DOT/FAA/TC-07/12

Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

A Human Factors Simulation of Required Navigation Performance Converging Approach Procedures

Anton Koros, Northrop Grumman Information Technology
Randy Sollenberger, Ph.D., Human Factors Team – Atlantic City, ATO-P
Pamela Della Rocco, Ph.D., Human Factors Team – Atlantic City, ATO-P

August 2007

Technical Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-07/12		

4. Title and Subtitle	5. Report Date
A Human Factors Simulation of Required Navigation Performance Converging Approach Procedures	August 2007
	6. Performing Organization Code AJP-6110
7. Author(s) Anton Koros, Northrop Grumman Information Technology Randy Sollenberger, Ph.D., Human Factors Team – Atlantic City, ATO-P Pamela Della Rocco, Ph.D., Human Factors Team – Atlantic City, ATO-P	8. Performing Organization Report No. DOT/FAA/TC-07/12
9. Performing Organization Name and Address Federal Aviation Administration Human Factors Team – Atlantic City, ATO-P William J. Hughes Technical Center Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Aviation Administration Required Navigation Performance Program Office 800 Independence Avenue, S.W. Washington, DC 20591	13. Type of Report and Period Covered Technical Report 14. Sponsoring Agency Code ATO-R

15. Supplementary Notes

16. Abstract

The National Airspace System Human Factors Research and Engineering Group (HFREG) Human Factors Team – Atlantic City, ATO-P, assessed a proposed Required Navigation Performance (RNP) procedure into San Francisco International Airport (SFO). RNP technology offers several operational benefits including more efficient utilization of airspace, reduced flying time, and reduced air-to-ground communications. The simulation focused on human factors issues affecting Air Traffic Control Specialists (ATCSs) when operating a converging runway approach procedure into the SFO Runway 28R during reduced visibility conditions. Sixteen ATCSs participated in the simulation that we conducted at the Northern California Terminal Radar Approach Control in December 2004. The simulation assessed the controllers' ability to identify blundering aircraft using an Airport Surveillance Radar-9 (ASR-9) display. It also evaluated the propensity for nuisance breakouts, communications options, No Transgression Zone placement options, and the impact of high traffic levels. The simulation comprised a reaction time task and a series of high fidelity operational scenarios designed to assess the viability of the proposed approach. The study confirmed that monitor controllers identified blundering aircraft accurately and timely when using the ASR-9 display. Sector performance remained high across all conditions, and controllers demonstrated no serious operational deficiencies. Overall, the controllers provided positive ratings and comments regarding the proposed 28R RNP approach and procedure. The simulation resulted in two primary recommendations (a) incorporate Air Traffic procedures for RNP approaches into Federal Aviation Administration Order 7110.65 to ensure that ATCSs receive RNP-specific training and (b) present Flight Management System/RNP equipment information in the datablock.

17. Key Words	18. Distribution Statement
Aircraft Blunder Aircraft Deviation No Transgression Zone Required Navigation Performance	This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161. A copy is retained for reference at the William J. Hughes Technical Center Library.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	118	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Table of Contents

Page

List of Illustrations

Tables Page

Acknowledgments

The authors acknowledge Air Traffic Control Subject Matter Experts John Goldman and Joe Toland (Northrop Grumman Information Technology) and Randy Phillips (Cleveland Air Route Traffic Control Center, Federal Aviation Administration [FAA]) for their extensive work developing the traffic scenarios and Air Traffic procedures for this simulation and their significant contributions to this report. We thank the members of the travel team comprising the Simulation Support team, Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE), Target Generator Facility, and simulation pilots for their critical role in making this simulation a success. The on-site simulation support team included Otto Smith, Wallace Daczkowski, Mark Hale, Jim Hamilton, and Dan Johnson (Titan Systems, Inc.), James McGhee (Northrop Grumman Information Technology), and Randy Sollenberger (FAA). The on-site simulation pilots were Bob Engile, Tru Hall, Dale Laudenslager, and Bruce Slack (FAA) and Cindy Hogan (Titan Systems, Inc). We thank the Northern California Terminal Radar Approach Control facility for their enthusiasm and support of this simulation and, especially, for their exceptional kindness hosting our team. We thank April Jackman, Jean Dunn, and Linda Johnson (Northrop Grumman Technical Editors) for their valuable edits to this report. We also acknowledge the Required Navigation Performance Program Office (ATO-R) for sponsoring this valuable research, and we recognize Janettarose Greene for her tireless coordination efforts that ensured the successful completion of this project.

Executive Summary

The Required Navigation Performance Program Office (ATO-R) requested that the National Airspace System Human Factors Research and Engineering Group (HFREG) Human Factors Team – Atlantic City, ATO-P, conduct an assessment of a proposed Required Navigation Performance (RNP) procedure into San Francisco International Airport (SFO). RNP is an advanced cockpit-based technology that enables aircraft to follow extremely accurate routes without having to fly directly over ground-based navigation aids. This technology offers several operational benefits including more efficient utilization of airspace, reduced flying time, and reduced air/ground communications. The simulation focused on human factors issues affecting Air Traffic Control Specialists (ATCSs) when operating a converging runway approach procedure into SFO Runway 28R during reduced visibility conditions.

The research team conducted the simulation at the Northern California Terminal Radar Approach Control training facility in December 2004. The researchers conducted the study using a traveling air traffic simulation capability developed by the Research Development and Human Factors Laboratory. Sixteen ATCSs certified in the sectors of interest participated in the simulation. The simulation addressed five primary objectives:

1. Assess the controllers' ability to identify aircraft blunders using an Airport Surveillance Radar-9 (ASR-9) display.
2. Evaluate the propensity for nuisance breakouts.
3. Compare the approach and tower override communications options.
4. Compare the No Transgression Zone (NTZ) placement options.
5. Evaluate the potential impact of high traffic levels during RNP operations in SFO.

The simulation comprised a reaction time task and a series of high fidelity operational scenarios. The reaction time task measured ATCSs' response times as a result of varying aircraft deviation angles and deviation locations. The participants completed this task independently. The operational scenarios investigated the effect of NTZ placement, communications options, and traffic load on controllers during highly realistic simulated operations. During these scenarios, four ATCSs staffed the Woodside approach, Foster approach, Woodside monitor, and Foster monitor controller positions.

Results of the reaction time task and operational scenarios confirmed that monitor controllers were able to identify blundering aircraft timely and accurately when using an ASR-9 display. Their performance ranged from 7.4 seconds (when monitoring a single target) to 11.5 seconds (during operationally representative conditions).

The second objective focused on the incidence of nuisance breakouts. The RNP procedure mandates that a 2000 ft (610 m) Wide NTZ be placed equidistant between the two approaches. If a paired aircraft turns toward and penetrates the NTZ, the monitor controller on the associated approach path must break out their traffic. A nuisance breakout occurs when a paired aircraft deviates toward the NTZ, but never enters it, and the associated monitor controller still breaks

out their traffic. Nuisance breakouts are detrimental to an operation because they increase aircraft time in sector, aircraft miles flown, controller workload, and number of communications. In addition, nuisance breakouts reduce the aircraft arrival rate. Nuisance breakout rates for the reaction time task and operational scenarios were very low, averaging approximately 1%.

The simulation evaluated SFO Tower Override and Approach Override communications options. During the Tower Override condition, monitor controllers were responsible for pairing aircraft along the NTZ to the SFO outer marker. Their transmissions blocked the ongoing SFO tower recording being played over the radio frequency. For the Approach Override condition, approach controllers maintained control of aircraft until the end of the NTZ at the SFO outer marker. Monitor controllers' push-to-talk transmissions blocked ongoing communications made by their associated approach controller. This objective was confounded since monitor controllers assumed pairing responsibilities in addition to their monitoring duties during the Tower Override condition. However, this was the only way procedurally that the researchers could implement it. The results validated that both communications options were viable for the proposed RNP approach. Sector performance was equivalent to approach override in terms of number of aircraft landed, pairs landed, and double breakouts. Although national and local operational considerations would drive the ultimate decision as to which communications procedure would be the most appropriate, the Approach Override procedure reflected results that are slightly more favorable. During the Approach Override procedure, monitor controllers identified aircraft blunders approximately 1 second faster; the minimum distance between blundering aircraft pairs was 0.4 nmi greater; monitor controllers blocked significantly fewer radio communications; and ratings of controller situation awareness were higher.

In addition, the research team conducted operational scenarios and a reaction time task to evaluate NTZ placement options. The operational scenarios investigated the impact of placing the NTZ 1150 ft (351 m), 1800 ft (549 m), and 3700 ft (1128 m) from the approach path. The results demonstrated that controllers were able to use the ASR-9 display effectively to control traffic and resolve blunders at each of the separation distances. There was essentially no difference between the conditions in terms of number of aircraft landed, aircraft pairs landed, breakouts, or number of double breakouts. Minimum separation distances between conflicting aircraft pairs resulting from scripted blunders were 1.26 nmi (2.34 km) at the 1150 ft (351 m), 1.33 nmi (2.46 km) at the 1800 ft (549 m), and 1.38 nmi (2.56 km) at the 3700 ft (1128 m) separation distance. Based on overall performance and operational considerations, the research team considered 1800 ft (549 m) to be a reasonable option for initial implementation. This distance resulted in no nuisance breakouts, lower workload ratings, and better performance ratings. In addition, results from the reaction time task suggested that on average, aircraft were 1188 ft (362 m) from the NTZ when a controller indicated that the aircraft would violate the NTZ.

In the High Traffic condition, the researchers attempted to stress the RNP converging approach procedures to identify potential shortcomings. Aircraft arrivals reached an hourly equivalent rate of 59 individual aircraft with 23 aircraft pairs during these scenarios. Even under these traffic loads, the participants maintained satisfactory performance and experienced relatively low levels of workload. We identified no weaknesses in the RNP procedures. RNP equipage/capability rates, mixed equipage, operational considerations at SFO and adjacent facilities, and environmental conditions would drive the arrival rates achieved in the operational environment.

The current simulation confirmed the viability of the proposed RNP converging approach into SFO Runway 28R during reduced visibility conditions. The results demonstrated that monitor controllers were able to identify blundering aircraft timely and accurately when using an ASR-9 display. Sector performance remained high across all conditions and demonstrated no serious operational deficiencies. Overall, the participants provided positive ratings and comments regarding the proposed 28R RNP approach and procedure. The simulation resulted in two primary recommendations for the effective implementation of an RNP approach (a) incorporate Air Traffic procedures for RNP approaches into Federal Aviation Administration Order 7110.65 to ensure that ATCSs receive RNP-specific training and (b) present Flight Management System/RNP equipment information in the datablock.

1. INTRODUCTION

The Federal Aviation Administration (FAA) recently outlined their plan for continuing to "build an aviation system for the 21st century with efficiency and capacity improvements needed to meet the growing demand for air travel and cargo shipment" (FAA, 2002b, p. 1). The Operational Evolution Plan (OEP) notes that although the number of airport operations dropped approximately 10% in 2002 from the 2000 levels, airlines have increased their usage of smaller aircraft, adding to the already complex traffic flow management and contributing to the expectation that the demand for aviation services will increase to pre-911 levels. In response, the FAA has proposed the creation of area navigation (RNAV) arrival and departure routes to address constraints within the terminal environment.

1.1 Background

In April 2003, the Required Navigation Performance Program Office (ATO-R) requested the National Airspace System (NAS) Human Factors Research and Engineering Group (HFREG) Human Factors Team – Atlantic City, ATO-P, to conduct a human factors assessment of a proposed Required Navigation Performance (RNP) converging approach procedure into San Francisco International Airport (SFO). This study focuses on the human factors-related issues affecting Air Traffic Control Specialists (ATCSs) when operating simultaneous approaches using the 28R RNAV "Z" approach.

The primary human factors issues include (a) the ability of the existing Automated Radar Terminal System (ARTS) IIIE display to provide sufficient information to controllers so that they maintain the safety and efficiency of the operation, (b) the implications of the proposed approach on controller performance and workload, and (c) the ATCSs informational requirements.

The research team conducted a high fidelity real-time Human-in-the-Loop (HITL) simulation to investigate the impact of the approach. HITL is an effective technique for investigating the implications of changes in automation and operational procedures (Manning, 2000). This methodology is among the most effective means of investigating the impact of changes on controller performance without the risks associated with testing in an operational environment. We ensured that the simulation, including traffic patterns and associated equipment, closely matched those within SFO operations to ensure high fidelity and the ability to extrapolate findings to the real world environment.

1.1.1 Area Navigation and Required Navigation Performance

The OEP reports that approximately 90% of delays occur at the major NAS hub airports, and forecasts suggest that over the next 10 years the demand at these airports will increase by 200 million passengers (FAA, 2002b). One solution that the FAA is pursuing is the creation of RNAV arrival and departure routes. These routes, which rely on the capabilities of modern aviation systems, offer several advantages. Among the operational benefits of terminal RNAV routes are reduced air-to-ground (A/G) communications, improved schedule predictability, reduced flying time and potential fuel savings, and improved situational awareness (SA) for controllers and pilots (Center for Advanced Aviation System Development, 2001). In 2003, the FAA released its roadmap for the integration of RNP into the NAS (FAA, 2003a).

RNAV is a navigation method that relies on a variety of ground navigation aids (e.g., Very High Omnidirectional Radio [VOR] range, Distance Measuring Equipment [DME], and Long Range Navigation-C), self-contained systems (e.g., inertial reference systems), and space-based systems (e.g., a Global Navigation Satellite System) to determine aircraft position (Nakamura, 2000). Aircraft equipped with this capability can fly any specified route and do not necessarily have to fly directly over ground-based navigation aids. Basic RNAV capability is common among commercial aircraft today. A survey at the Chicago O'Hare International Airport reported that 82% of commercial aircraft were equipped with RNAV (Cotton, Foggia, & Gosling, 2001).

An emerging tool supporting the development of more efficient airspace and operations is the concept of RNP (Nakamura, 2000). This is a relatively new concept that describes navigation requirements without identifying a specific sensor or navigation technology (Wright, 1997). More specifically, the International Civil Aviation Organization (ICAO) and the Radio Technical Commission for Aeronautics (RTCA) define RNP as a statement of the navigation performance accuracy necessary for operation within a defined airspace (RTCA, 1997). Though clearly defining accuracy requirements, RNP does not encompass integrity, availability, coverage, and other important system aspects. As a result, the aviation industry is pursuing RNP RNAV as a means of meeting RNP airspace and operations requirements. The FAA has established an RNP Program Office to effectively implement RNP (FAA, 2002a).

Recently, the RTCA/EUROCAE committees tasked with the development of an RNP RNAV Standard determined that additional requirements beyond those already contained in the RNP specification were essential. The supplemental requirements that the organization addressed included system performance integrity, system performance continuity, functional integrity, operational integrity, and consistency in system capabilities and operations. The resulting standard, designated RNP-(x) RNAV, specifies the Total System Error (TSE) requirements by phase of flight. Within the United States, the following apply:

- RNP-2 RNAV in en route,
- RNP-1 RNAV in the terminal area, and
- RNP-0.3 RNAV in approach airspace (Meyer & Bradley, 2001).

The designation identifies the maximum permissible TSE. Aircraft must be within the TSE during 95% of the flight time. For example, an aircraft using an RNP 0.3 approach would be required to be within 1823 ft (556 m) (i.e., 0.3 of a nautical mile) of the designated path during 95% of the flight time. An RNP of 0.11 equates to 668 ft (204 m).

A promising application of RNAV RNP is the proposed converging approach procedure into SFO. During adverse weather conditions, SFO must adopt a single stream operation, which cuts the Airport Acceptance Rates (AARs) in half to approximately 30 aircraft per hour. The new RNP approach would preserve a dual stream operation into SFO during these conditions. Cotton et al. (2001) provide in-depth information regarding this and other technologies to increase capacity at SFO. In accordance with FAA Order 7110.65P, section 5-9-7 for *Simultaneous Independent Instrument Landing System (ILS)/Microwave Landing System (MLS) approaches*, the proposed approach would incorporate a 2000 ft (610 m) Wide No Transgression Zone (NTZ) between the final approach courses and a separate monitor controller for each approach (FAA, 2005). In October 2004, the FAA implemented a Simultaneous Offset Instrument Approach (SOIA) into SFO for weather conditions with a 2100 ft (640 m) ceiling and 4 miles (6.6 km) of visibility. The RNP and SOIA approaches are very similar, but the SOIA version implements a 3000 ft Wide NTZ and mandates the use of a Precision Runway Monitor (PRM) with 1.0-second radar updates. Similar to the RNP approach tested during this simulation, the RNP Parallel Approach Transition (RPAT) is a procedure that will take advantage of RNP capabilities in the terminal area without the need for the use of a PRM (FAA, 2003a). The RPAT is an instrument approach procedure for use at airports with parallel runways that are at least 750 ft (229 m) apart and ceilings 2100 ft (640 m) or greater. This procedure supports the objective to increase capacity to meet projected demands described in the Administrator's Flight Plan (FAA, 2004b).

1.1.2 Literature Review

ATCSs' monitoring performance has been the subject of significant research, particularly with respect to parallel approaches and PRM (Magyarits & Ozmore, 1999, 2002; Reynolds & Hansman, 2003; Reynolds, Hansman, Bolczak, & Tarakan, 2004; Richards, Transue, & Timoteo, 1992; Shank & Hollister, 1994; Wickens, Mavor, Parasuraman, & McGee, 1998). Results of this research have culminated into several FAA Orders including FAA Order 7110.65P: *Air Traffic Control* (FAA, 2005), FAA Order 8260.39: *Close Parallel ILS/MLS Approaches*, and FAA Order 8260.49: *SOIA*.

Researchers at the FAA William J. Hughes Technical Center (WJHTC) conducted more than 20 HITL simulations in support of the Multiple Parallel Approach Program (MPAP) (Magyarits & Ozmore, 1999, 2002). The MPAP evaluated simultaneous approaches into quadruple, triple, and closely spaced dual parallel runways in instrument meteorological conditions. In one study that included more than 146 blunders, controllers monitored aircraft arrivals using a PRM display with a 1.0-second update rate (Magyarits & Ozmore, 2002). The simulation resulted in a recommendation to approve the procedure in the operational environment for simultaneous approaches to triple runways spaced 4000 ft (1219 m) and 5300 ft (1615 m) apart when using a PRM display. Magyarits and Ozmore (1999) documented results from more than 20 separate simulations conducted by the MPAP evaluating technological and procedural considerations for triple and quadruple approaches. Among the simulated display systems the program investigated were Fully Digital Alphanumeric Display System, Digital Entry Display Subsystem, and Final Monitor Aid displays. The report summarizes recommendations regarding simultaneous ILS approaches to multiple parallel runways. The simulations resulted in recommendations for dual straight-in, dual offset, and triple straight-in approaches. The researchers recommended use of radar displays with 1.0-second update rates, or faster, (i.e., PRM) for straight-in approaches to dual parallel runways spaced 3400 ft - 4300 ft (1036 m - 1311 m) apart, and offset approaches to dual parallel runways spaced 3000 ft - 3400 ft (914 m - 1036 m) with 2.5 - 3.0 degrees localizer offset.

Reynolds and Hansman (2003) noted that due to surveillance and workload limitations, as well as the need to track numerous aircraft, controllers often do not detect aircraft deviations until they are significant. They reported that effective conformance monitoring could be achieved using advanced surveillance systems with higher accuracy, higher update rates, and higher orders of dynamic state information.

1.2 Study Objectives

This investigation examined the Air Traffic Control (ATC) human factors operational- and workload- related aspects of managing the RNP converging visual approach procedure into SFO 28R during reduced visibility weather conditions. Based on results of the operational and reaction time scenarios, in conjunction with feedback from the participants, the researchers identify human factors considerations related to the implementation of the proposed RNP approach. The specific objectives of the study assess

1. the ATCSs' ability to accurately distinguish between a Standard Track Error (STE) in executing the SFO RNP converging approach procedure and "blunder" situations when using an ARTS Color Display (ACD) depicting Airport Surveillance Radar-9 (ASR-9) data;
2. the propensity for "nuisance breakouts" when implementing the RNP converging approach procedure in a simulated environment;
3. the overall sector performance and ATCS workload when implementing two different transfers of communication points;
4. the overall sector performance and ATCS workload when implementing two NTZ placement options; and
5. the overall sector performance and ATCS workload under moderate and high traffic levels.

1.3 Assumptions

The assumptions for the current study were as follows:

1. The proposed RNP converging approach procedure will be used when weather conditions represent a 2100 ft (640 m) ceiling and 5 miles (8 km) of visibility.
2. After the missed approach point, the pilot must execute a missed approach if they cannot acquire and maintain visual separation (in-trail) from the aircraft on the ILS 28L approach.
3. The simulation environment will provide a reasonable emulation platform of the existing SFO approach controller workstation.
4. The published standard operating procedures (SOPs) for the 28R RNP converging approach procedure will be similar to those tested during this study.

1.4 Operational Definitions

The research team used the following operational definitions for this study.

- Blunder: When an aircraft on the final approach course deviates off the prescribed track toward the adjacent approach.
- Breakout: When an aircraft on an adjacent approach blunders and enters, or in the controllers judgment will enter, the NTZ and the aircraft on the approach is vectored away from the blundering aircraft.

- Nuisance Breakout: When an aircraft is instructed to breakout because of a blundering aircraft on the adjacent approach; however, the blundering aircraft adjusts its course and does not enter the NTZ.
- Standard Track Error: A typical slight variation from an expected flight path.

We define aircraft deviations and aircraft blunders in detail because of their importance to the simulation. Both represent artificially injected events into the simulation to investigate controller performance and the effectiveness of the proposed procedures.

1.4.1 Aircraft Deviation

When an aircraft's Flight Management System (FMS) follows an assigned path, the actual flight path drifts slightly, both laterally and vertically, over time. These drifts from the expected path (i.e., STEs) occur as a result of navigational sensor errors, winds, aircraft navigation equipment, and other factors. Technological upgrades, such as DME/DME and Global Positioning System updated inertial reference systems have improved lateral performance from variability of near 2.5 nmi in the 1960s generation aircraft to 0.2 nmi in the 1990s generation aircraft (Reynolds & Hansman, 2003).

For purposes of this simulation, an aircraft deviation refers to an intentional and significant turn by an aircraft from the assigned path toward the NTZ (see Figure 1). By this definition, the STEs demonstrated by the simulated targets did not represent aircraft deviations. During the operational scenarios, we introduced deviations of 30°. For the reaction time task, we included deviations of 15°, 30°, 45°, and 60°. Figure 1 illustrates an aircraft deviating from the assigned path toward the NTZ and reestablishing on the assigned path before entering the NTZ. To implement a deviation during the operational scenarios, we instructed the simulation pilots to initiate a 30° turn toward the NTZ and to remain available to respond immediately to any ATC directives. Therefore, if a monitor controller identified a deviation and contacted the deviating simulation pilot in a timely manner, then the aircraft could avoid an NTZ violation; Figure 1 illustrates this situation.

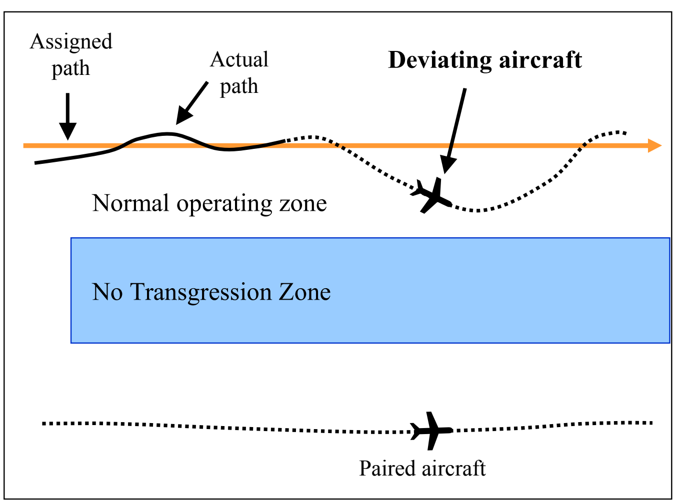

Figure 1. An aircraft deviation.

For parallel approaches, such as the one depicted in Figure 1, each approach requires a dedicated final approach monitor controller. It is the monitor controllers' responsibility to contact pilots of deviating aircraft on their assigned approach and turn them away from the NTZ. If feasible, the monitor controller will re-establish the aircraft on the approach. If this is not feasible, they will instruct the pilot to execute a missed approach. In the event that a deviating aircraft continues through the normal operating zone into the NTZ, it is the responsibility of the paired monitor controller to vector traffic away from the NTZ. This is referred to as a breakout.

A nuisance breakout refers to the situation in which a deviating aircraft does not enter the NTZ, but the paired aircraft is broken out anyway. Though safety remains paramount, it is important to minimize the incidence of nuisance breakouts because they hold significant operational and controller workload implications.

1.4.2 Aircraft Blunder

We introduced blunders into the operational scenarios. An aircraft blunder refers to the situation in which a deviating aircraft continued through the normal operating zone into the NTZ (see Figure 2). When an NTZ transgression occurred, it was the responsibility of the monitor controller for the paired approach to vector traffic away from the NTZ, as depicted in Figure 2. To implement a blunder during the operational scenarios, we instructed the simulation pilots to initiate a 30° turn toward the NTZ and not to respond to ATC directives until the aircraft entered the NTZ. Therefore, each of these events resulted in an NTZ violation and required the paired aircraft to be broken out.

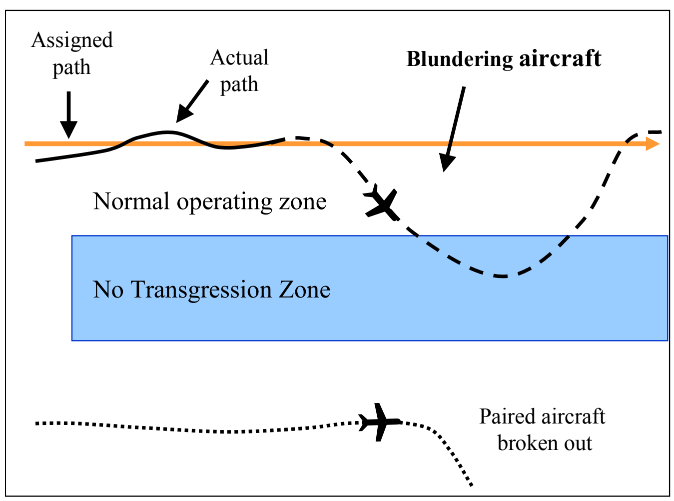

Figure 2. An aircraft blunder.

2. METHOD

This HITL simulation investigated two configurations for the NTZ, two options for transferring communications, and two levels of traffic. The purpose of the moderate and high traffic levels was to investigate the impact of increased traffic levels while using RNP operations. The RNP approach does not have an equivalent procedure in today's operation. During weather conditions like those reflected in this simulation, SFO typically closed Runway 28R and used a single arrival stream to 28L. This study included moderate and high traffic load conditions using the new operation. Employing traffic levels above those experienced today enable researchers to identify limitations of the proposed operation and to predict performance as the number of aircraft increase in the future. The design resulted in information on (a) the viability of the proposed RNAV concept as tested; (b) adequacy of the procedures, roles, and responsibilities used in the simulation; and (c) the propensity for nuisance breakouts when running the operation.

2.1 Participants

Sixteen Northern California Terminal Radar Approach Control (TRACON) (NCT) ATCSs participated in the study. All participants were male and held a current medical certificate and certification in the Woodside and Foster approach sectors. Four ATCSs participated each day. The researchers followed routine ethical research guidelines, including informing participants of their rights and complying with the FAA WJHTC Research and Acquisitions Local Institutional Review Board process. All participants received and signed an Informed Consent Form (Appendix A). The research team coordinated the study through Labor Relations (formerly ATX-500), the Western Pacific Regional Office, and key personnel at NCT, including the Facility Manager and the National Air Traffic Controller Association facility representative. Table 1 shows a summary of the participants' responses to the Background Questionnaire (Appendix B).

Table 1. Participant Background

Item	Range (yrs)	Median (yrs)
Age	35 - 60	48.5
ATCS experience (FAA and military)	13 - 31	22.0
Terminal ATC experience	<1 - 31	15.0
SFO terminal airspace controller	<1 - 31	12.5

2.2 Research Personnel

Key personnel included the research team, simulation pilots, and Subject Matter Expert (SME) observers. We describe the roles and responsibilities for each group in the following sections.

2.2.1 Research Team

The research team included a test director and several test support personnel. Test personnel supported data collection as well as the Target Generation Facility (TGF) and the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) systems. The team engineers were responsible for installing and operating the test apparatus and all data collection activities.

2.2.2 Simulation Pilots

Five simulation pilots entered data into the TGF computers in response to controller-issued instructions (turn right heading one two zero, climb to and maintain FL270, and so on). The simulation pilots employed standard ATC phraseology and procedures during all A/G communications.

2.2.3 Subject Matter Experts

Two ATC SMEs observed the participants during each simulation session. One SME observed the Woodside approach position and the other the Foster approach position. They entered their observations on the Over-the-Shoulder (OTS) Rating Form (see Appendix C).

2.3 Test Facility

The research team conducted the high fidelity HITL simulation at the Enhanced Target Generator (ETG) training facility at NCT. The team coordinated use of this facility with the on-site training manager. The optimal configuration was to co-locate the two approach control positions next to each other and the two monitor positions next to each other (see Figure 3). The configuration of the controller workstations in the ETG did not permit the monitor controllers to be located in closer proximity to one another. Ideally, we would have located the monitor controllers side-by-side, in a similar manner to the Woodside and Foster approach controllers.

Figure 3. Enhanced Target Generator training facility at the NCT.

2.4 Apparatus

The researchers transported rack-mounted and laptop-based components to conduct the simulation. The primary components included the TGF, DESIREE, controller workstations, communications system, and Workload Assessment Keypad (WAK). This equipment provided realistic representations of SFO TRACON airspace and traffic on the ACDs in the training area.

2.4.1 Target Generation Facility

The TGF is a system developed by the FAA WJHTC to generate simulated digital radar messages for aircraft targets during simulations. It realistically reproduced aircraft performance and NAS characteristics by providing primary and beacon radar data. During the current simulation, the TGF forwarded aircraft data to DESIREE for presentation to the controller. The simulation pilots entered commands (e.g., altitude, heading, and speed) into the TGF in response to ATCS commands to simulate pilot compliance with the controllers' directives. The researchers used the detailed data recordings captured by the TGF and DESIREE to conduct post-simulation data reduction.

2.4.2 Distributed Environment for Simulation, Rapid Engineering, and Experimentation

The DESIREE is a simulation platform developed by the FAA Research Development and Human Factors Laboratory (RDHFL) for rapid prototyping and HITL experiments. It processes TGF data and realistically emulates terminal and en route radar ATCS displays and functionality. DESIREE also supports data acquisition and analysis. The researchers used the Standard Terminal Automation Replacement System (STARS) interface for the current simulation, although SFO has ARTS IIIE. We used this interface because DESIREE only simulated STARS at the time of the study. Comments from ATCS participants in a previous WJHTC simulation indicated that the STARS interface did not interfere with their performance even though they used ARTS at their home facility (Truitt, McAnulty, & Willems, 2004).

