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Technical Report
This report presents the results of a safety study conducted on pilot/controller Human-In-The-Loop (HITL) interface during a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) operation. The primary purpose of this study was to assess operational and human factor issues during a fully-integrated terminal environment employing an RPAT operation. This safety evaluation report was conducted by the FAA Flight Operations Simulation Branch (AFS-440) using a B737-800 Level D Full Flight Simulator and Airport Surveillance Radar (ASR)-9 Standard Terminal Automation Replacement System (STARS) displays located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma.

All aircrews stated that flying the RPAT operation was within their capabilities, given their training and experience. The controllers also expressed confidence with using the ASR-9 STARS displays to effectively sort, pair, and merge the Enhanced Target Generator (ETG) aircraft. However, subjective feedback from the controllers and observers indicated that there are still a number of issues that need to be resolved in sorting, pairing, and merging aircraft. Chief amongst these issues was the tagging of RNP aircraft, ensuring the Heavy aircraft is the trailing RNP aircraft, and airspeed differentials between the ILS aircraft and RNP aircraft. All participants noted a steep learning curve on the part of the controllers as they became more familiar with the RPAT operation. Generally though, both the observers, pilots and controllers expressed positive feedback on the operational viability of RPAT operations. Overall, workload (mental and physical) for pilots and controllers was on par with current workload during normal approaches.
Executive Summary

This report presents the results of a safety study conducted on pilot/controller Human-In-The-Loop (HITL) interface during a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) operation. The primary purpose of this study was to assess operational and human factor issues during a fully-integrated terminal environment employing an RPAT operation. This safety evaluation report was conducted by the FAA Flight Operations Simulation Branch (AFS-440) using a B737-800 Level D Full Flight Simulator and Airport Surveillance Radar (ASR)-9 Standard Terminal Automation Replacement System (STARS) displays located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma.

The first phase of the RPAT safety studies involved pilot-only HITL operational and human factor issues using the FAA’s B737-800 Level D Full Flight Simulator. The findings from this first phase were used to support the initiatives of the Performance-Based Operations Aviation Rulemaking Committee (PARC) to develop a draft RPAT Operational Plan\(^1\) \([1]\). The draft RPAT Operational Plan defines initial implementation requirements for the RPAT operation which will enable benefits as soon as possible by using current standards and guidance from Advisory Circular (AC) 90-101, Approval Guidance for RNP Procedures with Special Aircrew and Aircraft Authorization Required (SAAAR) \([6]\) and FAA Order 8260.52, United States Standards for Required Navigation Performance (RNP) Approach Procedures with Special Aircraft and Authorization Required (SAAR) \([7]\). The plan also recognizes the opportunity for future developments and applications of RNP approaches as more operators and aircraft become RNP equipped and advancements in new technology and automation that will provide additional benefits well beyond the initial implementation of RPAT.

Three pilot-only HITL safety studies have been conducted in the FAA’s B737 simulator with airline industry-qualified pilots flying multiple scenarios. These scenarios included day and nighttime operations, Navigational System Errors (NSEs), autopilot usage, loss of visual acquisition of the parallel traffic, and aircraft aligning with the incorrect runway. The results of these simulations have been summarized in three reports generated by AFS-440 \([2]\).

The second phase of the RPAT studies involves incorporating Air Traffic Control (ATC) operations with the RPAT concept. Specifically, this phase is designed to determine pilot and controller HITL operational interface and human factor issues while conducting an RPAT operation. To accomplish this, (Airport Surveillance Radar) ASR-9 radar data displayed on STARS radar display screens were linked to the B737 simulator. Additionally, an Enhanced Target Generator (ETG) was used to create electronic “virtual aircraft” on the radar displays and both the B737 simulator’s visual windshield screens

\(^1\) The draft FAA RPAT Operations Plan is an RNP Office document developed by the RPAT Working Group. It has been approved by the PARC and being formalized for publication.
and Traffic Collision Avoidance System (TCAS). These “virtual aircraft” were electronic simulations of actual industry-type aircraft, with up to eight ETGs displayed on the B737 screens at any one time. While industry pilots flew the B737 simulator, Target Generator Operators (FAA pilots) controlled the ETGs from computer keyboard stations. See Figure A for an overview of this linking.

![Controllers](image)

**Figure A: Linking of Pilots, Simulator, and ATC**

This linking added an element of realistic terminal air traffic operations with real-time, real-world pilot/controller dynamic interface in providing radar vectors and speed control for the merging, sequencing, and pairing of multiple aircraft during an RPAT operation. Generally, this was a “free play” (heading, altitude and airspeed) operation with continuous flow (within various gaps) of aircraft. Specifically, the controlling aspect included providing instructions to multiple Large and Heavy weight category aircraft while maintaining proper separation standards between the paired Instrument Landing System (ILS) or RNP aircraft (RPAT pair), multiple trailing RPAT pairs, and/or any single stream ILS aircraft in accordance with FAA Order 7110.65, *Air Traffic Control* [5].

It must be emphasized that this test was an initial review of pilot/controller interface HITL studies during RPAT operations. As such, the results of this safety study maybe used for any future RPAT validations, criteria, and the finalized RPAT Operational Plan. This test did not address No Transgression Zone (NTZ) blunders, environmental impacts,
or noise abatement issues. Wake vortex issues were not addressed outside of the ATC separation requirements mandated by the draft RPAT Operational Plan [1].

All aircrews stated that flying the RPAT operation was within their capabilities, given their training and experience. Despite some communications infrastructure issues, the controllers also expressed confidence with using the ASR-9 STARS displays to effectively sort, pair, and merge the ETG aircraft. However, subjective feedback from the controllers and observers indicates that there are still a number of issues that need to be resolved in sorting, pairing, and merging aircraft. Chief amongst these issues was the tagging of RNP aircraft, ensuring the Heavy aircraft is the trailing RNP aircraft, and airspeed differentials between the ILS aircraft and RNP aircraft. But all participants noted a steep learning curve on the part of the controllers as they became more familiar with the RPAT operation. Generally though, both the observers, pilots and controllers expressed positive feedback on the operational viability of RPAT operations. Overall, the physical and mental workload for pilots and controllers was on par with current workload during normal approaches.

Recommendations:

1. Develop an RPAT training program for both pilots and controllers.

2. Establish guidelines for RPAT charting including an Aircrew All Users Page.

3. Determine RNP aircraft tagging so as to differentiate RNP/RPAT capable aircraft from other terminal aircraft.

4. Study wake vortex issues in RPAT scenarios (closely spaced operations and aircraft weight categories.

5. Enhance the ETG communication hardware to allow more realistic communications with the controllers.
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1.0 Introduction

This report presents the results of a safety study conducted on pilot/controller Human-In-The-Loop (HITL) interface during a Required Navigation Performance (RNP) Parallel Approach Transition (RPAT) operation. This safety evaluation report was conducted by the FAA Flight Operations Simulation Branch (AFS-440) using a B737-800 Level D Full Flight Simulator and Standard Terminal Automation Replacement System (STARS) displays located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma.

1.1 Purpose and Structure of the Report

The primary purpose of this study was to assess operational and human factors issues of the pilot/controller HITL interface during an RPAT operation. This report provides background information from previous RPAT studies and describes the evaluation plan, explains the data collection methods and analysis, and presents conclusions based on this study.

1.2 Background RPAT Studies

The first phase of the RPAT safety studies involved pilot-only HITL operational and human factor issues using the FAA’s B737-800 Level D Full Flight Simulator. The findings from this first phase were used to support the initiatives of the Performance-Based Operations Aviation Rulemaking Committee (PARC) to develop a draft RPAT Operational Plan2 [1]. The draft RPAT Operational Plan defines initial implementation requirements for the RPAT operation which will enable benefits as soon as possible by using current standards and guidance from Advisory Circular (AC) 90-101, Approval Guidance for RNP Procedures with Special Aircrew and Aircraft Authorization Required (SAAAR) [6] and FAA Order 8260.52, United States Standard for Required Navigation Performance (RNP) Approach Procedures with Special Aircraft and Authorization Required (SAAR) [7]. The plan also recognizes the opportunity for future developments and applications of RNP approaches as more operators and aircraft become RNP equipped and advancements in new technology and automation that will provide additional benefits well beyond the initial implementation of RPAT.

Three pilot-only HITL safety studies have been conducted in the FAA’s B737 simulator with industry-qualified pilots flying multiple scenarios. These scenarios included day and nighttime operations, Navigational System Errors (NSEs), autopilot usage, loss of visual acquisition of the parallel traffic, and aircraft aligning with the incorrect runway.

2 The draft FAA RPAT Operations Plan is an RNP office document developed by the RPAT Working Group. It has been approved by the PARC and is being formalized for publication.
The results of these simulations have been summarized in three reports generated by AFS-440 [2].

