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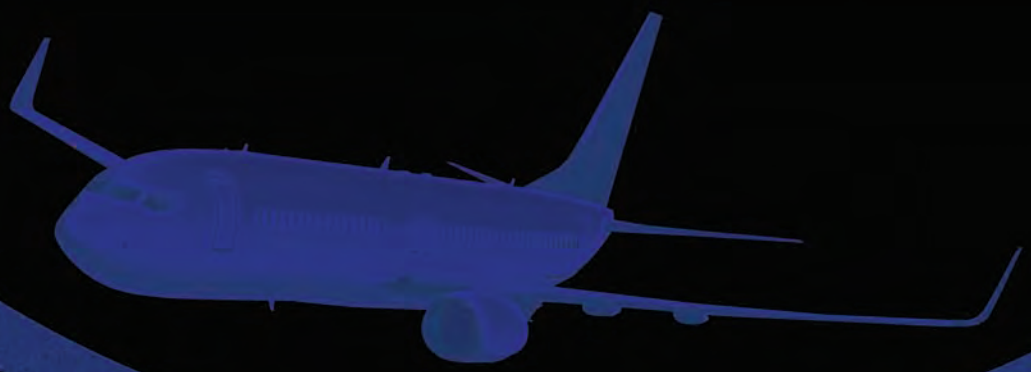

Safety Study Report on a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation During Night/Dusk Conditions Using FAA B737-800 Simulator

Flight Operations Simulation Laboratory
DOT-FAA-AFS-440-36

February 2008

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OK-08-2348

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Flight Operations Simulation Branch
Flight Technologies and Procedures Division
Flight Standards Service

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January 2008

Technical Report

Technical Report Documentation Page

1. Report No. DOT-FAA-AFS-440-36	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Safety Study Report on a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation During Night/Dusk Conditions Using FAA B737-800 Simulator		**5. Report Date** January 2008
6. Author(s) Richard Dunham, AFS-440 Mark Reisweber, AFS-440 Ricky Zoellner, AFS-440 Dr. Sherri Avery, ATSI		**7. Performing Organization Code**
8. Performing Organization Name and Address Flight Operations Simulation, AFS-440 6500 S. MacArthur Blvd, STB Annex, RM 217 Oklahoma City, Oklahoma 73169		**9. Type of Report and Period Covered** Technical report
10. Sponsoring Agency Name and Address Flight Operations Simulation, AFS-440 6500 S. MacArthur Blvd, STB Annex, RM 217 Oklahoma City, Oklahoma 73169		
11. Supplementary Notes		

12. Abstract

This report presents the results of a safety study conducted on a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) operation during night/dusk conditions. The primary purpose of this study was to assess RPAT operational and human factor issues. This safety evaluation reported was conducted by the FAA Flight Operations Simulation and Analysis Branch (AFS-440) using a B737-800 Level D Full Flight Simulator located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma. This study was conducted under simulated night/dusk conditions using the following basic scenarios: nominal, induced Navigation System Errors (NSEs) left and right, and autopilot ON and OFF. Overall results indicated that pilots experienced little difficulty with night/dusk operations. Stabilized flight during the scenarios was within established guidelines. However, participating aircrews did express some concern with recognizing fore/aft in-trail spacing due to reduced visual acuity at night. Aircrew vigilance and coordination workload increased the closer the ILS aircraft was to the 3 o'clock position. As in previous studies, aircrews also indicated that crew and individual workload increased with autopilot OFF scenarios.

13. Key Words Required Navigation Performance (RNP), RNP, Parallel Approach Transition (RPAT), Area Navigation (RNAV), Navigation System Error (NSE)	**14. Distribution Statement** Controlled by AFS-440
15. Security Classification of This Report Unclassified	**16. Security Classification of This Page** Unclassified

Executive Summary

This report presents the results of a safety study conducted on a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) operation during night/dusk conditions. The primary purpose of this study was to assess RPAT operational and human factor issues. This safety evaluation was conducted by the FAA Flight Operations Simulation and Analysis Branch (AFS-440) using a B737-800 Level D Full Flight Simulator located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma.

A previous RPAT simulator safety study *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1] explored induced Navigation System Errors (NSEs), autopilot use, and pilot workload issues during daytime conditions. General results from this study indicated that during an induced NSE, pilots were able to recognize the NSE and maintain stabilized flight throughout the approach. Additionally, autopilot use during the approach clearly reduced pilot workload. When autopilot was not used, workload increased and pilots tended to deviate off the Area Navigation (RNAV) course, biasing away from the Instrument Landing System (ILS) aircraft.

The previous RPAT study *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1] recommended addressing issues outside its original scope. Because [1] focused on daytime RPAT operations, its results could not be generalized to nighttime conditions. Furthermore, the previous study recommended validating Pilot Flying (PF) versus Pilot Monitoring (PM) issues with the ILS aircraft on the right side of the RNAV aircraft. All previous RPAT studies were conducted with the ILS aircraft on the left side of the RNAV aircraft. Because this is a human factor study, feedback from the captain, the more experienced aircrew member with the ultimate authority and responsibility, might garner a different perspective on cross-cockpit PF/PM responsibilities.

This study was conducted under simulated night/dusk conditions using the following basic scenarios: nominal, induced Navigation System Error (NSE) left and right, and autopilot ON and OFF. For the left and right NSE scenarios, the same error magnitude of 0.10 nautical miles was used as in [1]. In addition, multiple simulated “ghost” aircraft were added to the scenarios as well as the ILS aircraft on an intercept angle to the localizer course versus already established on the localizer course as in previous studies.

Overall results indicated that pilots experienced little difficulty with night/dusk operations. Stabilized flight during the scenarios was within established guidelines. However, some aircrews did express some concern with recognizing fore/aft in-trail spacing due to reduced visual acuity at night. Aircrew vigilance and coordination workload increased the closer the ILS aircraft was to the 3 o’clock position. As in previous studies, aircrews also indicated that crew and individual workload increased with autopilot OFF scenarios.

The following conclusion and recommendations are made as a result of this RPAT operation safety study:

1. Nighttime conditions presented no particular operational problems for aircrews participating in this study.

2. A RPAT training program should be developed to address aircrew coordination, workload, and checklist management procedures and strategies. This is a repeat recommendation of *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1].

3. The mandatory use of autopilot for RPAT operations should be strongly considered to mitigate pilot workload issues and to ensure RNAV course guidance is maintained for closely spaced runway operations. This is a repeat recommendation of [1].

4. For RPAT operations in general, Pilot Flying (PF) duties should be assigned to the seat position opposite the side of the ILS aircraft and consequently, the Pilot Monitoring (PM) duties will fall to the seat position on the side of the ILS aircraft.

5. Standards should be developed for charting instrument approach procedures associated with RPAT operations. In particular, the naming, applicability, and charting of the "abandon approach" procedure needs attention.

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1.0 Introduction

This report presents the results of a safety study conducted on a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) operation during night/dusk conditions. This safety evaluation report was conducted by the FAA Flight Operations Simulation and Analysis Branch (AFS-440) using a B737-800 Level D Full Flight Simulator located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma.

1.1 Purpose and Structure of the Study

The primary purpose of this study was to assess RPAT operational and human factors issues under night/dusk conditions. This report provides background information from previous RPAT studies and describes the evaluation process, explains the methods used to analyze the data, and presents conclusions and recommendations based on this study.

1.2 Background RPAT Simulator Study

A previous RPAT simulator safety study *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1] explored induced Navigation System Errors (NSEs), autopilot use, and pilot workload issues during daytime conditions. General results from this study indicated that during an induced NSE, pilots were able to recognize the NSE and maintain stabilized flight throughout the approach. Additionally, autopilot use during the approach clearly reduced pilot workload. When autopilot was not used, workload increased and pilots tended to deviate off the Area Navigation (RNAV) course, biasing away from the Instrument Landing System (ILS) aircraft.

The previous RPAT study [1] recommended addressing issues outside its original scope. Because [1] focused on daytime RPAT operations, its results could not be generalized to nighttime conditions. Furthermore, the previous study recommended validating Pilot Flying (PF) versus Pilot Monitoring (PM) issues with the ILS aircraft on the right side of the RNAV aircraft. All previous RPAT studies were conducted with the ILS aircraft on the left side of the RNAV aircraft. Because this is a human factor study, feedback from the captain, the more experienced aircrew member with the ultimate authority and responsibility, might garner a different perspective on cross-cockpit PF/PM responsibilities.