2.4.3 Controller Workstations

Research team engineers collaborated with NCT Technical Operations personnel to connect the simulation platform to four Sony 2K color displays and ACD keyboards in the training facility (see Figure 3). This enabled DESIREE to display the simulated terminal radar environment on the existing ETG monitors and to accept inputs from the existing keyboard and trackball. The workstations presented the Woodside and Foster SFO approaches and their associated monitor positions. The video map realistically depicted the existing airspace maps, with the addition of an NTZ. The display presented flight datablocks with aircraft identification, beacon code, and altitude for all targets. The display updated target positions automatically at 4.8-second intervals, in compliance with existing SFO display equipment.

2.4.4 Communications System

Team engineers installed and configured a temporary voice communications system at the ETG. This system provided interconnectivity for all A/G and ground-to-ground communications between the ATCS participants and simulation pilots. The Push-To-Talk (PTT) interface was identical to those in use at the facility. The research team recorded all radio communications and ambient communications between the monitor controllers.

2.4.5 Workload Assessment Keypad

The research team installed a WAK at each controller workstation. The WAK is a small device with keys numbered from 1 to 10 that is used to collect real time workload assessments. Stein (1985) validated this uni-dimensional rating technique as an effective real-time method for assessing controller workload. Several researchers used the technique in a number of laboratory and field studies (Sollenberger, McAnulty, & Kerns, 2003; Willems & Truitt, 1999). Truitt, Durso, Crutchfield, Moertl, and Manning (2000) also used this device in a study at the Cleveland

and Jacksonville Air Route Traffic Control Centers. The WAK instrument is equivalent to the Air Traffic Workload Index Technique but does not rely on a touchscreen interface for the ATCS. More recently, participants reported that the WAK technique caused little interference with their ATC performance (Sollenberger et al., 2003; Truitt et al., 2004).

During the current simulation, participants entered their real-time workload estimate in response to visual and auditory prompts from the device. At 5-minute intervals, the WAK emitted a tone and the keys lit to indicate that a response was needed. The ATCS participants entered their current cognitive workload estimate on a scale ranging from a rating of 1 (very low), 5-6 (moderate), and 7-10 (very high). The researchers recorded ratings from the four participants using a single laptop computer.

2.4.6 Airspace and Traffic Routes

Researchers and SMEs from the NAS HFREG Human Factors Team – Atlantic City, ATO-P, integrated the airspace characteristics into the simulation environment. Figure 4 shows the airspace, standard ILS approach path, and the proposed RNP approaches used for this simulation. The Foster approach sector encompasses the airspace north of the NTZ, and the Woodside approach sector encompasses the airspace south of the NTZ. Figure 4 presents the standard 2000 ft (610 m) Wide NTZ between the Runway 28L and 28R approaches.

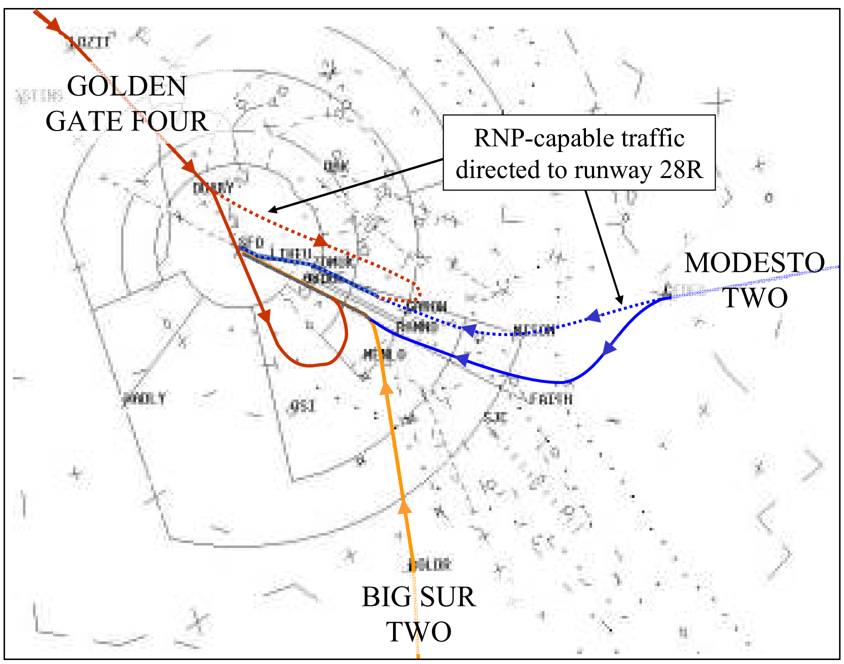

Figure 4. Arrival Approaches into San Francisco International airspace.

The simulation emulated the Woodside and Foster final approach controllers with associated final monitor positions on a SFO West operation. The simulator handed off traffic from the NILES and BOLDER controllers to the Woodside and Foster controllers. Traffic to Woodside arrived via the Golden Gate Four, Modesto Two, and Big Sur Two approaches. RNP-capable traffic arriving via Golden Gate Four and Modesto Two was directed to Foster and landed on 28R.

Traffic inbound via Golden Gate Four to 28L was cleared from 11000 ft (3353 m) or 12000 ft (3658 m) to 6000 ft (1829 m) and slowed to 210 kt (389 kilometers per hour). Aircraft inbound on the Modesto Two arrival was descended from 11000 ft (3353 m) to 7000 ft (2134 m) and slowed to 210 kt (389 kilometers per hour). Controllers accepted handoffs, and then they were responsible for assigning aircraft speeds and turning aircraft toward the airport. The Woodside controller controlled all arrivals to Runway 28L, vectoring them onto the ILS approach. Foster traffic consisted of two primary arrival streams: Alaska Airlines traffic via Golden Gate and Continental B737 arrivals via the Modesto Two approach. To efficiently direct ILS traffic to 28L and RNP traffic to 28R, the research team modified current procedures for Niles and Foster approach sectors. For purposes of this simulation, the Foster approach controller utilized altitudes currently assigned to the Niles approach sector. Foster approach controllers did not descend traffic until they had cleared the Oakland International Airport (OAK) final approach. During the Approach Override communications condition, handoff to the SFO Tower occurred at OKDUE for 28L arrivals and ZOMUK for the 28R. For the Tower Override communication condition, handoff to the SFO Tower occurred prior to the loss of vertical separation or 3 miles between the 28R and 28L paired traffic.

2.4.7 Weather Conditions

For purposes of the operational scenarios, we simulated weather conditions of 2100 ft (640 m) overcast with 5 miles (8 km) of visibility. For purposes of this simulation, 28R aircraft did not report visual separation of the 28L arrival until both aircraft were below 2100 ft (640 m). The SFO operation represented the West Plan with ILS traffic to 28L and RNP traffic to 28R and non-simulated aircraft departing on 1R and 1L. The participants employed normal Instrument Flight Rules (IFR) separation between all arrival aircraft until they were established on the final approach course inside GAROW and the corresponding point on the ILS 28L final approach course.

2.5 Procedures

2.5.1 Shakedown

The research team participated in significant shakedown and team training at the Technical Center in preparation for on-site data collection. The training ensured that all members of the research team were familiar with their duties in support of the simulation and that data collection capabilities were adequate and in place.

2.5.2 Data Collection

At the beginning of each day of data collection at the NCT, the researchers conducted an orientation session with the participants. During the orientation, the researchers identified the goals of the study, the participants' rights as volunteers, and ATC procedures for the simulation. Participants then completed the Informed Consent Form (Appendix A), Background Questionnaire (Appendix B), and Controller Familiarization Materials (Appendix D). The briefing concluded with two training scenarios depicting each of the NTZ and communications options. Each of these scenarios lasted approximately 15 minutes. The purpose of these scenarios was to let participants gain familiarity with the ATC procedures and simulation equipment. The training scenarios were brief because all participants were certified in the airspace and, therefore, familiar with the traffic characteristics, airspace standard routes, SOPs, and letters of agreement.

Following the orientation session, the participants completed five data collection sessions. One of the sessions represented a reaction time task and the remaining four sessions represented operational scenarios. The controllers staffed the same position for all sessions. Participants on the first and third days of the simulation completed the operational scenarios before the reaction time task. On the other 2 days, the participants performed the reaction time task first. The research team counterbalanced the presentation order of operational and reaction time scenarios to control for practice and fatigue effects. At the conclusion of each day, the participants participated in an exit-debriefing session.

2.6 Experiments

This study comprised two primary experiments. These included a reaction time task and a series of operational scenarios. The purpose of the reaction time task was to measure ATCS response times to varying aircraft deviation angles and deviation locations. During the reaction time task, controllers monitored a single aircraft for deviations from the assigned approach path. Unlike the operational scenarios, they were not responsible for monitoring multiple aircraft, providing aircraft separation, or communicating with pilots. The operational scenarios provided an opportunity to characterize the effect of NTZ placement, communications, and traffic load on sector performance during more realistic operational conditions. We describe each of the experiments in detail (see sections 2.6.1 and 2.6.2).

A key requirement underlying both of the experiments was the ability to measure and characterize controller response times to deviation events. In support of this requirement, we developed a model of an aircraft deviation (see Figure 5). Figure 5 illustrates important steps in the process of identifying and responding to an aircraft deviation. The process begins with the introduction of an aircraft deviation and proceeds to a loop depicting ATCS, pilot, and aircraft responses to that event.

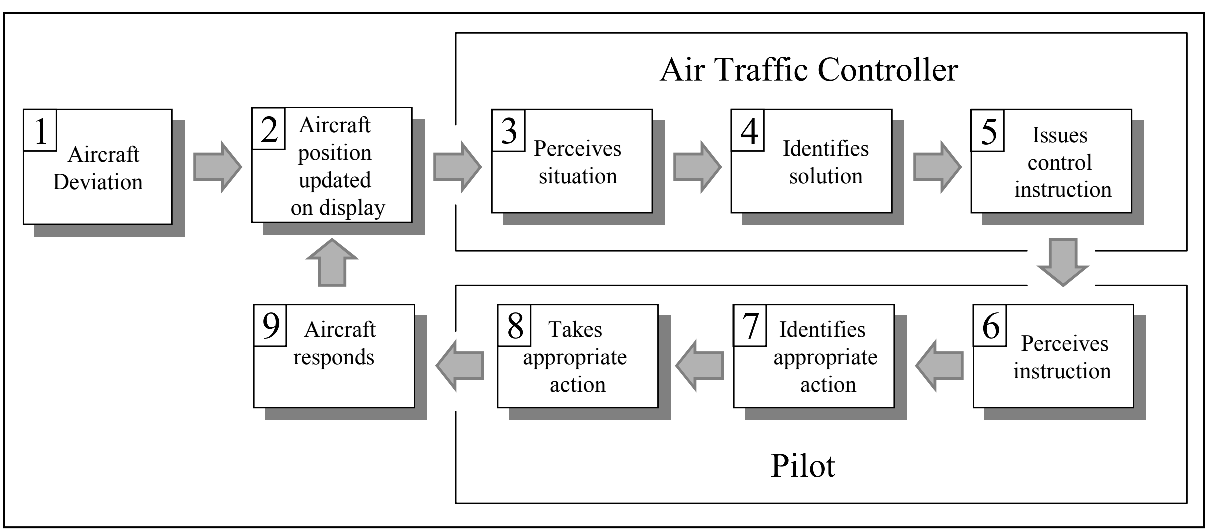

Figure 5. Model of an aircraft deviation.

The reaction time task focused specifically on controller reaction time from the initiation of a deviation (Step 2) to perception of that event (Step 3). Because we asked the participants to press a key instead of verbally issuing a corrective action, they did not have to identify a solution (Step 4).

This, combined with the presentation of only one aircraft at a time, minimized controller reaction time. Therefore, these results represent estimates of optimal controller performance in identifying an aircraft deviation when using an ATC display depicting ASR-9 data.

The researchers used the operational scenarios to determine time requirements for many of the components depicted in Figure 5. This comprehensive approach enabled the team to characterize time distributions for many of these elements during operationally representative conditions. We used PTT, TGF, and DVD recordings to determine these measures. Specifically, we captured the time of the onset of a deviation by the simulation pilot (Step 1), ATCS control instructions (Step 5), pilot verbal and non-verbal responses (Step 8), and subsequent aircraft updates (Step 2).

2.6.1 Reaction Time Task

One of the key objectives of this study was to determine the amount of time required by a controller to identify a blunder when using an ASR-9 display. We designed the reaction time task to assess the "best case" or optimal reaction time for these events. The participants worked independently to complete the 35-minute task. DESIREE simultaneously presented a series of 20 aircraft, one at a time, on the four workstations. The display depicted the Woodside approach airspace configured to a typical Woodside monitor configuration.

The participants observed the aircraft turn onto the final approach course and as it became established on the SFO Runway 28L ILS approach. Their task was to indicate when an aircraft deviated from the final approach course by pressing any key on the ACD keyboard. The researchers instructed the participants to keep their hands near the keyboard so that they could respond as quickly as possible to the event. Diverging aircraft turned 15º, 30º, 45º, or 60º. Eight of the 20 aircraft deviated toward the NTZ, representing a deviation rate of 40%. The deviations occurred either soon after the aircraft was established onto the approach or near the end of the NTZ just before the outer marker (see Figure 6).

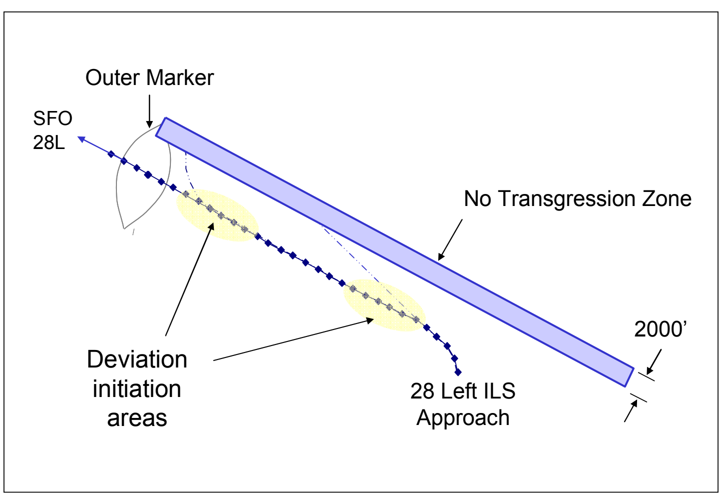

Figure 6. Approach path for reaction time task aircraft.

The boxes on the approach path represent display updates. All deviating aircraft continued on the divergent path until they entered the NTZ. For this task, the participants could only observe the aircraft and could not correct the path because they were unable to communicate with the pilot. We instructed them to press the key a second time to indicate when they were sure the deviating aircraft would penetrate the NTZ.

The aircraft updates for the reaction time task occurred at 4.6 s intervals instead of the standard ASR-9 rate of 4.8 s. The targets appeared at the appropriate location for an aircraft traveling at 200 kt (370 kilometers per hour) using a 4.8 s representation. This difference was an inadvertent artifact of the testing process in preparation for the study. The researchers considered the impact on the data collected to be negligible because 0.2 s was equivalent to one extra update across the entire 2.5 min aircraft flight path. In addition, the SMEs and the controller participants reported no unusual aspects in terms of performance of the display or update rates. The target update rate for the operational scenarios reflected the standard ASR-9 rate of 4.8 s.

2.6.1.1 Independent Variables

The independent variables for the reaction time task were angle of deviation and location of deviation. Angle of deviation comprised four levels (i.e., 15º, 30º, 45º, and 60º). Deviation location included two levels (i.e., shortly after becoming established on the 28L approach and near the end of the approach).

2.6.1.2 Dependent Variables

The dependent variables for this task were controller reaction time. The researchers collected the amount of time from the onset of a turn toward the NTZ until the participant pressed a key to indicate that a deviation had occurred. We also measured the time when they pressed the key again to indicate that the aircraft was entering the NTZ.

2.6.2 Operational Scenarios

The operational scenarios provided an opportunity to investigate NTZ placement, communications options, and the implications of increased traffic levels. The research team developed four 45-min operational scenarios to evaluate each of these areas. The four conditions represented Standard NTZ, Wide NTZ, Tower Override, and High Traffic. We developed the scenarios based on Enhanced Traffic Management System data and technical direction from personnel familiar with the SFO TRACON traffic patterns to ensure an accurate representation of NCT operations for the Woodside and Foster approach sectors. We describe the comparisons in the following sections.

2.6.2.1 NTZ Placement

The research team evaluated NTZ placement options by comparing the Standard NTZ and Wide NTZ configuration (see Figure 7). The Standard NTZ condition included a 2000 ft (610 m) Wide NTZ located equidistant between the 28L and 28R approaches. The minimum separation distance from the 28L and 28R approaches to the NTZ was 3700 ft (1128 m). The Wide NTZ condition was identical to this condition except that we modified the NTZ. During the Wide NTZ condition, we moved the NTZ boundary so that it was 1150 ft (351 m) from the 28L ILS approach and 1800 ft (549 m) from the 28R approach. These distances approximated characteristics for an RNP 0.11 approach and a RPAT operation.

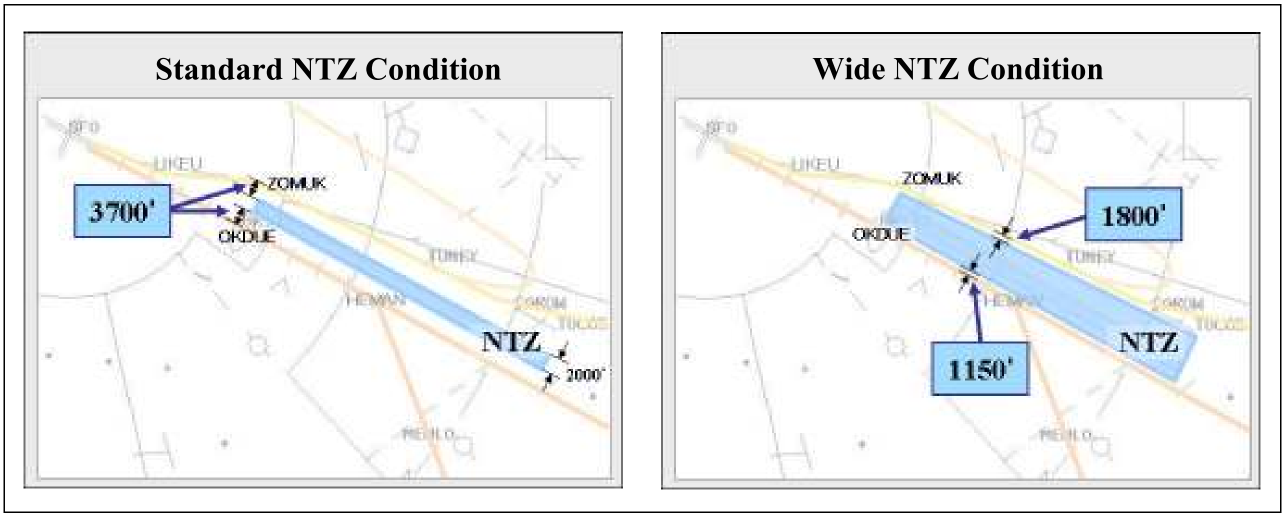

Figure 7. The Standard NTZ and Wide NTZ conditions.

Both of the conditions reflected a moderate traffic level with approximately 35 aircraft arriving every 45 minutes (i.e., 22 to 28L, 13 to 28R). Approach controllers did not handoff aircraft to the SFO Tower until near the end of the NTZ at the SFO outer marker. Specifically, Woodside approach controllers had to complete the handoff before OKDUE. Foster approach controllers had to complete the handoff before ZOMUK (see Figure 7). Monitor controllers were only responsible for blunder detection and correction. Their transmissions blocked approach control radio communications. All of the operational scenarios presented a target update rate of 4.8 seconds, which is typical of an ASR-9 sensor representation.

During both scenarios, we inserted aircraft deviations. These deviations were 30º in accordance with the Standard Deviation (*SD*) turn angle used in previous research (Magyarits & Ozmore, 1999, 2002). For each scenario, we introduced two deviations and two blunders. For the deviation events, we instructed the simulation pilots to respond to all ATC instructions. In the case of a blunder, simulation pilots did not respond to ATC instructions until the aircraft entered the NTZ. The deviation events permitted the researchers to investigate monitor controller response times to aircraft deviations and to exercise the operational procedures for these occurrences. Blunders forced the participants to exercise a break out of the paired traffic to enable an assessment of the overall operational impact.

2.6.2.2 Communications Override Options

We evaluated two communications configurations (see Figure 8). The first configuration, approach sector override, occurred during the Standard NTZ condition. In this condition, the monitor controller's radio communications blocked transmissions of the associated final approach sector controller. For example, the Woodside monitor's transmissions blocked the Woodside final approach controller. Approach controllers maintained responsibility for pairing traffic. The approach controllers did not handoff aircraft to the SFO Tower until near the end of the NTZ at the SFO outer marker (i.e., OKDUE or ZOMUK). Monitor controllers were responsible for blunder detection and correction.

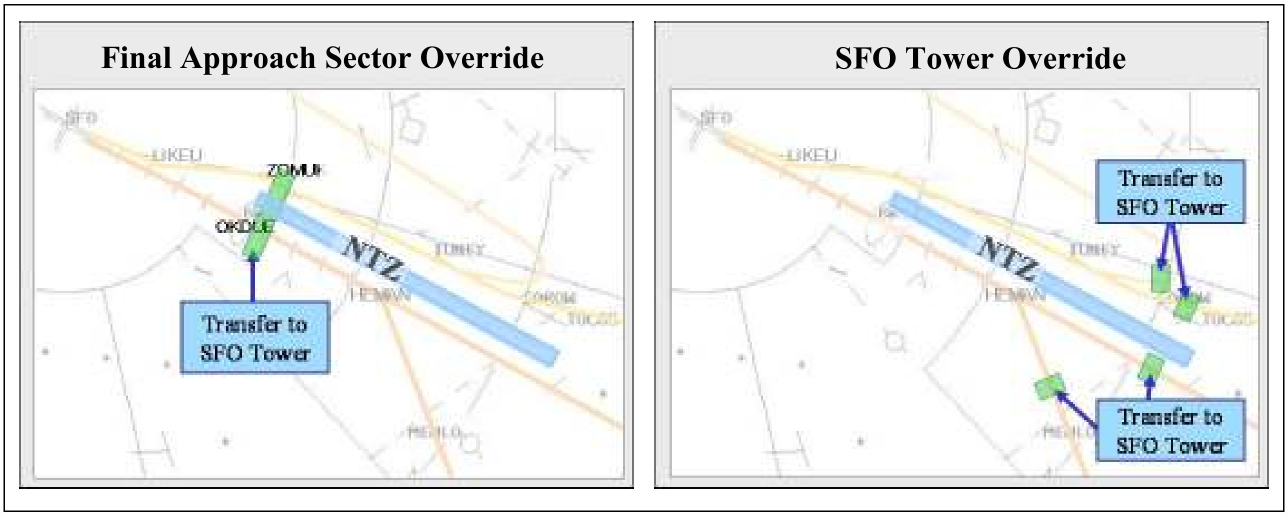

Figure 8. The communications override configurations.

The portable DESIREE simulator captured all ATCS and pilot PTT communications to a data file. The file included a timestamp for each communication transmission and identified the party initiating the transmission. We used these files to determine counts and duration for each radio communication.

The SFO Tower Override condition introduced significant changes in the controllers' communications procedures and responsibilities. The Woodside and Foster approach controllers handed off their aircraft to the SFO Tower much sooner than in the previous condition. Handoffs to the SFO Tower had to be completed prior to loss of vertical separation or when paired Runway 28L and 28R traffic reached a 3-mile separation (see Figure 8). During the scenario, we played a recording of the SFO Tower West Plan operation over the monitor controllers' radio frequency. Any time that the Woodside monitor or Foster monitor controllers made a radio transmission, they blocked the ongoing SFO Tower recording. During the SFO Tower Override condition, the monitor controllers assumed the pairing responsibilities from the aircraft handoff to SFO until the aircraft reached the SFO outer marker. They were still responsible for detecting and correcting aircraft deviations. Both scenarios represented moderate traffic levels and included aircraft deviation events.

2.6.2.3 Traffic Level

The research team investigated the impact of traffic level by comparing moderate and high traffic level conditions. The moderate traffic level scenario represented an average arrival rate of 35 for the 45-minute scenario compared to 45 aircraft during the High Traffic condition. For both scenarios, the Woodside approach sector experienced the heaviest demand.

During the moderate traffic condition, the Woodside approach sector received approximately 23 arriving aircraft compared to Foster's 13 aircraft. In the High Traffic condition, the number of Woodside arrivals increased to 27 and Foster arrivals to 18. Both scenarios reflected the Standard NTZ configuration and Approach Override communications conditions. We did not introduce deviation events into the High Traffic condition so that the participants could experience the RNP operation without these atypical events.

2.6.2.4 Independent Variables

The independent variables for the operational scenarios included NTZ configuration, ATC communications, and traffic level. Each of these variables consisted of two levels. For NTZ configuration, the two levels included Standard NTZ and Wide NTZ implementations. For communications, the levels consisted of the monitor controller overriding the approach controller and the monitor controller overriding the tape of SFO Tower operations. Traffic reflected moderate or high traffic levels.

2.6.2.5 Dependent Variables

The dependent variables included four primary dimensions of system performance, safety, sector performance, ATCS communications, and ATCS workload. As Table 2 shows, the dimensions included objective and subjective measures. The researchers used the post-simulation TGF Data Reduction and Analysis Tool (DRAT) to derive much of the subjective system performance data. We used this in combination with PTT time recorded data to determine reaction time and overall communications time.

Table 2. Summary of Dependent Variables for Operational Scenarios

Dimension	Type	Data
Safety	Objective	• Number of separation violations • Duration of separation violations • Minimum separation
	Subjective	• Participant post-session rating of overall safety • SME ratings of maintaining safe/efficient traffic flow
Sector Performance	Objective	• Reaction time from onset of deviation • Number of nuisance breakouts • Number of aircraft landed
	Subjective	• SME ratings of maintaining safe/efficient traffic flow, maintaining attention/situational awareness, prioritizing, providing control information, technical knowledge, and communicating • Participant post-session rating of RNP operations • Exit questionnaire ratings of RNP operations and general comments regarding these operations
ATCS Communications	Objective	• Number of PTT transmissions • Total PTT usage (percent) • Number of overrides • Type of communications overridden • Type of NCT communication
ATCS Workload	Objective	• Number of PTT transmissions • Number of aircraft landed
	Subjective	• WAK rating at 5-minute intervals during each session • Participant post-session ratings of six NASA-Task Load Index (TLX) dimensions

During each operational scenario, two SMEs unobtrusively observed the Woodside and Foster final approach control positions to evaluate overall system performance. At the conclusion of the session, they completed the OTS Rating Form (see Appendix C) that was specifically designed for ATC performance evaluation research (Sollenberger, Stein, & Gromelski, 1996). Researchers have used this observer rating form extensively in previous research (Sollenberger, La Due, Carver, & Heinze, 1997; Willems, Allen, & Stein, 1999; Willems & Heiney, 2002). The ATCSs provided real-time workload ratings using the WAK when prompted during each run. The researchers trained participants in use of the device during the simulation familiarization session, and we provided operational definitions for the 10-point rating scale (Willems & Heiney). The Post-Scenario Questionnaire (PSQ) and Exit Questionnaire appear in Appendix E and Appendix F, respectively.

3. RESULTS

The research team conducted the simulation at the NCT ETG lab from December 7-10, 2004. The on-site research team included 14 representatives from the FAA WJHTC. The research team employed several objective and subjective measures to assess the impact of the proposed RNP converging approach procedure into SFO. The primary dimensions we assessed were safety, sector performance, ATCS communications, and ATCS workload. The traveling ATC simulation system captured and stored systems data during each session. The primary types of system-stored data included TGF recordings, DESIREE recordings, video analyses, radio communication log files, and WAK ratings. We present the results of each in the following sections.

3.1 TGF Recordings

The research team used TGF recordings to investigate spacing, number of aircraft landed, and scripted aircraft events. We present the results in the following sections.

3.1.1 Spacing

We used the TGF DRAT to determine in-trail separation between aircraft at 1-second intervals for all scenarios. We averaged these data to calculate the average distance and minimum in-trail separation for each aircraft pair (see Table 3). In Table 3, we differentiate between the two approach sectors. We conducted a 4 (condition) x 2 (sector) mixed Analysis of Variance (ANOVA). The results indicated a significant main effect for condition, $F(3, 15) = 6.84$, $p = .004$. The Tukey Honestly Significant Difference (HSD) post hoc tests revealed that in-trail separation during the High Traffic condition was statistically lower than for the Wide NTZ and Tower Override conditions.

Table 3. In-Trail Separation Between Aircraft on Approach

Condition	**Average (nmi)**		***SD* (nmi)**		**Minimum (nmi)**	
	Woodside	**Foster**	**Woodside**	**Foster**	**Woodside**	**Foster**
Standard NTZ	4.5	4.3	0.1	0.4	2.8	3.4
Wide NTZ	4.6	4.6	0.3	0.6	2.6	3.2
Tower Override	4.8	4.1	0.3	0.7	2.7	3.3
High Traffic	4.3	3.8	0.2	0.2	2.6	2.9

We determined the lateral closest point of approach (CPA) spacing for all scripted deviations. The average distance was 1.38 nmi (*SD* = .48 nmi), 1.29 nmi (*SD* = .10 nmi), and 1.17 nmi (*SD* = .40 nmi) for the Standard NTZ, Wide NTZ, and Tower Override conditions, respectively. The relatively low *SD* for the Wide NTZ condition was due to the proximity of the approaches to the NTZ. In the Wide NTZ condition, controllers had to react almost immediately to any turn toward the NTZ.

3.1.2 Number of Aircraft Landed

Typical arrival rates into SFO today are as high as 60 aircraft per hour during Visual Flight Rules conditions when both 28L and 28R are operating. During low ceiling conditions, the facility must adopt a single stream 28 ILS operation and the arrival rate drops to approximately 30 aircraft per hour. For this simulation, we used the TGF recorded data in conjunction with DVD recordings of the ACD screens to determine the average number of aircraft landed and the number of aircraft pairs landed (see Table 4). Table 4 shows all aircraft that traveled along the 28L ILS or 28R RNP approach to the end of the NTZ and were, subsequently, handed off to the SFO Tower. The number of aircraft landed and number of aircraft pairs was essentially equivalent across the three moderate traffic scenarios. Extrapolating the 12, 22, and 35 aircraft landed during the 45-minute session roughly equates to 16, 30, and 47 aircraft landed per hour, respectively. The Woodside arrival rate of 29 per hour is very similar to that published by the facility during low visibility conditions.

Table 4. Aircraft Landed per 45-Minute Session

Condition	Average				*SD*			
	Woodside	Foster	Total	Pairs	Woodside	Foster	Total	Pairs
Standard NTZ	22.8	12.3	35.0	11.3	1.7	0.5	1.8	1.0
Wide NTZ	22.8	12.5	35.3	10.5	1.0	0.6	0.5	1.3
Tower Override	22.3	13.0	35.3	12.3	0.5	0.8	1.0	1.0
High Traffic	26.8	18.0	44.8	17.8	1.0	0.0	1.0	0.5

3.1.3 Scripted Aircraft Events

We implemented one aircraft deviation and one blunder to each approach (i.e., 28L and 28R) during the Standard NTZ, Wide NTZ, and Tower Override scenarios. We provide operational definitions for these events in section 1.4. These events provided the opportunity for the participants to experience the RNP approach procedures in a simulated environment and permitted the research team to characterize team performance.