1.3 Pilot and Controller Operational Interface

While the first phase of the RPAT studies involved only pilots, the second phase of the RPAT studies involves incorporating Air Traffic Control (ATC) operations with the RPAT concept. Specifically, this phase is designed to determine pilot and controller HITL operational interface and human factor issues while conducting an RPAT operation.

To integrate ATC operations into the RPAT concept, the Airport Surveillance Radar (ASR-9) radar data displayed on STARS radar display screens were linked to the B737 simulator. Additionally, an Enhanced Target Generator (ETG) was used to create electronic “virtual aircraft” on the radar displays and both the B737 simulator’s visual windshield screens and Traffic Collision Avoidance System (TCAS). These virtual aircraft were electronic simulations of actual industry-type aircraft, with up to eight ETGs displayed on the B737 screens at any one time. While industry pilots flew the B737 simulator, Target Generator Operators (FAA pilots) controlled the ETGs from computer keyboard stations. See Figure 1 for an overview of this linking.
This linking added an element of realistic terminal air traffic operations with real-time, real-world pilot/controller dynamic interface in providing radar vectors and speed control for the merging, sequencing, and pairing of multiple aircraft during an RPAT operation. Generally, this was a “free play” (heading, altitude and airspeed) operation with continuous flow (within various gaps) of aircraft. Specifically, the controlling aspect included providing instructions to multiple Large and Heavy weight category aircraft while maintaining proper separation standards between the paired Instrument Landing System (ILS) or RNP aircraft (RPAT pair), multiple trailing RPAT pairs and/or any single stream ILS aircraft in accordance with FAA Order 7110.65, *Air Traffic Control* [5].

Note that the RNP aircraft must always be the trailing aircraft within the RPAT pair [1]. The need to properly pair the two aircraft with respect to in-trail spacing is important from three perspectives. First, the RNP aircraft must be positioned to visually acquire the ILS aircraft prior to the Precise Final Approach Fix (PFAF). Second, the RPAT pair should land as closely as possible to allow the most efficient flow of arrivals and departures. Lastly, within the RPAT pair, the RNAV aircraft is always the heavier weight category aircraft for wake vortex mitigation [1].

It must be emphasized that this safety study was an initial review of pilot/controller interface HITL studies during RPAT operations. As such, the results of this safety study maybe used for any future RPAT validations, criteria, and the finalized RPAT Operational Plan. This test did not address No Transgression Zone (NTZ) blunders, environmental impacts, or noise abatement issues. Wake vortex issues were not addressed outside of the ATC separation requirements mandated by the draft RPAT Operational Plan [1].

### 2.0 Test Objectives

The following were the overall objectives for this safety study:

- Evaluate capabilities and limitations in sorting, pairing, and merging multiple Large and Heavy weight category aircraft during an RPAT operation.

- Measure and evaluate potential controller mental workload changes (during scenarios both with and without a coordinator) while sorting, pairing, and merging multiple Large and Heavy weight category aircraft during an RPAT operation.

- Evaluate controllers’ ability to vector single ILS aircraft and multiple RPAT paired aircraft to achieve proper separation as shown in Figure 3 and in accordance with the draft RPAT Operational Plan [1] and FAA Order 7110.65 [5]. The RNP aircraft must always be the trailing and heavier weight category aircraft in the pair.
3.0 General RPAT Concept and Test Set-Up

This section of the report (1) describes the general RPAT concept of operation for closely spaced parallel runways; (2) clarifies the separation standards between the paired ILS and RNP aircraft (RPAT pair), multiple trailing RPAT pairs and/or any single stream ILS or RNP aircraft; (3) describes the communication linking plan; (4) describes the RNP approach procedure used in this test; (5) describes how the NSE was simulated; and (6) provides a synopsis of the different scenarios used in the B737-800 simulator and STARS displays. This section also includes details about the participants in the study and provides information about the human factors considerations.

3.1 General RPAT Concept of Operation

The RPAT concept for closely spaced parallel runways places two aircraft paired by ATC on the intermediate segments of respective RNAV and ILS instrument approaches with the RNP aircraft abeam or behind the ILS aircraft by the PFAF. Prior to the PFAF, the RNP aircrew must have visually acquired the ILS aircraft and must have reported this fact to ATC. For the purposes of the test, the aircrew reported the aircraft in sight on initial call to the tower at the PFAF. While the RNP aircrew visually monitored the position of the ILS aircraft, the RNP aircraft continued to fly the designated RNP approach lateral and vertical path. Between the PFAF, Final Roll-Out Point (FROP) and the runway threshold, the RNAV aircrew assumed responsibility for wake vortex avoidance and separation from the ILS aircraft. Figure 2 depicts the general RPAT concept.

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3 This Global Positioning System accuracy was documented in Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches—Phases 1A and 2A [3] to 100 meters on a 95% basis. 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.
3.1.1 In-Trail Separation Standards for RPAT Operations

A generalized pictorial of ATC separation goals for RPAT is shown in Figure 3. The in-trail spacing goal for the RPAT pair is between 6,000 feet or 1 NM and no less than parallel/abreast between the ILS and RNP aircraft at the runway threshold [1]. The RNP aircraft is not allowed to pass the ILS aircraft. To achieve this runway threshold separation goal, principle ATC separation adjustments (heading/airspeed) are required to be made prior to the Final Approach Fix (FAF)/PFAF since the RNP aircrew are responsible for separation from the PFAF to the runway threshold.

Meeting these requirements could potentially include building additional spacing to accommodate varying final approach airspeeds based on different weight category aircraft. For example, the potential exists that the ILS aircraft could depart the FAF with the RNP aircraft 1.5 NM in-trail. Subsequently, the RNP aircraft would close the spacing to 1 NM or less by the runway threshold based on the airspeed differential. However, it is unlikely that the RNP aircraft could close that spacing to less than 1 NM by the runway threshold based on the short 4.5 NM final approach segment. (Note: this would require a greater than 20-knot airspeed differential and is subject to aircrew/aircraft airspeed reduction capabilities and company guidelines/procedures.)

In addition, in-trail radar separation standards apply at the runway threshold between Large and Heavy RNP aircraft in accordance with FAA Order 7110.65 [5]. In-trail spacing between the lead RPAT pair and the subsequent ILS aircraft (either an RPAT pair or single aircraft) would be standard radar separation plus a 1 NM buffer. This standard radar separation assumes that the RNP aircraft is always the full 1 NM in trail of its paired ILS aircraft. Since the principle portion of this test is to evaluate controller workload and pairing/merging capabilities, separation measurements were taken at both the runway threshold and the PFAF.
3.2 RPAT Airport and Approach

This HITL study was conducted using Memphis International Airport (MEM) as the model for the airport site. Memphis Runway 36R was the RNAV runway, separated by 927 feet from the ILS Runway 36C. Figure 4 shows the RNAV (RNP) Runway 36R approach chart⁴ (used for test purposes only) for this RPAT operation.

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⁴ 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 [8].
The approach’s intermediate segment from CF36R to PFAFR was offset approximately 5,000 feet (minimum approach path spacing allowed in the intermediate segment) from the ILS 36C 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 36R centerline. The RF legs required approximately 10 degrees of bank. After FROPR, lateral guidance continued to the Runway 36R threshold.
(RWY36R). A barometric Vertical Navigation (VNAV) path of three degrees was provided between CF36R and RWY36R. A RNP level of 0.30 NM and Global Positioning System (GPS) requirement was specified to conduct the approach.

The ILS approach to Runway 36C is shown in Figure 5. Both the ILS Runway 36C and RNAV (RNP) 36R approaches were available to the ETG/simulator pilots and ATC for this RPAT operation. In addition, the Runway 36R ILS was also available to the ETG/simulator pilots and ATC to be used as necessary for aircraft gap fillers. All other runways and approaches were not available for this test.
3.3 STARS Display

ASR-9 radar data were displayed on STARS-like radar screens. Figure 6 shows the actual radar map that the Memphis airport uses for the north runways. This map was modeled and a multi-target database created using the Computer Refined En Route and Terminal Enhancement Program (CREATE 2000). The CREATE 2000 program allows the creation of an airspace environment, active sectors, flight plans, and scenario events. In addition to CREATE 2000, a charter program was also used to provide air traffic simulation-hosting capability, pivotal in providing real-world simulation such as moving target aircraft and accounting for the effects of wind, weather, and altitude compression affects. The umbrella system used for this airspace simulation is Simulation and Integration of Ground Network and Air Links (SIGNAL) which controls both CREATE 2000 and the charter program. SIGNAL is currently used by the FAA Academy for Air Traffic Control training.

Figure 6: Memphis North Radar Map
3.4 Communications Plan

Figure 7 shows the general communications plan. Communication connectivity between the ATC final controllers (FC) and both the four ETG pilots and B737 simulator pilots was accomplished through software-generated frequencies. Separate software-generated frequencies were created for the west and east Memphis arrival sectors. As shown in the general description of RPAT operations (Figure 2), an NTZ would normally require the need for monitor controllers to ensure NTZ integrity. However, since no NTZ blunders were planned, the monitor positions were eliminated for this test.