This study was conducted under simulated night/dusk conditions using the following basic scenarios: nominal, induced NSE left and right, and autopilot ON and OFF. For the left and right NSE scenarios, the same error magnitude of 0.10 nautical miles (NM)

was used as in *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1]. This Global Positioning System accuracy was documented in *Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches—Phases 1A and 2A* to 100 meters on a 95% basis [2]. A 0.10 NM error was estimated to more closely reflect a 99% GPS accuracy NSE associated with the equipage and capability of RNP-approved aircraft. This safety study evaluated pilot actions in visual acquisition and recognition, resolution, and maintenance of stabilized flight on a RNAV approach during nominal, NSE of 0.10 NM (607 feet), and autopilot ON and OFF scenarios.

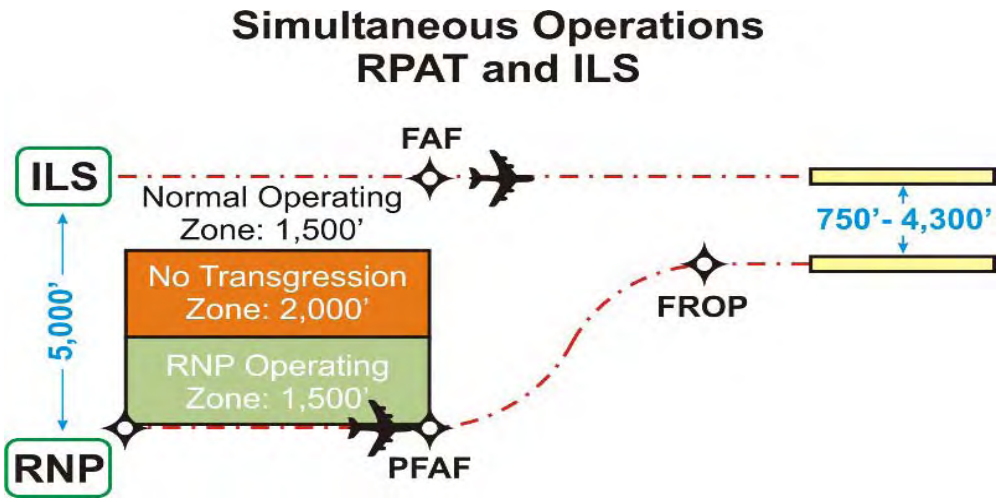
2.0 Description of the Study

This section of the report describes the RPAT concept for closely spaced parallel runways, explains how the NSEs were simulated, and provides a synopsis of the twenty different runs used in the B737-800 simulation. This section also includes details about the participants in the study and provides information about the human factors considerations.

2.1 General RPAT Concept of Operation

The RPAT concept for closely spaced parallel runways places two aircraft paired by Air Traffic Control (ATC) on the intermediate segments of respective RNAV and ILS instrument approaches with the RNAV aircraft abeam or behind the ILS aircraft. Prior to the Precision Final Approach Fix (PFAF), the RNAV aircrew must have visually acquired the ILS aircraft and must have reported this fact to ATC. While the RNAV aircrew visually monitored the position of the ILS aircraft, the RNAV aircraft continued to fly the designated RNAV approach lateral and vertical path. Between the PFAF, Final Roll-Out Point (FROP) and the runway threshold, the RNAV aircrew has to assume responsibility for wake vortex avoidance and separation from the ILS aircraft. Figure 1 depicts the general RPAT concept.

Figure 1: General RPAT Concept of Operations



2.2 RPAT Airport and Approach

This simulator study was conducted using Seattle International Airport (SEA) as the model for the airport site. SEA Runway 16C was the RNAV runway, separated by 1,680 feet from the ILS Runway 16R (Note: The real-world Runway 16R is currently being constructed and thus was simulated for the purposes of this study). Figure 2 shows the RNAV (RNP) Runway 16C approach chart[1] (used for test purposes only) for this RPAT operation.

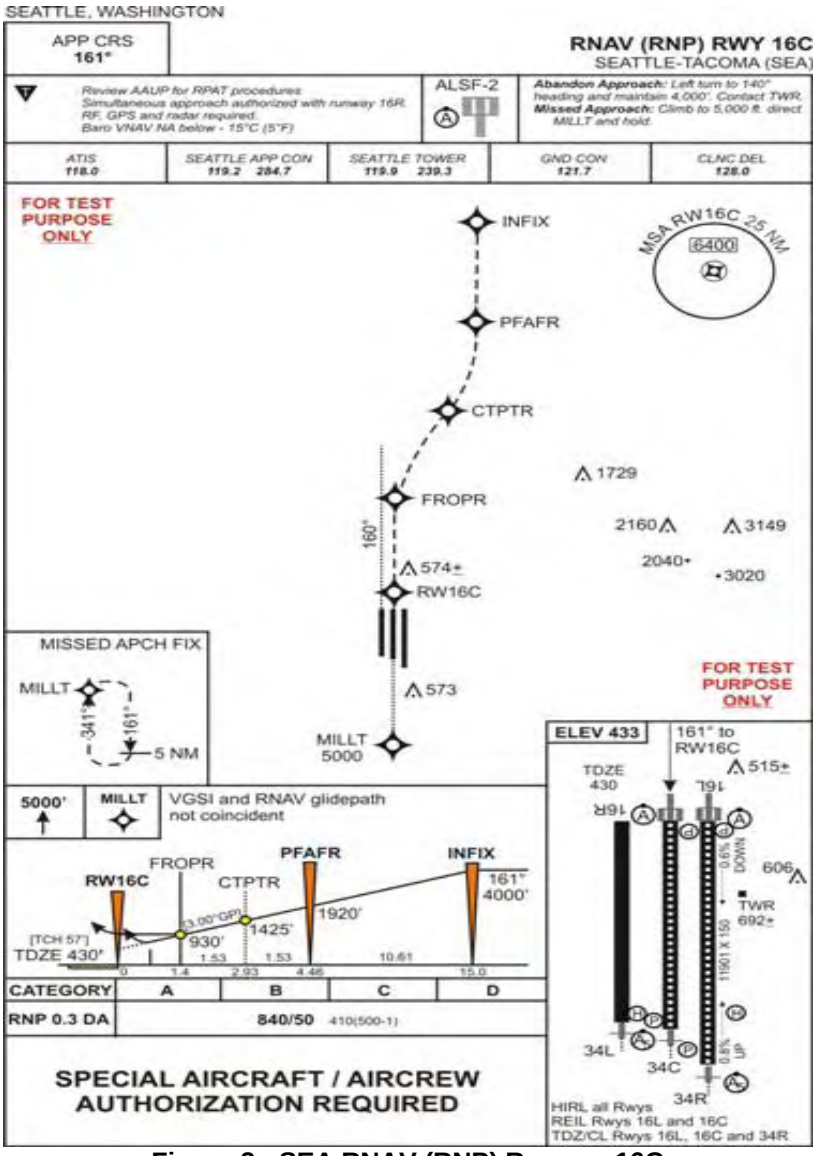


Figure 2: SEA RNAV (RNP) Runway 16C

[1] This chart was used for the simulator testing environment only because RPAT charting specifications have not been formalized with the Aeronautical Charting Forum, under FAA Order 7910.5B.

The approach segment from INFIX to PFAFR was offset approximately 5,000 feet from the ILS 16R localizer course. The approach contained two Radius-to-Fix (RF) legs: one from PFAFR to CTPTR and another from CTPTR to FROPR. These RF legs provided a smooth, repeatable transition from the intermediate segment to the course corresponding to the extended Runway 16C centerline. The RF legs required approximately 10 degrees of bank. After FROPR, lateral guidance continued to the Runway 16C threshold (RWY16C). A barometric Vertical Navigation (VNAV) path of 3 degrees was provided to RWY16C. A RNP level of 0.30 NM and GPS were required to conduct the approach.

2.3 Navigation System Error Simulation

To simulate NSEs equal to 0.10 NM, three different versions of the RNAV 16C approach were programmed into the B737-800 simulator. These approach tracks were nominal, 0.10 NM left of course, and 0.10 NM right of course. The nominal programmed approach represented the RNAV (RNP) 16C approach with no attendant NSE. The 0.10 NM left and right approaches were programmed with all waypoints offset 0.10 NM to the left or right, respectively, to represent an approach in which the NSE resulted in a maximum 0.10 NM left or right error. The navigational databases for 0.10 NM left and right also shifted the SEA runway coordinates so that the cockpit navigational display showed the proper relationship of the runway to the final approach courses.

Though rare, pilots could encounter GPS-induced NSEs of 0.10 NM periodically. Given the present state of GPS with Selective Availability OFF, the 0.10 NM left and right offset approaches were thought to represent an approximate 99% probability level NSE. As such, this study evaluated scenarios to assess pilot actions and flyability characteristics of the RPAT operation with potential NSEs of this magnitude.