During these scripted events, the simulation pilots turned their aircraft 30º toward the NTZ. In the case of a blunder, pilots did not respond to ATC instructions until their aircraft entered the NTZ, forcing the associated monitor controller to break out their aircraft. For aircraft deviations, we instructed the pilots to respond immediately to an ATC instruction. For deviations, there was an opportunity for a nuisance breakout. A nuisance breakout refers to the situation when a paired aircraft deviates toward the NTZ; the associated monitor controllers break their aircraft off the approach, but the deviating aircraft is able to adjust its course so that it never enters the NTZ. Nuisance breakouts hold implications for important considerations such as operational efficiency and controller workload.

We introduced a total of 48 scripted events during the operational scenarios. These events comprised 24 blunders and 24 deviations. The monitor controllers reacted appropriately by breaking out the paired aircraft in all but one of the scripted blunders.

We provide the results of the deviation events in Table 5. Monitor controllers experienced one scripted aircraft deviation event on their respective approach during the moderate traffic scenarios (i.e., Standard NTZ, Wide NTZ, and Tower Override conditions). This resulted in 12 deviations to the 28L (Woodside) approach and 12 deviations to the 28R (Foster) approach. In Table 5, we identify whether the deviating aircraft entered the NTZ and the nature of the controllers' response to that event. For deviations, the monitor controllers were able to avoid an NTZ transgression if they responded quickly. None of the deviating aircraft for the Standard NTZ condition entered the NTZ. As noted earlier, the separation between the approach and NTZ during this condition was 3700 ft (1128 m). All of the eight deviation events in the Wide NTZ condition resulted in the deviating aircraft entering the NTZ. During this condition, the distance from Woodside to the NTZ and Foster to the NTZ was 1150 ft (351 m) and 1800 ft (549 m), respectively.

Table 5. Summary of Deviation Events and Outcomes

	Number of Deviations (valid cases)	**NTZ Entered**		**Controller Response**			
		No	**Yes**	**No Action (correct)**	**No Action (incorrect)**	**Breakout (correct)**	**Nuisance Breakout**
Standard NTZ	8	8	0	6	0	0	2
Wide NTZ	8	0	8	0	1	7	0
Tower Override	8	4	4	4	1	3	0

Using practices employed by the Signal Detection Theory, we prepared a matrix showing the stimulus and response for all scripted events (see Figure 9). On the left of the figure, we present the two possible outcomes for an aircraft turn toward the NTZ (i.e., not entering the NTZ or entering the NTZ). By definition, the only outcome for the 24 blunder events was an NTZ violation. The 24 deviations could result in either outcome.

We present potential controller responses at the top of Figure 9. Monitor controllers could either take no action (i.e., no breakout) or break the paired aircraft off the approach (i.e., breakout). The correct response was dependent on whether an NTZ violation occurred. In each of the four cells of the matrix, we characterize the nature of the response and provide a count for each of the simulation conditions. A *correct rejection* indicates that the deviating aircraft did not enter the NTZ and that the monitor controller made an appropriate choice not to break out the paired traffic.

		Controller Response	
		No Breakout	**Breakout**
Aircraft Turn toward NTZ	**No NTZ Violation**	*CORRECT REJECTION* • Standard NTZ (6) • Wide NTZ (0) • Tower override (4)	*NUISANCE BREAKOUT* • Standard NTZ (2) • Wide NTZ (0) • Tower override (0)
	NTZ Violation	*MISS* • Standard NTZ (0) • Wide NTZ (1*) • Tower override (1*)	*CORRECT BREAKOUT* • Standard NTZ (8) • Wide NTZ (15) • Tower override (11)

* Non-valid events

Figure 9. Signal detection matrix for scripted blunders and deviations.

Nuisance breakouts represent situations in which a monitor controller terminated the approach for a paired aircraft even though the deviating aircraft never entered the NTZ. When implementing a breakout, the monitor controllers must climb the aircraft and return it to the approach controller for resequencing into their traffic flow. Unnecessarily terminating an aircraft approach increases controller workload and decreases operational efficiency. This occurred twice during the study, with both occasions representing the Standard NTZ condition. This represented a false alarm rate of just 1% if considered across all landed aircraft during the Standard NTZ conditions (i.e., 2 of 140). The other conditions did not reflect *nuisance breakouts* at least in part because they resulted in fewer opportunities for this to occur. For instance, all eight of the Wide NTZ deviations resulted in an NTZ transgression and therefore a breakout was the appropriate action. Half of the Tower Override deviations resulted in an NTZ transgression.

As shown in the bottom row of Figure 9, the two circumstances represent situations when the deviating aircraft transgressed into the NTZ. If the monitor controller did not respond, Figure 9 presents this as a *miss*. This represents an important safety consideration for the implementation of any ATC procedure. There were three occasions when a paired aircraft did not break out in response to an NTZ violation as required by the procedures. During one of the Tower Override sessions, a simulation pilot failed to follow a monitor controller instruction to break out. This was the appropriate action; therefore, we represent it in Figure 9 as a correct breakout. We identify the two remaining events as non-valid events in Figure 9. We reviewed DVD recordings of these incidents, which were attributable to the same controller team. We determined that in both circumstances the monitor controller did not issue a break out instruction because the deviating aircraft had turned and was already increasing separation. In post data collection discussions with the participants and SMEs, we learned that part of the reason for the non-action may have been the limited training time for this group (i.e., they did not recognize the need to immediately break out the aircraft upon NTZ violation from a paired aircraft). There may also have been an underlying monitoring-induced component. The non-action by these participants may have reflected circumstances similar to those we observed during shakedown. In these situations, a monitor controller who had been working for several minutes simply observed a deviating aircraft and did not respond until prompted by their associated monitor. During the study, the monitor controllers may not have become actively aware until the associated monitor had already implemented a control instruction and the separation between the aircraft was already increasing. Our judgment is that these circumstances did reflect a training shortcoming because the three remaining groups, in which we emphasized the need to respond to an NTZ transgression during training, demonstrated no misses and responded quickly to deviation events. We are confident that if the failure to respond immediately was solely one of lack of training, it would not occur in the field. All controllers and pilots would certainly undergo comprehensive and effective training before the FAA deployed a new procedure in the operational environment. However, we recommend that when the FAA implements this approach, they closely monitor it for potentially similar events.

The majority of scripted events (i.e., 36 of the 48) resulted in an NTZ violation and forced the monitor controllers to initiate a breakout. In these situations, a breakout was the appropriate response and, therefore, we identified it in Figure 9 as a *correct breakout*.

Half of the NTZ deviations resulted in an NTZ transgression, bringing the total of NTZ violations to 36. In 33 of these cases, the controllers appropriately broke the paired traffic off the approach. The misses reflected non-valid cases; therefore, the only remaining inappropriate actions were two nuisance breakouts.

3.2 DESIREE Recordings

The research team based blunder identification and NTZ entry results on the data recorded by DESIREE during the reaction time scenarios. DESIREE captured the system time for all display updates and controller entries. We used these data to calculate the following results.

3.2.1 Reaction Time Task: Blunder Identification

The researchers determined average reaction time for all blunders presented in the reaction time task. We calculated the time from the first update after initiation of a deviation until the controller pressed a key to indicate that the aircraft had blundered. Figure 10 presents the average time to identify a deviation across all participants. Deviation angle appears on the x-axis, and average time for the controller to respond in seconds appears on the y-axis. The lower line (△) shows the average time controllers required to identify a deviation that occurred soon after an aircraft was established on the approach path. The upper line (□) presents the average time participants required to respond when the deviation was near the end of the approach path.

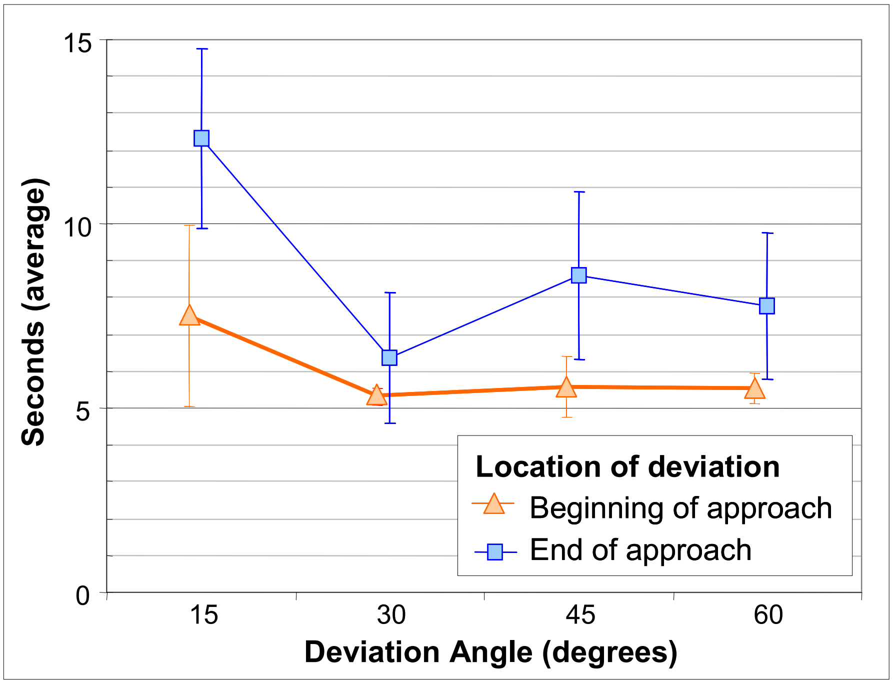

Figure 10. Average amount of time for a controller to identify a deviation.

The average response time across all reaction time task conditions was 7.4 s. We conducted a 2 x 4 repeated-measures ANOVA to compare controller response times for deviation location and deviation angle. The first factor, deviation location, included two levels (i.e., soon after the aircraft was established on the approach or near the end of the approach). The second factor, deviation angle, had four levels (i.e., 15º, 30º, 45º, and 60º). There was a significant interaction for deviation location by angle, $F(3,45) = 10.53$, $p <.001$. To investigate this interaction, we conducted an analysis of simple main effects for the deviation location. For turns at the beginning of the approach, there were significant differences in how quickly controllers identified blunders, $F(3,45) = 12.48$, $p <.001$. The Tukey HSD post hoc comparisons indicated that controllers took longer to identify deviations of 15º compared to all other angles. For turns at the end of the approach, there were also significant differences among the deviation angles, $F(3,45) = 47.15$, $p <.001$. They identified deviations of 30º faster than 15º and 45º. We also conducted an analysis of simple main effects for the deviation angle. The results indicated that for each of the four deviation angles, controllers were faster at identifying blunders when the turn occurred at the beginning of the approach compared to the end of the approach.

To investigate the performance implications of these data, we examined the number of radar updates required before controllers were able to identify an aircraft as deviating. Figure 11 presents the cumulative percent of deviations identified for each subsequent radar update. The figure presents results for all four deviation angles; the results demonstrated differences based on location of the deviation and are therefore presented separately. When deviations occurred shortly after an aircraft became established on the approach, all participants were able to identify deviations of greater than 15° in one update. For 15° deviations, 60% of the participants identified the deviation on the first update. The remaining 40% required a second update.

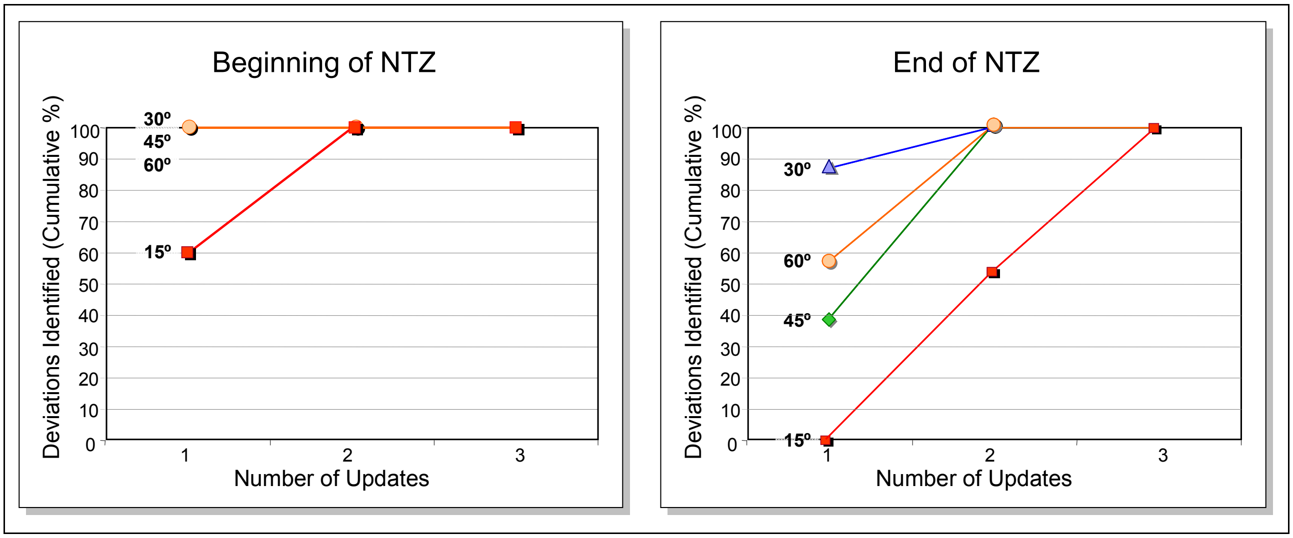

Figure 11. Number of radar updates required to identify a deviation.

When a deviation occurred at the end of the NTZ, performance was not as high. None of the participants identified a 15° deviation on the first update. By the second update, approximately half identified the deviations, with the remaining requiring a third update. Turns of 45° and 60° returned very similar results. Approximately half of the controllers identified the deviation after one update and the rest after one more update (i.e., in two updates). Deviations of 30° did not fall between the 15° and higher turn rates as we had anticipated. Instead, almost 90% of the participants identified a 30° deviation in just one update. As was the case with 45° and 60º, all participants identified the deviation before the third update.

We calculated the false alarm rate for the reaction task. On six occasions, participants erroneously indicated that an aircraft was deviating from the 28L ILS approach path toward the NTZ. There were a total of 320 trials (i.e., 4 participants x 4 days x 20 aircraft) resulting in a false alarm rate of 1%.

3.2.2 Reaction Time Task: NTZ Entry

The reaction time task consisted of two distinct objectives that directly support the RNP Program Office in the design and development of future RNP approaches. The first goal was to characterize the amount of time and distance for a controller to identify an aircraft deviation using an ASR-9 sensor representation (see “Blunder” in Figure 12). The second goal identified the point at which a controller made the determination that the aircraft would enter the NTZ. We instructed the participants to press any key on the ACD keyboard at the point “when the aircraft penetrates or, in their judgment, will penetrate the NTZ” (see “Entering NTZ” in Figure 12). This was in accordance with FAA Order 7110.65P for simultaneous independent ILS/MLS approaches (FAA, 2005, section 5-9-7). This FAA Order states that monitor controllers must issue control instructions as necessary to ensure aircraft do not enter the NTZ. The goal of this portion of the task was to determine the relative distance from the NTZ that controllers made this decision. As with the first goal, we investigated whether there were differences due to the angle at which the aircraft approached the NTZ. The researchers hypothesized that controllers would have to react more quickly to avoid an NTZ violation if an aircraft deviated at 60º (i.e., compared to an aircraft that deviated at 15º). As a result, we expected the participants to allow aircraft on less acute approach angles to get closer to the NTZ before pressing the key to indicate that the aircraft was entering the NTZ.

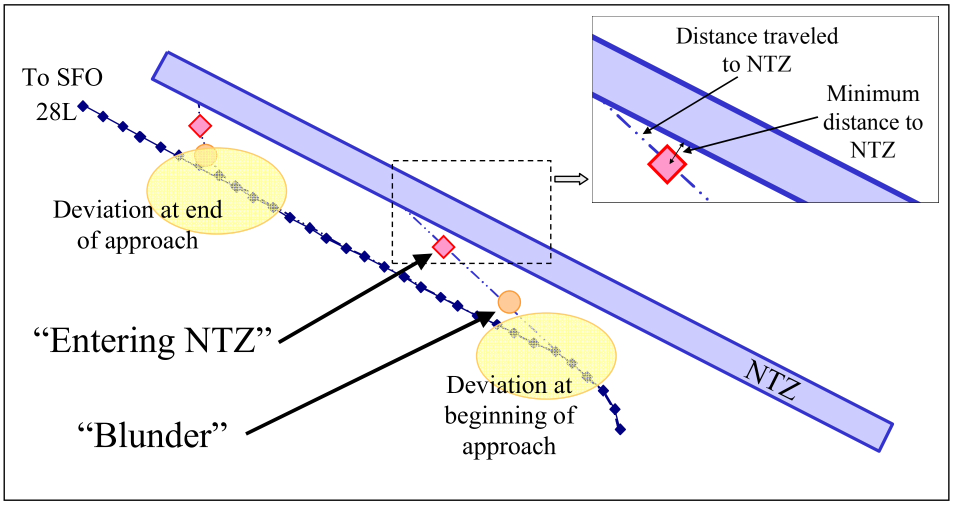

Figure 12. Minimum distance and distance traveled to NTZ.

The box in Figure 12 identifies the distance traveled to the NTZ and minimum distance to the NTZ, from the point at which participants indicated that the aircraft would enter the NTZ. Table 6 shows a summary of the data for the distance traveled to the NTZ. We also include the average for each deviation angle at the beginning and end of the approach (see Table 6). The results demonstrated that as the angle of deviation increased, the distance from the NTZ entry point decreased. For example, controllers indicated at approximately 4900 ft (1494 m) from the NTZ entry point that an aircraft deviating at 15º would enter the NTZ. For deviations of 60º, this distance averaged approximately 1100 ft (335 m).

Table 6. Distance Traveled to NTZ from Controller Indication that Aircraft was Entering the NTZ

Deviation Angle (degrees)	**Beginning of Approach (feet)**		**End of Approach (feet)**		**Overall (feet)**	
	Average	**Range**	**Average**	**Range**	**Average**	**Range**
15°	4781	1901 - 8624	5025	2653 - 7711	4907	1901 - 8624
30°	2619	560 - 4233	2549	1474 - 4253	2584	560 - 4253
45°	1751	776 - 2289	2032	80 - 2752	1887	80 - 2752
60°	1043	567 - 1115	1269	205 - 3897	1163	205 - 3897

We conducted a one-way ANOVA using deviation angle as the factor of interest. We did not include location of the deviation in this analysis because the participants had ample time after the initiation of the deviation to observe and respond to the stimulus. The results indicated that there were significant differences in the distance from the NTZ when controllers indicated that the aircraft was entering the NTZ, $Z(3, 119) = 65.1$, $p < .001$. The Tukey HSD post hoc analyses showed significant differences between all angles of deviation, with the single exception of the comparison between 30º and 45º. This comparison showed a trend toward significance, $p < .08$. The results demonstrated essentially a linear trend toward responding closer to the NTZ as the severity of the approach angle increased. This was in direct opposition to the direction the researchers anticipated.

Figure 13 presents the average location at which controllers indicated that a deviating aircraft would enter the NTZ. The figure includes the points for each deviation angle and location. We drew a line to join data points representing equivalent deviation angles. For example, we connected the two data points representing a 15° deviation (i.e., at the beginning of the approach and at the end of the approach). Next, we determined the average minimum distance across all deviation angles, and we included it in Figure 13 (i.e., the dashed line). We considered this important because it was our best estimate of the controllers' "decision point" or distance from the NTZ that a controller could initiate an action in response to a perceived imminent NTZ violation. Depending on the proximity to the NTZ, their action could range from continuing to closely monitor the aircraft, pointing out the aircraft to the associated approach monitor, or immediately communicating an ATC instruction to the pilot. The average decision point was essentially parallel to the NTZ and overlaid the lines for each of the deviation angles. The minimum distance from the decision point to the NTZ boundary was approximately 1188 ft (362 m), regardless of the angle of deviation. As illustrated previously in Figure 12, the minimum distance represented the shortest distance to the NTZ boundary, not the actual distance that an aircraft traveled.

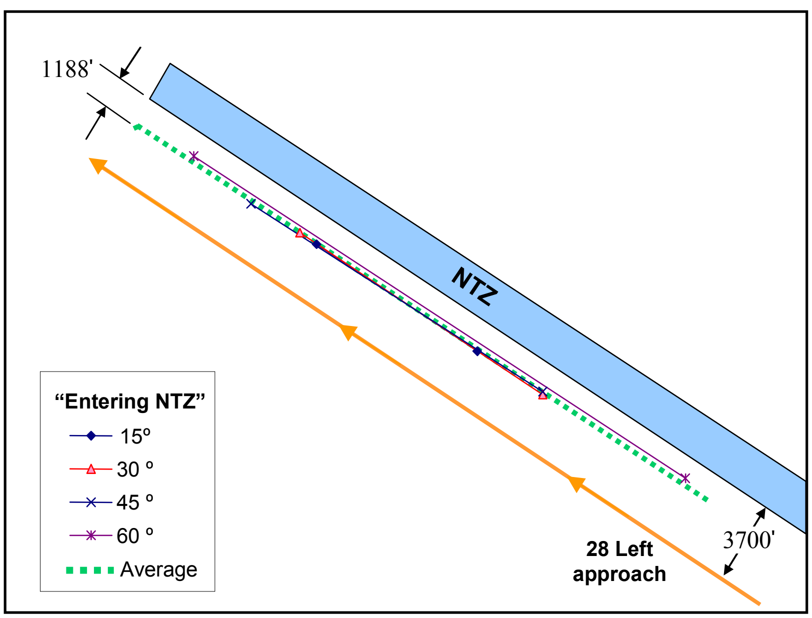

Figure 13. Average controller "decision point" for when an aircraft entered the NTZ.

3.3 Video Analyses

During each operational scenario, we captured the ACD screens and the audio communications to DVD. The cameras recorded the two monitor controller ACDs and a combined view of the Woodside and Foster approach controller ACDs. We used the video to determine the number of aircraft landed per session and the number of breakouts per session. The DVDs also supported the response time analyses for the operational scenarios.

3.3.1 Number of Breakouts

Unlike section 3.1.3, which only focused on breakouts in response to planned deviations, this section addresses all breakouts regardless of their cause. The research team reviewed the DVD recordings to determine the number of breakouts during each scenario. Controllers implemented breakouts for several reasons. Among the most common causes were forced breakouts due to paired aircraft violating the NTZ because of insufficient in-trail separation between arrivals or because a pilot did not acquire visual separation from a paired aircraft as required by the SFO RNP procedure. The latter resulted when either the Woodside or Foster arrival traffic had not been descended sufficiently below the cloud ceiling to acquire visual separation from their paired traffic.

Each of the Standard NTZ, Wide NTZ, and Tower Override scenarios included four scripted events. Two of these events were *blunders* and two were *deviations.* In the case of a *blunder*, the pilot did not respond to ATC directives until they had entered the NTZ, thereby forcing monitor controllers to break out the paired traffic. Therefore, each of these scenarios resulted in at least two breakouts. In most instances, the monitor controllers implemented a missed approach for one aircraft in response to an NTZ violation; however, in some situations, they found it necessary to break out both aircraft. There were 17 occasions across the 16 data collection sessions when this occurred and the participants broke out both the 28L and 28R traffic. One of the four teams accounted for only one of these incidences. The minimum breakout rate due to the introduction of scripted blunders was approximately 5.5% for all scenarios, except for the High Traffic condition, which had no scripted blunders. There were approximately two more breakouts for the Wide NTZ and Tower Override conditions than for the Standard NTZ. We reviewed DVDs of the events and learned that for the Standard NTZ condition, the monitor controllers were able to reestablish deviating aircraft onto the approach before they entered the NTZ. However, in the case of the Wide NTZ and Tower Override conditions, the deviations often resulted in an NTZ violation, forcing the monitor controller to execute a missed approach for the paired aircraft. We did not insert scripted deviation events into the High Traffic scenarios; therefore, the breakouts were much lower and primarily reflected the need to increase in-trail separation between arrivals.

Table 7 shows a summary of the breakout events; it includes the count, average per 45-minute session, and overall rate. We calculated the rate by summing the total number of breakouts and dividing the result by the total number of aircraft landed for that condition. We differentiate between scripted and non-scripted events because aircraft deviations are extremely rare in the operational environment (see Table 7). We artificially introduced the scripted events into the simulation to evaluate the breakout procedure. The breakouts due to non-scripted events are more representative of what could be anticipated in the operational environment. It is worth noting that the lowest rate of breakouts and double breakouts occurred during the High Traffic condition.

Table 7. Summary of Aircraft Breakouts

Condition	Due to Scripted Events			Due to Non-scripted Events			Double Breakouts (Average per session)
	Count	Average per session	Rate (%)	Count	Average per session	Rate (%)	
Standard NTZ	8	2	6	10	3	7	1
Wide NTZ	16	4	11	8	2	6	1
Tower Override	12	3	9	13	3	9	2
High Traffic	0	0	0	5	1	3	0.3

3.3.2 Controller Response Times

We determined controller response times to each of the scripted deviation and blunder events using data captured by TGF in combination with DVD recordings. Because we wanted to determine realistic estimates of controller response times, we captured these data during the operational scenarios. By replicating an operational environment, there was no direct method to measure when a controller identified a deviation. The most efficient estimate we identified was to determine the exact time that the simulation pilot entered the command into TGF to turn an aircraft toward the NTZ, and then use the DVD recordings to determine the time at which the monitor controllers commented on that event.

The following sections address the time required for controllers to respond to scripted events. In Table 8, we present the average time for a monitor controller to identify a deviation, issue a control instruction, and latent time available to identify a solution. The research team analyzed data for 34 of the 36 NTZ violations that occurred as a result of scripted events. We could not analyze the other two circumstances because they did not result in a breakout, as noted in section 3.1.3. For each item, we include the *SD* and range of values.

Table 8. Average Monitor Controller Response Times to Scripted Events

	Time to Identify a Deviation (seconds)			Time to Issue a Control Instruction (seconds)			Time to Identify a Solution (seconds)		
	Average	*SD*	Range	Average	*SD*	Range	Average	*SD*	Range
Standard NTZ	11.4	3.9	3-17	13.8	5.7	7-27	3.0	3.5	0-10
Wide NTZ	10.9	3.5	5-16	12.2	3.3	7-17	1.3	1.8	0-5
Tower Override	12.2	3.9	1-16	14.3	2.8	11-22	2.6	4.4	0-12
All Conditions	11.5	3.7	1-17	13.3	4.1	7-27	2.1	3.2	0-12

3.3.2.1 Time to Identify a Deviation

The time from the onset of the deviation until the monitor controller acknowledged the event is presented as *Time to identify a deviation.* Their acknowledgment could be verbal, such as an ambient comment to the associated monitor controller or issuing a control instruction immediately to the deviating pilot; or it could be physical in nature, such as pointing out the event to their associated monitor controller. Monitor controller responsibilities varied from monitoring/correcting deviations (i.e., Standard NTZ and Wide NTZ) to pairing traffic/correcting deviations (i.e., Tower Override). The average time to identify a solution or issue a control instruction did not demonstrate statistical differences between these conditions. Overall, the Wide NTZ condition had a tendency to demonstrate shorter response times. This likely resulted from the more limited separation distances between the approaches and the NTZ during this condition (i.e., monitor controllers had less time to respond than for the Standard NTZ configuration).

3.3.2.2 Time to Issue a Control Instruction

Next, we identified the time from the onset of the deviation until the monitor controller issued an ATC instruction to the pilot to correct the deviation. *Time to issue a control instruction* appears in the second set of columns in Table 8. The time represents total time from the initiation of the turn. For example, during the Standard NTZ condition, controllers identified a deviation at 11.4 s and issued a control instruction 2.4 s later or 13.8 s after initiation of the event.

3.3.2.3 Time to Identify a Solution

By subtracting the time when the participants issued a control instruction from the time when they identified the deviation, we were able to determine the available *Time to identify a solution*. We define it as time *available* to identify a solution because it is really the latency between the two known events. In some instances, the monitor controllers were coordinating a solution; however, in many cases, they made no such communications and we could not determine what information they were processing. Because these averages also include the time for the monitor controllers to conclude any ambient comments regarding the deviation, or perform other actions, we cannot confirm that they were actively determining a solution during the entire time described as *available* in Table 8. Previous research suggests that experienced controllers demonstrate recognition primed decision making, which is characterized by extremely quick and accurate solutions based on the recognition of the patterns of a situation (Klein, 1997). At least once in each condition, the participants did not coordinate a strategy with the associated monitor controller, preferring to issue a control instruction immediately to the deviating pilot. As a result, *Time to identify a solution* resulted in a minimum range of 0 across all conditions. In 18 of the 34 events, we were able to analyze no apparent discussion before issuing a control instruction.

3.3.2.4 Response Time

The research team conducted additional analyses. We determined the amount of time from when the simulation pilots' initiated the turn toward the NTZ until they entered the command to correct the turn in response to a monitor controllers' instruction. The average time was 31.5 s (SD = 14.9 s) for the Standard NTZ, 21.6 s (SD = 4.3 s) for the Wide NTZ, and 34.7 s (SD = 12.6 s) for the Tower

Override conditions. We present the simulation pilot response times only as additional information for the reader, recognizing that as a simulation, the responses may not be truly characteristic of pilot performance in the operational environment.

3.4 Radio Communications

Radio communications is one measure of controller workload. The research team relied primarily upon the PTT log files to characterize controller radio communications. However, because the simulator did not automatically log communications during the Tower Override condition, we used a combination of PTT log files and video analysis for this condition. Due to the level of detail and the different methodology required to assess the effects of implementing two different communications procedures, we present the radio communications across all conditions followed by a more thorough description for the Tower Override condition.

3.4.1 All Conditions

This section presents the number and duration of ATCS communications across all operational scenarios.

3.4.1.1 Number of Communications

We used the PTT communication to determine counts and duration for each radio communication. Figure 14 shows the average number of communications for each ATCS position. The figure includes average counts for each simulation condition (i.e., Standard NTZ, Wide NTZ, Tower Override, and High Traffic). The asterisk in Figure 14 identities those positions with statistically significant differences. We describe these analyses in the following paragraphs.