Additionally, current closely spaced runway operations such as Simultaneous Offset Instrument Approaches (SOIAs) have aircraft switch to the tower frequency well before the FAF. An alternate communication procedure is being proposed to have the aircraft remain on the FC’s frequency until the PFAF/FAF. This alternate communication procedure was used for this test. The FCs instructed aircraft to contact the tower at the FAF/PFAF. The test director, located in the B737 simulator, acted as the tower controller. FCs had complete autonomy to transfer the ETG and B737 simulator to a different sector frequency as necessary for runway load balancing and pairing sequencing needs. All transmissions made by either the FCs, ETG pilots, or B737 simulator pilots were received by all other players on that frequency.

![Figure 7: General Communications Plan](image-url)
3.5 Navigation System Error Simulation

To simulate NSEs equal to 0.10 NM, three different versions of the RNAV 36R 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) 36R 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 MEM runway coordinates so that the cockpit navigational display showed the proper relationship of the runway to the final approach courses. Figure 8 shows the two NSEs and the nominal “on course” approaches used during this test.

![Figure 8: NSE Pictorial](image)

Although rare, pilots could encounter GPS-induced NSEs of 0.10 NM. The 0.10 NM left and right offset approaches are thought to represent the outer limit of an approximate 99% GPS accuracy expected during an RPAT scenario. As such, this study evaluated scenarios to assess pilot actions and flyability characteristics of the RPAT operation with potential NSEs of this magnitude.

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5 This GPS accuracy was documented in Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches—Phases 1A and 2A [3] to 100 meters on a 95% basis. 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.
3.6 Operational Runs

This safety study used varying ATC operational runs and B737 simulator runs to evaluate pilot and controller capabilities while sorting, pairing, and merging multiple aircraft during an RPAT operation.

3.6.1 Air Traffic Control Operational Runs

Each test day consisted of three testing periods lasting one hour each. Each testing period consisted of a two-person or three-person FC crew depending on whether the coordinator position was staffed: one FC for the Runway 36C approach, one FC for the Runway 36R approach, and possibly a coordinator. The coordinator position was used on Day 1 and Day 3 of the test to evaluate any change in workload levels.

ETG aircraft were produced on the STARS radar scope at a variable rate. For the first six testing periods (Day 1 and Day 2), the variable rate consisted of either 40 or 50 ETG aircraft per hour. The final six testing periods (Day 3 and Day 4) consisted of 60 to 70 ETG aircraft per hour. The target aircraft equipage mix was approximately 70% RNP and 30% non-RNP. The ETG aircraft started at 40 NM from the Memphis airport using one of the four Standard Terminal Arrival Routes (STARs) shown in Appendix A. The northeast arrivals began at 8,000 feet Mean Sea Level (MSL), northwest arrivals at 9,000 feet MSL, and both southeast and southwest arrivals at 10,000 feet MSL.

Both the STARs and arrival altitudes are the actual arrival procedures for Memphis airport. Airspeed for all aircraft started at 250 knots indicated airspeed (KIAS). In-trail spacing between all aircraft varied from 10 miles to 20 miles. Each target aircraft type was identified in the aircraft data tag on the STARS display by a code box as a CRJ, MD-80, MD-11, A-320, B777, or A-330. The data tag also included a “R” to denote whether the aircraft was RNP-capable. Once at the FAF or PFAF, the ETG aircraft were pre-programmed to slow to final approach airspeed based on maximum landing weight and 80 degrees at the generalized speed reduction rate of 5 knots per three seconds: CRJ at 140 KIAS, MD-88 at 140 KIAS, MD11 at 158 KIAS, A320 at 140 KIAS, A330 at 145 KIAS, and B777 at 150 KIAS.

---

6 A MITRE Corporation estimation based on a year 2012 forecast for industry equipage.
3.6.2 B737 Simulator Operational Runs

Twelve different runs were programmed in the B737-800 simulator. These runs are shown in Table 1. The B737 simulator began each test run in Visual Meteorological Conditions at the Larue waypoint (Appendix A), which was 40 NM from the Memphis airport. The B737 simulator was in level flight at 10,000 feet MSL, stabilized on the lateral and vertical approach paths at 250 KIAS. In addition, the B737 simulator was in a clean configuration and 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 TCAS was set to the Resolution Advisory (RA) mode.

<table>
<thead>
<tr>
<th>Run</th>
<th>NSE</th>
<th>Pilot Flying</th>
<th>Autopilot</th>
<th>Lost Sight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nominal</td>
<td>Captain</td>
<td>ON</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>Nominal</td>
<td>First Officer</td>
<td>ON</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Nominal</td>
<td>Captain</td>
<td>OFF</td>
<td>Y</td>
</tr>
<tr>
<td>4</td>
<td>Nominal</td>
<td>First Officer</td>
<td>OFF</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>0.10L</td>
<td>Captain</td>
<td>ON</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>0.10R</td>
<td>First Officer</td>
<td>ON</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>Nominal</td>
<td>Captain</td>
<td>OFF</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>0.10L</td>
<td>First Officer</td>
<td>ON</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>Nominal</td>
<td>Captain</td>
<td>ON</td>
<td>N</td>
</tr>
<tr>
<td>10</td>
<td>Nominal</td>
<td>First Officer</td>
<td>ON</td>
<td>Y</td>
</tr>
<tr>
<td>11</td>
<td>0.10R</td>
<td>Captain</td>
<td>ON</td>
<td>N</td>
</tr>
<tr>
<td>12</td>
<td>Nominal</td>
<td>First Officer</td>
<td>OFF</td>
<td>N</td>
</tr>
</tbody>
</table>

Table 1 shows the following facts concerning the remaining flight simulator scenarios:

- Two runs used the NSE 0.10 NM left approach tracks and two runs used the NSE 0.10 NM right approach tracks. The remaining eight runs used the nominal RNAV approach.

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

- Two runs contained a lost sight scenario where the ILS aircraft descended into a cloud bank inside the PFAF resulting in the RNP pilots abandoning the approach.

- Each captain and first officer had an equal number of nominal, NSE, and autopilot OFF approaches.
(Note: Due to the dynamic nature of this test, if an aircrew elected to abandon approach or fly the missed approach procedure, they continued to be radar vectored to another RPAT pairing. The run ended on accomplishing a landing.)

3.7 Meteorological Conditions

Meteorological conditions included a layered cloud deck with Instrument Meteorological Conditions (IMC) beginning at 10,000 feet Above Ground Level (AGL) to 8,000 feet AGL, then Visual Meteorological Conditions from 8,000 feet AGL to 5,000 feet AGL, and finally IMC from 5,000 feet AGL to a 2,000 feet AGL cloud base (500 feet above the PFAF altitude). Visibility was four statute miles. This ceiling and visibility combinations allowed B737 simulator aircrews to visually acquire the ILS aircraft during the 5,000-foot intermediate parallel approach segment with at least 30 seconds prior to the PFAF. Winds began with 50 knots at 10,000 feet AGL and linearly decreased to 10 knots direct crosswind into the ILS approach track (090 degrees). Daytime conditions were used for all test runs.

3.8 Simulator Data Collection

Forty-one different parameters were recorded at a 5-Hertz rate during each B737 simulator session. These parameters are shown below:

- Crew number
- Pilot flying
- Aircraft latitude (degrees)
- Aircraft longitude (degrees)
- Aircraft radio altitude (feet)
- Aircraft rate of climb (feet per minute)
- Captain’s column position (inches)
- Captain’s wheel position (inches)
- Aircraft pedal position (inches)
- Aircraft flaps position (degrees)
- Aircraft horizontal stabilizer position (degrees)
- Aircraft landing gear position (up or down)
- Aircraft indicated airspeed (knots)
- Aircraft roll angle (degrees)

---

7 The draft RPAT Operations Plan [1] 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. The CPTPR is 3.28 NM in this case study.
8 The 10-knot crosswind restriction was adopted from San Francisco International Airport Simultaneous Offset Instrument Approach Procedures (SOIA), Volume I [4].
Data collection began from the time the B737 simulator was in motion and was continuous for the ETG aircraft. The collected data parameters supported analysis of Test Criteria Violation (TCV) metrics of interest regarding this test. TCVs provided the ability to flag the metrics of interest that may need further analysis and clarification from audio, video, questionnaires, and observer inputs:

1. Simulator 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 is for TCV benchmark purposes only and is not FAA Advisory Circular guidance.

2. Simulator airspeed deviations from 500 feet AGL to runway threshold exceeding less than $V_{REF}$ or greater than $V_{REF} + 10$ for more than three seconds. This 3-second duration is for TCV benchmark purposes only.
3. Simulator touchdown point exceeding 3,000 feet, i.e., aircraft landing outside the landing zone.