2.4 B737-800 Flight Simulator Operational Runs

Twenty different runs were programmed in the B737-800 simulator. These runs are shown in Table 1.

Table 1: Operational Scenarios

Run #	NSE	Pilot Flying	Autopilot	Dusk	Notes
Warm-up	ILS	Capt			ILS 16C
Warm-up	ILS	First Off			ILS 16C
1	Nominal	Capt	ON	N	
2	Nominal	First Off	ON	N	
3	Nominal	Capt	OFF	N	
4	Nominal	First Off	OFF	N	
5	0.10L	Capt	ON	Y	
6	0.10R	First Off	ON	Y	
7	Nominal	Capt	ON	Y	
8	0.10L	First Off	ON	N	
9	0.10R	Capt	ON	N	
10	Nominal	First Off	OFF	N	
11	Nominal	Capt	ON	Y	
12	0.10L	First Off	ON	Y	
13	0.10R	Capt	ON	Y	
14	Nominal	First Off	OFF	N	
15	0.10L	Capt	ON	N	
16	Nominal	First Off	ON	Y	
17	Nominal	Capt	OFF	N	
18	0.10R	First Off	ON	N	
19	Nominal	Capt	OFF	N	
20	Nominal	First Off	ON	Y	

All runs were conducted with auto-throttles OFF to address standardization amongst aircrews and to account for variations in industry equipage and usage. Table 1 shows the following facts concerning the remaining flight simulator scenarios:

- Four scenarios used the NSE 0.10 NM left approach tracks and four scenarios used the NSE 0.10 NM right approach tracks. The remaining 12 scenarios used the nominal RNAV approach.

- Autopilot was used on all the NSE 0.10 NM approaches. Autopilot was not used for six nominal approaches.

- Twelve scenarios were conducted during nighttime conditions. Eight scenarios were conducted during dusk conditions.

- Each captain and first officer had an equal number of nominal, NSE, and autopilot OFF approaches.

Weather conditions included a 2,100-foot ceiling and 2,800-foot tops with a visibility of four statute miles. This ceiling and visibility combination allowed aircrews to visually

acquire the ILS aircraft during the 5,000-foot intermediate parallel approach segment, then enter a cloud base during the descent prior to the PFAF. Approximately 30 seconds from the PFAF, the RNAV aircraft would exit the cloud base, allowing the aircrew to visually reacquire the ILS aircraft prior to the PFAF.

The draft RPAT Operations Plan [3] dictates that the runway environment must be visually acquired by the beginning of the second RF turn (CPTPR in Figure 2) or four statute miles, whichever is greater. Because this RPAT operation was conducted during nighttime conditions, the runway lighting allowed the aircrews to acquire the runway well before to the second RF turn.

The RNAV aircraft began each test run in Visual Meteorological Conditions at INFIX waypoint, which was 15 NM from the SEA airport. The RNAV aircraft was in level flight at 4,000 feet Mean Sea Level (MSL), stabilized on the lateral and vertical approach paths at 170 knots indicated airspeed. In addition, the RNAV aircraft was configured with flaps 5 degrees, flight director was ON with command steering bars for Lateral Navigation/Vertical Navigation (LNAV/VNAV) engaged. Depending on the scenario, the autopilot was either ON or OFF. Even though the B737-800 simulator is equipped with a Head-Up Display, it was not used due to variations in industry fleet equipage. The Traffic Collision Avoidance System (TCAS) was set to the Resolution Advisory (RA) mode.

Five “ghost” aircraft were digitally produced, both on the simulator’s flight deck windows (visual screens) and on the TCAS. All ghost aircraft lighting was functioning (wingtip strobes and rotating beacon). Two ghost aircraft were simulating a RPAT operation 5 NM in front of the RNAV aircraft. Two ghost aircraft were positioned on east and west downwind of SEA airport heading north (in the opposite direction of the RNAV aircraft). The final ghost aircraft was the Runway 16R ILS aircraft (a CRJ) at 170 knots and positioned on a 30-degree intercept angle to the Runway 16R localizer approach course. The ILS aircraft localizer intercept occurred at 3,000 feet MSL and 10.5 NM from Runway16R. There was approximately 4,000 feet in-trail spacing and 1,000 feet vertical separation between the two aircraft at the localizer intercept.

At the beginning of each run, the aircrew could visually acquire the aircraft lights of the ILS aircraft turning into the RNAV aircraft at approximately the 1 o’clock position on the simulator flight deck windows and TCAS. Subsequently, the RNAV and ILS aircraft entered a cloud base and the aircrew lost visual contact with the ILS aircraft. On exiting the cloud base, the aircrew had 30 seconds to reacquire the ILS aircraft prior to departing the PFAF. At the PFAF, the aircrew was expected to slow to a V_{REF} + 5 speed of 145 knots indicated airspeed. The ILS aircraft was programmed to slow at the Final Approach Fix to 145 knots indicated airspeed at the rate of 5 knots per 3 seconds. The captain and first officer alternated approaches with the captain designated as the Pilot Flying (PF) for the odd-numbered runs while the first officer flew the even-numbered runs.

A total of 100 RPAT runs were conducted. All resulted in landings except three in which aircrews executed the RPAT approach abandonment maneuver. These abandonment maneuvers were executed by the pilots in the RF turns, two during a nominal approach and one during a right NSE approach. There were no RA alerts. Of the 100 RPAT runs, 30 nominal runs were without autopilot, 30 nominal runs were with autopilot, 20 runs were 0.10 NM left, and 20 runs were 0.10 NM right.

2.5 Simulator Data Collection

Forty-one different parameters were recorded at a 5-Hertz rate during each simulator session. These parameters are shown below:

- Crew number
- Pilot flying
- Aircraft latitude (degrees)
- Aircraft longitude (degrees)
- Aircraft radio altitude (feet)
- Aircraft rate of descent (feet per minute)
- Captain's column position (inches)
- Captain's wheel position (inches)
- Aircraft pedal position (inches)
- Aircraft flaps position (degrees)
- Aircraft horizontal stab position (degrees)
- Aircraft landing gear position (up or down)
- Aircraft indicated airspeed (knots)
- Aircraft roll angle (degrees)
- Aircraft pitch angle (degrees)
- Aircraft heading angle (degrees)
- Aircraft aileron position (degrees)
- Aircraft elevator position (degrees)
- Aircraft rudder position (degrees)
- Wind speed and direction at aircraft (knots, degrees)
- Left and right engine thrust (pounds)
- Left and right N1 (RPM)
- Left and right throttle lever angle (degrees)
- Main Landing Gear Weight on Wheels switch
- Autopilots A and B
- LNAV engage
- VNAV engage
- Take Off/Go-Around (TOGO) switch activation
- Left Flight Management Computer (FMC) cross track deviation (feet)
- Left FMC Vertical Deviation (feet)

- Left FMC RNP (nautical miles)
- Left FMC ANP (nautical miles)
- Aircraft distance to runway threshold (feet)
- Aircraft distance to runway centerline (feet)
- ILS aircraft latitude (degrees)
- ILS aircraft longitude (degrees)
- ILS aircraft altitude, Above Ground Level (feet)
- Visual modes (day/night/dusk)
- TCAS RA announcement
- TCAS Traffic Advisory (TA) announcement
- Time (seconds)

The collected data parameters supported analysis of the following Test Criteria Violation (TCV) metrics of interest regarding the RPAT scenarios:

1. Bank angles greater than 25 degrees sustained for more than three seconds above 500 feet, or greater than 5 degrees below 500 feet. Descent rate after the PFAF (final approach segment) greater than 1,000 feet per minute sustained for more than three seconds. This 3-second duration was for TCV benchmark only and not FAA Advisory Circular guidance.

2. Airspeed deviations from 500 feet Above Ground Level (AGL) to runway threshold exceeding less than V_{REF} or greater than V_{REF} +10 for more than three seconds. This 3-second duration was for TCV benchmark only.

3. Touchdown point of the RNAV aircraft exceeding 3,000 feet, i.e., aircraft landing outside the landing zone.

4. Flight Technical Error (cross track error) from programmed RNAV approach course exceeding 200 feet (TCV benchmark only)[2].

5. Vertical navigation deviation from programmed RNAV vertical flight path profile exceeding 75 feet (FAA Advisory Circular guidance).

Metrics 1 through 3 were considered general approach parameters and indicated how well the aircrews conducted a stabilized approach. Metrics 4 and 5 were RPAT-specific parameters and provided a quantitative measure of the effectiveness and viability of the RPAT operation and pilot workload issues.