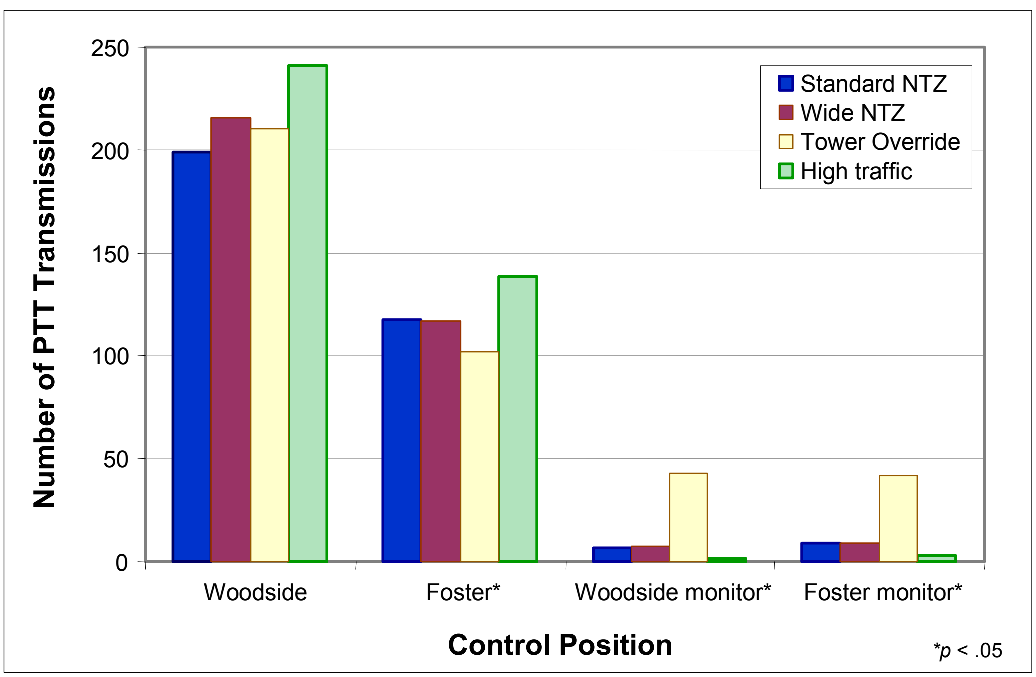

Figure 14. Average count of controller PTT transmissions.

We conducted a 4 (position) x 4 (condition) ANOVA on the number of PTT communications for each session. This reflected a mixed design, with "condition" representing a *within*-groups factor and "position" as a *between*-groups factor. The analyses indicated the presence of a significant interaction, $F(3, 12) = 71.221$, $p < .001$, between condition and position. The researchers anticipated this result because the participants had different responsibilities between conditions, and we directed much more traffic to the Woodside approach than the Foster approach. To investigate the exact nature of the relationship between the two independent variables, we used a simple effects analysis. We conducted two series of analyses (a) "Holding position" constant and then (b) "Holding condition" constant. By holding position constant, we investigated the relationship of the simulation conditions on each position independently (i.e., separate tests for the Woodside approach, Foster approach, Woodside monitor, and Foster monitor positions). Next, we repeated a similar procedure for each of the simulation conditions to investigate the effect on each position.

The analyses confirmed that the Woodside monitor, $F(3, 9) = 62.0$, $p < .001$; and Foster monitor, $F(3, 9) = 23.5$, $p < .001$, initiated significantly more communications during the Tower Override condition than all other conditions. This finding is directly attributable to their additional responsibilities for pairing aircraft on the approach during these sessions. For the second set of analyses, we conducted four separate analyses comparing the number of communications between controller positions during the Standard NTZ, Wide NTZ, Tower Override, and High Traffic conditions. For these, we restricted the comparisons to contrast the Foster approach to the Woodside approach and the Foster monitor to the Woodside monitor position. Directly comparing the approach to monitor positions was not valid because they had different responsibilities. There were no real differences in the number of communications made by the Woodside monitor and Foster monitor controllers across the conditions. Woodside approach controllers initiated more communications than Foster approach controllers in all conditions. This was a direct result of the much higher traffic count using the Woodside approach. During the moderate traffic scenarios, for example, the equivalent hourly aircraft arrival rate was 31 to Woodside and 15 to Foster.

3.4.1.2 Duration of Communications

Another important aspect of communications was the overall amount of time that controllers spent using PTT communication because this was a direct reflection of their workload. The research team summed the duration of each individual communication and then determined the amount of time, as a percentage of the total, for the scenario (see Figure 15). As the counts suggested in Figure 14, Woodside approach controllers performed more verbal communications than their Foster counterparts. Woodside controllers were actively speaking on their frequency approximately 25% of the time; whereas, for Foster approach controllers, the amount of time was closer to 15%. The highest percent of time for the approach controllers occurred during the High Traffic condition. For the monitor positions, the average time of PTT usage was approximately 1% for the Standard and Wide NTZ conditions. Monitor controllers recorded their highest percent of time, approximately 4%, during the Tower Override condition when they assumed responsibility for pairing approach traffic. For the High Traffic condition when the team initiated no planned aircraft deviations, the monitors essentially spent 0% of time on frequency.

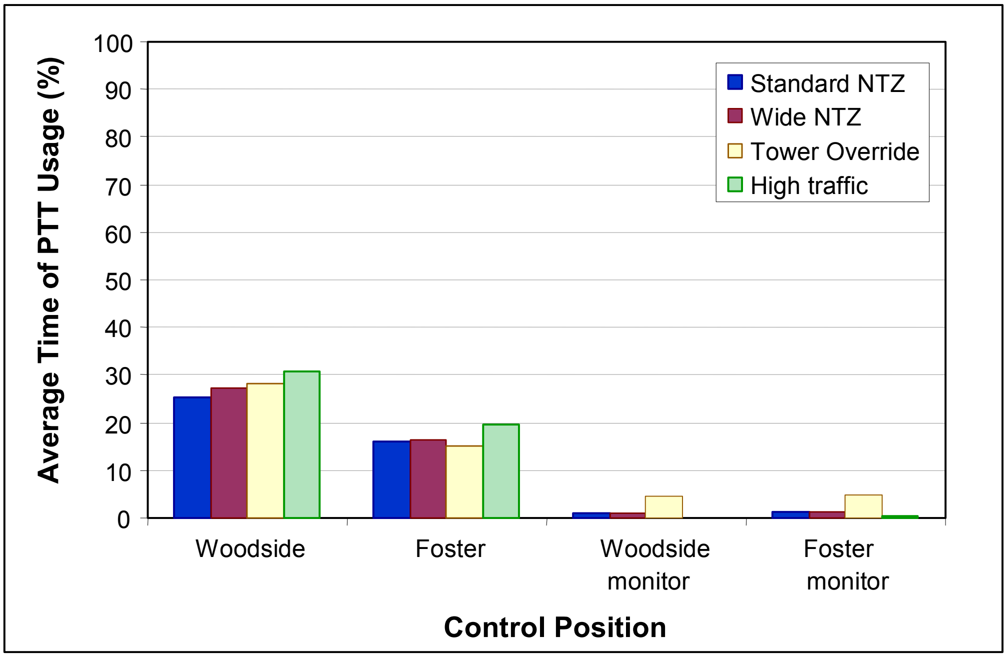

Figure 15. Average time of PTT usage.

3.4.2 Tower Override Condition

This section specifically addresses Objective 3 for the study, which was to assess overall sector performance and ATCS workload when implementing two different transfer of communication points.

The simulation included one experimental condition to compare monitor controllers' communications procedures for the SFO Tower Override and NCT Approach Override conditions. During the Approach Control Override condition, PTT transmissions made by monitor controllers blocked ongoing transmissions made by their associated approach controller. Specifically, the Woodside monitor blocked any simultaneous transmission made by the Woodside approach controller, and the Foster monitor blocked the Foster approach controller. In the case of the SFO Tower Override condition, monitors blocked the SFO Tower recording playing on their frequency.

There were also important differences in terms of monitor controllers' responsibilities between the two conditions. For the approach control override condition, monitor controllers were only responsible for blunder detection and resolution. During these sessions, they used PTT communications to issue control instructions only when an aircraft deviated toward the NTZ. For the SFO Tower Override condition, monitor controllers maintained these same duties, but they were also responsible for pairing aircraft with the traffic on the converging approach. These additional duties held significant implications on the number of communications that participants were required to make and, ultimately, on the number of overrides.

The research team relied primarily upon the PTT log files and DVD recordings to investigate communications overrides across both conditions. The results reflect data averaged across all four of the times we ran the condition. We include only those overrides that exceeded 0.5 s. To support further analyses, the researchers categorized all monitor controller communications during the Tower Override condition. We identified the communications as either related to their blunder correction responsibilities or to their responsibility for pairing traffic on the associated approach. We considered this an important discrimination for two reasons. First, it could be used as an estimate of controller workload with and without these additional duties. Second, the nature of these responsibilities was different. Our assumption was that monitor controllers had to respond immediately to an apparent aircraft blunder and could not delay their transmission. In the case of pairing, the participant could choose to wait until an ongoing communication was completed.

Due at least in part to their additional duties, monitor controllers made over five times more PTT transmissions during the Tower Override conditions (see Figure 16). Figure 16 presents the combined results for the Woodside monitor and Foster monitor. Most of the transmissions (i.e., 63%) reflected these additional pairing duties, as represented in the figure by the white portion of the bar. In Figure 16, the second set of data show the average number of transmissions resulting in the monitor controller overriding another controller. During the standard NTZ sessions, monitor controllers blocked their associated approach controller approximately three times, accounting for around 18% of all their transmissions.

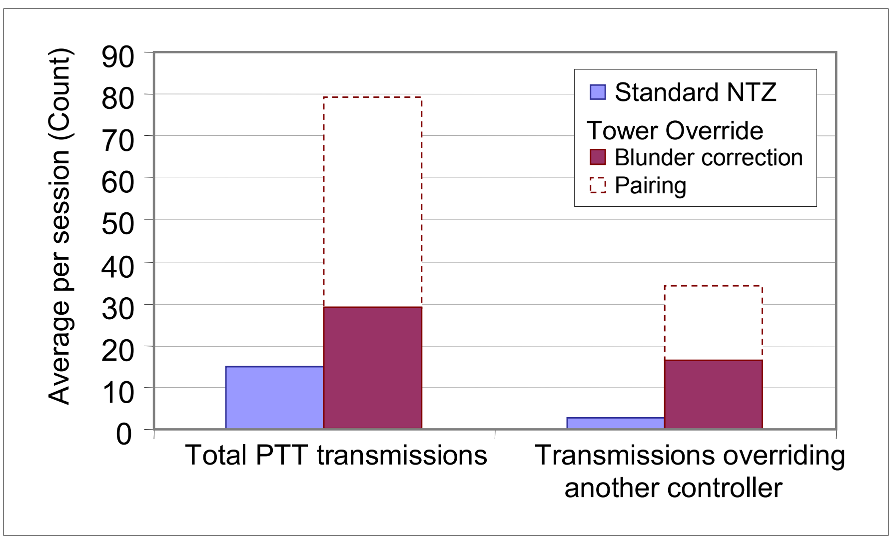

Figure 16. Average number of Monitor Controller PTT transmissions and overrides per 45-minute session.

During the Tower Override condition, when monitor controllers blocked the SFO Tower recording, approximately half of their transmissions resulted in stepped on communications. Monitor controllers averaged 34 overrides per 45-minute session. Approximately half of their communications were to respond to aircraft blunders. The remaining communications represented control actions to promote or maintain pairing with aircraft on the adjacent approach.

Because of the criticality and time pressure imposed on ATC communications, the researchers considered the number and type of overridden SFO communications to be of particular interest. We collaborated with two SMEs to categorize all SFO communications on the SFO Tower recording. The recording represented a 20-minute sample of SFO Tower operations while running the Runway 28 arrival and Runway 01 departure operation. We looped the recording to fill the entire 45-minute session. In the first two columns of Table 9, we summarize the average number and type of tower communication across all SFO Tower Override sessions. The italicized items represent types of communications that the SMEs considered to be particularly time critical. Pilot acknowledgments were by far the largest category overall. Taxi clearances represented the most frequent of the shaded communication types. The researchers categorized monitor controllers' communications as either related to blunder correction or to pairing responsibilities. In the third and fourth columns, we identify the type of monitor controller communication that was responsible for blocking the SFO Tower. Table 9 shows that overrides were about equally distributed between the two monitor responsibilities.

Table 9. Average SFO Tower Communications Per 45-Minute Session

Type of SFO Tower Communication	**Count**	**Overrides by Monitor Controller**		
		Blunder Correction	**Pairing**	**Total**
Pilot acknowledgment	149	5.3	3.8	9.0
Landing clearance	*32*	*2.8*	*3.5*	*6.3*
Taxi clearance	*56*	*1.3*	*4.0*	*5.3*
Position report	34	1.8	2.5	4.3
Frequency change	*24*	*3.0*	*1.0*	*4.0*
Takeoff clearance	*21*	*1.3*	*1.0*	*2.3*
Tower acknowledgment	13	0.5	1.0	1.5
ATIS	4	0.5	0.3	0.8
Vehicle acknowledgment	3	0.3	0.0	0.3
Tower request	4	0.0	0.3	0.3
Other clearance (e.g., squawk)	4	0.0	0.3	0.3
Clearance request	*7*	*0.3*	*0.0*	*0.3*
Total	**351**	**16.8**	**17.5**	**34.3**

Even when we remove communications related to pairing, the number of PTT transmissions was higher during the Tower Override condition, and the number of times they blocked another controller was higher than during the Approach Override condition. The researchers attribute this to a combination of factors. First, the participants were aware that the SFO Tower traffic was a recording and, as such, was not truly relevant to their current picture and did not reflect a real person. In the Approach Override configuration, all communications were relevant to the ongoing traffic situation and the controller initiating the communication was sitting in the same room. The researchers noted that when feasible, even during Tower Override sessions, monitor controllers frequently held off their communication until an ongoing transmission was completed. This likely reflected typical operational practices, although it was less important in the simulation environment. Another potential source of the increased override rate was the amount of time that the frequency was busy.

Figure 17 illustrates that, on average, the approach frequency was in use just over 30% of the time during Standard NTZ sessions, whereas during the SFO Tower Override sessions, the frequency was busy almost 50% of the time. Pilot communications accounted for much of the difference, reflecting almost twice as much time in the Tower Override condition (i.e., approximately 17% vs. 9%). Monitor controller communications increased due to their additional pairing responsibilities. In the SFO Tower sample, the tower controllers reflected a higher percentage of time transmitting compared to their approach counterpart (i.e., around 25% vs. 20%).

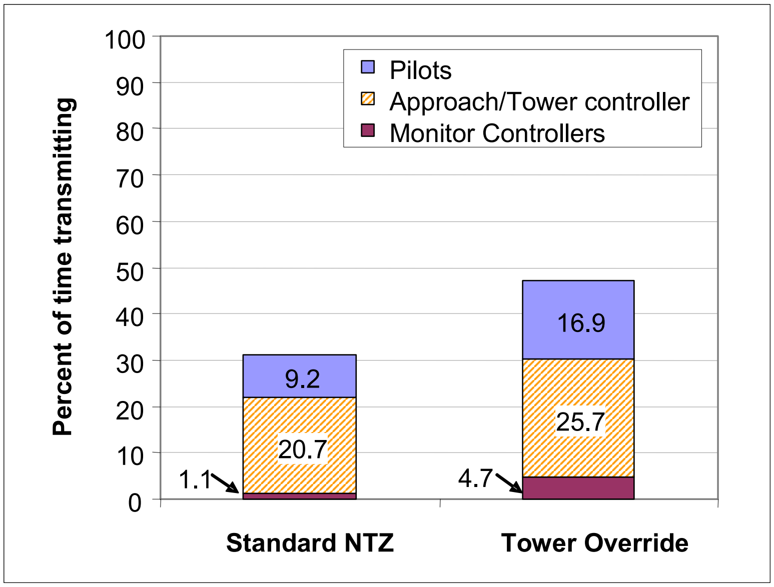

Figure 17. Average percent of usage for Standard NTZ and SFO Tower Override conditions.

The experimental design provided for comparison of overall communications across all controller positions. Figure 18 presents the average number of total PTT transmissions for the Standard NTZ and Tower Override conditions. It shows counts of communications by the Woodside approach, Foster approach, Woodside monitor, and Foster monitor positions.

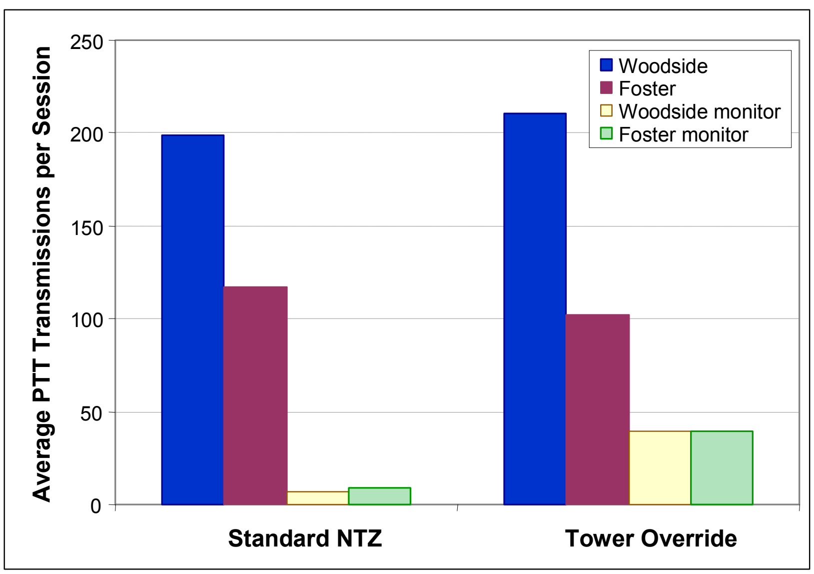

Figure 18. Average PTT transmissions by controller position for Standard NTZ and Tower Override conditions.

As noted previously, monitor controllers made many more communications during the Tower Override condition because of their additional pairing responsibilities. However, the data indicate that the number of communications by the Woodside and Foster approach controllers did not decrease even though they shed responsibilities for pairing in the Tower Override condition.

3.5 Workload Assessment Keypad Ratings

The participants provided workload ratings at 5-minute intervals during each operational scenario. The data demonstrated considerable uniformity across conditions. The average ratings ranged from 2.2 for the Standard NTZ to 2.5 for the Tower Override and Wide NTZ conditions. The High Traffic condition returned an average of 2.3. In Figure 19, we present the average workload ratings and *SD* for each controller position across the test conditions. The ratings remained relatively low for all simulation conditions, typically falling between 2 and 3. Only one average exceeded 3 on the 10-point scale, and it still remained below the *moderate* workload level. Of the total 541 individual ratings, the highest rating was 7 and represented five instances.

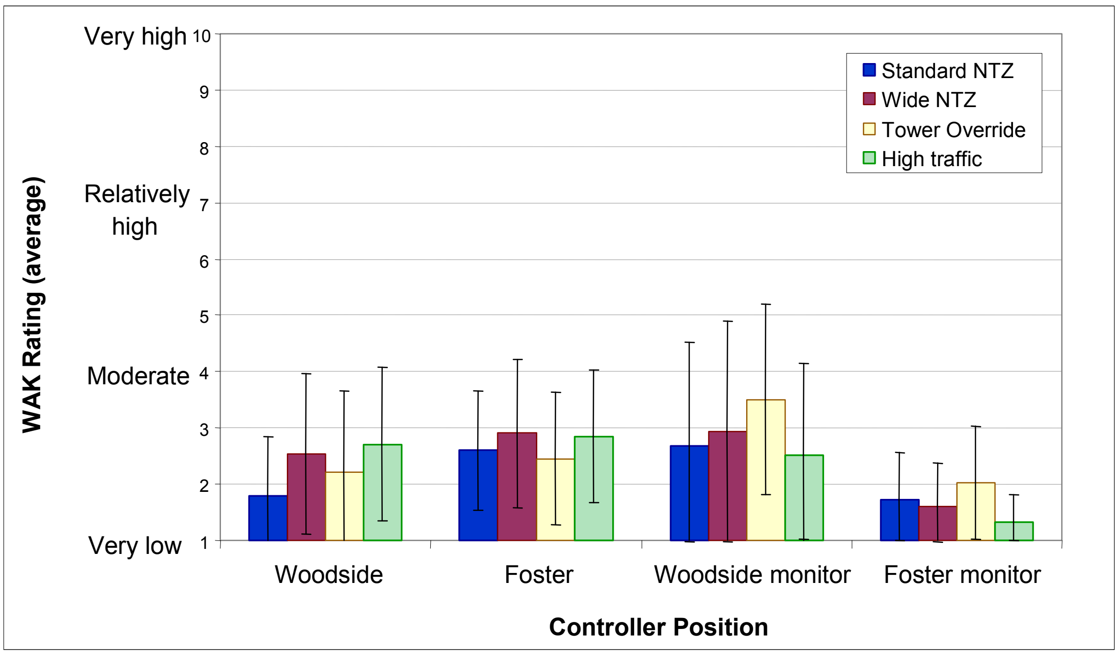

Figure 19. WAK workload ratings by controller position.

The ratings across the conditions demonstrated similar trends for each of the approach control positions and for the monitor positions. Ratings for the Woodside and Foster control positions demonstrated similar distributions and levels, even though the Woodside approach was responsible for more traffic. For both positions, workload levels had a tendency to be highest for the Wide NTZ and High Traffic conditions.

For the monitor positions, the Tower Override condition had a tendency to be the highest. This most likely reflected their additional responsibilities for aircraft pairing. The Woodside monitor ratings were typically higher than all other control positions. This is most likely due to individual differences and not a reflection of traffic count.

During the Standard NTZ condition, workload ratings for Foster appeared to be higher than those for Woodside. The difference may have reflected the very limited airspace and additional vectoring required for aircraft approaching from the north. Foster approach controllers have very limited airspace in which to vector aircraft arriving via DUXBY, and this represented the most common approach to the Foster sector for the current simulation. Almost immediately after accepting the handoff, the Foster controllers must descend and slow the traffic as it arrives above the OAK airspace. They are responsible for turning this traffic within the very constrained airspace approximately 120º to intercept the RNVZ-28R approach. Arrival traffic to the Woodside approach predominantly followed the Big Sur Two arrival stream from the southeast and merged almost straight onto the 28L (Woodside) approach. Woodside controllers had to descend the traffic as the Foster controllers did, but they were required to do much less vectoring.

The Standard NTZ, Wide NTZ, and Tower Override conditions represented moderate traffic levels and averaged near 35 arrivals per 45-minute session. During the High Traffic condition, the number of arrivals increased to nearly 45 per session. Woodside and Foster approach controller ratings had a tendency to be highest during high traffic. However, the participants provided similar workload ratings for the Wide NTZ, even though this condition represented a moderate traffic level. Monitor controllers had a tendency to provide their lowest workload ratings during the High Traffic condition. In this condition, they essentially had little or no workload because we inserted no aircraft deviations. They issued an ATC directive only in the event that an approach controller took an action that forced an NTZ violation. Although the amount of traffic was comparable for the Standard NTZ, Wide NTZ, and Tower Override conditions, monitor controllers provided higher ratings for the Tower Override condition because of their additional pairing responsibilities.

We averaged the participants' individual WAK ratings for each session to calculate an overall workload level. We analyzed these ratings using a 4 (condition) x 4 (position) mixed design ANOVA. Condition represented a within-groups factor and position represented a between-groups factor. The analyses returned non-significant results. These results suggest that workload levels, as measured by the WAK, did not differ significantly based on controller position or across conditions. In all cases, the workload levels never approached high workloads.

3.6 Post-Scenario Questionnaire

The participants completed a PSQ immediately following the conclusion of each session. This questionnaire had 20 items designed to compare important aspects of the simulation across each of the conditions. We informed the participants to restrict their ratings to the session just completed. The functional areas addressed by the PSQ included overall performance, controller workload, SA, 28R RNP operations, and simulation realism. We analyzed controllers' responses to each of the items on the PSQ using a 4 x 4 mixed design ANOVA. The first factor, condition, represented a within-groups factor. The four levels were Standard NTZ, Wide NTZ, Tower Override, and High Traffic. The second factor was a between-groups factor and represented four levels of controller position (i.e., Foster approach, Woodside approach, Foster monitor, and Woodside monitor). For significant main effects, we applied the Tukey HSD post hoc comparisons.

We report results of 0.06 as a trend in the data. For items that resulted in significant interactions, we used simple effects analyses. We present the PSQ results in terms of overall effectiveness, National Aeronautics and Space Administration (NASA)-Task Load Index (TLX), RNP operations, and simulation realism.

3.6.1 Overall Effectiveness

Important aspects of overall effectiveness included maintaining separation and resolving conflicts, detecting pilot deviations, correcting deviations in a timely manner, conducting effective communications, and maintaining SA. These represent PSQ items 1 through 4 and 11, respectively. In Figure 20, we present the average ratings and *SD* for each simulation condition. The participants rated their performance near the top of the scale (i.e., *extremely good*) for all four conditions. The Standard NTZ condition received the highest ratings for all items. Only two averages fell beneath 8 on the 10-point scale, and both reflected the Wide NTZ condition. These two items were controller effectiveness in detecting deviations and correcting them in a timely manner. The results reflected the limited time available for a controller to respond during the Wide NTZ condition. The distance between the approach path and NTZ was much smaller during the Wide NTZ condition, representing 1150 ft (351 m) for the Woodside monitor and 1800 ft (549 m) for the Foster monitor versus 3600 ft (1097 m) during the Standard NTZ condition.

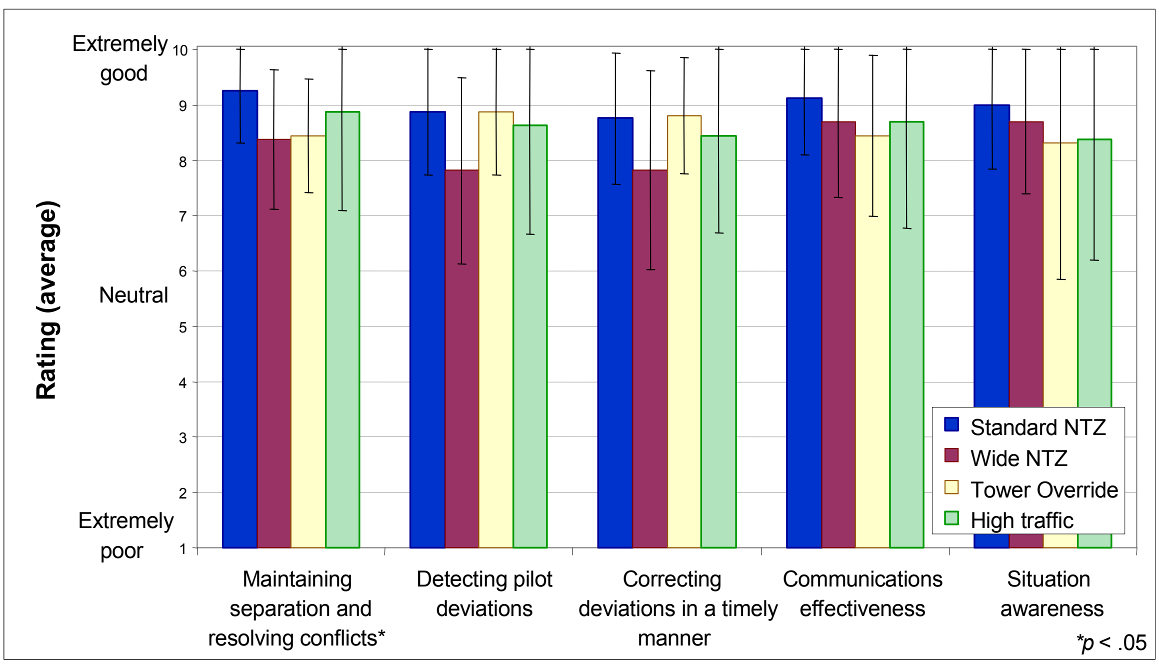

Figure 20. Overall effectiveness ratings.

Only the first item returned a statistically significant result. Controller self-ratings on their ability to maintain separation and resolve conflicts resulted in a significant main effect for condition, $F(3, 36) = 5.7975$, $p = .002$. The Tukey HSD post hoc comparisons indicated that controllers rated their performance better for the Standard NTZ condition than the Wide NTZ and Tower Override conditions. The next two items, detecting pilot deviations and correcting them in a timely manner, showed similar trends.

These results indicate that overall, the participants considered their performance in controlling traffic, correcting deviations, communicating, and maintaining SA to remain high regardless of the simulation condition. The Wide NTZ and Tower Override conditions slightly decreased their performance ratings for resolving conflicts. In addition, the results demonstrated a trend for slightly reduced performance in detecting and correcting deviations in a timely fashion during the Wide NTZ condition.

3.6.2 NASA-Task Load Index

PSQ items 6 through 10 addressed the six standard NASA-TLX dimensions of performance, mental demand, physical demand, temporal demand, effort, and frustration. Figure 21 shows the average rating and *SD* for these items. The first item represents performance, and so a high rating is a positive response. The remaining five items represent demand or a negative dimension, and so a lower rating is favored. Average NASA-TLX ratings across all dimensions were 4.9 for the Standard NTZ, 5.1 for the Wide NTZ, 5.4 for the Tower Override, and 4.8 for the High Traffic conditions (see Figure 21).

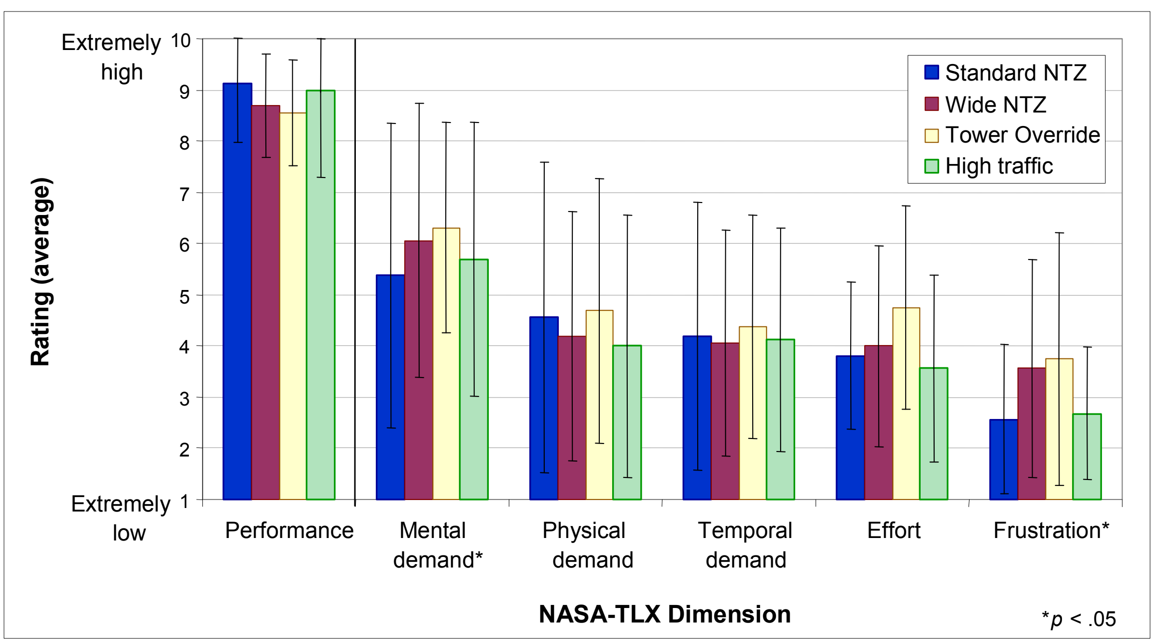

Figure 21. NASA-TLX ratings.

On average, the participants rated their level of performance near nine for all conditions (i.e., the first set of columns in the figure). Their ratings fell just under the *extremely high* upper-most point of the scale confirming that they considered their performance to remain high in all conditions.