4. Simulator Flight Technical Error (cross track error) from programmed nominal RNP approach course exceeding 200 feet (TCV benchmark purposes only)\(^9\).[4]

5. Simulator vertical navigation deviation from programmed RNP vertical flight path profile exceeding 75 feet [6].

6. ILS and RNP aircraft (RPAT paired) in-trail separation greater than 1.5 NM and no less than abreast between the ILS and RNP aircraft when the RNP aircraft reaches the PFAF. The RNP aircraft must always be the trailing and heavier weight category aircraft.

7. ILS and RNP aircraft (RPAT paired) in-trail separation greater than 1.0 NM and no less than abreast between the ILS and RNP aircraft when the ILS aircraft reaches the runway threshold. The RNP aircraft must always be the trailing and heavier weight category aircraft.

8. Separation between a ILS aircraft in trail of an RPAT pair of aircraft passing the PFAF less than the following values (values add 1 NM for RNP to ILS in-trail within the pair):

<table>
<thead>
<tr>
<th>RNP #1</th>
<th>ILS #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>Heavy/Large</td>
</tr>
<tr>
<td>Heavy</td>
<td>Large</td>
</tr>
<tr>
<td>Heavy</td>
<td>Heavy</td>
</tr>
</tbody>
</table>

Note: If existing separation at the PFAF is less, separation is measured at the threshold where it should be no less than standard.

Metrics 1 through 3 are considered general approach parameters and indicate how well the aircrews conducted a stabilized approach. Metrics 4 through 8 are RPAT-specific parameters and provide a quantitative measure of the effectiveness and viability of the RPAT operation and pilot/controller workload issues.

\(^{9}\) 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 927 feet at Memphis, which can impact wake vortex encounters, there currently are no studies on wake vortex based on varying runway spacing for closely spaced parallel operations [4].
3.9 Subject Pilots

A total of eight pilots (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. 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 no experience to six years of experience.

A week before the test, each pilot received a brief description of the RPAT concept, a test copy of the MEM RNAV (RNP) 36R approach chart, and a test copy of the Aircrew All Users Page (AAUP) (Appendix B). Prior to each simulator session, the AFS-440 test director reviewed the RPAT concept and briefed each aircrew on the test procedures and conditions.

<table>
<thead>
<tr>
<th>Crew #</th>
<th>Crew Position</th>
<th>Ratings</th>
<th>Total Flight Hours</th>
<th>RNAV Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Captain SWA</td>
<td>ATP/B737</td>
<td>15,500</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>First Officer</td>
<td>ATP/B737, B757, B767</td>
<td>10,500</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Captain ASA</td>
<td>ATP/B737, B707, B727, DC-9, L0382</td>
<td>25,000</td>
<td>6 years</td>
</tr>
<tr>
<td></td>
<td>First Officer</td>
<td>ATP/B737, CL601</td>
<td>5,000</td>
<td>6 years</td>
</tr>
<tr>
<td>3</td>
<td>Captain DAL</td>
<td>ATP/B737, B757, B767</td>
<td>9,500</td>
<td>3 years</td>
</tr>
<tr>
<td></td>
<td>First Officer</td>
<td>ATP/B737, B727</td>
<td>12,000</td>
<td>6 years</td>
</tr>
<tr>
<td>4</td>
<td>Captain AA</td>
<td>ATP/B737, 757, 767</td>
<td>9,300</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>First Officer</td>
<td>AT/B737, DC-9, B777</td>
<td>8,000</td>
<td>Familiar</td>
</tr>
</tbody>
</table>

Table 2: Subject Pilots' Qualifications

10 The briefing was in the form of a PowerPoint presentation and is available upon request from AFS-440.
3.10 Subject Controllers

A total of five air traffic controllers participated in this study. The controllers were qualified to perform approach control duties using a common STARS/Automated Radar Terminal System (ARTS) IIIe display with an ASR-9 radar system. Table 3 contains the Terminal Radar Approach Control (TRACON) region and experience level of each controller. Each controller received an RPAT package consisting of ATC procedures for RPAT.

Since this was a RPAT first-look exposure for controllers, a scope set-up and RPAT procedures familiarization was conducted before the test. As previously stated, each testing period consisted of a two-person or three-person controller crew, depending on whether the coordinator position was staffed: one controller for the Runway 36C approach, one controller for the Runway 36R approach, and one coordinator. The coordinator position was filled on Day 1 and Day 3. As aircraft blunders in the NTZ were not planned for this test, a monitor controller was not required.

<table>
<thead>
<tr>
<th></th>
<th>TRACON</th>
<th>Ratings</th>
<th>Years Experience</th>
<th>Simultaneous Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Atlanta</td>
<td>TRACON</td>
<td>25</td>
<td>21 years</td>
</tr>
<tr>
<td>2</td>
<td>Dallas/Ft Worth</td>
<td>Tower/TRACON</td>
<td>20</td>
<td>13 years</td>
</tr>
<tr>
<td>3</td>
<td>Houston</td>
<td>TRACON</td>
<td>21</td>
<td>17 years</td>
</tr>
<tr>
<td>4</td>
<td>Chicago (Ret)</td>
<td>Tower/TRACON</td>
<td>26</td>
<td>20 years</td>
</tr>
<tr>
<td>5</td>
<td>Chicago (Ret)</td>
<td>Tower/TRACON</td>
<td>20</td>
<td>16 years</td>
</tr>
</tbody>
</table>

3.11 Human Factors Evaluation

HITL analysis is a key factor in validating the RPAT concept. The HITL analysis employed both subjective and objective metrics. To capture subjective feedback from pilots and controllers, post-run and post-test questionnaires were designed specifically to elicit responses from the test subjects. 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. Objective analysis included primary and secondary task performance metrics.

For simulator pilots, the primary task measures included all those tasks and maneuvers directly associated with and specific to performing this type of RPAT operation (e.g., flying a curved path, visually acquiring and maintaining contact with parallel traffic, reacting to no autopilot/auto-throttles, abandoning the approach, etc.). Secondary task measures included all those tasks that pilots are expected to perform as part of normal flight duties (e.g., completing the checklist; maintaining heading, airspeed, and altitude; monitoring communications; etc.).
For the controllers, primary tasks measures included all those tasks associated with communication and sorting, pairing, and merging aircraft during an RPAT operation at various airport arrival rates (40, 50, 60, or 70 aircraft arrivals per hour). Secondary task measures included all those tasks that controllers normally perform (e.g., managing strips, ARTS maps and data, information systems, scope, and flight following, etc.). As such, any “task shedding” in either the primary or secondary task areas may be indicative of workload changes specific to this RPAT operation and may warrant further investigation.

Following each run, both simulator pilots completed a post-run questionnaire to capture immediate subjective views and comments. Controllers completed post-simulation questionnaires at approximately 45-minute intervals to capture initial feedback on the RPAT operation. After the test completion, both pilots and controllers completed an overall post-simulation questionnaire.

A test director and observers also evaluated the performance of the pilots and controllers as they performed primary and secondary tasks. These tasks were observed during periods of induced high/low activity (e.g., NSE or increased ETG flow rate). The aircrews’ omission of any primary or secondary tasks may indicate changing workload conditions, necessitating further investigation of this operation.

The post-run questionnaire and post-simulation questionnaire given to pilots are provided in Appendix C and Appendix D, respectively. Controllers were given a questionnaire after each simulation period. Appendix E contains a copy of this questionnaire. In addition to the questionnaires, a post-simulation debriefing was held with each aircrew using the format shown in Appendix E: Post-Simulation Debriefing. Post-simulation questionnaires were administered prior to conducting the post-simulation debriefing to elicit pilot and controller responses. Synopses of the pilot and controller responses are shown in Appendix F and Appendix G, respectively.

4.0 Summary of Aircraft Data and Pilot/Controller Questionnaires Analysis

This study collected data on (1) sorting, pairing, and merging of aircraft, (2) TCVs, and (3) pilot and controller responses to post-run and post-simulation questionnaires. The study focused on controller workload and their capabilities to sort, pair, and merge multiple aircraft and pilot workload under a high traffic/radio communications scenario.

A number of issues surfaced during the test that had a direct bearing on the data presented below. Although the controllers received a briefing on RPAT operations, none of the controllers were from the Memphis TRACON so they had very limited familiarity with Memphis airspace while interjecting a new closely spaced simultaneous approach operation concept. Although there is no RPAT training program for controllers, it appeared that the controllers’ strategies matured over the four-day testing period. Second, as this was the first test of this magnitude and kind, there were pauses in the
scenario flow to resolve verbal communication issues among the controllers, ETG pilots, and B737 simulator. Lastly, the most significant impact to the controller portion of the test was the ergonomic infrastructure issues with the ETG pilots.