[2] This 200-foot TCV was incorporated from SOIA wake vortex studies for the San Francisco International Airport (SFO) closely spaced parallel operations during the merge. Although the runways at SFO are spaced 750 feet apart compared to the 1,680 feet at SEA which can impact wake vortex encounters, there currently are no studies on wake vortex based on varying runway spacing for closely spaced parallel operations].

2.6 Subject Pilots

A total of five aircrews (i.e., one captain and one first officer) participated in this study. The aircrews were qualified to perform the duties required of their respective crew positions. Four major airline companies were represented with one crew from the US Navy. Pilots from different companies did not fly together (e.g., an Alaska Airlines pilot did not fly with an American pilot). Table 2 contains the ratings, total flying hours, and RNAV experience of the aircrews. As Table 2 shows, the aircrews were highly experienced, all had B737 type-rating or qualification, and their RNAV exposure ranged from minimal to six years.

Table 2: Subject Pilots' Qualifications

Crew #	Crew Position	Ratings	Total Flight Hours	RNAV Experience
1	Captain AA	ATP/B737, DC-9	20,000	Minimal
	First Officer FAA	ATP/B737, DC-8	11,500	Sim Only
2	Captain Navy	ATP/B737, B707, BE400	2400	Minimal
	First Officer Navy	ATP/B737, B707, BE400	2300	Minimal
3	Captain AA	ATP/B737, 757, 767	9,300	Minimal
	First Officer AA	ATP/B737	7,500	2 years
4	Captain ASA	ATP/B737, B707, B727, DC-9, L0382	25,000	6 years
	First Officer ASA	ATP/B737, CL601	4,000	6 years
5	Captain AWA	ATP/737, A320, DHC-8	15,000	2 years, trained to RNP 0.3
	First Officer AWA	ATP/B737, A320	4,000	2 years, RNAV Instructor

A week before the test, each pilot received a brief description on the RPAT concept, a test copy of the SEA RNAV (RNP) 16C approach chart, and a test copy of the Aircrew All Users Page (AAUP) (Appendix A). Prior to each simulator session, the AFS-440 test director reviewed the RPAT concept and briefed each aircrew on the test procedures and conditions[3].

[3] The briefing was in the form of a PowerPoint presentation and is available upon request from AFS-440.

2.7 Human Factors Evaluation

The human-in-the-loop analysis employed both subjective and objective metrics. Subjective performance measures included post-run and post-simulation questionnaires designed specifically to elicit comments from the subject pilots. A numerical weighting procedure was used to rate several human factors issues. The questionnaires focused on any potential changes in either mental or physical workload encountered during the RPAT operation.

A test director and observer also evaluated the performance of the pilot and aircrew as they performed primary and secondary tasks. These tasks were observed during periods of induced high activity in the cockpit or when unusual situations, such as an NSE problem, were interjected. For the purposes of this evaluation, primary task measurements included actions specific to performing this type of RNAV approach and RPAT operation, e.g., making RF turns, visually acquiring and maintaining contact with parallel traffic, responding to runway alignment (nominal and induced NSEs), and dealing with weather conditions. Secondary task measurements included normal commercial aircraft operations, e.g., maintaining aircraft heading/airspeed/altitude, completing checklists, following communication procedures, and making aircraft configuration changes. The aircrews' omission of any primary or secondary tasks may indicate changing workload conditions, necessitating investigation of this operation.

The post-run questionnaire and post-simulation questionnaire are provided in Appendixes B and C, respectively. In addition to the questionnaires, a post-simulation debriefing was held with each aircrew using the format shown in Appendix D: Post-Simulation Debriefing. Post-simulation questionnaires were administered prior to conducting the post-simulation debriefing to elicit pilot responses. A synopsis of the pilot responses are shown in Appendix D.

3.0 Summary of Aircraft Data and Pilot Questionnaires Analysis

This study collected data on (1) nominal and induced NSE approaches, (2) TCVs, and (3) pilot responses to post-run and post-simulation questionnaires. This section of the report examines the aircraft performance data, commensurate with subjective pilot questionnaire data collected during the nighttime simulation.

3.1 Nominal and Induced NSE Approach Analysis

Of the original 100 scenarios, the study contained 60 nominal runs (30 autopilot ON and 30 autopilot OFF) to measure cross track errors and analyze workload issues. The other 40 runs (20 with an induced NSE of 0.10 NM left and 20 with an induced NSE of 0.10 right) were conducted to measure pilot corrective actions.

3.1.1 Nominal Approaches

During the 60 nominal runs, there were *zero* touchdown point, bank angle, and airspeed TCVs. However, the descent rate data for all the runs appear to be corrupted and unusable. During greater than 80% of all the runs after the PFAF (final approach segment), the data indicated a descent rate TCV of more than 1,000 feet per minute for longer than 3 seconds (some runs achieved TCVs longer than 15 seconds). Attempts at replicating these TCVs during a post-test review, using multiple varying airspeeds and configuration rates, were unsuccessful. Additionally, observer notes and video recordings provided no substantiating information to validate the descent rate TCVs.

During the 30 autopilot ON nominal runs, the average absolute value cross track error (deviation from the programmed RNAV approach course) was 22 feet with zero 200-foot TCVs. The maximum autopilot ON cross track error was 118 feet to the right and 94 feet to the left of the RNAV approach course (resolution was in 23 feet increments).

During the 30 autopilot OFF nominal runs, the average absolute value cross track error was 59 feet with twelve (40%) 200-foot TCVs left and five (17%) 200-foot TCVs right of the RNAV approach course. Absolute value considers all numbers as positive versus a deviation to the right of course negating a deviation left of course. This same level of pilot bias away from the converging traffic, i.e., to the left of the RNAV approach in this case, was also noted in *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1]. Of the 30 autopilot OFF runs, the maximum cross track error was 474 feet to the left and 356 feet to the right of the RNAV approach course. Figure 3, Figure 4, and Figure 5 show specific autopilot OFF tracks flown during this RPAT nighttime test that best represent the average absolute value cross track error (59 feet), maximum left cross track error (474 feet), and maximum right cross track error (356 feet), respectively. The conservative bias (away from the ILS aircraft) to the left of the RNAV course is circled in red.