Results for the five independent demand-oriented dimensions indicated that task demands were relatively low. This distribution is very closely aligned with NASA-TLX results from other ATC research (Truitt et al., 2004; Zingale, McAnulty, & Kerns, 2003). Due to the nature of the controllers' task, mental demand reflected the highest of these dimensions, followed by physical demand, temporal demand, and effort. The temporal demands on an ATCS are apparent; however, physical demands may be less obvious. Among the physical aspects of their task are verbal communications. For the current simulation, the Woodside approach controllers used PTT communications for approximately 25% of the entire scenario. The Tower Override condition consistently reflected the highest demand values, particularly for effort.

Two of the items reflected statistically significant differences. Mental demand demonstrated a significant interaction, $F(9, 36) = 2.20$, $p = .05$. We investigated this interaction using an analysis of simple main effects for controller position and a separate analysis for condition. Foster monitors rated mental demand significantly higher during the Wide NTZ condition (mean = 6.5) than the Standard NTZ condition (mean = 3.5). One potential explanation for this finding is the limited amount of time to respond to a deviation. For the Standard NTZ condition, the approach path was 3600 ft from the NTZ compared to 1800 ft (549 m) for the Wide NTZ condition. Woodside monitors showed a similar trend for higher mental demand ratings for the Wide NTZ versus the Standard NTZ. The time available to respond for the Woodside monitor was even more limited because the 28R approach path was 1150 ft (351 m) from the NTZ. Some participants commented on the proximity of the target to the 28L approach path during the Wide NTZ configuration.

The NASA-TLX dimension of frustration returned a significant main effect for condition, $F(3, 36) = 3.3$, $p = .03$. The participants rated the Wide NTZ condition as resulting in more frustration (mean = 3.6) than the Standard NTZ (mean = 2.6) or High Traffic (mean = 2.7) conditions. The Tower Override condition demonstrated a trend for higher frustration ratings than the Standard NTZ condition. Both suggest that controllers were less comfortable with the Wide NTZ and Tower Override conditions. Potential explanations may be that the participants found the Standard NTZ and High Traffic conditions to be much more like typical operations, or perhaps the limited exposure to the Wide NTZ and Tower Override conditions contributed to an increase in frustration.

3.6.3 RNP Operations

A set of questions investigated the participants' assessment of RNP operations. These items addressed overall assessment of the approach, impact on safety, ease in differentiating between a pilot deviation and STEs, time available to react to a deviation, and effort exerted to remain vigilant of aircraft approaching the NTZ. Figure 22 shows the average rating and *SD* for each of the items. We shaded the last item in the figure because its rating scale is reversed. A high rating for effort is a negative reflection on the operation.

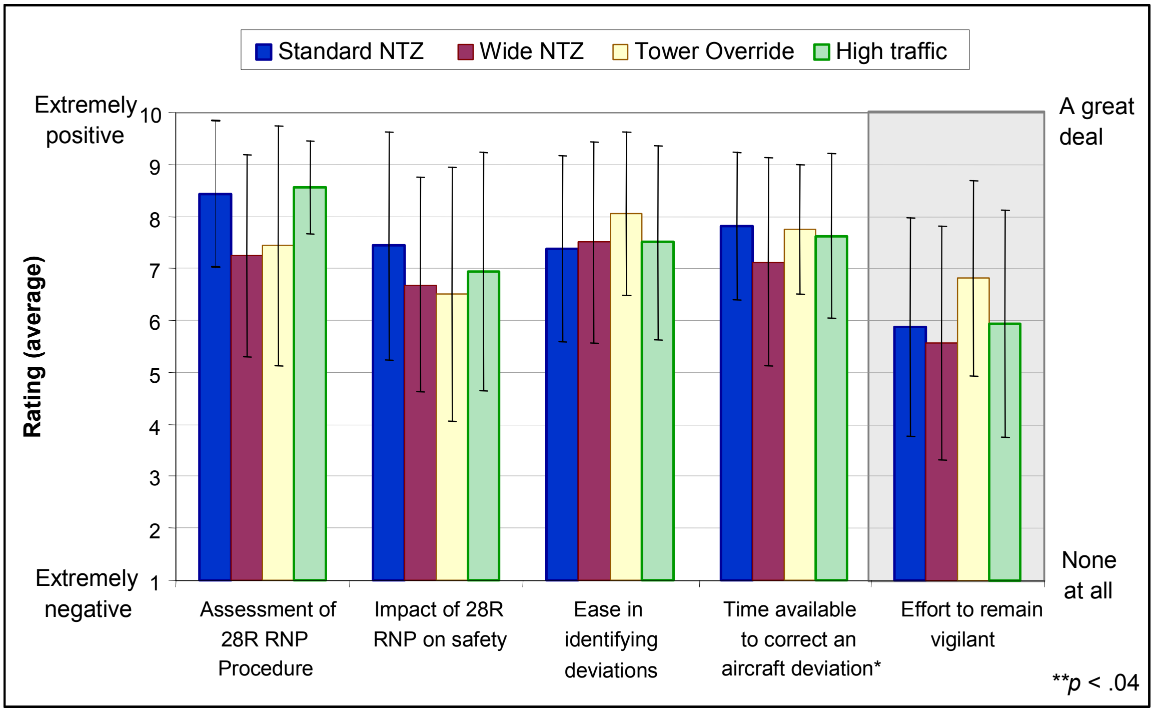

Figure 22. RNP operations ratings.

The participants' overall assessment of the RNP operation was positive. The anchors for this item ranged from 1 (completely unacceptable) to 10 (completely acceptable). Responses averaged higher than 7 for all conditions and were especially favorable for the Standard NTZ and High Traffic conditions.

The participants rated the impact of the RNP operation on safety. For this item, we indicated that a rating of 5-6 reflected no difference from standard operations. In all simulation conditions, their average responses were toward the positive end of the scale, reflecting a positive effect on safety from normal operations.

One item addressed the ease of identifying aircraft deviations. The scale ranged from 1 (extremely difficult) to 10 (extremely easy). The participants averaged above 7 for all conditions suggesting that they found it relatively easy to differentiate between aircraft deviations and STEs.

Another important consideration of this approach was the amount of time available for a controller to react to a deviation. The ratings were favorable, averaging above 7 on the scale (10 = completely acceptable). This was the only item in Figure 22 to return a statistically significant result for the 2-way ANOVA. The results demonstrated a significant interaction, $F(9, 36) = 2.3$, $p = .04$, suggesting that the condition affected the controller positions differently. We conducted a simple effects analysis holding *condition* constant and a second analysis holding *position* constant. The *t*-tests showed that Woodside monitors rated the Wide NTZ (mean = 5.0) much lower than the High Traffic condition (mean = 8.0) with respect to time available to react to an aircraft deviation. As noted earlier, the NTZ location was 650 ft (198 m) closer to the approach for the Wide NTZ condition. The Foster approach controllers also rated the amount of time available much lower than their counterparts from the Woodside approach, returning averages of 7.1 and 8.1, respectively. This likely resulted from the limited separation in the Wide NTZ condition, particularly for the Foster approach.

On average, the participants rated the amount of effort to remain vigilant as higher during the Tower Override condition than the other simulation conditions; however, this difference was not statistically significant. It is likely that they exerted additional effort during the Tower Override condition as a result of changes in their roles and the need to constantly remind themselves of the different conditions. Ratings above 8 or 9 would clearly suggest the need to investigate further, however, none of the ratings exceeded 7.

This section of the PSQ also contained items addressing the ease of identifying aircraft certified for the 28R RNP approach and those using the approach, items 15 and 16, respectively. However, the procedures dictated that all aircraft landing on 28R were certified for that approach; and they returned no statistically significant differences, so we did not include these results in the figure. The participants rated the ease of identifying RNP-certified aircraft at 7.5 and aircraft using the approach at 7.8.

3.6.4 Simulation Realism

The final item on the questionnaire addressed simulation realism. We always include this item in the PSQ so that we could determine if the realism of any individual scenario suffered as a result of potential equipment or other failures. We noted no such occurrences directly affecting controller interactions during the study. The most pervasive issue was that trackball picks almost always required two activations before being accepted. The participants indicated that this was a nuisance but did not significantly affect the realism of the scenarios, as supported by their ratings, which were consistently high across all conditions. They averaged above 7 on the scale that ranged from 1 (extremely unrealistic) to 10 (extremely realistic). Of the 56 individual ratings for this item, only 1 rating was below 4. This participant provided a rating of 1 during a tower session, indicating that the number of aircraft resulted in an unacceptable scenario. Another more common observation was that traffic to Woodside was higher than during typical operations. This was a result of the operating procedures used for this simulation to maximize the efficiency in landing RNP-equipped aircraft. Several participants noted that the simulation modified Foster and Niles approach procedures from current operating procedures. They noted that unlike current operations, the simulation required Foster approach controllers to avoid descending traffic until the aircraft had cleared the OAK Runway 29 final approach course. They also indicated that current operations do not route Foster traffic as far as 15 miles east of SFO. Four participants commented regarding the lack of winds in the simulation, which resulted in somewhat less complexity.

3.7 Exit Questionnaire

At the conclusion of all sessions, the participants completed the Exit Questionnaire (see Appendix F). The first seven items addressed their assessment of the RNP operation based on their performance after completing all simulation conditions. Each of the items provided a 10-point rating scale that ranged from 1 (very negative) to 10 (very positive). Figure 23 illustrates the average ratings and *SD* for each of the Exit Questionnaire items. We present the results for each item in Appendix G.

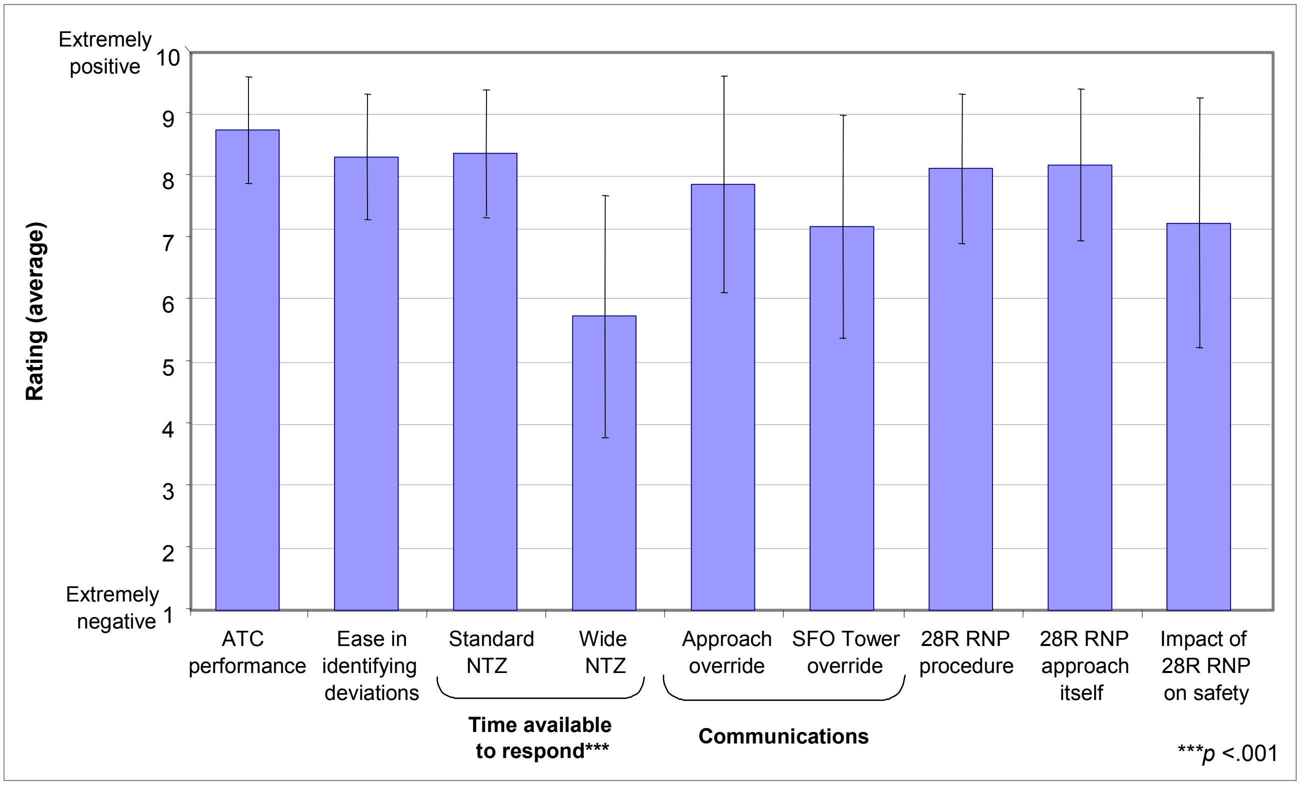

Figure 23. Exit Questionnaire ratings.

The participants rated their overall ATC performance as very high. No rating fell below 8 on the 10-point scale. They also indicated that it was relatively easy to differentiate between deviations and STEs, as the second item in the figure shows. Items 3a and 3b addressed the acceptability of the time to react for the Standard NTZ and Wide NTZ conditions. The ratings were much lower for the Wide NTZ (mean = 5.8) than the Standard NTZ condition (mean = 8.4). These differences were statistically significant, $t(1, 15) = 4.24$, $p = .001$. In fact, three participants provided a rating of 3, indicating an unacceptable amount of time to react for the Wide NTZ condition.

The ratings for acceptability of the Approach Override versus the Tower Override condition were very similar. The controllers rated the Approach Override condition slightly higher (mean = 7.9) than the Tower Override condition (mean = 7.2). The distribution of ratings was comparable, with an identical range (i.e., 3-10) and very similar *SD*s (i.e., 1.7 versus 1.8). These ratings suggest that, from a controller's perspective, either override condition may be viable and that operational and other considerations should drive the ultimate decision.

The responses were very favorable when assessing the 28R RNP approach and procedures. For both items, no participant provided a rating less than the midpoint on the scale, and two of them indicated that the approach and procedures were completely acceptable. Average ratings for both items were above 8. This supports the feasibility of implementing the approach in a configuration similar to the one tested.

The last item in Figure 23 reflects participant ratings of the impact on safety of the RNP operation when compared to existing operations. A rating of 5-6 reflected no difference. Overall, 63% of the participants rated the 28R RNP operation as having a positive impact on safety, 25% rated it as equivalent to existing operations, and 13% rated it as being slightly negative. The participants' comments reinforced the importance of knowing far enough in advance which approach an aircraft is on so that the aircraft can be descended and slowed sufficiently. None of the participants rated the safety impact as very negative (i.e., 1 or 2).

The next four items on the Exit Questionnaire asked the participants for their insights regarding the implementation of RNP in general and specific recommendations for SFO. This provided them an opportunity to summarize their experiences after completing all of the simulation conditions. We present the responses with limited editing because we considered it important to keep the responses in context (see Table 10). Items 9 and 11 required a yes/no response, so we grouped them together in the first two rows of the table. These items inquired about situations in which the controllers would not want to use the RNP procedure and whether there were substantial differences between this approach and other navigation procedures.

The participants made several positive responses regarding the implementation of the 28R RNP converging approach procedure at SFO. When evaluating the differences between the RNP and other procedures (Item 11), 5 of the participants commented that it was easier, less restrictive, or more efficient. Almost half of the participants were able to provide examples of situations when they would not consider the RNP approach to be the most appropriate option. Their examples focused primarily upon specific operations at adjacent facilities, but they also made reference to the challenges of strong north winds and very tight holes.

In response to two items in the Exit Questionnaire (Appendix F), controllers provided comments regarding their performance during the simulated RNP operations. As Table 10 outlines, items 10 and 12 addressed important aspects regarding the impact and implementation of RNP approaches. The participants emphasized the importance of high participation and equipage rates as well as the need for RNAV-specific procedures and user training. They echoed the need for ATCS training when asked for SFO-specific suggestions regarding implementation (Item 12). In response to this item, 3 participants expressed a strong interest in implementing this approach as soon as feasible. Overall, more than half of the participants commented favorably on the approach, and none raised serious concerns. Communications was another area that drew comments. Two of the participants reiterated their preference for not transferring communications until reaching the final approach fix.

The remaining three items on the questionnaire asked the participants to evaluate the realism of the simulation with respect to equipment, aircraft performance, and simulation pilot performance. Items 13 to 15 addressed simulation realism with respect to the STARS interface, WAK device, and overall realism. The research team included the first two items because of their importance in identifying and accounting for any differences as well as supporting decisions for future research simulations. Fourteen participants rated the impact of the STARS interface and the WAK device. The scale ranged from 1 (none at all) to 10 (a great deal). Their mean ratings for the impact of the STARS interface and WAK device were 3.6 and 2.9, respectively.

Table 10. Responses to Items Regarding 28R RNP Operations

Item	Representative Comments (counts)
9. Are there situations or conditions when you would not want to use the 28R RNP converging approach procedure? (No = 9, Yes = 7)	• When OAK is using the VOR approach to Runway 29. • When SFO is landing Runway 28 and OAK is landing and departing Runway 11. • When SFO is landing Runway 28 and San Jose International Airport is landing and departing Runway12. • If you have to delay the down the bay aircraft farther than 15 DMC, you run right into the Oakland final (unless the procedure keeps aircraft above OAK final). • When the weather is marginal. • During strong north winds. • Very tight holes.
11. Are there substantial differences between the proposed 28R RNP converging approach procedure and other area navigation approaches? (No = 9, Yes = 7)	• Monitor radar (2). • Easier operation. • Less restrictive - waypoints well thought out from north downwind. • Other approaches require at least 15-20 mile final established and frequency to turn. A little more control when doing RNP approaches. • Can run more traffic with less restrictions. • RNP is more efficient than SOIA. • None of the others are converging approaches.
10. What aspects impact you the most when using an area navigation approach	• Non-participants/equipage rates (4). • Having regulations to guide the RNAV procedures. • Having all users trained on the procedures. • Knowing the FMS/RNP equipment in data tag. • Knowing what frequency any associated traffic is on. • If you know what approach each aircraft can take far enough out, it's not a problem. • Experience of pilots on the approach. • Strong crosswinds creating difficult intercepts. • Getting speeds under control. • Easier to run this approach than when we tried side-bys with low ceilings.
12. Do you have any suggestions regarding the implementation or use of the proposed 28R RNP approach?	• Implement it at SFO (4). • Make sure the CPCs are trained and we use it often. • If monitors are responsible for in-trail separation, it is important to have the aircraft on frequency as soon as possible. • Do not transfer communication to tower until final approach fixes. • Keep communication procedures same as tested. Do not copy PRM/SOIA communications process. • Make sure everyone is a player. • Get the planes down low and slow or this won't work.

These ratings suggest that the STARS interface was more noticeable but remained relatively unobtrusive. Even though they used an ACD during their normal day-to-day operations and had never used STARS, 4 participants indicated that the STARS interface had no impact on their ATC performance. The highest rating provided for this item was a 6. The ratings regarding the WAK reflected less of an influence on their performance with six of them reporting no impact at all. The final item in this section of the questionnaire investigated the extent to which these differences, or other differences, compromised the overall realism of the scenarios. The scale ranged from 1 (extremely unrealistic) to 10 (extremely realistic). The mean rating was 7.3, demonstrating that even with the differences noted, they considered the simulation very realistic. Only one rating fell below the midpoint of the scale.

The research team provided space for the participants to elaborate on the differences between the simulation and their normal working environment. We specifically asked them to note equipment, aircraft performance, and pilot differences; however, they could provide comments on any dissimilarity. The equipment differences they identified included difficulty using the trackball selection key, the different look and feel of the STARS interface, and their inability to use their own ACD preset preferences. They also noted that they did not have the ability to measure miles between aircraft and that the datablocks did not include the runway assignment. Four participants reported the next aspect, aircraft performance, to be very good. The differences the participants noted with respect to this area were that some aircraft descended slower than expected, turn rates of the approach aircraft were typically slower, and no winds were incorporated into the simulation. Their assessment regarding the performance of the simulation pilots was extremely positive and included comments such as *great* and *perfect*.

3.8 Over-the-Shoulder Ratings

The ATC SMEs observed and rated performance of the Woodside approach and Foster approach sectors. At the conclusion of each session, they evaluated controller performance using the OTS Rating Form (see Appendix C). The form was developed by the NAS HFREG Human Factors Team – Atlantic City, ATO-P, for air traffic research (Sollenberger, et al., 1996). In addition to the standard OTS Rating Form questions, the SMEs provided ratings on five items designed to evaluate important aspects of performance for the simulation (see Figure 24).

The supplemental items addressed overall ATC performance, timeliness in identifying and responding to blunders, and communications. Items 4 and 5 address two dimensions of communications. We hypothesized that there may be important differences in intra- and inter-team communications as a result of changes in monitor responsibilities. During the Tower Override condition, monitor controllers had to coordinate speed adjustments to pair the aircraft on their respective approaches. This was not the case during all other sessions.

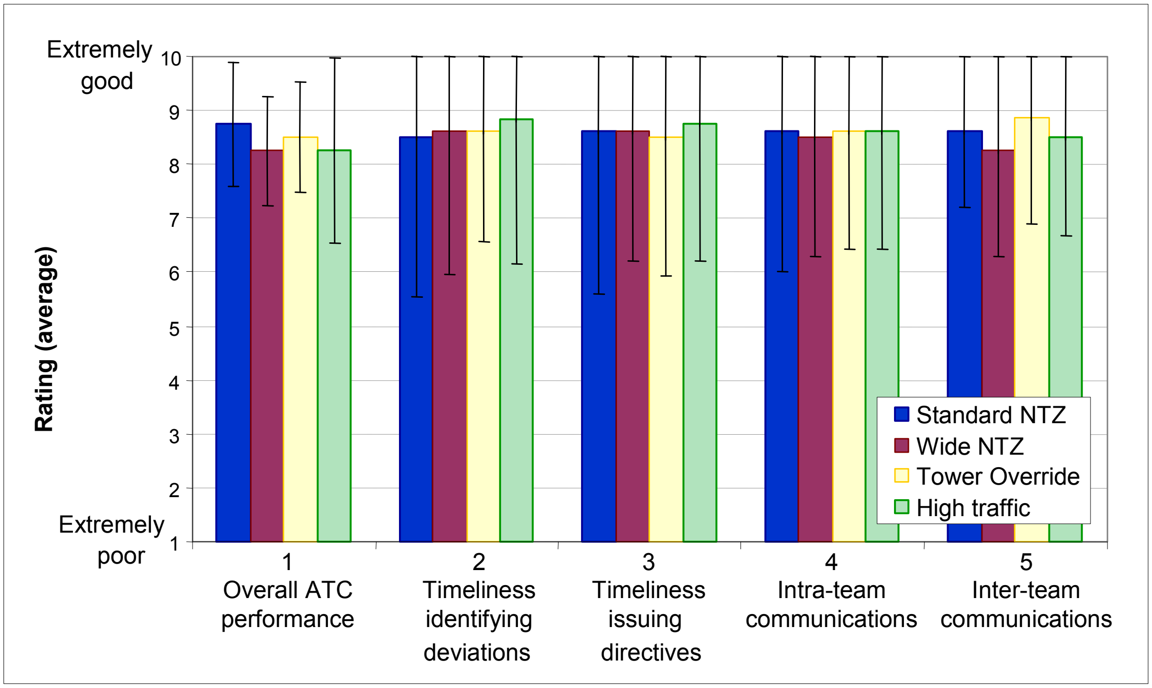

Figure 24. Average SME ratings for supplemental items.

Figure 24 presents the average ratings across both sectors. Controller performance remained high for each of the items. Only 1 rating averaged less than 8 on the 10-point scale. This rating reflected timeliness to issue a directive to a deviating aircraft during the Tower Override condition. In this condition, the monitor controllers had additional responsibilities. They were required to issue speed adjustments to pair aircraft on the approach in addition to their blunder correction responsibilities. The quality of intra- and inter-team communications did not appear to change between the simulation conditions.

The average ratings for the six primary ATC dimensions contained in the OTS Rating Form appear in Figure 25. These dimensions included safe and efficient traffic flow, attention and SA, prioritizing, providing control information, technical knowledge, and communicating. This standardized rating form reflects an 8-point rating scale. Average SME ratings averaged near 7 (very good) on the 8-point scale and showed little variation across conditions for each of the dimensions. The Standard NTZ condition had a tendency to be among the highest ratings; however, the values remained very closely distributed. The results confirm that the performance of ATCSs remained high in all conditions for each of these primary dimensions.

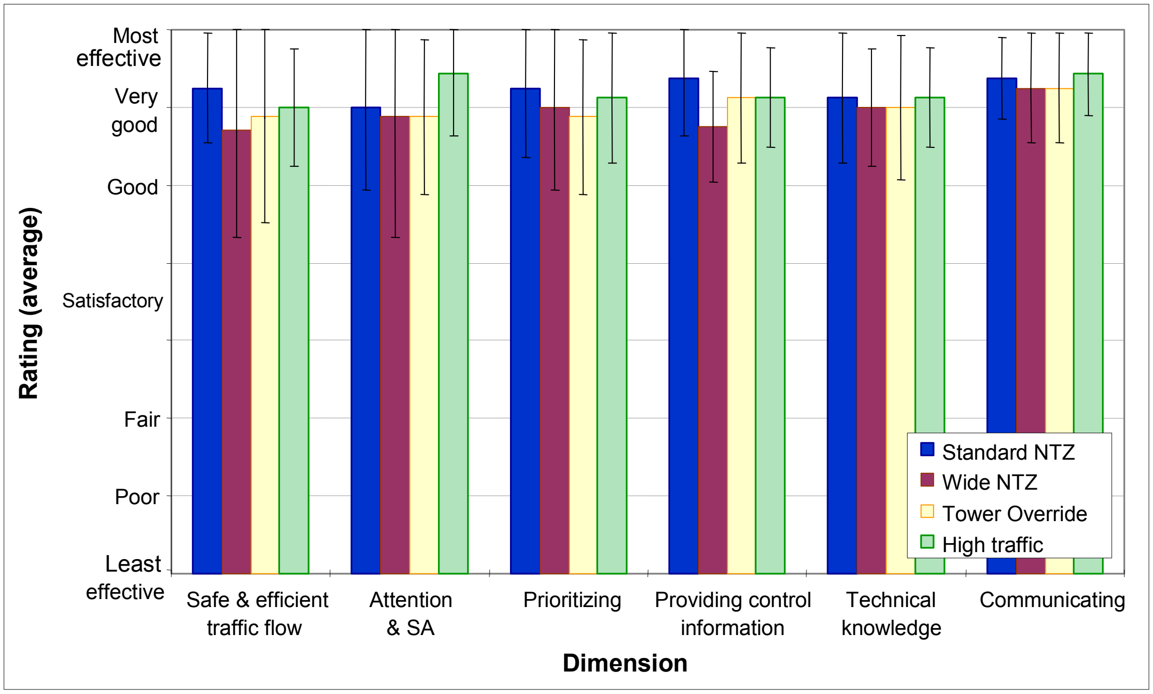

Figure 25. Average SME ratings across ATC dimensions.

4. DISCUSSION

We organized the discussion in terms of the five primary objectives of the simulation:

1. Assess the controllers' ability to identify aircraft blunders using an ASR-9 representation.
2. Evaluate the propensity for nuisance breakouts.
3. Compare the approach and tower override communications options.
4. Compare the NTZ placement options.
5. Evaluate the potential impact of high traffic levels during RNP operations in SFO.

We discuss each of these objectives in the sections that follow. When interpreting the results, note that monitor controller performance for the current simulation most likely represents a best case in terms of response times. Factors such as target intensity, duration, frequency, and background event rate affect performance on vigilance tasks (Wickens, Mavor, & McGee, 1997). For a vigilance task like the monitor controller is required to perform under normal operations, the literature suggests that there would be a vigilance decrement and monitoring performance would degrade after about 30 minutes. Our task, however, had high stimulus rates, which would maintain better performance than very low stimulus rates. Our simulation introduced blunders at an exceptionally high rate of approximately one every 5 minutes. To put this in perspective, in the field, controllers may never experience a blunder as it occurred in this simulation. This extreme target rate most likely resulted in controllers maintaining good vigilance, which resulted in superior response times.

4.1 Blunder Detection

The monitor controllers' ability to detect and correct blundering aircraft is fundamental to the safety of the proposed RNP operation. As with any ATC surveillance system, their ability to identify flight path deviations is subject to hardware, software, and human characteristics of the system. We employed two methods to investigate ATCSs' performance in identifying aircraft blunders when using an ASR-9 representation: Reaction Time Task and High Fidelity HITL Operational Scenarios.

In the reaction time task, the participants observed a single radar target and had no separation responsibilities. The goal of this condition was to characterize detection performance in its optimum state (i.e., without distractions from other radar targets and without the need to formulate a solution or communicate an ATC instruction). Their only overt behavior requirement was to press a key.

The high fidelity HITL simulations/operational scenarios allowed the team to characterize controller performance in a highly realistic environment. During these operational scenarios, controllers were responsible for providing separation between multiple targets, formulating solutions to conflicts, and communicating instructions to pilots, just as they would in their day-to-day operation.

On average, controllers identified a blundering aircraft in 7.4 s during the reaction time task and in 11.5 s during the operational scenarios. The data demonstrated some other interesting findings.

4.1.1 Reaction Time Task

On average, controllers required 7.4 s to identify that an aircraft had blundered from the projected flight path during the reaction time task. The results suggested that controllers responded faster when a blunder occurred soon after an aircraft was established on the approach versus when it was near the end of the approach path (i.e., 6 s vs. 8.7 s). The participants demonstrated extremely good performance at identifying blunders. They typically identified blunders within two updates. The only exception was for aircraft that initiated a 15º turn near the end of the approach path. In these situations, controllers required three updates before all controllers identified the event.

We offer a few potential explanations for this finding. First, based on their ATC experience, controllers recognize that in the very rare circumstances that a blunder does occur, it is more likely to happen as an aircraft turns onto the ILS approach and not after it is established on the path. For example, approach sector controllers report that they occasionally observe an aircraft cross the localizer approach path before turning to rejoin it. These situations typically occur as the result of a strong crosswind. Another possible contributing factor is that because this was a vigilance task, the participants were required to keep their attention on the display. It may be especially challenging to observe a single aircraft that has demonstrated no anomalous activity for nearly 2 minutes, particularly after it has initiated a turn and established itself on the ILS approach path. During true operational conditions, controllers are responsible for monitoring several aircraft, maintaining aircraft separation, communicating with pilots, and performing several other tasks.

We compared controller response times for the reaction time task across each of the deviation angles. We had anticipated that these times would decrease essentially linearly as the angle increased from 15º to 30º, 45º, and 60º. With the exception of 30º, the response times did demonstrate a linear trend toward becoming shorter as the angle of deviation increased. However, on average, participants responded most quickly to blunders of 30º (5.8 s) followed by 60º (6.7 s), 45º (7.1 s), and 15º (9.9 s), respectively. The superior performance at 30º may be due to everyday familiarity with this turn rate and distrust of rates more extreme than those typically experienced. Controllers frequently use 30º as a standard turn for merging aircraft onto an approach or when vectoring aircraft for traffic. The authors believe that when the separation between the target on the display and the projected location (i.e., the location at which the controller expected the target to be) approximated what they saw for a standard turn, controllers readily recognized that a blunder had occurred. For rates greater than 30º, we speculate that controllers may be responding more slowly due to distrust of the unusual separation distance between the target and projected location, potentially resulting in them waiting for the next update to confirm the trend.