During the first day of the test, two ETG pilots attempted to simultaneously “fly” more than ten aircraft each. The ETG pilots were physically (through the computer keyboard) and mentally (listening to the controller directions) incapable of simultaneously tracking and maneuvering that number of aircraft. To address this problem, two additional ETG pilots were added to reduce the ETG pilot workload. However, communication gaps with the controllers still remained. When controllers gave three or more instructions (e.g., heading, altitude, and airspeed) in one transmission, the ETG pilots were essentially incapable of completing and reading back the three instructions for one ETG aircraft while at the same time receiving new controller instructions for another ETG aircraft. As a result, ETG response time did not meet realistic controller expectations of aircraft movement, i.e., the ETG aircraft did not behave entirely as if it were the real world. Hence, the controllers were forced to restrict their normal controlling options to a maximum of two instructions per ETG aircraft, thus potentially impacting the sorting, pairing, and merging as well as wake turbulence and operational procedure standards in accordance with FAA Order 7110.65, *Air Traffic Control* [5].

### 4.1 Sorting, Pairing, and Merging

A primary objective of this test was to determine any difficulties that ATC may have in sorting, pairing, and merging aircraft into RPAT pairs, and then providing the proper in-trail spacing between the subsequent ILS aircraft. To aid in determining results, in-trail measurements were taken of the ETG aircraft at their respective thresholds as well as the FAF and PFAF. There were 127 RPAT pairs achieved from a total of 430 ETG and B737 simulator aircraft that accomplished a landing during the test (30%).

The controller goal for the in-trail spacing between aircraft in the RPAT pair was 6,000 feet (1 NM). For the RPAT paired aircraft, in-trail data indicated that the controllers achieved an average offset in-trail spacing of 5,186 feet, measured from the position of the RNP aircraft at the point the ILS aircraft crossed its respective runway threshold. Of the 127 pairs, ten pairs (12%) had the ILS and RNP aircraft inside of 4 NM, but greater than 1.5 NM, placing them at greater risk to a wake turbulence encounter.

The RNP aircraft in the lead RPAT pair and the trailing ILS aircraft (either as a single aircraft or as a RPAT pair, see Figure 3) averaged 27,054 feet (4.5 NM). Fourteen trailing ILS aircraft were inside the 4 NM in-trail radar separation standards.

Data indicated that six ETG RNP aircraft were in front of the ILS aircraft at the PFAF, which conflicted with guidelines outlined in the draft RPAT Operational Plan [1]. This would have resulted in an abandoned approach procedure for the RNP aircraft if under actual conditions.
4.2 Controller TCVs

The SIGNAL program used to create the ATC infrastructure contains the capability to track the number of ETG aircraft and any separation and operational/procedural errors in accordance with FAA Order 7110.65, *Air Traffic Control* [5]. Table 4 through Table 7 show the number of operational/procedural errors based on the ETG arrival flow rate. Note that the information presented is an overall representation of each level of ETG flow rate.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Number of Aircraft</th>
<th>% of 40 A/C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td>Total Aircraft Controlled by Sector*</td>
<td>23</td>
<td>27</td>
</tr>
<tr>
<td>Operational Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separation Loss</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Wake Turbulence Separation Loss</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Procedural Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach Glide Slope (Vectored below slope)</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Approach Intercept Angle (31 degrees or more)</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Approach Gate (Vectored inside gate)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*The number of total aircraft controlled by sector is larger than the number of aircraft in the scenario because of handoffs between sectors.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Number of Aircraft</th>
<th>% of 50 A/C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td>Total Aircraft Controlled by Sector*</td>
<td>27</td>
<td>34</td>
</tr>
<tr>
<td>Operational Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separation Loss</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Wake Turbulence Separation Loss</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Procedural Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach Glide Slope (Vectored below slope)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Approach Intercept Angle (31 degrees or more)</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Approach Gate (Vectored inside gate)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*The number of total aircraft controlled by sector is larger than the number of aircraft in the scenario because of handoffs between sectors.
Table 6: Separation and Operational/Procedural Errors: 60 Aircraft Scenario – With Coordinator

<table>
<thead>
<tr>
<th>Situation</th>
<th>Number of Aircraft</th>
<th>% of 60 A/C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td>Total Aircraft Controlled by Sector*</td>
<td>39</td>
<td>41</td>
</tr>
<tr>
<td>Operational Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separation Loss</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Wake Turbulence Separation Loss</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Procedural Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach Glide Slope (Vectored below slope)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Approach Intercept Angle (31 degrees or more)</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Approach Gate (Vectored inside gate)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*The number of total aircraft controlled by sector is larger than the number of aircraft in the scenario because of handoffs between sectors.

Table 7: Separation and Operational/Procedural Errors: 70 Aircraft Scenario – Without Coordinator

<table>
<thead>
<tr>
<th>Situation</th>
<th>Number of Aircraft</th>
<th>% of 70 A/C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td>Total Aircraft Controlled by Sector*</td>
<td>44</td>
<td>46</td>
</tr>
<tr>
<td>Operational Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separation Loss</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>Wake Turbulence Separation Loss</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Procedural Errors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach Glide Slope (Vectored below slope)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Approach Intercept Angle (31 degrees or more)</td>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td>Approach Gate (Vectored inside gate)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*The number of total aircraft controlled by sector is larger than the number of aircraft in the scenario because of handoffs between sectors.

Note that the wake turbulence separation shown above is measured for aircraft that are directly in-trail and not for paired aircraft that are offset in-trail. Although the overall percentages of separation and operational/procedural errors appear to be high, it must be remembered that this study was the initial review of the RPAT operation and no previous training was conducted before the test. In addition, the communication infrastructure issues between the ETG pilots and controllers also contributed to the seemingly high percentages of errors.

The data and observer notes indicated the importance of a coordinator. Observer notes verified and above data indicates that a coordinator would aid the RPAT operation as the percentage of aircraft separation loss was approximately two to one when a coordinator was not used. The observers also noted a dramatic change in the coordination efforts between sectors and “flow” between Day 1 and Day 4. As the controllers gained experience (and mitigated the ETG communication shortfall through experience and
anticipation), the overall operation clearly indicated that the sorting, pairing, and merging success rate improved.

### 4.3 B737 Simulator Pilot TCVs

As this was a “free play” environment, the number of actual runs throughout the test varied per aircrew and day. Of the original 48 runs planned, only 36 runs were accomplished because of approach abandonments (lost sight after the PFAF), TCAS RA, or test director reset due to simulator anomalies. Of the 36 runs, Table 8 highlights the TCVs for the simulator.

<table>
<thead>
<tr>
<th>Test Criteria Violation</th>
<th>Nominal A/P ON</th>
<th>A/P OFF</th>
<th>NSE 0.10L</th>
<th>NSE 0.10R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank Angle &gt; 25°, above 500´ AGL</td>
<td>11%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Bank Angle &gt; 5°, above 500´ AGL</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Descent Rate &gt; 1,000´/min</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Airspeed &lt; 145 knots</td>
<td>33%</td>
<td>40%</td>
<td>29%</td>
<td>50%</td>
</tr>
<tr>
<td>Airspeed &gt; 155 knots</td>
<td>11%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Cross Track &gt; 200´ right</td>
<td>11%</td>
<td>60%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cross Track &gt; 200´ left</td>
<td>0%</td>
<td>0%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Touchdown Zone &lt; 3,000 feet</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
</tr>
<tr>
<td>Vertical Deviation &gt; 75´</td>
<td>11%</td>
<td>20%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The bank angle greater than 25 degrees TCVs occurred when the autopilot was disconnected during the abandonment and TCAS RA. The pilots over-controlled the bank angle when they disconnected the autopilot, but no pilot exceeded 30 degrees of bank (no audio warning).

The TCVs for the airspeed less than 145 knots (RNP aircraft $V_{REF}$ plus 5 knots speed for the approach) and greater than 155 knots all occurred when the RNP aircraft was less than one mile from the approach end of the runway. The autopilot and auto-throttles were disconnected at this point. No airspeed callouts were made by the pilot monitoring. It is surmised that both pilots fixated on the landing without monitoring the airspeed.

The cross track error greater than 200 feet to the right of the nominal track is most significant for the autopilot OFF runs. This is a repeat trend from previous RPAT testing [2]. It is surmised that RNP pilots preferred to remain on a flight track that ensured more conservative clearance from the ILS aircraft. However, this cross track error may pose an issue with obstacle conflicts.

Previous RPAT tests indicated a 33% vertical deviation greater than 75 feet with the autopilot OFF. Although both the autopilot ON and autopilot OFF runs indicated a TCV deviation for this test, data indicated that all the deviations occurred when the autopilot
was OFF (i.e., the run started with the autopilot ON and was subsequently disengaged). Overall, this was surmised to have occurred from poor crew coordination duties for RPAT-type operations and poor pilot flying and pilot monitoring cross check of the flight director while monitoring the ILS traffic.

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.

4.4 Pilot and Controller Questionnaires Analysis

The study evaluated pilots’ and controllers’ perception of the RPAT operation commensurate with physical, mental, and crew workload. Evaluated workload factors of interest included (1) controllers sorting, pairing, and merging of multiple aircraft and (2) pilots completing the configuration checklist while being vectored for the approach and conducting autopilot OFF operations while simultaneously changing 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 [2]. Pilot and controller responses from this evaluation also revealed a perception of increased workload during RPAT operations.