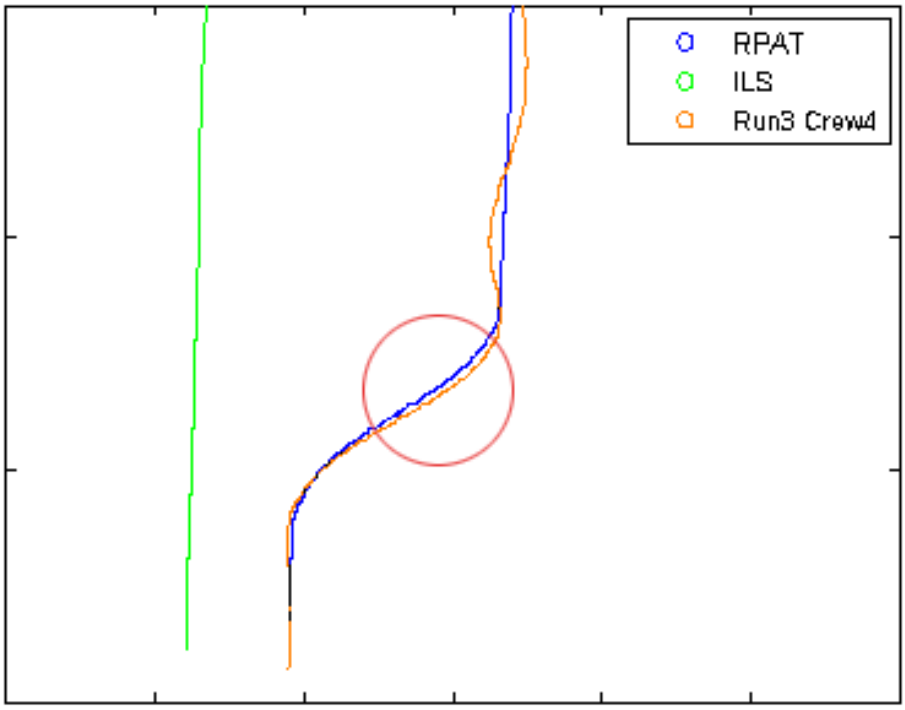


Figure 3: Average Absolute Value Cross Track Error

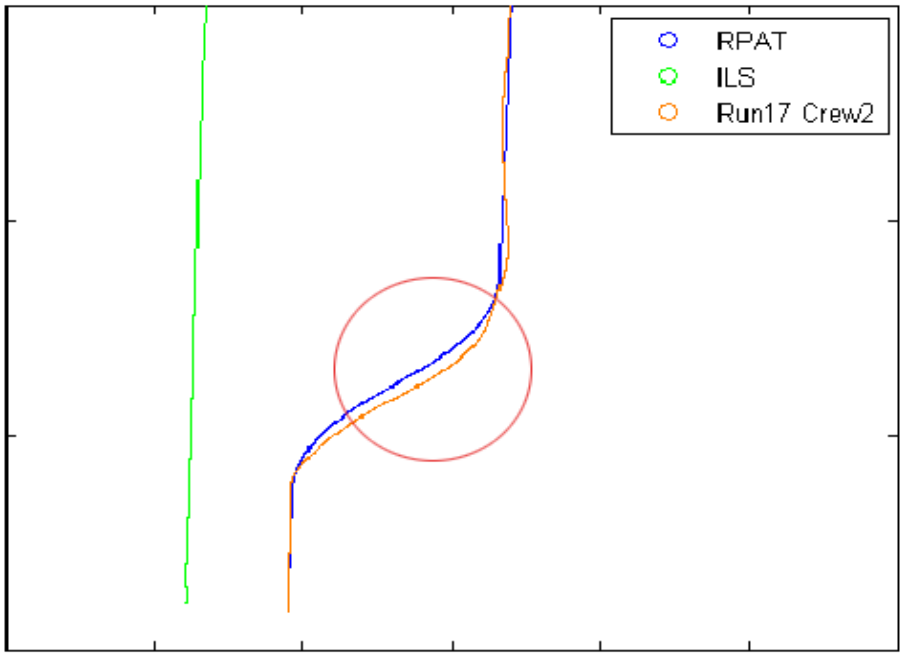


Figure 4: Maximum Left Cross Track Error

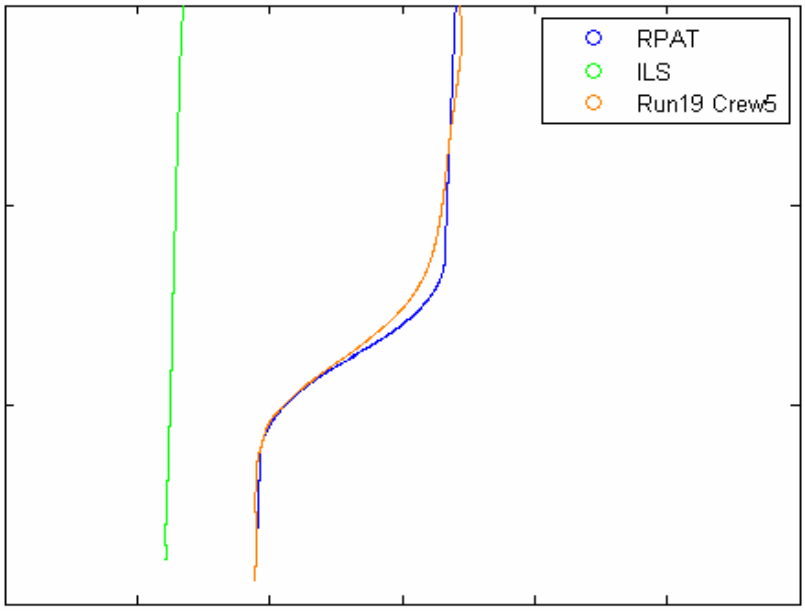


Figure 5: Maximum Right Cross Track Error

As compared to previous RPAT studies, aircrews performed nighttime RPAT operations similar to daytime RPAT operations. The autopilot OFF runs indicated a significant number of TCVs with a pilot bias towards the conservative side of the RNAV approach during the merge (RF turns).

For the vertical navigation deviation, the autopilot ON absolute value average was 11 feet with *zero* TCVs. With the autopilot OFF runs, the vertical navigation deviation average absolute value was 22 feet with 10 TCVs (33%).

Two of the three approach abandonment maneuvers were accomplished during the nominal approaches, both during the merge, i.e., second RF leg. Both pilots expressed concern with the ILS aircraft at the 2-3 o'clock position during the merge and were unsure whether the ILS aircraft was lined up on the correct runway.

3.1.2 NSE Approach Analysis

This analysis evaluated pilot actions in recognition, resolution, and stabilized flight criteria during a NSE of 0.10 NM.

There were 20 runs with an induced NSE of 0.10 NM left and 20 runs with an induced NSE of 0.10 NM right of the nominal track. In all but one case, the pilots recognized a

runway alignment issue and took manual corrective actions to align with the landing runway. When presented with an induced NSE, pilot corrective actions initially involved disconnecting the autopilot and making manual corrections to align with the runway. Data showed that the autopilot was disengaged primarily near the CTPTR waypoint at approximately 2.5 NM from landing (during the second RF leg). (All induced NSEs scenarios began with the autopilot engaged.) Except for the one approach abandonment maneuver occurring during a right induced NSE, all induced NSEs runs resulted in landings.

There were *zero* bank angle and airspeed TCVs during the NSEs that resulted in landings. However, there was one bank angle TCV during the right induced NSE that occurred during an approach abandonment maneuver. This TCV happened at approximately 800 feet AGL, when the pilot achieved 38.9 degrees of bank angle.

There were two touchdown TCVs with a maximum landing distance of 3,300 feet past the threshold. Both touchdown TCVs occurred during the right induced NSE. There were no touchdown TCVs during *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1]

Overall, the induced 0.10 NM left or right NSEs had negligible effect during this nighttime RPAT evaluation.

3.2 Percentage Test Criteria Violations

Table 3 shows overall percentages of TCVs by autopilot usage and induced NSE as previously described in Sections 3.1.1 and 3.1.2.

Table 3: Percentage Test Criteria Violations

Test Criteria Violation	Nominal		NSE 0.10L	NSE 0.10R
	A/P ON	A/P OFF		
Bank Angle > 25°, above 500´ AGL	0%	0%	0%	0%
Bank Angle > 5°, above 500´ AGL	0%	0%	0%	0%
Descent Rate > 1,000´/min	N/A	N/A	N/A	N/A
Airspeed < 145 knots	0%	0%	0%	0%
Airspeed > 155 knots	0%	0%	0%	0%
Cross Track > 200´ right	0%	17%	N/A	N/A
Cross Track > 200´ left	0%	40%	N/A	N/A
Touchdown Point > 3,000´	0%	0%	0%	2%
Vertical Deviation > 75´	0%	33%	N/A	N/A

3.3 Pilot Questionnaires Analysis

The study evaluated pilots' perception of the RPAT night/dusk operation in relation to approach construction, stabilized flight, and physical, mental, and aircrew workload. Workload factors of interest included maintaining in-trail spacing, completing the configuration checklist, and conducting autopilot OFF operations while reducing airspeed. Generally, workload is difficult to quantify without using equipment to measure physiological responses, e.g., eye movement and heart rate. Given the intrusive nature of any such physiological metrics, this study focused primarily on the pilots' perception through post-run and post-simulation questionnaires as well as observation of primary and secondary task performance.

Subjective observer and pilot comments from *previous testing* indicated that checklist management and crew coordination while simultaneously flying a challenging approach in close trail of a parallel traffic revealed increased pilot workload level. Pilot responses from this evaluation also revealed a perception of increased workload during nighttime conditions RPAT operations that was similar to daytime condition operations.

As in the previous daytime conditions RPAT simulator study, physical, mental, and crew workload increased during normal operations after passing the PFAF. Factors that impacted workload were slowing to final approach airspeed, configuring the aircraft, communicating to ATC, and completing the checklist items while monitoring the ILS aircraft. Observer reports indicated that some aircrews did not complete the required checklist until below 1,000 feet, during the RF legs, and within 2 to 3 NM from the runway. Late checklist completion added to the aircrew's workload during a critical phase of flight. However, those aircrews that elected to complete the landing checklist, i.e., configure the aircraft for landing, prior to the PFAF showed a marked reduction in workload during the critical final approach segment.

Additionally, during those runs with the autopilot disengaged, pilots indicated a perceivable increase in individual and crew workload. As the in-trail spacing narrowed (near the 2-3 o'clock position), the increased vigilance required to maintain visual acquisition of the parallel aircraft and remain "outside" the cockpit resulted in increased workload level.

3.3.1 Average Visual Acquisition Scores

Question #1 on the post-run questionnaire asked pilots if, during the approach, they noticed other aircraft in addition to the ILS aircraft on the TCAS. The intention of this question was to validate whether pilots fixated exclusively on the parallel ILS aircraft or if they scanned out to an extended range of their flight paths. All the pilots indicated that they noted other aircraft on the TCAS. No comments were recorded indicating confusion with the TCAS display nor were any observable maneuvers taken with regard to any aircraft other than the ILS aircraft.