Previous ATC simulations have employed a worst-case blunder, which is characterized by an aircraft turning 30º toward an adjacent approach and the pilot not responding to ATC directives (Magyarits & Ozmore, 2002). However, results from the current study suggest that 30º might not be the worst case with respect to ATCS conflict detection performance. Blunders of 30º may provide an optimistic result; therefore, we recommend that other deviation angles be included in future studies.

4.1.2 Operational Scenarios

During the operational scenarios, we investigated SFO controllers' ability to distinguish between STEs and aircraft blunders when using an ACD depicting ASR-9 data in a high fidelity simulation environment. The experimental design permitted the team to assess the effect of changes in the proximity of the NTZ to the approach routes, changes in transfer of communication points, and increased traffic load on sector performance.

The simulator recordings indicated that controllers were very effective at identifying deviations from the assigned flight path. On average, they took 11.5 s to identify a blunder during the operational scenarios compared to 7.4 s for the reaction time task. Typically, they identified a blundering aircraft within 11 to 12 s of initiation of the turn, which is equivalent to two updates on the ACD radar screen. The participants' ratings on the PSQ suggested that they experienced minimal difficulty identifying blunders and that they considered their performance controlling traffic, correcting blunders, and maintaining SA to remain high across all simulation conditions.

Figure 26 provides a timeline summarizing the average response times for those steps that we were able to measure during the simulation. The times are cumulative, beginning at 0 s for Step 1 and terminating at 29.3 s for Step 9. Step 2 through 9 represent a continuous loop that requires approximately 30 s to complete one time. Radar updates occur at 4.8 s intervals; therefore, the amount of delay until a turn appears on the screen is variable but cannot exceed this value. As was the case for the reaction time task, controllers typically demonstrated a tendency to wait for a second update to confirm that an aircraft was really deviating. On average during the Standard NTZ condition, for example, controllers identified a blunder at 11.4 s and issued a control instruction 2.4 s later or 13.8 s after initiation of the event.

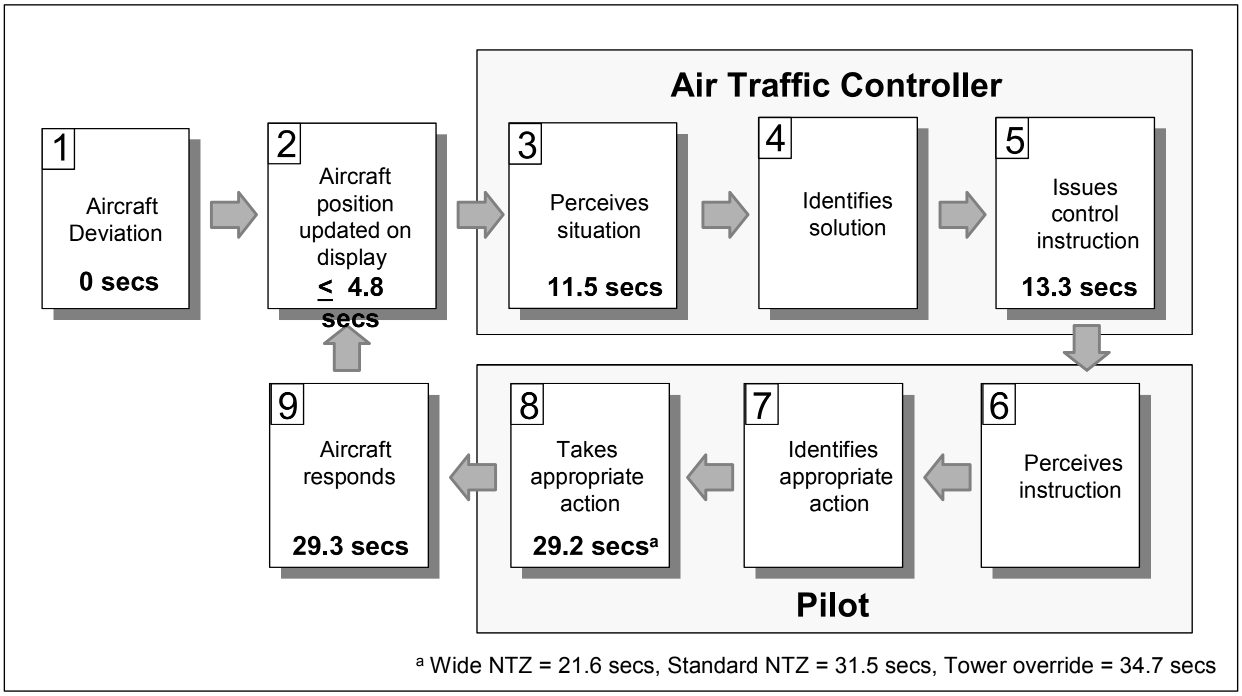

Figure 26. Timeline for aircraft blunders.

4.2 Nuisance Breakouts

Another primary objective of this simulation was to assess the propensity for nuisance breakouts when implementing the RNP converging approach procedure in a simulated environment. A nuisance breakout occurs when a paired aircraft deviates toward the NTZ; the associated monitor controller instructs the other pilot to execute a missed approach, but the deviating aircraft is able to adjust its course so that it never enters the NTZ. Nuisance breakouts reduce the overall efficiency of the operation by decreasing the arrival rate and increasing controller communication and workload requirements.

The participants were extremely effective at distinguishing between aircraft blunder situations and STEs. The nuisance breakout rate for the operational scenarios was 1%. During the High Traffic condition that reflected levels much higher than expected for typical SFO operational traffic levels, the overall missed approach rate did not exceed 3%. In fact, the controllers implemented breakouts for these scenarios to meet in-trail separation requirements and not in response to an aircraft turning toward the NTZ. In the reaction time task, a false response was analogous to a nuisance breakout in an operational scenario. A false response occurred when a controller pressed an ACD key to indicate that an aircraft was blundering even though the aircraft was still established on the approach path. There were four false responses during the 320 total trials (i.e., 1%). This was equivalent to the rate of nuisance breakouts for the operational scenarios with moderate traffic levels.

A broader consideration regarding the RNP converging approach into SFO is the total number of breakouts, not just nuisance breakouts. The following discussion does not include those breakouts resulting from scripted events because they would not have occurred in the operational environment. The rate of breakouts for the moderate traffic scenarios (i.e., without the scripted events) averaged 7% compared to 3% for the High Traffic scenario. This suggests that by introducing deviations and blunders into the moderate traffic scenarios, we influenced the rate of breakouts. Among potential explanations for this are (a) breaking out the aircraft increased controller workload and coordination, possibly resulting in other situations that required a breakout and (b) by introducing deviations, we increased the likelihood that a monitor controller would breakout an aircraft. The first explanation is not completely supported by the data because even with a missed approach, the number of aircraft handled did not reach the number handled during the High Traffic condition. Still, it is possible that this event diverted the controllers' attention from other areas of the display. We base the latter explanation on the assumption that controllers learned that this was not a *typical* operational environment and that aircraft were deviating toward the NTZ at an uncharacteristic rate, and so they adjusted their sensitivity threshold to adjust to this situation. Even taking into account all breakouts, acceptance rates during the moderate traffic conditions were substantially higher than the 30 afforded by the typically single stream operation SFO used today during 2100 ft (640 m) ceiling conditions. Aircraft acceptance rates averaged 35.6 per 45 minutes during the moderate traffic scenarios, equivalent to 44.5 per hour.

The separation distance of the approach path to the NTZ, in particular, influenced the propensity for breakouts and nuisance breakouts. In the case of the Standard NTZ condition, the 3700 ft (1128 m) separation provided sufficient time for a monitor controller to contact a deviating pilot and correct the deviation before the aircraft entered the NTZ. This raised the potential for a nuisance breakout, ultimately resulting in two nuisance breakouts during the Standard NTZ condition. For the Wide NTZ condition, the separation distances were 1150 ft (351 m) for 28L and 1800 ft (549 m) for 28R. In all eight scripted instances that an aircraft deviated toward the NTZ, they entered the NTZ before the pilot could implement an ATC instruction to avoid entering the NTZ. The Tower Override condition replicated the same 3700 ft (1128 m) separation distance as the Standard NTZ. Interestingly, four of the eight scripted deviations for this condition resulted in an NTZ violation. On average, monitor controllers issued an ATC command to correct an aircraft deviation 3 s later than during the Standard NTZ condition. This delay could be the result of several factors including the added responsibility of pairing traffic, waiting for an SFO Tower communication to conclude because it reflected a much higher frequency occupancy rate than that for the approach frequency, or some other cause. Even so, this delay alone is not sufficient to account for the NTZ violations.

4.3 Communications Override Options

This study simulated two separate communications conditions: SFO Tower Override and final approach control override. The Tower Override condition reflected similar procedures used today for simultaneous independent ILS/MLS approaches. These are described in the FAA Order 7110.65P for *Air Traffic Control* (FAA, 2005, section 5-9-7). As such, the Woodside and Foster final approaches had separate monitor controllers with transmit/receive capability on the local tower frequency. The monitor controllers' communications blocked the ongoing SFO Tower recording being played over the radio frequency. During the Approach Override condition, the monitor controllers' PTT transmissions blocked ongoing communications made by their associated approach controller.

Another significant difference between the two conditions was with respect to the monitor controllers' responsibilities. Monitor controllers were responsible for identifying and resolving aircraft deviations toward the NTZ in both conditions. However, during the SFO Tower Override condition, they were also responsible for pairing aircraft with the traffic on the associated approach. These additional duties held significant implications on the number of communications participants were required to make and ultimately on the number of overrides. However, this was the only means that could procedurally be implemented for this simulation. During Tower Override sessions, final approach controllers handed aircraft off to the tower at approximately 18 miles (29 km) from SFO. Speed adjustments were still necessary to maintain pairing until visual separation could be established. It was not practical to have the simulated tower or approach controllers assume these responsibilities.

We compared several aspects of sector performance, communications, and subjective ratings between the Tower Override and Approach Override (i.e., Standard NTZ) conditions. In Table 11, we summarize some of the key metrics including response times, sector performance, communications, and subjective ratings. As noted earlier, the response times for monitor controller performance represent the best case. Because of the high stimulus rates in this simulation, monitor controllers would be expected to maintain better performance. On average, monitor controllers took almost 1 s longer to identify a deviation and 0.5 s to issue a correction during the Tower Override condition.

Table 11 includes results of the scripted deviation events. During the Tower Override condition, the monitor controllers were unable to issue control instructions in time to prevent NTZ entry in 4 of the 8 deviation events. None of the scripted deviations resulted in an NTZ violation during the Approach Override condition. On average, blundering aircraft were within 1.2 nmi of another. Aircraft during the Tower Override condition were 0.4 nmi closer than during the Approach Override condition. We calculated the average CPA between conflicting aircraft resulting from the scripted events. The average for the Tower Override condition was 7300 ft (2225 m) with a range of 4000 ft - 8500 ft (1219 m - 2591 m) compared to an average of 9700 ft (2957 m) with a range of 6800 ft - 14500 ft (2073 m - 4420 m) for the Approach Override condition. Both conditions represented identical NTZ and approach path configurations. The closer proximity for aircraft pairs in the Tower Override condition may have resulted from several factors. Monitor controllers had added responsibilities and may have taken longer to respond, possibly, as a result of mental demands in pairing aircraft or completing a radio communication. In addition, the monitor controller heard the SFO transcript, which had a higher radio frequency usage rate, and may have waited for a communication to conclude before issuing a directive.

The number of aircraft landed, pairs landed, and double breakouts were comparable for both conditions. Due to the increased responsibilities, monitor controllers made significantly more communications during the Tower Override conditions. The average number of radio communications they made increased from 8 to 42 per session when they assumed the additional pairing responsibilities. This resulted in an increase in radio occupancy usage from approximately 1% for the Standard NTZ condition to 5% for the Tower Override condition.

Table 11. Comparison of Key Metrics for Communications Override

Measure	Communications: Tower Override	Communications: Approach Override
Blunder Identification		
- Reaction time task	• Overall 7.4 s to identify a deviating aircraft • 15^{o} turns averaged 9.9 s (up to 3 updates or 14.4 s) • > 15^{o} turns averaged 6.6 s (up to 2 updates or 9.6 s)	
- Operational scenarios (30º turn)	• 12.2 s	11.4 s
Response time		
- NTZ Entry (RT task)	• 1188 ft average "decision point" from NTZ violation	
- Time to issue a control instruction	• 14.3 s	• 13.8 s
- Time from deviation to simulation pilot correction	• 34.7 s	• 31.5 s
- In-trail separation	• 4.5 nmi between arrivals	• 4.4 nmi between arrivals
Scripted deviations		
- NTZ violations (# violations/# events)	• 4/8 events (# violations/# events)	• 0/8 events
- Nuisance breakouts	• 0	• 2
- CPA	• 1.2 nmi	• 1.6 nmi
Sector performance		
- Aircraft Landed	• 35.3 per 45 min	• 35.0 per 45 min
- Aircraft pairs landed	• 12.3 per 45 min	• 11.3 per 45 min
- Breakouts	• 3 per 45 min (9%)	• 3 per 45 min (7%)
- Double breakouts	• 2 per 45 min	• 1 per 45 min
Radio communications		
- Woodside Approach	• 210 per 45 min	• 199 per 45 min
- Foster Approach	• 102 per 45 min	• 118 per 45 min
- Monitor controllers	• 40 per 45 min (incl. pairing duties)	• 8 per 45 min
Radio communication usage		
- Approach controllers	• WA 28%, FA 15%	• WA 25%, FA 16%
- Monitor controllers	• 4% (incl. pairing duties)	• 1%
Subjective ratings		
- Real-time workload rating (WAK)	• 2.3 Approach sectors • 2.8 Monitors (incl. pairing duties)	• 2.2 Approach sectors & Monitors (Monitors had no pairing duties)
- PSQ: NASA-TLX mental demand	• 3.4 Approach sectors • 4.2 Monitors (incl. pairing duties)	• 2.7 Approach sectors • 2.6 Monitors (no pairing duties)
- PSQ: NASA-TLX frustration	• 3.4 Approach sectors • 4.2 Monitors (incl. pairing duties)	• 2.7 Approach sectors • 2.6 Monitors (no pairing duties)
- PSQ: NASA-TLX overall average	• 5.4 (across 6 dimensions)	• 4.9 (across 6 dimensions)
- PSQ: maintaining separation & resolving potential conflicts	• 8.6 Approach sectors • 8.3 Monitors (incl. pairing duties)	• 9.5 Approach sectors • 9.0 Monitors (no pairing duties)
- PSQ: Assessment of RNP approach	• 6.9 Approach sectors • 8.0 Monitors (incl. pairing duties)	• 8.3 Approach sectors • 8.6 Monitors (no pairing duties)
- Exit Questionnaire: RNP approach based on comm. condition	• 6.5 Foster approach	• 7.7 Foster approach
- OTS Rating Form (6 scales)	• 7.0	• 7.2

The communications resulted in more overrides, increasing from an average of 1.5 for each monitor controller to nearly 20. More than half (i.e., 63%) of their transmissions during the Tower Override conditions were to conduct the additional pairing duties. We categorized the SFO Tower communications and determined that the five most commonly blocked SFO Tower communications were pilot acknowledgments, landing clearances, taxi clearances, position reports, and frequency changes. Combined, the monitor controllers averaged nine blocked pilot acknowledgments and four blocked frequency changes per session. The rate of blocked transmissions may be higher for the Tower Override than the Approach Override because of a few factors. First, the radio communications occupancy rate for the SFO Tower was slightly higher (25%) than for the approach sector (20%). Second, although the monitor controllers could typically delay their transmission by 1 to 2 seconds, which was often enough to avoid blocking a pilot acknowledgment or other short communication, they may have been less likely to do this for a recorded non-relevant communication in this simulation. However, during the Tower Override sessions, when it was feasible, monitor controllers often held off their communication until they completed an ongoing transmission. This likely reflected typical operational practices, although it was less important in the simulation environment.

The Woodside monitors' and Foster monitors' WAK ratings were slightly higher for the Tower Override condition; however, the results were not statistically significant. Their NASA-TLX ratings on the PSQ also demonstrated similar trends. These results are consistent with vigilant research that has confirmed that monitoring tasks can impose considerable mental workload on the operator (Wickens et al., 1997). The monitor controllers and the approach controllers rated their ability to maintain separation and resolve conflicts as reduced during the Tower Override condition. Monitor controllers' overall assessment of the RNP approach was lower on both the PSQ and the Exit Questionnaires. The increase in workload and the overall reduced ratings on important aspects of the RNP approach were likely due to the increased aircraft pairing responsibility.

Due to the procedural requirements described previously, approach controllers off-loaded pairing responsibilities to the monitor controllers during the Tower Override sessions. This provided an opportunity to investigate the effects of added responsibilities on monitor controller performance as a secondary objective. A monitor controller's task is passive in nature and may pose a challenge, particularly after long periods of time, in terms of boredom, loss of SA, or workload. Vigilance research demonstrates that performance decline can occur after approximately 30 minutes spent continuously at a task (Wickens et al., 1997). The authors also report that monitoring tasks can impose considerable mental workload on the operator. We speculated that with the increased duties, monitor controllers' response times to deviations would be slightly longer but, because of their increased involvement, these decrements might be accompanied by improved SA and less effort to maintain vigilance. Monitor controllers did take approximately 1 second longer to identify aircraft deviations during Tower Override conditions. This loss of performance in responding to a deviation may be due in part to increased pairing responsibilities (e.g., completing an ongoing communication or scanning another aircraft pair to determine the need for a speed adjustment). Increasing monitor controllers' responsibilities did not result in a positive effect on monitor controller SA or vigilance. In fact, controller self-ratings and observer post-session ratings demonstrated a slight decrement in SA. Their ratings also suggested that they needed to expend more effort to remain vigilant of aircraft approaching the NTZ during the Tower Override condition, when they had the additional duties (i.e., 6.8 s for the Tower Override condition compared to 5.9 s for the Approach Override condition). It is possible that the additional pairing tasks may have competed with the primary task of monitoring aircraft for compliance with their assigned path.

Although approach controllers offloaded their pairing responsibilities during the Tower Override condition, their NASA-TLX and WAK workload ratings had a tendency to be higher than for the Approach Override condition. Specifically, their ratings on the dimensions of physical demand, temporal demand, and effort were higher, with mental demand and frustration reaching statistical significance. These results, combined with the somewhat detrimental effects on monitor controller performance described previously, suggest that there was no benefit to assigning aircraft pairing responsibilities to the monitor controller.

4.4 NTZ Placement Options

We collected data on NTZ placement options using the reaction time task and operational scenarios. During the reaction time task, controllers indicated when they were sure an aircraft would penetrate the NTZ. These data provided information on the effect of deviation angle on the relative distance from the NTZ boundary when controllers made this decision. The operational scenarios investigated the performance impacts of three different approach path distances to the NTZ: 1150 ft (351 m), 1800 ft (549m), and 3700 ft (1128 m). Combined, these data will aid in the optimum placement of NTZ for RNP approaches. When interpreting the response time data that follows, note that monitor controller performance represents best case because of the unusually high blunder rates used in the simulation.

4.4.1 NTZ Transgression Decision Point

The reaction time task determined the distance from the NTZ when a controller made the decision that an NTZ violation was imminent. Knowledge of this distance will aid in the optimum placement of NTZ boundaries.

During the reaction time task, participants indicated when an aircraft would, in their judgment, penetrate the NTZ. Their results demonstrated a tendency to wait until a fixed distance from the boundary of the NTZ to decide whether an aircraft would enter the NTZ. On average, this distance was 1188 ft (362 m) to the closest point of the NTZ and was essentially constant for all deviation angles. We had anticipated that the controllers would react further from the NTZ for 60º deviations than for 15º because it would take longer for the aircraft to turn away from the NTZ.

Figure 27 presents the estimated location of radar updates on an ACD for an aircraft making a 15º turn while traveling at a constant rate of 180 kt (333 kilometers per hour). The figure includes markers for each of the separation distances we used during the operational scenarios. We illustrate a turn rate of 15º because we considered the more extreme turn rates that we used during the reaction time task to be very unlikely in the operational environment. The figure includes a shaded box delineating the average distance and number of updates for a controller to make the decision that an aircraft is deviating (i.e., the Decision Range). This box begins just after the first update and ends after the third update at the 1188 ft (362 m) decision distance noted previously. The results from the reaction time task demonstrated that if a deviation occurs soon after an aircraft is established on the approach, approximately 60% of controllers would identify the turn in one update. The remaining 40% will require one more update. In this situation, controllers would have one update remaining before the aircraft had traveled 1150 ft (351 m) from their original path. When a deviation occurs well after an aircraft is established on the approach, the results suggest that virtually no controllers will identify the blunder in one update, half by the second update, and the remaining half will require a third update. It is likely that half of the controllers anticipate that the next aircraft update would be beyond 1150 ft (351 m) laterally from the aircrafts original flight path. This group would still have up to two updates before reaching 1800 ft (549 m) lateral distance from the original flight path and almost eight updates to reach 3700 ft (1128 m).

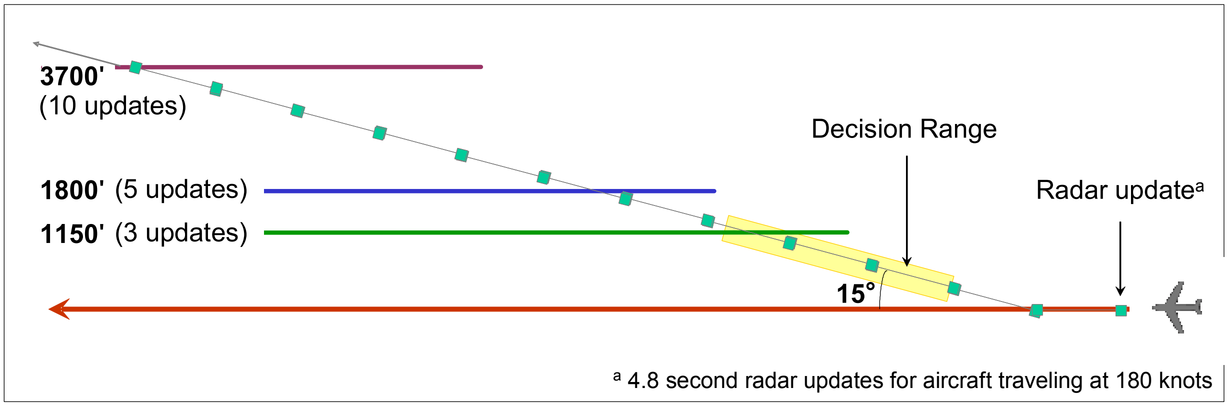

Figure 27. ASR-9 updates for a 15º deviation.

When the NTZ is located at 1150 ft (351 m) from the approach path, all targets are already within the average distance that controllers demonstrated as their decision point for whether an aircraft was going to enter the NTZ. Therefore, we anticipated that data from the operational scenarios would support the significance of this distance. Ratings by monitor controllers using an 1150 ft (351 m) separation distance were less favorable than ratings provided by controllers who experienced the 1800 ft (549 m) separation distance. Their ratings averaged at least one point lower on six PSQ items. These included overall effectiveness maintaining separation and resolving potential conflicts, overall effectiveness of communications, impact of the 28R RNP approach on safety, amount of effort required to remain vigilant of aircraft approaching the NTZ, ease in differentiating between an aircraft deviation and STE, and time available to react to an aircraft deviation. The last two items reflected differences of two points or more. In addition, ratings of frustration were 1.5 points higher for the Woodside monitor than the Foster monitor when we compared the Standard and Wide NTZ conditions. While commenting on the proximity of the targets to the NTZ when using the 1150 ft (351 m) distance, one participant stated, "The target is so big [it's] almost on the No Transgression Zone all the time." Target sizes implemented for the current simulation represented the minimum system azimuth change pulse (ACP) with the Precision Approach Monitor function applied. This resulted in a target size of ⅜ inches at 10 miles.

4.4.2 Operational Impacts of NTZ Location

We investigated the impact of the proximity of the NTZ to the approach path using a high fidelity HITL simulation. Using operational scenarios, we implemented three different approach path-to-NTZ distances: 1150 ft (351 m), 1800 ft (549 m), and 3700 ft (1128 m). During the Wide NTZ condition, Woodside approach controllers experienced an approach path-to-NTZ distance of 1150 ft (351 m), and Foster approach controllers experienced 1800 ft (549 m). For the Standard NTZ scenarios, both approaches were 3700 ft (1128 m) from the NTZ.

We observed no losses of separation or other serious operational impacts during any of the scenarios. In Table 12, we summarize the average separation distance for each aircraft pair when we injected scripted deviations. The separation distance was 3700 ft (1128 m) for both the Woodside and Foster approaches during the Standard NTZ condition; therefore, we averaged the data into a single value. As a result, the *SD* for this distance is somewhat larger than for the other two distances. However, the smaller deviations may also be a product of the proximity of the approach to the NTZ because controllers had to react immediately. In fact, the results show that on average, controllers identified deviations during the 1150 ft (351 m)/1800 ft (549 m) sessions in 10.9 s compared to 11.4 for the 3700 ft (1128 m) sessions. As Table 12 shows, separation distances between blundering aircraft pairs had a tendency to be greater when the distance from the approach path to the NTZ was larger. However, this effect did not hold across all trials. For instance, during one 3700 ft (1128 m) scenario, blundering aircraft reached within 1.15 nmi of each other.

Table 12. Minimum Separation Between Aircraft Pairs in Response to Scripted Deviations

Distance from approach path to NTZ	Average (nmi)	*SD* (nmi)
1150 ft (351 m)	1.26	0.10
1800 ft (549 m)	1.33	0.08
3700 ft (1128 m)	1.38	0.48

The intent of the scripted aircraft deviations was to determine whether there was sufficient time for controllers to prevent an NTZ violation in an operationally representative environment. During the scripted deviations, we instructed the simulation pilots to respond immediately to ATC directives. Therefore, they could implement heading changes immediately in response to a controller's instruction. As a result of the experimental design, we inserted four aircraft deviations with the approach path-to-NTZ distance at 1150 ft (351 m), four at 1800 ft (549 m), and eight at 3700 ft (1128 m). At the 1150 ft (351 m) distance, all four deviating aircraft penetrated the NTZ before the controller was able to contact the pilot and implement a heading change. This was also the case at 1800 ft (549 m) (i.e., all four deviating aircraft entered the NTZ). In all eight instances, when the separation distance was 3700 ft (1128 m), controllers were able to contact pilots and implement heading changes so that none of the aircraft entered the NTZ. The total number of breakouts due to a deviation was also equivalent at all distances. The more restrictive 1150 ft (351 m) separation distance also did not appear to significantly impact sector or controller performance. Equivalent numbers of aircraft landed, SME ratings of controller performance remained high, controller self-ratings of SA remained high, and workload levels were not adversely impacted.

ATC procedures for simultaneous parallel ILS/MLS approaches require the implementation of a 2000 ft (610 m) Wide NTZ and that it be located an equal distance (i.e., equidistant) between parallel final approach courses (FAA, 2004a, section 5-4-15b). During the Wide NTZ condition, we implemented an 1150 ft (351 m) approach path to NTZ distance on the 28L final approach and an 1800 ft (549 m) distance on the 28R approach. Therefore, we extrapolated the data to estimate the potential outcome if an equidistant NTZ had been implemented (see Table 13).

Table 13. Estimated Closest Point of Approach for Equidistant NTZ

Distance from Approach to Equidistant NTZ	**Count**	**Average (feet)**	***SD* (feet)**	**Range (feet)**
1150 ft (351 m) (estimated)	4	7285	195	7065 - 7462
1800 ft (549 m) (estimated)	4	8879	586	8263 - 9657
3700 ft (1128 m)	8	9702	2341	6851 - 14544

Table 13 represents our best estimate of the proximity that an aircraft pair might be expected to encounter if one of the aircraft deviated toward the NTZ. Our assumptions in preparing Table 13 are that

1. the pilots for both aircraft are available and able to respond immediately to an air traffic control instruction;
2. the CPAs represent realistic estimates of overall system performance (i.e., including effects of the display update rate, controller response times, pilot response times, and aircraft response characteristics);
3. the distances of 1150 ft (351 m), 1800 ft (549 m), and 3700 ft (1128 m) represent the minimum distance from the approach path to the NTZ and occur where the NTZ terminates near SFO (i.e., because the two approaches are converging); and
4. the NTZ is located equidistant between the approaches in accordance with current FAA directives.

We calculated the 1150 ft (351 m) equidistant NTZ using Woodside deviation events only. These represented the only condition in which the aircraft path was 1150 ft (351 m) from the NTZ, and as such is the best estimate of controller response times for this distance. To correct for the 1800 ft (549 m) separation used on the Foster approach, we subtracted the difference (i.e., 650 ft or 198 m) from the CPA. We used a similar procedure to predict the CPA for an 1800 ft (549 m) equidistant NTZ. However, in this case, we restricted the data to the Foster deviations only, and we added 650 ft (198 m) to the CPA to simulate moving the Woodside approach path out to 1800 ft (549 m). We did not correct the CPA for the 3700 ft (1128 m) separation results shown in Table 13 because the NTZ was 3700 ft (1128 m) for both the Woodside and Foster approach paths.

The largest average CPA distance occurred during the 3700 ft (1128 m) condition. This most likely resulted from the relatively large distance between the approach path and the NTZ. At this distance, controllers had time to wait for a pilot response before breaking out a paired aircraft and, as a result, the average range and *SD* had a tendency to be larger. Of the ranges depicted in Table 13, the results for 1800 ft (549 m) are the most favorable. Table 14 provides a comparison of some of the key metrics in terms of NTZ placement. It includes controller response times, key operational aspects, and subjective ratings.

Table 14. Comparison of Key Metrics for NTZ Placement

Measure	**NTZ Location**		
	1150 ft (351 m)	**1800 ft (549 m)**	**3700 ft (1128 m)**
Blunder Identification			
- Operational scenarios (30º turn)	• 10.9 s		• 11.4 s
Response time			
- Time to issue a control instruction	• 12.2 s		• 13.8 s
- Time from deviation to simulation pilot correction	• 21.6 s		• 31.5 s
Scripted deviations			
- NTZ violations (# violations/# events)	• 4/4 events	• 4/4 events	• 0/8 events
- Nuisance breakouts (count)	• 0	• 0	• 2
- CPA	• 1.3 nmi	• 1.4 nmi	• 1.6 nmi
Sector performance			
- In-trail separation	• 4.6 nmi		• 4.4 nmi
- Aircraft Landed	• 35.3 per 45 min (23 WA, 12 FA)		• 35.0 per 45 min
- Aircraft pairs landed	• 10.5 per 45 min		• 11.3 per 45 min
- Breakouts	• 2 per 45 min (6%)		• 3 per 45 min (7%)
- Double breakouts	• 1 per 45 min (6%)		
Radio Communications			
- Counts	• WA 216 per 45 min	• FA 117 per 45 min	• WA 199 per 45 min • FA 199 per 45 min
	• Monitors 8 per 45 min		
- Usage rate	• WA 26%, FA 16%, Monitors 1%		
Subjective Ratings			
- Real-time workload rating (WAK)	• 2.7 WA	• 2.3 FA	• 2.2 WA & FA
- PSQ: NASA-TLX mental demand	• 6.5 WM & FM		• 4.5 WM, 3.5 FM
- PSQ: NASA-TLX frustration	• 4.3 WA	• 3.3 FA	• 2.3 WA, 2.8 FA
- PSQ: maintaining separation & resolving potential conflicts	• 8.1 overall	• 8.6 overall	• 9.3 overall
- PSQ: Detecting & correcting devs	• 7.8 WM	• 7.5 FM	• 9.3 WM, 9.0 FM
- PSQ: Assessment of RNP appch	• 7.5 WA	• 7.0 FA	• 8.6 WA, 8.3 FA
- OTS Rating Form (6 scales)	• 6.9 overall		• 7.2 overall
- Exit Questionnaire: Time to react	• 5.5 WM	• 5.7 FM	• 8.8 WM, 8.3 FM

4.5 Traffic Levels

The purpose of the High Traffic condition was two-fold. First, it provided controllers an opportunity to experience the converging RNP approach in a high fidelity simulation without the introduction of scripted deviation events. In this respect, it was more representative of the operational environment than the other conditions. Second, it allowed the research team to stress the procedure to determine potential shortcomings without the risk of testing in the operational environment.