As in previous RPAT simulator studies, physical, mental, and crew workload for pilots most noticeably increased when passing the PFAF. For the controllers, physical, mental, and team workload most noticeably increased prior to the PFAF. Sorting and merging were the principle workload generators for the controllers. For the pilots, slowing to final approach airspeed, configuring the aircraft, communicating with ATC, and completing the checklist items while monitoring the ILS aircraft increased workload.

The pilot and controller average scores are presented in three sections. Section 4.4.1 contains the pilot average scores elicited from each run. Section 4.4.2 includes the pilot post-simulation scores. Section 4.4.3 contains the controller average scores determined from each post-simulation period.
4.4.1 Pilot Average Post-Run Scores

Following are the average subjective scores completed by the pilots following each run.

4.4.1.1 Average Pilot Visual Segment Scores

Table 9 and Table 10 show the average visual segment scores during an RPAT operation as compared to other normal approaches for each scenario experienced by the pilot flying (PF) and pilot monitoring (PM), respectively. Generally, the pilots reported no issues with visually acquiring the ILS aircraft or with the overall level of effort during the visual segment of the approach (PFAF to the runway) for all scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>3.3</td>
<td>3.5</td>
<td>5.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>3.0</td>
<td>3.7</td>
<td>4.3</td>
<td>4.0</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.5</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>2.0</td>
<td>4.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>4.0</td>
<td>4.0</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>3.0</td>
<td>3.3</td>
<td>4.0</td>
<td>3.3</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>2.0</td>
<td>4.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
4.4.1.2 Average Pilot Comfort Level Scores

Table 11 and Table 12 show the average comfort level scores for each scenario as reported by the PF and PM, respectively. In general, all the aircrews felt comfortable performing the RPAT operation under all scenarios. However, the PM for Crew 1 did score the NSE 0.10 NM to the right of the runway (highlighted in red) as uncomfortable. The PM for this run was the captain while the first officer flew the approach. The crew experienced a TCAS RA during the approach due to being high on the glide path and a high intercept angle correcting for the NSE. As reported by the aircrew, the TCAS RA and NSE had a direct bearing on the comfort score.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>4.0</td>
<td>2.5</td>
<td>5.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.5</td>
<td>3.7</td>
<td>6.0</td>
<td>4.0</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 12: Q2: Comfort Level Given the Proximity of the Parallel Traffic – Pilot Monitoring

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>3.7</td>
<td>2.5</td>
<td>6.0</td>
<td>3.7</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>4.0</td>
<td>2.7</td>
<td>4.3</td>
<td>2.7</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.5</td>
<td>3.0</td>
<td>4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>4.0</td>
<td>3.0</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
4.4.1.3 Average Pilot Aircraft Stabilization Scores

Table 13 and Table 14 show the average aircraft stabilization scores by scenario reported by the PF and PM, respectively. Generally, pilots reported the aircraft bank angles, descent rates, and any pilot-induced NSE flight path corrections experienced during the RNP approach to be similar to or more stable than normal airline industry type operations. Crew 3 PM did score aircraft stabilization low during the nominal autopilot ON runs (highlighted in red). Note: During these nominal runs with the autopilot ON, the simulator experienced some traffic linking anomalies causing the aircrew to abandon the approach.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>4.0</td>
<td>3.5</td>
<td>6.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.5</td>
<td>3.3</td>
<td>5.0</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.5</td>
<td>6.0</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>3.0</td>
<td>3.5</td>
<td>7.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.0</td>
<td>2.7</td>
<td>4.7</td>
<td>2.3</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>3.0</td>
<td>3.0</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>4.0</td>
<td>3.0</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
4.4.1.4 Average Pilot Physical Workload Scores

Table 15 and Table 16 show the average physical workload scores for each scenario experienced by the PF and PM, respectively. These scores are slightly lower than in previous RPAT testing and indicate no additional physical workload was experienced during the RPAT operation. Note that the pilots indicated that the use of the autopilot had very little bearing on the physical workload during a RPAT operation. This is counter to scores recorded in previous tests.

Table 15: Q4: Average Physical Workload – Pilot Flying
(1=Much Lower, 5=Same as Typical Operation, 9=Much Higher)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>3.7</td>
<td>4.0</td>
<td>5.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.5</td>
<td>5.0</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.5</td>
<td>4.0</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>2.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 16: Q4: Average Physical Workload – Pilot Monitoring
(1=Much Lower, 5=Same as Typical Operation, 9=Much Higher)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>2.3</td>
<td>3.5</td>
<td>6.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
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<td>4.3</td>
<td>5.3</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>3.0</td>
<td>3.0</td>
<td>5.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
4.4.1.5 Average Pilot Mental Workload Scores

Table 17 and Table 18 show the average mental workload scores for each scenario experienced by the PF and PM, respectively. Generally, the crews reported mental workload at or less than that required during normal operations. Crew 3 PM did score mental workload high during the nominal autopilot ON runs (highlighted in red). As in the aircraft stabilization scores above, during these nominal runs with the autopilot ON, the simulator experienced some traffic linking anomalies causing the aircrew to abandon the approach.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>3.3</td>
<td>4.5</td>
<td>6.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.5</td>
<td>5.0</td>
<td>5.3</td>
<td>4.3</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>2.3</td>
<td>4.0</td>
<td>7.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.5</td>
<td>4.3</td>
<td>5.0</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
<td>2.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>3.0</td>
<td>3.0</td>
<td>5.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
### 4.4.1.6 Average Aircrew Workload Scores

Table 19 and Table 20 show the average crew workload scores for each scenario recorded by the PF and PM, respectively. Overall, crew workload scores did not deviate from the workload values from both the individual physical and mental workload scores. Generally, they indicated less workload than during normal operations.

**Table 19: Q6: Perception of Crew Workload While Flying This Approach – Pilot Flying**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
<td>4.0</td>
<td>4.0</td>
<td>5.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.0</td>
<td>4.3</td>
<td>5.7</td>
<td>4.0</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.0</td>
<td>4.0</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Table 20: Q6: Perception of Crew Workload While Flying This Approach – Pilot Monitoring**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
<th>Crew 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom A/P ON</td>
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<td>4.0</td>
<td>4.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Nom A/P OFF</td>
<td>2.5</td>
<td>3.5</td>
<td>4.7</td>
<td>3.3</td>
</tr>
<tr>
<td>NSE 0.10L</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>NSE 0.10R</td>
<td>3.0</td>
<td>3.0</td>
<td>5.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

### 4.4.2 Pilot Post-Simulation Questionnaires 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 in previous testing and indicate no areas of concern.

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, etc.? (1=Very Safe, 5=Same as Typical Operation, 9=Very Unsafe)

   Capt: 4.3  
   F/O: 2.3

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: 4.3  
   F/O: 3.3
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: 3.8  
   F/O: 3.0

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: 3.8  
   F/O: 3.0

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: 5.3  
   F/O: 4.0

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: 4.3  
   F/O: 2.8

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: 5.5  
   F/O: 4.8
4.4.3 Controller Post-Simulation Questionnaires Average Scores

This section contains the average subjective scores completed by the controllers following each testing period (three testing periods per day). When reviewing the results, note that a coordinator was used on Day 1 and Day 3, and the flow rate was 40 to 50 aircraft per hour on Day 1 and Day 2 and 60 to 70 aircraft per hour on Day 3 and Day 4. These variable changes of using coordinator and the variability of the flow rate may have a subjective impact to the controllers’ perception of individual and team workload.

4.4.3.1 Average ARTS Displays Realism

Figure 9 shows controllers’ perception of the ARTS display and ETG aircraft compared to a realistic depiction of actual operations. However, as noted previously, communication issues during Day 1 among the controllers, simulator, and ETG pilots resulted in less than realistic operational conditions.

![Question 1 graph](Figure 9: Q1: Compared to Actual ARTS Displays That You Have Used, Rate the Realism of This System's Automation Display/Voice System)
4.4.3.2 Average Difficulty in Sorting, Pairing, and Merging With a Coordinator

Figure 10 shows the average difficulty in sorting, pairing, and merging when a coordinator was part of the controller team as compared to when a coordinator was not part of the controller team. Generally, controllers indicated that sorting, pairing, and merging was more difficult than normal operations, but as the test progressed and experience increased, the difficulty level decreased to the easy level.

![Figure 10: Q2: Difficulty Level in Sorting, Pairing, and Merging the ILS and RNP Aircraft as Compared to Normal Parallel or Simultaneous Operations With a Coordinator](image)
4.4.3.3 Average Difficulty in Sorting, Pairing, and Merging Without a Coordinator

Figure 11 depicts difficulty in sorting, pairing, and merging when a coordinator was not part of the controller team as compared to when a coordinator was part of the controller team. Generally, controllers indicated that sorting, pairing, and merging was much more difficult than normal operations, but again, as subjects’ experience increased, the difficulty level decreased to the easy level.