Table 4 and Table 5 show the average visual acquisition scores for each scenario experienced by the PF and PM, respectively. Generally, the pilots reported no issues with visually acquiring the ILS aircraft during nighttime operations.

Table 4: Q2: Average Visual Acquisition Score by Scenario Pilot Flying (1=Much Easier, 5=Same as Typical Operation, 9=Very Difficult)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.2	3.7	5.2	4.5	5.0
Nom A/P OFF	5.3	4.7	5.5	5.0	5.0
NSE 0.10L	4.3	4.5	5.0	5.0	5.0
NSE 0.10R	5.5	4.5	5.3	5.0	5.0

Table 5: Q2: Average Visual Acquisition Score by Scenario Pilot Monitoring (1=Much Easier, 5=Same as Typical Operation, 9=Very Difficult)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.0	4.2	4.3	5.0	5.0
Nom A/P OFF	5.3	4.3	5.2	4.3	5.0
NSE 0.10L	5.0	3.8	5.3	4.8	5.0
NSE 0.10R	5.0	4.5	5.0	4.5	5.0

3.3.2 Average Comfort Level Scores

Table 6 and Table 7 show the average comfort level scores for each scenario as reported by the PF and PM, respectively. In general, Crews #2 and #3 indicated a marked decrease in comfort level (displayed in red) and Crew #4 a slightly higher increase in comfort level (displayed in green). Crews #2 (Navy) and #3 (American Airlines) indicated minimal experience with RNAV approaches. Crew #4 (Alaska Airlines) indicated extensive experience with RNAV approaches. This wide disparity in RNAV/RNP experience could account for the wide divergence in comfort level scores.

Table 6: Q3: Average Comfort Level Score by Scenario Pilot Flying (1=Very Comfortable, 5=Same as Typical Operation, 9=Very Uncomfortable)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.0	6.0	5.5	3.0	5.0
Nom A/P OFF	5.3	6.2	5.7	3.3	5.3
NSE 0.10L	5.3	6.0	6.0	3.0	5.0
NSE 0.10R	5.3	5.8	6.3	2.8	5.3

Table 7: Q3: Average Comfort Level Score by Scenario Pilot Monitoring (1=Very Comfortable, 5=Same as Typical Operation, 9=Very Uncomfortable)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.5	5.8	5.8	3.0	5.2
Nom A/P OFF	5.2	4.7	5.8	2.8	5.2
NSE 0.10L	5.3	5.3	6.0	3.0	5.3
NSE 0.10R	5.3	6.0	5.8	2.8	5.3

3.3.3 Average Aircraft Stabilization Scores

Table 8 and Table 9 show the average aircraft stabilization scores by scenario given by the PF and PM, respectively. Generally, pilots reported the aircraft bank angles, descent rates, and any pilot and/or induced NSE flight path corrections experienced during the RNAV approach to be similar to or more stable than normal airline industry type operations.

Table 8: Q4: Average Aircraft Stabilization Score by Scenario Pilot Flying (1=Very High, Same as Typical Operation, 9=Very Low)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.3	3.7	5.0	2.8	5.0
Nom A/P OFF	5.5	4.0	4.5	3.7	5.0
NSE 0.10L	5.5	6.0	5.3	4.0	5.8
NSE 0.10R	5.5	4.3	5.3	2.8	5.3

Table 9: Q4: Average Aircraft Stabilization Score by Scenario Pilot Monitoring (1=Very High, Same as Typical Operation, 9=Very Low)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.2	3.3	4.3	2.7	5.3
Nom A/P OFF	5.5	3.8	5.0	2.7	5.0
NSE 0.10L	5.5	4.3	5.0	3.3	5.5
NSE 0.10R	5.8	4.0	5.0	2.8	5.0

3.3.4 Average Physical Workload Scores

Table 10 and Table 11 show the average physical workload scores for each scenario experienced by the PF and PM, respectively. As expected, the physical workload reported by the PF and PM is slightly higher than for typical operations. This increase in physical workload is attributed to the requirement to maintain visual acquisition of the ILS aircraft while manually controlling airspeed and subsequently configuring the aircraft for landing. Note that the pilots indicated that the use of the autopilot slightly reduced the physical workload during a RPAT operation.

Table 10: Q5: Average Physical Workload Score by Scenario Pilot Flying (1=Much Lower, 5=Same as Typical Operation, 9=Much Higher)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.7	5.7	5.5	4.7	5.5
Nom A/P OFF	6.0	6.8	6.0	4.7	6.2
NSE 0.10L	5.5	6.3	5.8	5.3	6.3
NSE 0.10R	5.3	6.8	6.0	4.8	6.0

Table 11: Q5: Average Physical Workload Score by Scenario Pilot Monitoring (1=Much Lower, 5=Same as Typical Operation, 9=Much Higher)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.7	5.7	5.7	5.2	5.7
Nom A/P OFF	5.5	5.3	5.5	4.3	5.3
NSE 0.10L	5.6	5.8	6.3	5.0	5.8
NSE 0.10R	5.5	6.5	5.8	4.5	5.8

3.3.5 Average Mental Workload Scores

Table 12 and Table 13 show the average mental workload scores for each scenario experienced by the PF and PM, respectively. With the exception of Crew #4 (Alaska Airlines), all the pilots reported a slight increase in mental workload as compared to typical Part 121-type operations. Factors that most likely contributed to these responses were requirements to monitor in-trail spacing, navigation instruments during back-to-back RF turns, and aircraft position relative to other aircraft. Configuring the aircraft for landing and slowing to final approach airspeed during the merge with the ILS aircraft could also be included as a potential factor.

Table 12: Q6: Average Mental Workload Score by Scenario Pilot Flying (1=Much Lower, 5=Same as Typical Operation, 9=Much Higher)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.7	5.8	5.7	4.5	5.5
Nom A/P OFF	5.7	6.7	6.0	5.0	6.0
NSE 0.10L	5.8	6.0	5.8	4.5	6.3
NSE 0.10R	5.8	6.5	6.3	4.5	5.8

Table 13: Q6: Average Mental Workload Score by Scenario Pilot Monitoring (1=Much Lower, 5=Same as Typical Operation, Much Higher)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.8	6.0	5.7	5.2	5.8
Nom A/P OFF	5.3	5.2	5.7	4.3	5.7
NSE 0.10L	6.0	5.5	5.8	4.5	5.8
NSE 0.10R	5.8	6.3	6.0	4.5	5.8

3.3.6 Average Crew Workload Scores

Table 14 and Table 15 show the average crew workload scores for each scenario experienced by the PF and PM, respectively. Overall, crew workload scores represent a slight decrease in workload from both the individual physical and mental workload scores.

Table 14: Q7: Average Crew Workload Score by Scenario Pilot Flying (1=Much Lower, 5=Same as Typical Operation, 9=Much Higher)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.5	5.3	5.3	4.3	5.3
Nom A/P OFF	5.5	6.2	5.7	4.7	5.8
NSE 0.10L	4.3	6.3	5.5	5.0	5.8
NSE 0.10R	5.5	6.0	5.8	4.5	5.5

Table 15: Q7: Average Crew Workload Score by Scenario Pilot Monitoring (1=Much Lower, 5=Same as Typical Operation, 9=Much Higher)

Scenario	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Nom A/P ON	5.7	5.7	5.3	5.0	5.0
Nom A/P OFF	5.5	5.3	5.0	4.3	5.5
NSE 0.10L	4.5	5.5	5.3	4.5	5.5
NSE 0.10R	5.5	5.8	5.3	4.5	5.5

3.3.7 Post-Simulation Questionnaire Average Scores

The post-simulation questionnaire scores are shown below. All scores have been averaged across both the captain and first officer responses, respectively. They are generally consistent with the scores reflected in the post-run questionnaires shown previously. It is important to note the overall workload as outlined in question #7. With the ILS aircraft on the right side of the RNAV aircraft, thus necessitating the captain to look cross-cockpit, the overall captains' scores indicated a significant increase in workload.