During the moderate traffic level condition, controllers were able to land an average of 44 aircraft per hour and 14 aircraft pairs. For the High Traffic condition, the number increased to 56 aircraft per hour and 22 pairs. These numbers are higher than could realistically be expected in the operational environment. Landing rates are completely dependent upon the number of RNP-equipped aircraft, arrival rates, and other important factors. For example, we considered that all aircraft using Runway 28R were RNP equipped and that the aircrew was certified and trained using the approach. In addition, in the short term, controllers face the challenges of an ATC environment with mixed-aircraft capabilities. As airlines gradually remove ageing aircraft from service, the number of RNAV-capable aircraft will increase. The number is already quite high. In a sample of 35 OEP airports reported in 2003, 81% of aircraft flying at FL290 and 66% overall were RNAV capable (FAA, 2003b).

During the simulation, the controllers averaged a landing rate on 28L equivalent to 28.5 aircraft per hour for the moderate traffic conditions, which simulated reduced visibility. This rate is virtually identical to the 30 afforded by the single stream 28L ILS operation that SFO uses today during reduced visibility conditions. Furthermore, we would anticipate that the rate would be slightly higher if we had not introduced blunders into the simulation. On average, controllers paired Foster traffic with every other 28L aircraft. We might expect the actual rate in operations to be somewhat less due to aircraft or aircrew capabilities. The most significant driver for this rate would likely be aircraft equipage rates, although other operational aspects could also have an impact. If the equipage rate was sufficiently high, controllers may be capable of pairing the Foster traffic with every second or third 28L aircraft. Extrapolating at this rate suggests that if all arriving Foster traffic was RNP capable and certified, AARs of 38 to 42 per hour (i.e., 28.5 on 28L, 9.5 to 14 on 28R) may be achievable. The lower estimate is in line with the projections forwarded by the Independent Technology Panel for RNP operations to 28R (Cotton et al., 2001).

In Table 15, we provide a comparison of some of the key measures with respect to traffic levels. As the researchers anticipated, controllers decreased in-trail separation on the approaches in response to increased traffic levels. The gap of 4.1 nmi (7.6 km) during the High Traffic condition is comparable to the 3.6 nmi - 4.2 nmi (6.7 km - 7.8 km) experienced today that allow use of the crossing Runway 1L and 1R for departures (Cotton et al., 2001). Radio communications increased by approximately 5% during the High Traffic conditions but remained well within normal levels. This supported data collected using the WAK and NASA-TLX. These workload measures, in addition to controller comments, confirmed the acceptability of the traffic levels even during extremely high traffic loads.

Table 15. Comparison of Key Metrics Related to Traffic Level

Measure	Traffic Level	
	High	Moderate
Sector performance		
- In-trail separation	• 4.1 nmi between arrivals	• 4.4 nmi between arrivals
- Aircraft Landed	• 44.8 aircraft per 45 min	• 35.0 aircraft per 45 min
- Aircraft pairs landed	• 17.8 per 45 min	• 11.3 per 45 min
- Breakouts	• 1 per 45 min (3%)	• 3 per 45 min (7%)
- Double breakouts	• 0.3 per 45 min	• 1 per 45 min
Radio Communications		
- Counts	• WA 241 per 45 min • FA 138 per 45 min • Monitors 2 per 45 min	• WA 199 per 45 min • FA 118 per 45 min • Monitors 7 per 45 min
- Usage rate	• WA 31% • FA 20% • Monitors <1%	• WA 25% • FA 16% • Monitors 1%
Subjective ratings		
- Real-time workload rating (WAK)	• 2.6 Woodside approach • 2.1 Foster approach	• 2.2 Woodside & Foster approach
- PSQ: maintaining separation & resolving potential conflicts	• 8.9 avg	• 9.3 avg
- PSQ: Assessing RNP approach	• 8.6 avg	• 8.4 avg
- OTS Rating Form (6 scales)	• 7.2 (Safe/efficient traffic flow, attention/SA, prioritizing, providing control info, technical knowledge, and communicating)	

Controller ratings of the RNP approach were favorable across all conditions. SME ratings of key ATCS dimensions demonstrated that the participants maintained high performance in terms of providing safe and efficient traffic flow, maintaining SA, and providing control instructions.

The High traffic scenarios demonstrated the viability of the converging RNP approach for SFO. We did not identify any specific shortcomings in the procedure as a result of the High Traffic condition. In fact, on the Exit Questionnaire, 10 of the 16 controllers indicated that the 28R RNP operation would have a positive impact on safety when compared to existing operations. Four of the remaining 6 participants indicated that the RNP approach was just as safe as operations in place today. The participants identified crucial aspects and recommendations for the successful implementation of an RNP approach. The following list describes the most common considerations offered by the participants:

- The importance of high RNP participation/equipage rates;
- The need for RNP regulations;
- Training of all users, including ATCSs, on RNP procedures;
- Identifying FMS/RNP equipment in data tag;

- Avoiding use of this procedure during strong crosswinds, particularly North winds in the case of SFO, as it can make intercepts difficult; and
- Knowing far enough in advance which approach an aircraft is on, so that it can be descended and slowed sufficiently.

5. SUMMARY AND RECOMMENDATIONS

From an ATCS human factors perspective, this high fidelity simulation substantiated the viability of implementing a converging RNP approach into SFO 28R. This approach would provide a means of continuing dual stream operations to both Runways 28R and 28L during reduced weather conditions. Overall sector performance as well as controller ratings and comments were extremely positive with respect to the 28R RNP approach and procedures. The simulation fulfilled several objectives including (a) assessing the controllers' ability to identify aircraft blunders using an ASR-9 representation, (b) evaluating the propensity for nuisance breakouts, (c) comparing approach and tower override communications options, (d) comparing NTZ placement options, and (e) evaluating the potential impact of high traffic levels during RNP operations at the SFO.

There are several important aspects to consider regarding the implementation of this simulation. First, the research team modified current procedures for the Niles and Foster approach sectors so that RNP-equipped aircraft arrived to 28R. We accomplished this by having Foster approach use altitudes currently assigned to the Niles sector so that all ILS traffic could be directed to 28L. Foster approach controllers did not descend traffic until they had cleared the OAK Runway 29 final approach course. These or other viable procedures would most likely need to be implemented before RNP traffic could effectively be routed to 28R. Operational procedures would have to address the highly constrained airspace above the OAK final approach, particularly, if traffic is routed as far as 15 miles east of the SFO. Operationally implementing the procedures used for this simulation would almost certainly require the number of 28R aircraft to be reduced because of the restrictions and the effect of wind conditions. A second consideration was that we did not simulate the effects of wind on aircraft during the simulation. High winds can hold significant implications on ATC tasks, particularly when turning aircraft to intercept a final approach course. Another important consideration was that the objective to investigate communications options was confounded with regard to the assignment of speed control responsibilities. During the Tower Override condition, monitor controllers assumed pairing responsibilities because this was the only procedure that they could implement. The air traffic simulator presented some differences from typical equipment used in day-to-day operations. We employed a STARS interface instead of an ACD, and the participants provided workload ratings using the WAK device. The participants' ratings indicated that both areas represented minimal impact on their ATC performance. Their subsequent rating on the overall realism of the simulation supported this, with more than 80% providing a positive rating regarding this aspect of the simulation.

In the following sections, we present the conclusions regarding each of the primary objectives of the simulation. The last section provides general conclusions and recommendations regarding implementation of the proposed approach.

Objective 1: Blunder Detection. The simulation evaluated the ability of ATCSs to identify aircraft deviations when using an ASR-9 representation. We investigated controller response times using operational scenarios and a reaction time task. The operational scenarios represented a highly realistic HITL simulation of the proposed RNP converging approach procedure. We inserted aircraft deviations of 30º to investigate the monitor controllers' ability to identify a blundering aircraft when using an ASR-9 display. Their responses to these events were fast and accurate. Controllers typically identified a deviating aircraft within 11.5 s of the initiation of the turn and issued a control instruction 2.4 s later. During the High Traffic scenarios, controllers initiated a nuisance breakout (i.e., aircraft breakout when no NTZ transgression occurred) approximately 3% of the time. Their ratings indicated they experienced no difficulty maintaining separation and resolving conflicts, detecting pilot deviations, or correcting deviations in a timely manner.

The reaction time task characterized the controllers' optimum detection performance because they observed a single radar target and had no separation responsibilities. Overall, controllers were able to identify a deviating aircraft in 7.4 s, approximately 4 s faster than during the operational scenarios. False alarm rates (i.e., indicating that an aircraft was blundering when it was not) averaged 1%. The reaction time task also investigated controller detection times as a function of aircraft deviation angle and location. With the exception of 30º, controller response times demonstrated slower response times as the angle of deviation decreased. The participants identified blunders of 30º fastest (5.8 s) followed by 60º (6.7 s), 45º (7.1 s), and 15º (9.9 s), respectively. The controllers responded almost 3 s faster when a blunder occurred soon after an aircraft was established on the approach compared to when it was near the end of the approach. All participants were able to identify a blunder that occurred shortly after an aircraft was established on the approach in one radar update, compared to two radar updates if the blunder occurred near the end of the approach. The only exception was 15º, which required an extra update in both cases. These findings may reflect controller familiarity with aircraft performance or other characteristics. Based on their ATC experience, controllers recognize that although a blunder is rare, it is more likely to occur as an aircraft turns onto an approach. For instance, during strong crosswinds, an aircraft may cross through the localizer approach path before turning to rejoin it. Another possible contributing factor is the challenge of observing a single aircraft that has demonstrated no anomalous activity for nearly 2 minutes, particularly after it has initiated a turn and established itself on the ILS approach path. During true operational conditions, controllers are responsible for monitoring several aircraft, maintaining aircraft separation, communicating with pilots, and performing several other tasks.

Objective 2: Nuisance Breakouts. We assessed the propensity for nuisance breakouts when implementing the RNP converging approach procedure in an extremely high fidelity HITL simulation. A nuisance breakout refers to the event when a paired aircraft deviates toward the NTZ, the associated monitor controller instructs the other pilot to execute a breakout, but the deviating aircraft is able to adjust its course so that it never enters the NTZ. Nuisance breakouts reduce the overall efficiency of the operation by decreasing the arrival rate and increasing controller communication and workload requirements. The controllers were extremely effective at distinguishing between aircraft blunder situations and STEs. Nuisance breakout rates for the reaction time task and operational scenarios were just 1%. Only two nuisance breakouts occurred during the simulation. Both transpired during the Standard NTZ condition when the approach path to NTZ distance was 3700 ft (1128 m). The potential for nuisance breakouts was much lower for the Wide NTZ condition because of the limited distance (i.e., 1150 ft or 1800 ft) to avert a deviating aircraft. A broader consideration regarding the RNP converging approach into SFO is the total number of breakouts, not just nuisance breakouts. Average breakout rates for situations when an aircraft did not deviate from the approach path ranged from a high of 7% during moderate traffic conditions to 3% for High Traffic conditions. We speculate that the introduction of scripted deviations into the moderate traffic scenarios inflated the breakout rate. One potential explanation is that because aircraft were deviating toward the NTZ at an uncharacteristic rate, controllers learned that this was not a *typical* operational environment, and so they adjusted their sensitivity threshold to adjust to this situation.

Objective 3: Communications Override Options. This simulation evaluated two communications options: Approach Override and SFO Tower Override. This objective was confounded with regard to the assignment of speed control responsibilities. Monitor controllers assumed pairing responsibilities in addition to their monitoring duties during the Tower Override condition. However, this was the only way procedurally that they could implement it. The tower communications override condition reflected current ATC practices for simultaneous independent ILS/MLS approaches (FAA, 2005) with respect to having separate monitor controllers with transmit/receive capability on the local tower frequency. Because the final approach controllers handed off aircraft to the tower prior to loss of vertical separation at approximately 18 miles from SFO, minor speed adjustments were necessary to maintain pairing until they could establish visual separation. It was not feasible to have the simulated tower assume these responsibilities. Also, it was impractical for the approach controllers to keep responsibility for pairing because pilots would be required to monitor both the approach and tower frequencies. Therefore, after discussion with SMEs and facility representatives, we assigned pairing responsibilities to the monitor controllers during the Tower Override condition.

During the Tower Override condition, monitor controllers were responsible for pairing aircraft along the NTZ to the SFO outer marker. Their transmissions blocked the ongoing SFO tower recording being played over their radio frequency. For the Approach Override condition, approach controllers maintained control of aircraft until the end of the NTZ at the SFO outer marker. Monitor controllers' PTT transmissions blocked ongoing communications made by their associated approach controller.

The results validated that both the SFO Tower Override and approach control override conditions represent viable communications options for the proposed RNP approach. Clearly, a broad range of national and local operational considerations will drive the decision as to which communications procedure is most appropriate. Sector performance was equivalent to approach override in terms of number of aircraft landed, pairs landed, and double breakouts. However, based on several others measures we evaluated for this simulation, the Approach Override procedure reflected the most favorable outcome. With respect to the Approach Override condition,

- none of the eight deviation events resulted in an NTZ transgression (i.e., compared to four during the Tower Override condition);
- monitor controllers identified blunders approximately 1 s faster and issued a correction 0.5 s faster;

- minimum distance between blundering aircraft pairs was 0.4 nmi greater than for the Tower Override condition;
- monitor controllers blocked an average of 1.5 radio communications compared to 20 during the Tower Override condition;
- monitor controllers' self-ratings and observer ratings of SA were higher than for the Tower Override communication condition;
- monitor controllers' ratings of effort to remain vigilant of aircraft approaching the NTZ were lower; and
- monitor controllers' workload was lower, and remained low even during the Tower Override condition.

The additional pairing responsibilities, not the communications configuration itself, were most likely one of the major sources for the increased radio communications during the Tower Override condition. They accounted for approximately 60% of the monitor controllers' radio transmissions for these sessions. These additional communications may have contributed to the increased monitor controller workload ratings we observed. The number of communications overrides demonstrated a substantial difference between the two conditions. As noted previously, this may be attributable, at least in part, to the reluctance to override another participant during the Approach Override condition compared to overriding a recording of a non-current communication for the SFO Tower Override condition. However, the results may also reflect the benefit of gaining non-verbal cues when working in the same room with another controller.

<u>Objective 4: NTZ Placement Options.</u> The operational scenarios investigated three different NTZ placement options. The distances from the approach path to the NTZ represented 1150 ft (351 m), 1800 ft (549 m), and 3700 ft (1128 m). The Standard NTZ condition complied with the simultaneous parallel ILS/MLS approach requirement for a 2000 ft Wide NTZ located equidistant between parallel final approach courses. The distance from the approach path to the NTZ was 3700 ft (1128 m) for 28L and 28R. The Wide NTZ condition implemented a distance of 1150 ft (351 m) on 28L and 1800 ft (549 m) on 28R. We interpreted the data from operational measures, reaction time task results, and questionnaire ratings. The results demonstrate that controllers were able to effectively use an ASR-9 representation to control traffic on dual approaches at each of the separation distances and, more importantly, controllers were able to effectively identify blunders and deviations. However, based on overall performance differences and operational considerations, we recommend 1800 ft (549 m) as the preferred option for the separation distance between the approach path and NTZ for initial implementation. Although controllers were unable to contact pilots in sufficient time to avoid NTZ penetration for the eight scripted deviations, during the 1150 ft (351 m)/1800 ft (549 m) condition, the CPA for the conflicting aircraft pairs was very similar to results for the 3700 ft (1128 m) condition. This likely resulted from controllers responding more quickly to a deviation when using the smaller separation distances. We estimated the CPA for the two conflicting aircraft in a situation when one of the aircraft turns 30º toward the NTZ. The estimated CPA for an equidistant NTZ was approximately 9700 ft (2957 m) for the 3700 ft (1128 m) separation distance, 8800 ft (2682 m)

for the 1800 ft (549 m) separation distance, and 7200 ft (2195 m) for the 1150 ft (351 m) separation distance. Specifically, when comparing the 1150 ft (351 m)/1800 ft (549 m) implementation to the 3700 ft (1128 m) implementation,

- monitor controllers identified blunders approximately 0.5 s faster when using the 1150 ft (351 m)/1800 ft (549 m) distance;
- monitor controller performance while identifying blunders demonstrated less variability;
- the *SD* for the 1150 ft (351 m), 1800 ft (549 m), and 3700 ft (1128 m) distances were 0.10 nmi, 0.08 nmi, and 0.48 nmi, respectively;
- there was essentially no difference in the number of aircraft landed, aircraft pairs landed, breakouts, or number of double breakouts;
- there were no nuisance breakouts (i.e., breaking out an aircraft even though the NTZ violation never occurred) compared to two during the 3700 ft (1128 m) condition. Nuisance breakouts increase aircraft time in sector, aircraft miles flown, controller workload, number of communications, and reduce the aircraft arrival rate; and
- workload levels, as measured by the questionnaire, WAK, and number of communications were similar across conditions.

We consider implementation of the 1800 ft (549 m) separation distance to be favorable over 1150 ft (351 m), at least initially, for three primary reasons. First, the minimum separation between conflicting aircraft pairs in response to a blunder was 425 ft (130 m) greater when using the 1800 ft (549 m) separation distance. Second, controllers' subjective ratings and comments suggested that the 1150 ft (351 m) distance was more challenging due to the proximity of the NTZ. Their mental workload and frustration ratings were slightly higher, ratings of their performance in maintaining separation and resolving conflicts were lower, and they rated their time to react as worse. In fact, when using the 1150 ft (351 m) separation distance during one of the scenarios, a participant commented that even when an aircraft remained on the approach path, their radar target was almost touching the NTZ boundary. Third, results of the reaction time task suggest that the average distance from the NTZ is 1188 ft (362 m) when a controller decides that an aircraft will violate the NTZ. The data suggest that it typically takes two to three updates for all controllers to identify deviations of less than 30º (i.e., approximately 14 s). If an aircraft traveling at 180 kt (333 kilometers per hour) deviates 15º off its approach, it will travel approximately 1200 ft (366 m) laterally during that time.

Therefore, we consider that controllers prefer the 1800 ft (549 m) separation distance for initial operational implementation. The results suggest that the 1800 ft (549 m) separation distance provides sufficient time for controller intervention in the case of a blunder, minimizes the likelihood of a nuisance breakout, and compares to the other separation distances in terms of operational efficiency. A final consideration is that implementing the 1800 ft (549 m) distance would provide controllers additional time to react over the 1150 ft (351 m) separation while they gain familiarity and experience using the RNP converging approach procedures.

Objective 5: Effects of Traffic Level. The High Traffic condition provided controllers an opportunity to experience the converging RNP approach in a high fidelity simulation without the introduction of scripted deviation events. We increased traffic levels in an attempt to stress the RNP converging approach procedure to identify potential shortcomings. The participants demonstrated their ability to maintain satisfactory performance even under high traffic levels. Our traffic levels did not uncover weaknesses in the RNP procedure.

During the moderate traffic level condition, controllers were able to land aircraft at a rate roughly equivalent to 47 individual aircraft per hour with 15 aircraft pairs. For the High Traffic condition, the rate increased to approximately 59 individual aircraft with 23 aircraft pairs. These numbers may be higher than expected operationally because all 28R aircraft in our simulation were RNP equipped and the aircrew were certified and trained in using the approach. Operationally, in the short term, controllers would certainly face the challenges of an ATC environment with mixed-aircraft capabilities. Even with aircraft blunders inserted into the moderate traffic scenarios, the aircraft arrival rate to 28L averaged 30 per hour in this simulation. This rate is identical to that reported by SFO during the single stream 28L ILS operation used in reduced visibility conditions. Operating the RNP approach to 28R during these conditions would increase the acceptance rate. The controller teams consistently averaged an aircraft-pairing rate of 1.5 aircraft on 28L across both moderate and high traffic scenarios. Extrapolating this rate suggests that a rate of 45 aircraft per hour might be achievable with dual stream operations. Clearly this estimate must be tempered by RNP equipage/capability rates, operational considerations at SFO and adjacent facilities, and also environmental conditions such as high cross winds and shifting ceiling levels. This simulation supports the projections forwarded by the Independent Technology Panel regarding the implementation of an RNP approach to 28R at SFO (Cotton et al., 2001) that an AAR of 38 per hour might be realistically achievable during 2100 ft (640 m) overcast conditions.

Controllers maintained a satisfactory level of performance across all measures we collected during all scenarios, including the High Traffic conditions in which they experienced aircraft arrival rates equivalent to 59 per hour. Their ratings of the RNP approach remained favorable. The gap between arrivals of 4.1 during the High Traffic condition was comparable to the 3.6 - 4.2 nmi (6.7 - 7.8 km) experienced today that allow use of the crossing Runway 1L and 1R for departures. In comparison, in-trail separation on moderate scenarios averaged 4.4 nmi between arrivals. The participants averaged one breakout per session, much less than the three experienced during the moderate traffic conditions. Radio communications increased by approximately 5%, but workload levels remained relatively low. The controllers' ratings never averaged higher than moderate on the real-time workload measures, and their ratings for the NASA-TLX dimensions were essentially equivalent to those for moderate traffic. SME observers rated controller performance for high traffic and moderate traffic as comparable in terms of providing safe and efficient traffic flow and prioritization, SA and attention, control of information, and communication.

The high traffic levels conducted during the current simulation did not uncover weaknesses in the RNP procedure. Even with landing rates averaging 59 aircraft per hour, the participants maintained high levels of performance and experienced relatively low levels of workload. RNP equipage/capability rates, mixed equipage, operational considerations at SFO and adjacent facilities, and environmental conditions influence arrival rates achieved in the operational environment.

6. CONCLUSION

The current simulation investigated human factors aspects of implementing a converging RNP approach into SFO 28R. The proposed approach would provide a means of continuing dual stream operations to Runways 28R and 28L during reduced weather conditions. Today, these conditions require a single stream operation. The simulation confirmed that with high RNP participation rates, the Independent Technology Panel projection of an AAR of 38 per hour might be achievable during reduced visibility conditions. Results of the reaction time task and operational scenarios demonstrated that monitor controllers were able to identify blundering aircraft timely and accurately when using an ASR-9 display. Their performance ranged from 7.4 s, when monitoring a single target, to 11.5 s, during operationally representative conditions. Sector performance remained high across all conditions and demonstrated no serious operational deficiencies. The participants provided positive ratings and comments regarding the proposed 28R RNP approach and procedures. They forwarded facility specific examples of situations describing when the approach may not be the most appropriate option, such as

- during certain operations at adjacent facilities,
- when there are tight holes,
- if the weather is marginal, and
- during strong north winds.

The simulation resulted in recommendations for the effective implementation of RNP approaches. The two primary recommendations included (a) incorporating Air Traffic procedures for RNP approaches into Federal Aviation Administration Order 7110.65 to ensure that ATCSs receive RNP-specific training and (b) presenting Flight Management System/RNP equipment information in the datablock.

References

Center for Advanced Aviation System Development. (2001). *Flight Management System (FMS) Area Navigation (RNAV) terminal routing and procedures*. Retrieved May 6, 2003, from http://www.caasd.org/library/one_pagers/fms_rnav.pdf

Cotton, W., Foggia, J., & Gosling, G. (2001). *Potential future contribution of air traffic management technology to the capacity of San Francisco International Airport: Report of the independent technology panel*. Phoenix, AZ: Williams Aviation Consultants.

Federal Aviation Administration. (2002a). *FAA RNP Program Office: Briefing to SOIT*. Retrieved April 3, 2003, from http://gps.faa.gov/Library/Data/Briefings/December2002/RNP_SOITBrief12_09_02.PPT

Federal Aviation Administration. (2002b). *National airspace system operational evolution plan (OEP): A foundation for capacity enhancement 2003-2013* (Version 5.0). Washington, DC: Author.

Federal Aviation Administration. (2003a). *Aviation capacity enhancement plan 2003: Centennial of flight 1903-2003*. Washington, DC: Author.

Federal Aviation Administration. (2003b) (Version 1, July 2002). *Road map for performance-based navigation: Evolution for area navigation (RNAV) and required navigation performance (RNP) capabilities 2003-2020*. Washington, DC: Author.

Federal Aviation Administration. (2004a). *Aeronautical information manual: Official guide to basic flight information and ATC procedures*. Washington, DC: Author.

Federal Aviation Administration. (2004b). *Federal Aviation Administration flight plan 2005-2009*. Washington, DC: Author.

Federal Aviation Administration. (2005). *Air Traffic Control* (DOT/FAA/Order 7110.65P). Washington, DC: Author.

Klein, G. (1997). The recognition-primed decision (RPD) model: Looking back, looking forward. In C. E. Zsambok & G. Klein (Eds.), *Naturalistic decision making* (pp. 285-292). Mahwah, NJ: Lawrence Erlbaum Associates.

Magyarits, S., & Ozmore, R. (1999). *Terminal air traffic control radar and display system recommendations for monitoring simultaneous instrument approaches* (DOT/FAA/TC-TN-99/24). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Magyarits, S., & Ozmore, R. (2002). *Evaluation of triple independent instrument landing system approaches to runways spaced 4,000 ft and 5,300 ft apart using a precision runway monitor system* (DOT/FAA/TC-TN-02/16). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Manning, C. (2000). *Measuring air traffic controller performance in a high fidelity simulation* (DOT/FAA/AM-00/2). Oklahoma City: Civil Aeromedical Institute.

Meyer, T., & Bradley, J. (2001). *The evolution from area navigation (RNAV), required navigation performance (RNP), to RNP RNAV*. Global navigation satellite system panel meeting: Rio de Janeiro, Brazil (22 October - 1 November, 2001). Retrieved September 26, 2005, from http://gps.faa.gov/Library/Data/RNAVPaper.doc

Nakamura, D. (2000). *FMS RNAV workshop: General information on the functional and technical aspects of required navigation performance (RNP) area navigation (RNAV) and applications*. Retrieved May 3, 2003, from http://www.boeing.com/commercial/caft/reference/documents/RNP.pdf

Radio Technical Commission for Aeronautics. (1997, January). *Minimum aviation system performance standards: Required navigation performance for area navigation*. Washington, DC: Author.

Reynolds, T., & Hansman R. (2003). *Investigating conformance monitoring issues in air traffic control using fault detection approaches* (Report No. ICAT-2003-5). Cambridge, MA: Massachusetts Institute of Technology.

Reynolds, T., Hansman, R., Bolczak, R., & Tarakan, R. (2004). Improving surveillance of clearances in future air traffic control systems. Presented at *AIAA 4th Aviation Technology, Integration and Operations Forum.* Chicago, IL.

Richards, K. M., Transue, A. E., & Timoteo, D. (1992). *Visual approach data collection at San Francisco International Airport* (DOT/FAA/CT-90/23). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Shank, E., & Hollister, K. (1994). Precision runway monitor. *The Lincoln Laboratory Journal, 7*(9).

Sollenberger, R. L., La Due, J., Carver, B., & Heinze, A. (1997). *Human factors evaluation of vocoders for air traffic control (ATC) environments phase II: ATC simulation* (DOT/FAA/CT-TN-97/25). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Sollenberger, R. L., McAnulty, D. M., & Kerns, K. (2003). *The effect of voice communications latency in high density, communications-intensive airspace* (DOT/FAA/TC-TN-03/04). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Sollenberger, R. L., Stein, E. S., & Gromelski, S. (1996). *The development and evaluation of a behaviorally-based rating form for assessing air traffic controller performance* (DOT/FAA/CT-TN-96/16). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Stein, E. S. (1985). *Air traffic controller workload: An examination of workload probe* (DOT/FAA/CT-TN-84/24). Atlantic City International Airport, NJ: Federal Aviation Administration Technical Center.

Truitt, T., Durso, F., Crutchfield, J., Moertl, P., & Manning, C. (2000). *Reduced posting and marking of flight progress strips for en route air traffic control* (DOT/FAA/AM-00/5). Oklahoma City: Civil Aeromedical Institute.

Truitt, T., McAnulty, D. M., & Willems, B. (2004). *Effects of collocation and reduced lateral separation standards in the New York integrated control complex* (DOT/FAA/TC-TN-04/08). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Wickens, C. D., Mavor, A. S., & McGee, J. P. (1997). *Flight to the future: Human factors in air traffic control*. Washington, DC: National Academy Press.

Wickens, C. D., Mavor, A. S., Parasuraman, R., & McGee, J. P. (1998). *The future of air traffic control: Human operators and automation*. Washington, DC: National Academy Press.

Willems, B., Allen, R., & Stein, E. (1999). *Air traffic control specialist visual scanning II: Task load, visual noise, and intrusions into controlled airspace* (DOT/FAA/CT-TN-99/23). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Willems, B., & Heiney, M. (2002). *Decision support automation research in the en route air traffic control environment* (DOT/FAA/TC-TN-02/07). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Willems, B., & Truitt, T. R. (1999). *Implications of reduced involvement in en route air traffic control* (DOT/FAA/CT-TN-99/22). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Wright, M. (1997). *Human factors and operations issues in GPS and WAAS sensor approvals: A review and comparison of FAA and RTCA documents* (DOT-VNTSC-FAA-97-7). Cambridge, MA: The Volpe Center, U.S. Department of Transportation.

Zingale, C. M., McAnulty, D. M., & Kerns, K. (2003). *The effect of voice communications latency in high density, communications-intensive airspace phase II: Flight deck perspective and comparison of analog and digital systems* (DOT/FAA/TC-TN-04/02). Atlantic City International Airport, NJ: FAA William J. Hughes Technical Center.