Figure 11: Q3: Difficulty Level in Sorting, Pairing, and Merging the ILS and RNAV Aircraft as Compared to Normal Parallel or Simultaneous Operations Without a Coordinator
4.4.3.4 Average Comfort Level

Figure 12 shows the comfort level when conducting an RPAT operation as compared to normal approach operations. The comfort level improved from Day 1 to Day 4 and might be explained by experience and the effects of mitigating communication issues.

![Question 4 Comfort Level](image-url)

**Figure 12: Q4: Comfort Level in Conducting RPAT Operations as Compared to Normal Approach Operations**
4.4.3.5 Average Individual Workload Scores During the Approach

Figure 13 is a comparison of individual workload from the RPAT operation to other parallel or simultaneous operations. Again, as expected, higher workload values were recorded on Day 1, which is not surprising since this was the subjects’ initial experience with this RPAT operation. As the test progressed, individual workload values decreased to levels comparable to similar operations.

![Question 5](image)

**Question 5**

1 = Very Easy, 5 = Average, 9 = Very Hard

*Figure 13: Q5: Compared to Other Parallel and/or Simultaneous Instrument Approaches, Rate the Individual Workload*
4.4.3.6 Average Individual Workload Scores During an Abandonment and/or Missed Approach

Figure 14 depicts the individual workload values generated from an abandonment and/or a missed approach. There was one loss of visual acquisition inside the PFAF scenario that necessitated an approach abandonment. In addition, the B737 simulator pilots executed the missed approach procedure on four different occasions. Overall, unlike previous pilot scores concerning workload during the abandonment, the controllers scored the individual workload during the abandonment/missed approach as low.

![Figure 14: Q6: Level of Individual Workload During an Abandonment and/or Missed Approach for the RNAV Aircraft](image-url)
4.4.3.7 Average Team Workload Scores in Mental Demand

Figure 15 reflects the mental demand as it impacted the team workload. Similar to other workload scores, the mental demand was high on Day 1 and gradually lessened as experience increased. However, the mental demand was the highest of all the workload metrics and indicates that the RPAT operation commensurate with sorting, pairing, and merging is workload intensive from a controller intra-coordination standpoint.

![Figure 15: Q7: Level of Team Workload, From the Standpoint of Mental Demand for an RPAT Operation](image)

5.0 Test Director/Observer/Subject Pilot Observations

Observers noted that the controllers were unable to detect a NSE using ASR-9 data on the STAR displays. Pilots did not detect a NSE until the runways became visible. At this point, pilots disconnected the autopilot and manually corrected for the NSE. As previously stated, there were no bank angle or descent rate TCVs.

Pilot/controller communications between the B737 simulator pilots and controllers were acceptable from an operational point of view. No anomalies were detected. However, the test infrastructure set-up had numerous connectivity issues between the pilot, controllers, and ETG pilots at the beginning of the test series. Recommendations for an improved communications infrastructure are being incorporated for future tests.
6.0 Conclusion

The test looked at a number of RPAT workload issues for pilots and controllers. Primarily, ATC operations linked to pilot operations in a free play, dynamic environment provided a wealth of workload information in particular and RPAT flyability in general. All aircrews stated that flying the RPAT operation was within their capabilities, given their training and experience. Despite the communications infrastructure issues, the controllers also expressed confidence with using the ASR-9 STARS display to effectively sort, pair, and merge the ETG aircraft.

However, subjective feedback from the controllers and observers indicated that there are still a number of issues that need to be resolved in sorting, pairing, and merging aircraft. Chief amongst these issues was the tagging of RNP aircraft, ensuring the Heavy aircraft is the trailing RNP aircraft, and airspeed differentials between the ILS aircraft and RNP aircraft. But all participants noted a steep learning curve on the part of the controllers as they became more familiar with the RPAT operation. Although the data might point to less than optimum performance with separation and operational/procedural standards, many of these deviations may be attributed to the communication limitations with the ETG pilots.

Generally, both the observers, pilots and controllers expressed positive feedback on the operational viability of RPAT operations. Overall workload (mental and physical) for pilots and controllers was on par with current workload during normal approaches.

7.0 Recommendations

1. Develop an RPAT training program for both pilots and controllers.

2. Establish guidelines for RPAT charting including an Aircrew All Users Page.

3. Determine RNP aircraft tagging so as to differentiate RNP/RPAT capable aircraft from other terminal aircraft.

4. Study wake vortex issues in RPAT scenarios (closely spaced operations and aircraft weight categories).

5. Enhance the ETG communication hardware to allow more realistic communications with the controllers.
Appendix A: Memphis STARs

Figure A1: MEM RNAV LARUE Two Arrival
Figure A2: MEM RNAV LTOWN Two Arrival
Figure A3: MEM RNAV TAMMY Two Arrival
Figure A4: MEM RNAV BEERT Two Arrival
Appendix B: Aircrew All Users Page

Aircrew All User Page (DRAFT-TEST PURPOSE ONLY)
MEM RNAV (RNP) RWY 36R

SPECIAL USE OF MEM RNAV (RNP) RWY 36R 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 MEM RNAV (RNP) RWY 36R PFAF. Following the PFAF, the aircrew is responsible for safe separation.

1. **Condensed Briefing Points:**
   - Contact the Tower per ATC instructions
   - **Report** the PFAF position and **ILS traffic in sight**.
   - **Remain on the RNAV approach path** guidance
   - **DO NOT PASS** the ILS traffic.
   - **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**
   - **Approach abandonment** by turning to 045 degrees and climbing immediately to 3000 ft MSL. Contact ATC and expect radar vectors

2. **Breakouts.** All ATC “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 MEM airport is 2000 feet.

   b) **Phraseology – “TRAFFIC ALERT”:** If an aircraft enters the No Transgression Zone (NTZ), the controllers 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 36C, pilots
are authorized to continue past the PFAFR waypoint to align with the 36R
centerline when:

   a) The ILS traffic is in-sight (do not report prior to the PFAFR) and is
      expected to remain in sight, and

   b) Pilots have broadcasted that “traffic is in-sight” by the PFAF.
      ATC is not obligated to respond to this transmission.

If ILS traffic is not in sight, execute approach abandonment at PFAFR by
turning to 045 degrees and climbing immediately to 3000 ft MSL. Once
established at 3000 feet MSL, proceed direct OROCU and hold, 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 away from the RNAV approach path is
necessary for safe separation until landing (DO NOT PASS the ILS
aircraft), and providing wake turbulence avoidance, if applicable. **If
visual contact with the ILS traffic is lost OR the runway is not visually
acquired by CTPTTR, execute the published abandonment procedure
by turning to 045 degrees and climbing immediately to 3000 ft MSL.
Once established at 3000 feet MSL, proceed direct OROCU and hold.
Contact tower as soon as practical.** Note runway centerline spacing
between 36C and 36R is 927 feet.

NOTE: ATC may otherwise direct either aircraft to ensure aircraft separation.
Appendix C: Pilot Post-Run Questionnaire

PILOT
POST-RUN QUESTIONNAIRE

1. In general, compare the **VISUAL segment** of this RPAT procedure to other approaches that you perform (overall level of effort).

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Very Comfortable</th>
<th>Moderately Comfortable</th>
<th>Uncomfortable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>
6. Rate your perceived level of *crew workload* while flying this approach (e.g., thinking, coordinating, searching, communicating, etc.).

<table>
<thead>
<tr>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>
Appendix D: Pilot Post-Simulation Questionnaire

PILOT
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, etc.?

<table>
<thead>
<tr>
<th>Very Safe</th>
<th>Average</th>
<th>Very Unsafe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Very Comfortable</th>
<th>Moderately Comfortable</th>
<th>Uncomfortable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Too Short</th>
<th>Adequate</th>
<th>Too Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>
6. Describe the bank angles required during the visual portion of this RPAT approach procedure.

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

7. Rate the level of overall workload during no autopilot segment of this procedure.

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Moderately Easy</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>
Appendix E: Controller Post-Simulation Questionnaire

CONTROLLER SIMULATION QUESTIONNAIRE (PER PERIOD)

1. In general, compared to actual ARTS displays that you have used, rate the realism of this system’s automation display/voice system.

<table>
<thead>
<tr>
<th>Not Real</th>
<th>Real</th>
<th>Very Real</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

2. Rate your difficulty level in sorting, pairing and merging the ILS and RNAV aircraft during an RPAT operation as compared to normal parallel or simultaneous operations with a coordinator.

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

3. Rate your difficulty level in sorting, pairing and merging the ILS and RNAV aircraft during an RPAT operation as compared to normal parallel or simultaneous operations without a coordinator.