1. How safe is this RPAT procedure, considering the proximity to parallel traffic, with respect to maneuvering speed, stabilized visual approach segment, transition to the runway during nighttime operations, etc.? (1=Very Safe, 5=Same as Typical Operation, 9=Very Unsafe)

   Capt: 4.2
   F/O: 4.6

2. Compared to other approaches, rate the ***overall* workload** for this RPAT approach procedure. (1=Very Safe, 5=Same as Typical Operation, 9=Very Unsafe)

   Capt: 5.8
   F/O: 5.6

3. Rate your ***overall* comfort level** with having to monitor the close proximity parallel traffic while maneuvering on the RNAV approach. (1=Very Comfortable, 5=Same as Typical Operation, 9=Very Uncomfortable)

   Capt: 5.0
   F/O: 5.6

4. Rate the **level of difficulty** with the visual transition, from parallel traffic to the runway environment. (1=Very Easy, 5=Same as Typical Operation, 9=Very Difficult)

   Capt: 4.4
   F/O: 4.2

5. Rate the **sufficiency of the distance** allowed to execute the transition from parallel traffic to the runway. (1=Too Short, 5=Same as Typical Operation, 9=Too Long)

   Capt: 4.0
   F/O: 4.8

6. Describe the bank angles required during the visual portion of this RPAT approach procedure. (1=Very Easy, 5=Same as Typical Operation, 9=Very Difficult)

   Capt: 4.6
   F/O: 4.0

7. Rate the level of ***overall* workload** during the "no-autopilot" segment of this procedure. (1=Very Easy, 5=Same as Typical Operation, 9=Very Difficult)

   Capt: 6.6
   F/O: 5.4

4.0 Test Director/Observer/Subject Pilot Observations

All aircrews stated that flying this nighttime RPAT operation was within the capabilities of the aircraft and aircrew, but they expressed concerns about the requirement to monitor the ILS aircraft while simultaneously performing cockpit duties. These comments are consistent with those solicited in *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1]. Again, it is important to note that there is no established training program for RPAT operations.

4.1 In-Trail Spacing

As in [1], in-trail spacing was a key factor in a number of areas. The closer the ILS aircraft was to the 3 o'clock position (directly abeam) to the RNAV aircraft, the greater

the head movement required by the aircrew to monitor the ILS traffic, the more cockpit crosstalk between the pilots, the greater frequency of momentary deviations from flight parameters, and the more prevalent verbal concerns about passing and losing visual contact with the ILS aircraft. Concerns over this issue caused some aircrews to attempt to slow the aircraft below 170 knots prior to the PFAF. In-trail spacing between the RNAV aircraft and ILS aircraft crossing their respective thresholds yielded an overall average of 2,348 feet. The maximum in-trail spacing at the threshold was 5,496 feet with a minimum of 1,735 feet. Aircrews indicated that maintaining the ILS aircraft at the 1 o'clock position clearly reduced these types of workload concerns. The 1 o'clock position is estimated to be closer to 6,000 feet in-trail spacing and validates aircrew in-trail spacing concerns expressed in *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1].

4.2 ILS Frequency Monitoring

SEA Runway 16C currently has an established ILS approach. Some aircrews elected to monitor the ILS raw data on the Pilot Flight Director while flying the RNAV procedure to Runway 16C. It was clear that those that did monitor the ILS raw data were able to quickly discern, confirm, and correct a runway alignment discrepancy during the NSE scenarios. It appears that monitoring available ILS raw data augments situational awareness and mitigates potential mental anxiety precipitated by their position relative to the parallel traffic.

4.3 RPAT Charting

At the present time, there is no established charting standard for RPAT operations. One of the post-simulator debriefing discussions centered on the abandonment instructions that were listed at the top of the RNAV (RNP) RWY 16C chart (Figure 2). Aircrews expressed concerns over which segment of the approach that the approach abandonment maneuver applied to and when/where the missed approach procedure was applicable. Although these instructions are spelled out in the AAUP, aircrews expressed a preference for identification of the abandon maneuver to be shown in the chart pictorial, plan view for easy reference. Given that pilots typically tend to refer to the chart plan view first, quick-reference would be facilitated by publishing the abandon maneuver in the approach chart plan view.

4.4 Pilot Flying/Pilot Monitoring

All aircrews were asked for their individual preferences for which cockpit seat position should conduct the Pilot Flying (PF) duties. (Refer to Question 7 in Appendix D: Post-Simulation Debriefing Synopsis for the responses of all crews to this issue.) Unlike [1]

with the ILS aircraft positioned on the left side of the RNAV aircraft, three out of the five aircrews in this case believed that it did not matter which pilot was designated the PF, regardless of whether the ILS aircraft was left or right side of the RNAV aircraft. However, aircrews did state they felt they could at times monitor the ILS aircraft more easily when they did not have to look across the cockpit. When PMs were required to monitor across the cockpit, the closer the ILS aircraft was to their 3 o'clock position, the more difficult it was to monitor. Observers noted that in cross-cockpit monitoring conditions, aircrews commented on losing visual contact with the parallel traffic during the second RF turn (the merge) due to the aircraft's glare shield/windscreen railing. This was more prevalent when the ILS aircraft was closer to the 3 o'clock position.

4.5 Checklist

The experimental intent of this evaluation was to induce a small level of workload (mental and physical) distinctly more than that experienced under normal conditions. To accomplish this, the RNAV aircraft was not fully configured and the configuration checklist not completed at the start of each test run. This caused the pilots to perform several normal functions while negotiating the RPAT procedure. As in *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1], observers noted that during most simulator sessions, both pilots were "heads down" for a significant amount of time inside the cockpit while completing the checklist items during the RF turns (the merge). Some aircrews completed the checklist below 1,000 feet AGL. After approximately one-third of the initial runs, aircrews discovered that if they completed the checklist before the PFAF, it reduced their workload and allowed them to more closely monitor the ILS aircraft. Unexpectedly, checklist completion was a secondary task that, to some degree, was subjugated to the RPAT operation itself. This is an issue that would have to be addressed in training.

5.0 Recommendations

The following conclusion and recommendations are made as a result of this RPAT operation safety study:

1. Nighttime conditions presented no particular operational problems for aircrews participating in this study.

2. A RPAT training program should be developed to address aircrew coordination, workload, and checklist management procedures and strategies. This is a repeat recommendation of [1].

3. The mandatory use of autopilot for RPAT operations should be strongly

considered to mitigate pilot workload issues and to ensure RNAV course guidance is maintained for closely spaced runway operations. This is a repeat recommendation of *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator* [1].

4. For RPAT operations in general, Pilot Flying (PF) duties should be assigned to the seat position opposite the side of the ILS aircraft and consequently, the Pilot Monitoring (PM) duties will fall to the seat position on the side of the ILS aircraft.

5. Standards should be developed for charting instrument approach procedures associated with RPAT operations. In particular, the naming, applicability and charting of the "abandon approach" procedure needs attention.

Appendix A:

Aircrew All User Page (DRAFT-TEST PURPOSE ONLY) SEA RNAV (RNP) RWY 16C

SPECIAL USE OF SEA RNAV (RNP) RWY 16C FOR RNP PARALLEL APPROACH TRANSITION (RPAT) OPERATIONS

Special pilot training required. This operation will be flown IAW FAA RPAT Concept Plan. Standard parallel monitoring services will be provided by ATC for the intermediate approach segment up to a point abeam the SEA RNAV (RNP) RWY 16C PFAF. Following the PFAF, the aircrew is responsible for safe separation.

Condensed Briefing Points:

- When instructed, **immediately** contact the Tower.
- **Report** the PFAF position and **ILS traffic in sight**.
- **DO NOT continue the approach beyond the PFAFR waypoint** without visually acquiring the ILS traffic. **Execute approach abandonment at the PFAF.**
- **DO NOT continue the approach beyond the *CTPTR waypoint*** without visually acquiring the runway**. Execute the approach abandonment procedure**
- **DO NOT PASS the ILS traffic.**
- **Remain on the RNAV approach path** to the DA.
- **Approach abandonment** by turning to 140 degrees and climbing immediately to 4000 ft MSL, expect radar vectors

1. Dual VHF Communication Required. Pilots will contact approach control for instructions to conduct the approach. Pilots will ONLY transmit on the primary approach control frequency, but will monitor the monitor controller's frequency. It is important that pilots do not select the monitor frequency audio until instructed by approach to contact the tower. When instructed to do so, pilots will contact Tower and remain on that frequency until completion of the approach or as otherwise instructed by ATC. The Monitor controller's transmissions, if needed, will override Tower control frequency. The volume levels should be set about the same on both radios so that the pilots will be able to hear transmissions on at least one frequency if the other is blocked.

2. Breakouts. All "Breakouts" are to be hand flown to assure that the maneuver is accomplished in the shortest amount of time. Pilots, when directed by ATC to break off an approach, must assume that an aircraft is blundering toward their course and a breakout must be initiated immediately.

a) ATC Directed "Breakouts": ATC directed breakouts will consist of a turn and a climb or descent. Pilots must **always** initiate the breakout in response to an air traffic controller's instruction. Controllers will give a descending breakout only when there are no other reasonable options available, but in no case will the descent be below minimum vectoring altitude (MVA) which provides at least 1000 feet required obstruction clearance. MVA for SEA airport is 4000 feet.
b) Phraseology – "TRAFFIC ALERT": If an aircraft enters the No Transgression Zone (NTZ), the controller will breakout the threatened aircraft on the adjacent approach. The phraseology for the breakout will be:

"TRAFFIC ALERT, (aircraft call sign) TURN (left/right) IMMEDIATELY, HEADING (degrees), CLIMB/DESCEND AND MAINTAIN (altitude)".