Acronyms

AAR	Airport Acceptance Rate
ACD	ARTS Color Display
A/G	Air-to-ground
ANOVA	Analysis of Variance
ARTS	Automated Radar Terminal System
ASR-9	Airport Surveillance Radar-9
ATC	Air Traffic Control
ATCS	Air Traffic Control Specialist
CPA	Closest Point of Approach
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
DME	Distance Measuring Equipment
DRAT	Data Reduction and Analysis Tool
ETG	Enhanced Target Generator
FAA	Federal Aviation Administration
FMS	Flight Management System
HFREG	Human Factors Research and Engineering Group
HITL	Human-in-the-Loop
HSD	Tukey's Honestly Significant Difference
IFR	Instrument Flight Rules
ILS	Instrument Landing System
MLS	Microwave Landing System
MPAP	Multiple Parallel Approach Program
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASA-TLX	NASA-Task Load Index
NCT	Northern California TRACON
NTZ	No Transgression Zone
OAK	Oakland International Airport
OEP	Operational Evolution Plan
OTS	Over-the-Shoulder
PRM	Precision Runway Monitor

PSQ	Post-Scenario Questionnaire
PTT	Push-To-Talk
RNAV	Area Navigation
RNP	Required Navigation Performance
RPAT	Runway Parallel Approach Transition
RTCA	Radio Technical Commission for Aeronautics
SA	Situational Awareness
SD	Standard Deviation
SFO	San Francisco International Airport
SME	Subject Matter Expert
SOIA	Simultaneous Offset Instrument Approach
SOP	Standard Operating Procedure
STARS	Standard Terminal Automation Replacement System
STE	Standard Track Error
TGF	Target Generation Facility
TRACON	Terminal Radar Approach Control
TSE	Total System Error
VOR	Very High Frequency Omnidirectional Range
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center

Appendix A

Informed Consent Form

Human Factors Study of San Francisco International

Runway 28R Required Navigation Performance Converging Approach Procedure

Individual's Consent to Voluntary Participation in a Research Project

I,______________________________________, understand that this study, entitled "Human Factors Study of San Francisco International Runway 28 Right Required Navigation Performance converging approach procedure", is sponsored by ATO-R and is being directed by Dr. Pam Della Rocco and Anton Koros in support of the ACB-220 NAS Human Factors Laboratory.

Nature and Purpose:

I have been recruited to volunteer as a participant in the project named above. The purpose of this study is to explore human factors issues related to the operation of a simultaneous 28L ILS and 28R converging RNP approach into San Francisco International Airport (SFO). The research team will conduct real time human-in-the-loop simulations to investigate human factors implications of employing a simultaneous RNAV approach at SFO and assess your ability to distinguish between standard track error in aircraft approaches and "blunder" situations.

Experimental Procedures:

Participation will take one workday. Participants will work from 6:00 AM to no later than 2:30 PM with a lunch break and rest breaks following each traffic scenario. Four controllers will participate in the study each day. The first 60 minutes will consist of a review of your rights as a volunteer, an orientation to the goals of the study, and a hands-on simulation familiarization session. Participants will attend five data collection sessions.

During four sessions, participants will control 45 minutes of representative SFO approach traffic during moderate or high traffic levels. In these sessions, some aircraft will deviate from the approach path toward the NTZ and possibly enter this area. An automated data collection system will record controller operations and generate a set of system effectiveness measures, which include safety, capacity, efficiency, and controller workload. Subject-matter experts will make observations of controller effectiveness. After each scenario, controllers will complete brief questionnaires to evaluate implications of the use of the simultaneous ILS and converging RNP approach on their performance. The simulation will be audio-video recorded in case researchers need to re-examine any important simulation events. At the conclusion of the scenario, participants will complete a post-scenario questionnaire and receive a rest break.

One session will include a reaction time exercise lasting approximately 40 minute. Participants will monitor a series of single aircraft in the Woodside sector. The participants will indicate if a deviation occurs by pressing a button. They will press the button a second time to indicate the time at which the aircraft will penetrate the NTZ. Participants will receive a rest break at the end of each session.

At the end of the day participants will attend a 15-minute Question and Answer debriefing session. During this session they will complete an exit questionnaire and provide insights into operating the new approach.

Participant Responsibilities:

I am aware that to participate in this study I must be a certified professional controller who is qualified at the Northern California TRACON and holds a current medical certificate. I must also have normal color vision. I will control traffic and answer questions asked during the study to the best of my abilities. I will not discuss the content of the experiment with anyone until the study is completed.

Confidentiality and Anonymity:

I understand that records of this study will be kept confidential, and that I will not be identifiable by name or description in any reports or publications about this study. My name will not be attached to any information provided in any records. All collected information is for use within the Research and Development Human Factors Laboratory only. Data will be coded using numbers instead of the participant names and no permanent record of the participant names will be maintained.

Benefits

I understand that the only direct benefit to me is the satisfaction of knowing that I contributed to our knowledge about the use of the simultaneous ILS and converging RNP approach procedure into San Francisco International Airport.

Risks:

I understand that I will not be exposed to any foreseeable risks or intrusive measurement techniques.

Compensation and Injury:

I agree to immediately report any injury or suspected adverse effect to Anton Koros at (609) 485-5609. Local clinics and hospitals will provide any treatment, if necessary. I agree to provide, if requested, copies of all insurance and medical records arising from any such care for injuries/medical problems.

Participant's Assurances

I understand that my participation in this study is completely voluntary. I am participating because I want to. Any and all questions I have about this study, my participation, and the procedures involve have been answered. I understand that the researcher will be available to answer any questions concerning procedures throughout this study.

I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed. I have not given up any of my legal rights or released any individual or institution from liability for negligence by consenting to this survey. I understand that I can withdraw from the study at any time without penalty or loss of benefits to which I am otherwise entitled. I also understand that the researcher may terminate my participation if he feels this to be in my best interest.

If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Dr. Pam Della Rocco (609) 485-7376 or Anton Koros (609) 485-5609.

I have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described.

Research Participant: ______________________________ Date: ______________

Investigator: ______________________________________ Date: ______________

Witness: ____ Date: ______________

Appendix B

Background Questionnaire

SFO RNP Human Factors Study

BACKGROUND QUESTIONNAIRE

This questionnaire collects relevant information about your background and experience as an Air Traffic Control Specialist.

The information you provide will be kept completely confidential. It will be used to describe the participants in this simulation as a group. You will not be identified by name in any of the documents produced for this study.

Participant Code: __________

Date: ___________________

1. How long have you worked as an air traffic controller?

    a) Military Years: ______________ Months: ______________

    b) FAA Years: ______________ Months: ______________

2. How long have you been a Certified Professional Controller (or Full Performance Level)?

    Years: ______________ Months: ______________

3. How long have you actively controlled traffic in the terminal environment?

    Years: ______________ Months: ______________

4. What is your total experience as a SFO terminal airspace controller?

    Years: ______________ Months: ______________

5. How many of the past 12 months have you actively controlled traffic?

    Months: ______________

6. Which of the following sectors are you currently certified to operate?

    ☐ Woodside ☐ Niles

    ☐ Foster ☐ Boulder

7. How many years of experience do you have operating the following sectors?
   (Include monitor position if present)

    ☐ Woodside ________ years ☐ Niles ___________ years

    ☐ Foster ___________ years ☐ Boulder ___________ years

8. Will you be wearing corrective lenses during this simulation?

    ☐ Yes ☐ No

9. What is your gender?

    ☐ Male ☐ Female

10. What is your age?

    Years: ______________

Appendix C

Over-the-Shoulder Rating Form

SFO RNP Human Factors Study

Subject Matter Expert Observer Rating Form

INSTRUCTIONS

- **During the scenario**
  - **Take extensive notes** on what you see. Do not depend on your memory. Enter your observations in the space provided for each scale on page 1.
  - **Count the number of aircraft pairs** (see area at top of page 1)
- **At the conclusion of the scenario**
  1. Rate the operation for the items on page 1.
  2. Rate the operation for the 6 rating areas beginning on page 2.

Observer: ________________________ **Date:** _______________ **Session:** _______________

Communications
☐ Approach Override
☐ Tower Override

Position
☐ Woodside
☐ Foster

AIRCRAFT PAIRS (COUNT):	Enter comments on back page (e.g., adverse impacts not due to the participant—equipment, sim pilots, monitor controller, etc.)
I - MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW	
II - MAINTAINING ATTENTION AND SITUATION AWARENESS	
III – PRIORITIZING	
IV – PROVIDING CONTROL INFORMATION	
V – TECHNICAL KNOWLEDGE	
VI – COMMUNICATING	

AT THE CONCLUSION OF THE RUN

1. Rate the following for the scenario you just observed:

1. Rate the overall **level of ATC performance**.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
2. Rate the team on their timeliness in **identifying aircraft deviations**.	Extremely Slow	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
3. Rate the team on the timeliness in **responding to/ issuing directives** to deviating aircraft.	Extremely Slow	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
4. Rate the team on their **intra-team communications** (e.g., between the approach and monitor controller).	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
5. Rate the team on their **inter-team communication** (i.e., with the other controller team).	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good

2. Rate the operation for the following 6 domain areas using the rating scale provided below

SCALE	QUALITY	SUPPLEMENTARY
1	**Least Effective**	Unconfident, Indecisive, Inefficient, Disorganized, Behind the power curve, Rough, Leaves some tasks incomplete, Makes mistakes
2	**Poor**	May issue conflicting instructions, Doesn't plan completely
3	**Fair**	Distracted between tasks
4	**Low Satisfactory**	Postpones routine actions
5	**High Satisfactory**	Knows the job fairly well
6	**Good**	Works steadily, Solves most problems
7	**Very Good**	Knows the job thoroughly, Plans well
8	**Most Effective**	Confident, Decisive, Efficient, Organized, Ahead of the power curve, Smooth, Completes all necessary tasks, Makes no mistakes

I - Maintaining Safe and Efficient Traffic Flow	
1. Maintaining Separation and Resolving Potential Conflicts............ • using control instructions that maintain appropriate aircraft and airspace separation • detecting and resolving impending conflicts early • recognizing the need for speed restrictions and wake turbulence separation	**1 2 3 4 5 6 7 8**
2. Sequencing Aircraft Efficiently.. • using efficient and orderly spacing techniques for arrival, departure, and en route aircraft • maintaining safe arrival and departure intervals that minimize delays	**1 2 3 4 5 6 7 8**
3. Using Control Instructions Effectively/Efficiently......................... • providing accurate navigational assistance to pilots • issuing economical clearances that result in need for few additional instructions to handle aircraft completely • ensuring clearances require minimum necessary flight path changes	**1 2 3 4 5 6 7 8**
4. Overall Safe and Efficient Traffic Flow Scale Rating....................	**1 2 3 4 5 6 7 8**
Comments:	

II - Maintaining Attention and Situation Awareness	
5. Maintaining Awareness of Aircraft Positions................................ • avoiding fixation on 1 area of the radar scope when other areas need attention • using scanning patterns that monitor all aircraft on the radar scope	**1 2 3 4 5 6 7 8**
6. Giving and Taking Handoffs in a Timely Manner .... • ensuring that handoffs are initiated in a timely manner • ensuring that handoffs are accepted in a timely manner • ensuring that handoffs are made according to procedures	**1 2 3 4 5 6 7 8**
7. Ensuring Positive Control... • tailoring control actions to situation • using effective procedures for handling heavy, emergency, and unusual traffic situations	**1 2 3 4 5 6 7 8**
8. Detecting Pilot Deviations from Control Instructions.................... • ensuring that pilots follow assigned clearances correctly • correcting pilot deviations in a timely manner	**1 2 3 4 5 6 7 8**
9. Correcting Own Errors in a Timely Manner.................................. • acting quickly to correct errors • changing an issued clearance when necessary to expedite traffic flow	**1 2 3 4 5 6 7 8**
10. Overall Attention and Situation Awareness Scale Rating	**1 2 3 4 5 6 7 8**
Comments:	

III – PRIORITIZING	
11. Taking Actions in an Appropriate Order of Importance .... • resolving situations that need immediate attention before handling low priority tasks • issuing control instructions in a prioritized, structured, and timely manner	**1 2 3 4 5 6 7 8**
12. Preplanning Control Actions .... • scanning adjacent sectors to plan for future and conflicting traffic • studying pending flight strips in bay	**1 2 3 4 5 6 7 8**
13. Handling Control Tasks for Several Aircraft.................................. • shifting control tasks between several aircraft when necessary • communicating in timely fashion while sharing time with other actions	**1 2 3 4 5 6 7 8**
14. Marking Flight Strips while Performing Other Tasks .... • marking flight strips accurately while talking or performing other tasks • keeping flight strips current	**1 2 3 4 5 6 7 8**
15. Overall Prioritizing Scale Rating..	**1 2 3 4 5 6 7 8**
Comments:	

IV – PROVIDING CONTROL INFORMATION	
16. Providing Essential Air Traffic Control Information .... • providing mandatory services and advisories to pilots in a timely manner • exchanging essential information	**1 2 3 4 5 6 7 8**
17. Providing Additional Air Traffic Control Information................... • providing additional services when workload permits • exchanging additional information	**1 2 3 4 5 6 7 8**
18. Providing Coordination .... • providing effective and timely coordination • using proper point-out procedures	**1 2 3 4 5 6 7 8**
19. Overall Providing Control Information Scale Rating.....................	**1 2 3 4 5 6 7 8**
Comments:	

V – Technical Knowledge								
20. Showing Knowledge of LOAs and SOPs • controlling traffic as depicted in current LOAs and SOPs • performing handoff procedures correctly	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
21. Showing Knowledge of Aircraft Capabilities and Limitations • using appropriate speed, vectoring, and/or altitude assignments to separate aircraft with varied flight capabilities • issuing clearances that are within aircraft performance parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
22. Overall Technical Knowledge Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Comments:								

VI – Communicating								
23. Using Proper Phraseology • using words and phrases specified in the 7110.65 • using phraseology that is appropriate for the situation • using minimum necessary verbiage	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
24. Communicating Clearly and Efficiently • speaking at the proper volume and rate for pilots to understand • speaking fluently while scanning or performing other tasks • ensuring clearance delivery is complete, correct and timely • speaking with confident, authoritative tone of voice	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
25. Listening to Pilot Readbacks and Requests • correcting pilot readback errors • acknowledging pilot or other controller requests promptly • processing requests correctly in a timely manner	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
26. Overall Communicating Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Comments:								

Appendix D

Controller Familiarization Materials

Controller In-Briefing for the SFO RNP Human Factors Study

1) Background

The goal of this study is to investigate human factors issues related to an RNP operation using the ASR 9 radar and ACD monitors. To do this, we will be using the RNAVZ Runway 28R and ILS 28L approaches into SFO during reduced weather conditions. An RNP Operation is a RNAV approach using approved FMS equipment on the aircraft and specialized crew training. RNP provides a more accurate flight path than ILS or other similar approaches. We appreciate your participation because what we will learn from this week's data will assist in the implementation of RNP operations at this and other facilities.

2) Objectives

The primary objectives of the present study are:

1. To assess the Air Traffic Control Specialists' ability to distinguish between standard track error in aircraft following the SFO RNP converging approach procedure and blunder situations.
2. To assess sector performance and ATCS workload when implementing this approach in a simulated environment.
3. To identify human factors issues resulting from implementing the standard 28R RNP converging approach procedure simultaneously with arrivals to 28L in the simulation environment.

3) Brief Description of the Study

Today you will complete 4 traffic scenarios in a high fidelity simulation at the Woodside and, Foster sectors, or the associated monitor position. Each of the scenarios will last approximately 45-minutes. In addition to these operational scenarios, you will be asked to complete a 40-minute reaction time task. During this task you will indicate when an aircraft blunders from the expected path and when it will enter the NTZ.

4) Confidentiality and Anonymity

The results of the simulation will be presented in a technical report. No participants will be identifiable by name or description. We will keep all data records confidential and we will report only aggregate data. Your participation in this study is completely voluntary. You can withdraw at any time without any penalty or loss of benefits. (At this point the research team reviewed the informed consent form with all participants and collected the completed forms before continuing)

5) Other Information about the Simulation

- Some of the scenarios simulate NTZ and communications configurations that you do not use at this facility. These will provide information to the RNP Program Office for implementing RNP and RPAT (RNP Parallel Approach Transition) at other ATC facilities.
- We have a high rate of aircraft deviations in the simulations so we can gather data on these types of events. We have pre-selected which aircraft will blunder. The study is

designed to test the procedure, not your individual performance. By participating, you will help answer several important questions, including how effectively a 4.8 second radar update rate supports controllers in identifying these types of incidents.

- o While you are controlling traffic, we will be observing the overall operation over your shoulder and taking notes. We will also collect video data for data analysis.

6) Simulation Environment

a) Simulation Location

The simulation will be conducted at the Northern California TRACON Enhanced Target Generator training facility.

b) Equipment

Your workstation will include:

- voice communications equipment,
- a keypad (Workload Assessment Keypad), and
- an ARTS IIIE display.

Note: *The ARTS will display the Standard Terminal Automation Replacement System (STARS) interface. You will be given an opportunity to become familiar with this system.*

c) Workload Ratings

Your position will include a keypad, the Workload Assessment Keyboard (WAK). This is provided for you to rate your workload during the scenario. When the alert sounds, depress the key corresponding to your estimated workload using the following 1-10 scale.

Workload Rating Scale

|---------low----------|---------moderate-------------|--------------high----------------|----very high-------|

1	2	3	4	5	6	7	8	9	10

Rating	Operational Definition
1 - 2	Your workload is **low**. You can accomplish everything easily.
3, 4, 5	Your workload is **moderate**. The chance of error is still low but steadily increasing.
6, 7, 8	Your workload is **high**. There is some chance of making errors.
9 - 10	Your workload is **very high**. It is likely that you will have to leave some tasks unfinished.

7) Frequencies

The frequencies for the simulation appear below.

Type	Frequency
SFO Tower Frequency	120.500
Niles Approach	134.500
Foster Approach	120.350
Foster Monitor	127.675
Woodside Approach	135.650
Woodside Monitor	125.15

8) Standard Operating Procedures for the SFO RNP Evaluation

a) **Weather conditions:** Simulated at 2100 ft (640 m) overcast with 5 miles of visibility. (For experimental purposes the Runway28R aircraft will not see the 28L arrival until both aircraft are below 2100 ft (640 m)).

b) **SFO Operation:** West, ILS28L/RNVZ_28R, departing Runway 1R & 1L

c) **Separation:** Normal IFR separation shall be applied between all arrival aircraft until they are established on the final approach course inside GAROW & the corresponding point (RAMND) on the ILS28L final approach course.

d) **Traffic:** Simulated aircraft are reproduced using data from actual arrival strips from San Francisco. Times are adjusted to simulate an in-trail arrival flow being handed off from the NILES & BOLDER arrival sectors. In the 1700Z hour there were 53 scheduled arrivals for SFO. The arrival demand for Runway 28L is adjusted for 30 arrivals per hour plus an additional 12 Alaska and 2 Continental Boeing 737's requesting RNVZ-28R. Alaska aircraft will be arriving via the GOLDN 4 Arrivals & "down the bay" procedure. The Continental aircraft will be arriving via the MOD2 arrival They are all be RNP equipped and crews certified and requesting RNVZ-28R

e) **Arrival Control:** The experiment will use the Woodside and Foster final controllers with associated final monitor positions on a San Francisco west operation. The NILES and BOLDER controllers will be ghosted (meaning the Computer will be doing the work.). The Woodside and Foster controllers will be located along side one another and share the responsibility of pairing the Runway 28R and 28L arrival aircraft.

The simulator will feed arrival aircraft to Woodside via the GOLDN 4 and Big Sur 2 Arrivals with handoffs at SFO and BOLDR cleared from 11000 ft and 12000 ft to 6000 ft and slowed to 210 knots. Aircraft inbound on the Modesto 2 arrivals will be handed off en route FAITH descending from 11000 ft to 7000 ft slowing to 210 knots. Controllers have the option to modify speeds and have control for turns toward the airport. The Woodside controller will control all the arrivals to Runway 28L, vectoring them on the ILS approach.

The simulator will feed the Foster controller (responsible for the aircraft on the RNVZ-28R approach) Alaska aircraft on an east heading descending to 6000' and slowed to 210 knots from DUXBY and two Continental B737-900 arrivals on the MOD2 cleared via CEDES – MISON. Controllers have the option to modify speeds and control for turns after accepting handoffs.

f) **Final Monitor:** The final monitor positions will monitor the associated Normal Operating Zone (NOZ). Final monitor controllers will monitor the primary radar target with the associated datablock. They will have communications capabilities with the associated aircraft.

   i) **Approach Configuration**. The FM positions have override functions of the Foster and Woodside controllers. The final Monitor controllers will have responsibility for blunder detection and correction until the Runway 28R aircraft applies visual separation. Transfer of control to San Francisco Tower shall be at OKDUE for Runway 28L arrivals and ZOMUK for the Runway 28R arrivals. By that time the RNVZ aircraft on Runway 28R has identified the paired Runway 28 left arrival visually and both aircraft are inbound clear of the NTZ western boundary.

   ii) **Tower Configuration**. The FM positions have override functions of the SFO Tower Local controllers (128.650 right side and 120.5 left side) and are (simulated) simultaneously transmitting on the monitor frequencies of 127.675 for Foster monitor and 125.150 for Woodside monitor. During this operation the final monitor positions will have responsibility for blunder detection and correction and, in addition, share the responsibility of separation and pairing until visual separation is accomplished. Transfer of control to San Francisco Tower shall be prior to the loss of vertical separation or 3 miles between the Runway 28 right and left corresponding aircraft.

g) NTZ Location

   i) **Normal NTZ**. 2000' wide, parallel to the Runway 28L localizer located equidistant between the Runway 28L and 28R final approach courses at the ZOMUK waypoint. The western **edge** ends at ZOMUK and the eastern edge ends at GAROW.

   ii) **"FAT NTZ"** 1150' north of the centerline of the Runway 28L ILS course from OKDUE to RAMND then north to 1850 feet south of the GAROW waypoint and parallel to the centerline of the RNVZ_28R final approach course back to ZOMUK.

Operational Definitions

Blunder	When an aircraft on the final approach course deviates off the prescribed track toward the adjacent approach.
Breakout	When an aircraft on an adjacent approach blunders and enters, or in the controllers judgment will enter, the NTZ and the aircraft on the approach is vectored away from the blundering aircraft.
Nuisance Breakout	When an aircraft is instructed to breakout because of a blundering aircraft on the adjacent approach; however, the blundering aircraft adjusts its course and does not enter the NTZ.
Standard Track Error	A typical slight variation from an expected flight path.

Appendix E

Post-Scenario Questionnaire

SFO RNP Human Factors Study

POST-SCENARIO QUESTIONNAIRE

This questionnaire collects relevant information about your experience during **the current scenario.** Mark an X through the number that best reflects your experience for the scenario just completed.

Participant Code: __________

Session #: ________________

Sector: ☐ Woodside
☐ Woodside Monitor
☐ Foster
☐ Foster Monitor

Overall Performance, Workload, and Situational Awareness			
1. Rate your overall effectiveness **maintaining separation and resolving potential conflicts**.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
2. Rate your overall effectiveness **detecting pilot deviations from control instructions**.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
3. Rate your overall effectiveness **correcting deviations in a timely manner**.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
4. Rate your **overall effectiveness of communications**.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
5. Rate your **overall level of performance**.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
6. Rate your **mental demand** (planning, remembering, etc).	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
7. Rate your **physical demand** (strip marking, talking, etc.).	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
8. Rate your **temporal demand** (i.e., time pressure).	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
9. Rate your **effort** (i.e., how hard you had to work).	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
10. Rate your **frustration** (i.e., how stressed you were).	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
11. Rate your **overall level of situational awareness**.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good

28R RNP Converging Approach			
12. How many aircraft deviations occurred during this script?	28 L_______	28 R_______	
13. Rate your **overall assessment** of the 28R RNP approach procedure based on the current scenario.	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable
14. Rate the impact of the 28R RNP approach on **safety** based on the current scenario. (Note: *a rating of 5-6 indicates no real difference from normal operations*)	Very Negative	①②③④⑤⑥⑦⑧⑨⑩	Very Positive
15. Rate your ease in identifying aircraft **certified** for the 28R RNP approach.	Extremely Difficult	①②③④⑤⑥⑦⑧⑨⑩	Extremely Easy
16. Rate your ease in identifying aircraft **using** the 28R RNP approach.	Extremely Difficult	①②③④⑤⑥⑦⑧⑨⑩	Extremely Easy
17. Rate your ease in differentiating between an aircraft **deviation and standard track error**.	Extremely Difficult	①②③④⑤⑥⑦⑧⑨⑩	Extremely Easy
18. Rate the **time available** for you to react to an aircraft deviation.	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable

19. Rate the amount of effort you had to exert to remain vigilant of aircraft approaching the NTZ.	None At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

Simulation Realism

20. Rate the **realism** of the current simulation.	Extremely Unrealistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic

Describe any differences between the simulation and your normal working environment that may have affected your assessment of the 28R RNP converging approach procedure?

Comments

21. Please provide any additional comments or suggestions you may have about the proposed procedure or this simulation.

Appendix F

Exit Questionnaire

SFO RNP Human Factors Study

EXIT QUESTIONNAIRE

This questionnaire collects relevant information about your **overall experience** across all scenarios**.** Mark an X through the number that best reflects your experience.

Participant Code: __________

Overall Assessment			
1. Rate your overall **level of ATC performance** across all scenarios.	Extremely Poor	①②③④⑤⑥⑦⑧⑨⑩	Extremely Good
2. Rate your ease in differentiating between an aircraft **deviation and standard track error**.	Extremely Difficult	①②③④⑤⑥⑦⑧⑨⑩	Extremely Easy
3. Rate the **time available** for you to react to an aircraft deviation: (a) when using the standard NTZ,	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable
(b) when using the large NTZ.	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable
4. Rate your **overall assessment** of the 28R RNP approach **communications** when: (a) overriding approach communications,	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable
(b) overriding tower communications.	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable
5. Rate your **overall assessment** of the 28R RNP approach **procedures** based on all standard NTZ scenarios.	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable
6. Rate your **overall assessment** of the 28R RNP **approach** based on all standard NTZ scenarios.	Completely Unacceptable	①②③④⑤⑥⑦⑧⑨⑩	Completely Acceptable
7. Rate the impact of the 28R RNP approach on **safety** compared to existing operations. (Note: *a rating of 5-6 indicates no real difference from normal operations*)	Very Negative	①②③④⑤⑥⑦⑧⑨⑩	Very Positive

28R RNP Approach

8. Was all RNP-related **information** that you needed immediately available to you?
   - ☐ **No**. (*Identify what information was not readily available and how you gathered this information*)
   - ☐ **Yes**. (*How did you identify aircraft using and qualified for the RNP approach?)*

9. Are there **situations or conditions** when you would **not** want to use the 28R RNP converging approach procedure?
   - ☐ **No**.
   - ☐ **Yes**. (*Please explain below*)

10. What aspects **impact you the most** when using an area navigation approach (e.g., equipage rates, differing types of FMS equipment, traffic volume, transitioning between RNP and non-RNP operations)? *Briefly describe how they affect you.*

11. Are there substantial differences between the proposed 28R RNP converging approach procedure and other area navigation approaches?
    - ☐ **No**.
    - ☐ **Yes**. (*Please describe the differences below*)

12. Do you have any suggestions regarding the implementation or use of the proposed 28R RNP approach?

Simulation Realism			
13. To what extent did the **STARS interface interfere** with your ATC performance?	None At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
14. To what extent did the **Workload Assessment Keyboard (WAK) rating technique interfere** with your ATC performance?	None At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
15. Rate the **realism of the simulation** compared to your normal working environment.	Extremely Unrealistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic

If there were differences from your normal working environment, indicate whether they were due to:

- ☐ **Equipment** (voice communication equipment, STARS interface, etc.).
  Please explain: ______________________________

- ☐ **Performance of the aircraft** (target speeds, aircraft climb and descent rates, etc.).
  Please explain: ______________________________

- ☐ **Performance of the simulation pilots** (responding to control instructions, providing read backs, etc.).
  Please explain: ______________________________

- ☐ **Other**.
  Please explain: ______________________________

16. Is there anything about this study that we should have asked or that you would like to comment about?

____

Appendix G

Exit Questionnaire Results

Table G1. Average Ratings for Items Relating to Overall Assessment

Item	Range	Mean	SD	Scale
1. ATC performance across all scenarios	8 – 10	8.8	0.9	1 = Extremely poor 10 = Extremely good
2. Ease in differentiating between a deviation and standard track error	6 – 10	8.3	1.0	1 = Extremely difficult 10 = Extremely easy
3a. Standard NTZ: Time available to react	7 – 10	8.4	1.0	1 = Completely acceptable 10 = Completely unacceptable
3b. Wide NTZ: Time available to react	3 – 9	5.8	1.9	"
4a. Communications when overriding approach	3 – 10	7.9	1.7	"
4b. Communications when overriding tower	3 – 10	7.2	1.8	"
5. Overall assessment of the 28R RNP approach procedures	5 – 10	8.1	1.2	"
6. Overall assessment of the 28R RNP approach itself	5 – 10	8.2	1.2	"
7. Impact of 28R RNP on safety compared to existing operations	3 – 10	7.3	2.0	1 = Very negative 5 & 6 = No diff. from normal ops 10 = Very positive

Table G2. Responses to Yes/No Items Regarding 28R RNP Operations

Item	Count		Representative Comments (count)
	No	Yes	
9. Are there situations or conditions when you would not want to use the 28R RNP converging approach procedure?	9	7	• *When OAK is using the VOR approach to Runway 29.* • *When SFO is landing Runway 28 and 1) OAK is landing and departing Runway 11, or 2) SJC is landing and departing Runway 12.* • *Very tight holes.* • *When the weather is marginal.* • *If you have to delay the down the bay aircraft farther than 15 DMC, you run right into the Oakland final* (unless procedure keeps aircraft kept above OAK final) • *During strong north winds.*
11. Are there substantial differences between the proposed 28R RNP converging approach procedure and other area navigation approaches?	7	9	• *Monitor radar (2)* • *Easier operation* • *Less restrictive - waypoints well thought out from north downwind.* • *Other approaches require at least 15-20 mile final established and frequency to turn. A little more control when doing RNP approaches.* • *Can run more traffic with less restrictions.* • *None of the others are converging approaches.* • *RNP is more efficient than SOIA.*

Table G3. Responses to Open Ended Items Regarding 28R RNP Operations

Item	Representative Comments
10. What aspects impact you the most when using an area navigation approach?	• *Non-participants/equipage rates (4)* • *Having regulations to guide the RNAV procedures.* • *Having all users trained on the procedures.* • *Knowing the FMS/RNP equipment in data tag.* • *Knowing what frequency any associated traffic is on.* • *If you know what approach each aircraft can take far enough out, it's not a problem.* • *Experience of pilots on the approach.* • *Strong crosswinds creating difficult intercepts.* • *Getting speeds under control.* • *Easier to run this approach than when we tried side-bys with low ceilings.*
12. Do you have any suggestions regarding the implementation or use of the proposed 28R RNP approach?	• *Implement it at SFO (4)* • *Make sure the CPCs are trained and we use it often.* • *If monitors are responsible for in-trail separation, it is important to have the aircraft on frequency as soon as possible.* • *Do not transfer communication to tower until FAFs.* • *Keep communication procedures same as tested. Do not copy PRM/SOIA communications process.* • *Make sure everyone is a player.* • *Get the planes down low and slow or this won't work.*
16a. Differences from normal environment: **Equipment**	• *STARS looked/acted a bit different (3)* • *Could not use our presets (2)* • *Track ball tough* • *Could not measure miles between aircraft.* • *Entries to offset leader lines* • *Performance of simulation pilots- pretty good actually.* • *Put RWY assignment in datablock*
16a. Differences from normal environment: **Performance of the aircraft**	• *Looked very good (4)* • *Target heading seem to differ by about 20° from original heading (010 heading is like an 080 really)* • *Some aircraft slower to descend than usual* • *Turn rates of the aircraft approach were slower than normal during breakouts* • *No wind to simulate true finals*
16a. Differences from normal environment: **Performance of the simulation pilots**	• *Excellent/perfect (3)* • *Great/very good (3)* • *Worked great*