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

4. Rate your overall comfort level in conducting RPAT operations as compared to normal approach operations.

<table>
<thead>
<tr>
<th>Very Comfortable</th>
<th>Moderately Comfortable</th>
<th>Uncomfortable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

5. As compared to other parallel and/or simultaneous instrument approaches, rate the individual workload (pilot and controller coordination and implementation, etc.) for the RPAT operation.

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>
6. Rate your perceived level of **individual workload** during an abandonment and/or missed approach for the RNAV aircraft.

<table>
<thead>
<tr>
<th>Very Easy</th>
<th>Average</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>

7. Rate your perceived level of **team workload**, from the standpoint of mental demand (e.g., looking, searching, thinking, deciding, communicating, etc.) for an RPAT operation.

<table>
<thead>
<tr>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9</td>
</tr>
</tbody>
</table>
Appendix F: Pilot 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: Throughout, but speed differentials would’ve helped situational awareness
   Crew #2: More comfortable doing parallel ops with RNP than others, especially with lateral and vertical guidance
   Crew #3: Comfortable…no problems
   Crew #4: (No comment)

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: NSE created anxiety
   Crew #2: (No comment)
   Crew #3: (No comment)
   Crew #4: (No comment)

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

   Crew #1: High alert level on converging, more head out
   Crew #2: Much heavier workload with autopilot off
   Crew #3: (No comment)
   Crew #4: (No comment)

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: (No comment)
   Crew #2: (No comment)
   Crew #3: Yes, never compromised, even with Autopilot off
   Crew #4: (No comment)
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: (No comment)
   Crew #2: (No comment)
   Crew #3: Use of Autopilot should be encouraged, but not mandatory
   Crew #4: (No comment)

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: (No comment)
   Crew #2: (No comment)
   Crew #3: (No comment)
   Crew #4: (No comment)

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

   Crew #1: Pilot closest to the parallel traffic
   Crew #2: (No comment)
   Crew #3: (No comment)
   Crew #4: Either one, not a big deal

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

   Crew #1: (No comment)
   Crew #2: (No comment)
   Crew #3: In planview with brackets
   Crew #4: (No comment)
Appendix G: Controller 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?

Controller #1
Day 1 Comfort level high because approach no different than others
Day 2 Yes, very similar to ILS approach to Parallel Runways
Day 3 Yes, similar clearance for any other approach
Day 4 (Departed test, no debrief accomplished)

Controller #2
Day 1 Yes, just another approach to vector to
Day 2 Yes, with more experience, it will become easier
Day 3 Yes
Day 4 Yes, similar operation to any other SIAP

Controller #3
Day 1 Yes, under “normal circumstances”
Day 2 Having a sequence RNP on ILS as dependent is difficult.
Day 3 Yes
Day 4 (Departed Test, no debrief accomplished)

Controller #4
Day 1 Yes, we vector to approaches everyday
Day 2 Yes, just another approach
Day 3 Not as much due to increased traffic volume
Day 4 Yes, a vector is a vector

Controller #5
Day 1 Yes, but aiming aircraft at each other is unnatural
Day 2 Yes, although all extraneous issues should be simplified
Day 3 Too many arrivals crossing each other
Day 4 (Departed Test, no debrief accomplished)
2. At the vector to intercept the final, were you in an acceptable position to determine the spacing with the parallel traffic taking into consideration the compression effect? Why or why not?

Controller #1
   Day 1  Yes, position set-up with a display using a smaller scale would create much better operation
   Day 2  Difficult, as the sim aircraft seemed to be much slower for turns and speed reductions compared to ETGs
   Day 3  Yes, expanded the display for better viewing of the final
   Day 4  (Departed Test, no debrief accomplished)

Controller #2
   Day 1  Yes, it would be easier though with an expanded scope
   Day 2  Yes, even though tougher for me on the ILS side due to workload
   Day 3  Yes, hard to continually monitor the final due to other priorities
   Day 4  Yes, more familiar with range display

Controller #3
   Day 1  Yes
   Day 2  Not enough RNP aircraft. Difficult to run consistent spacing with fast (210+) aircraft
   Day 3  Yes
   Day 4  (Departed Test, no debrief accomplished)

Controller #4
   Day 1  Yes, once the finals were full, speeds came back, basic ATC
   Day 2  Yes, we talked between us quite a bit
   Day 3  Yes, but more difficult as volume increased
   Day 4  Yes, past experience

Controller #5
   Day 1  Yes
   Day 2  Yes
   Day 3  Yes
   Day 4  (Departed Test, no debrief accomplished)
3. Is a coordinator necessary to conduct RPAT operations?

Controller #1
Day 1  No, but nice to have and helpful
Day 2  Not until maximum traffic situations
Day 3  No
Day 4  (Departed test, no debrief accomplished)

Controller #2
Day 1  Helpful, but not necessary…more familiarity decreases need
Day 2  Very helpful, especially early in process in gaining experience
Day 3  Helpful, but not necessary
Day 4  During busy traffic pushes…yes

Controller #3
Day 1  If busy, coordinators necessary
Day 2  Situation dependant
Day 3  40-50 aircraft-no. 60-70 aircraft, yes and helpful
Day 4  (Departed Test, no debrief accomplished)

Controller #4
Day 1  Maybe, but with feeders, may not be necessary
Day 2  Could be helpful at times
Day 3  During moderate to heavy traffic, seems to work
Day 4  Sometimes

Controller #5
Day 1  Yes, if planes switched to other runway for flow
Day 2  Yes, especially if there are heavies and non-RNAV
Day 3  Yes, unless volume is low and no heavies
Day 4  (Departed Test, no debrief accomplished)
4. What additional mental or physical requirements, if any, were imposed on you during these parallel approaches?

Controller #1
- Day 1: Only a mental change to limit the amount of information issued to pilots
- Day 2: None
- Day 3: None
- Day 4: (Departed test, no debrief accomplished)

Controller #2
- Day 1: Mental was driven by communication not as real world and adjust instructions
- Day 2: No physical, mental was conditioning to vector aircraft side by side
- Day 3: None
- Day 4: None

Controller #3
- Day 1: With comm. Issues, it was very difficult to concentrate
- Day 2: Coordination was easy, but needed to change because of fast speed issue
- Day 3: Comm=slow response from ghost pilots, give short instructions
- Day 4: (Departed Test, no debrief accomplished)

Controller #4
- Day 1: Lack of timely response on instructions and repeat instructions
- Day 2: Heavy jets added some additional thought process
- Day 3: Numerous heavies and no where to go. Sequence became very difficult
- Day 4: Easier as the week progressed. Still some confusion with heavies

Controller #5
- Day 1: Data tags were constantly overlapping
- Day 2: Added requirements revolve around the need to switch runways
- Day 3: Dealing with everyone on a different page
- Day 4: (Departed Test, no debrief accomplished)
5. What impacted your performance most (i.e., monitoring the parallel traffic, vectoring for the desired spacing, adjusting the speeds for the desired spacing, sorting, pairing, merging)?

Controller #1
Day 1  No problem with monitoring/vectoring, issue with ghost pilot comms
Day 2  Difference between sim and ETG Groundspeed due to the winds
Day 3  ETG did not match the actual aircraft performance; data block needs more space for the ‘H’ symbol; similar sounding call signs.
Day 4  (Departed test, no debrief accomplished)

Controller #2
Day 1  Communication issues and performance of the ghost pilots, no expanded scope
Day 2  Not familiar with equipment, leader lines, hand-offs/automatic working on a smaller scale scope. Feeder concept would of helped
Day 3  RNAV aircraft on proper runway to maintain efficient interval.
Day 4  The ghost pilots

Controller #3
Day 1  Comm problems, caused issues, challenging and more difficult
Day 2  None
Day 3  Comm problems generated from the ghost pilots, smaller instructions
Day 4  (Departed Test, no debrief accomplished)

Controller #4
Day 1  Having to issue single instructions to ghost pilots, lack of timely responses
Day 2  Speeds on the aircraft and if the other arrival controller missed a sopont, workload increased
Day 3  Volume and Heavy (weight) traffic
Day 4  Speed, pairing if one or the other were late

Controller #5
Day 1  Comm issues
Day 2  Lack of SOP’s. One controller thinks one thing and the other something different
Day 3  Sorting the most difficult
Day 4  (Departed Test, no debrief accomplished)
6. Looking at the abandonment procedure…do you anticipate any issues?

Controller #1
Day 1  No
Day 2  No
Day 3  No
Day 4  (Departed test, no debrief accomplished)

Controller #2
Day 1  No
Day 2  No, unless ILS aircraft on a missed approach with tower
Day 3  No
Day 4  No

Controller #3
Day 1  Departures would be a concern
Day 2  Departures, otherwise normal operations
Day 3  Departures
Day 4  (Departed Test, no debrief accomplished)

Controller #4
Day 1  No, but curious how it might impact departures
Day 2  Don’t think so
Day 3  Heavy volume…no where to go
Day 4  Not for what we were doing

Controller #5
Day 1  No
Day 2  No
Day 3  No
Day 4  (Departed Test, no debrief accomplished)
References