3. Prior to PFAF: If ATC advises that there is traffic on the ILS 16R, pilots are authorized to continue past the PFAFR waypoint to align with RWY16C centerline when:

a) The ILS traffic is in-sight and is expected to remain in sight, and
b) Pilots have broadcasted that "traffic is in-sight."

If ILS traffic is not in sight, execute approach abandonment at PFAFR by turning to 140 degrees and climbing immediately to 4000 ft MSL, contact Tower.

4. PFAF to DA: Pilots are responsible for separating themselves visually from traffic on the ILS approach. Remain on the RNAV approach path unless maneuvering the aircraft is necessary for safe separation until landing (**DO NOT PASS**), and providing wake turbulence avoidance, if applicable. **If visual contact with the ILS traffic is lost OR the runway is not visually acquired by CTPTR, advise ATC as soon as practical and execute the published abandonment procedure by turning to 140 degrees and climbing immediately to 4000 ft MSL.** Note runway centerline spacing between 16C and 16R is 1680 feet.

NOTE: ATC may otherwise direct either aircraft to ensure aircraft separation.

Appendix B: Post-Run Questionnaire

1. Did you see any other aircraft on the TCAS during this approach?

YES	NO

2. Rate your **VISUAL acquisition** of the parallel traffic to the other approaches that you perform (overall level of effort)

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

3. Rate your comfort level with this RPAT approach procedure given the proximity of the parallel traffic.

Very Comfortable		Somewhat Comfortable		**Same as Typical Operation**	Somewhat Uncomfortable		Very Uncomfortable	
1	2	3	4	5	6	7	8	9

4. Rate your level of **aircraft stabilization** for the **VISUAL segment** portion of this approach based upon your organization's guidance for a stabilized approach.

Very High		High		**Same as Typical Operation**	Low		Very Low	
1	2	3	4	5	6	7	8	9

5. Rate your perceived level of **physical workload** (e.g. head movement, switchology, controls) while flying this approach.

Much Lower Workload		Somewhat Lower Workload		**Same as Typical Operation**	Somewhat Higher Workload		Much Higher Workload	
1	2	3	4	5	6	7	8	9

6. Rate your perceived level of **mental workload** (e.g., searching, thinking, deciding, calculating) while flying this approach.

Much Lower Workload		Somewhat Lower Workload		**Same as Typical Operation**	Somewhat Higher Workload		Much Higher Workload	
1	2	3	4	5	6	7	8	9

7. Rate your perceived level of **crew workload** (e.g., thinking, coordinating, searching, communicating, etc.) while flying this approach.

Much Lower Workload		Somewhat Lower Workload		**Same as Typical Operation**	Somewhat Higher Workload		Much Higher Workload	
1	2	3	4	5	6	7	8	9

Appendix C: Post-Simulation Questionnaire

1. How safe is this RPAT procedure, considering the proximity to parallel traffic, with respect to maneuvering speed, stabilized visual approach segment, transition to the runway during night operations, etc.?

Very Safe		Somewhat Safe		**Same as Typical Operation**	Somewhat Unsafe		Very Unsafe	
1	2	3	4	5	6	7	8	9

2. Compared to other approaches, rate the ***overall* workload** for this RPAT approach procedure.

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat More Difficult		Much More Difficult	
1	2	3	4	5	6	7	8	9

3. Rate your ***overall* comfort level** with having to monitor the close proximity parallel traffic while maneuvering on the RNAV approach.

Very Comfortable		Somewhat Comfortable		**Same as Typical Operation**	Somewhat Uncomfortable		Very Uncomfortable	
1	2	3	4	5	6	7	8	9

4. Rate the **level of difficulty** with the visual transition, from parallel traffic to the runway environment.

Very Easy		Somewhat Easy		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

5. Rate the **sufficiency of the distance** allowed to execute the transition from parallel traffic to the runway.

Too Short		Short		**Same as Typical Operation**	Long		Too Long	
1	2	3	4	5	6	7	8	9

6. Describe the bank angles required during the visual portion of this RPAT approach procedure

Very Easy		Somewhat Easy		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

7. Rate the level of **overall workload** during the “no-autopilot” segment of this procedure.

Very Easy		Somewhat Easy		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

Appendix D: Post-Simulation Debriefing Synopsis

1. Overall, did you feel comfortable with this approach, based upon your experience with all other approaches that you perform? Why or why not?

Crew #1: OK, not much
Crew #2: More uncomfortable than usual approaches, due to added workload of monitoring the parallel traffic. Use of autopilot is better.
Crew #3: Comfortable, but longer in-trail spacing better. Day would be better
Crew #4: Much better with frequency, w/experience, no big deal
Crew #5: Yes

2. Taking into consideration the Navigation System Error, at rollout for alignment with the runway centerline, were you in an acceptable position to complete a landing? Why or why not?

Crew #1: Once realized the severity, not a problem. Used ILS as back-up
Crew #2: Yes. Rollout on final after the RF legs was aligned with runway and constant VNAV path aided in positioning aircraft for landing.
Crew #3: Started to use TCAS to judge NSE approaches
Crew #4: Yes
Crew #5: Yes

3. What additional mental or physical requirements, if any, were imposed on you during this approach?

Crew #1: More head swivel. Spent more time looking for the traffic. Harder to maintain visual contact when at 3 o'clock.
Crew #2: Added scan requirement (outside cockpit) was almost as important and timely as instrument scan. This added to both mental and physical requirements.
Crew #3: Head out more than normal, not detriment to getting everything done
Crew #4: Speed management control critical, varying A/C types might be problematic, but certain things get done
Crew #5: No

4. Would you consider this approach to be stabilized based upon your company's/organization's guidelines for a "stabilized approach"? Why or why not?

Crew #1: Gets marginal. Lots of things going on with callouts. Easy to get behind. This is a big fuel waster if you have to configure early.
Crew #2: Yes, at 1,500' (NAVY guidelines) the approach was stable.
Crew #3: Yes, never felt unstable
Crew #4: No problems due to RNP experience
Crew #5: Yes

5. Did you have any difficulty monitoring the parallel traffic while flying this RNAV approach? How about without the autopilot? Explain why or why not?

Crew #1: The closer laterally to the runway, the more spacing you need..
Crew #2: Yes, especially while hand flying. Even with autopilot the approach was more difficult but was manageable.
Crew #3: A/P off increased workload tremendously, PM now more important
Crew #4: More difficult from cross-cockpit seat, but not insurmountable
Crew #5: No

6. What impacted your performance most, i.e., monitoring the parallel traffic, flying the RNAV approach, transitioning to the runway environment/lining up with the runway centerline, descent rate to the TDZ?

Crew #1: Transition to runway environment
Crew #2: Without a doubt, monitoring of the parallel traffic
Crew #3: None given
Crew #4: None given
Crew #5: NSE

7. Based on this particular demonstration, who do you feel should be the PF? Why?

Crew #1: No problem from either position. Less time to look without A/P
Crew #2: The pilot on opposite side of the traffic. Pilot closest to the traffic can visually acquire and monitor better.
Crew #3: PF should be cross-cockpit, PM in a better position to monitor
Crew #4: Not a big deal as the procedure, no appreciable difference
Crew #5: Does not matter. From human factor standpoint, the PM could react faster on that side.

8. Does flying night RPAT operations impact in anyway your perceived level of difficulty? How so?

Crew #1: None given
Crew #2: None given
Crew #3: Very little, would like some distance between A/C
Crew #4: Slightly more difficult at night, but should not change minimums
Crew #5: No, but depth perception could be a factor.

References

[1] Dunham, R., Reisweber, M., and Avery, S. *Safety Study Report on Navigation System Error, Autopilot Use, and Pilot Workload During a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) Operation Using FAA B737-800 Simulator.* DOT-FAA-AFS-440-23. March 2007.

[2] McCartor, G. and Ladecky, S. *Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches—Phases 1A and 2A.* DOT-FAA-AFS-440-29. April 2007.

[3] Porter, Donald, II. *Required Navigation Perforce (RNP) Parallel Approach Transition (RPAT) Operational Plan (Draft).* December 2006.

[4] Lankford, D. N., McCartor, G., Hasman, F., Greene, G. C., Yates, J., Ladecky, S., and Templeton, D. *San Francisco International Airport Simultaneous Offset Instrument Approach Procedures (SOIA), Volume I.* DOT-FAA-AFS-420-84. March 2000.