FAA, Paper 132.
9. Bakowski, D.L., Foyle, D.C., Hooey, B.L, Meyer, G.R. and Wolter, C.A. DataComm in flight deck surface trajectory-based operations. In *4th Applied Human Factors and Ergonomics Conference*, (San Francisco CA, 2012), CRC Press.