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Safety Study Report on San Francisco International Airport Simultaneous Approach Procedure Utilizing RNP and ILS

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June 2005

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Flight Operations Simulation and Analysis Branch
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Safety Study Report on San Francisco International Airport Simultaneous Approach Procedure Utilizing RNP and ILS

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12. Abstract

Alaska Airlines proposed conducting a special Required Navigational Performance (RNP) Area Navigation (RNAV) approach procedure to SFO Runway 28R with simultaneous operation of the Instrument Landing System (ILS) approach to Runway 28L. This has the potential to increase the airport arrival rate by allowing dual-stream simultaneous operations with weather conditions as low as 1,400 feet and 4 miles visibility. This "Special" procedure requires special aircraft, aircrew, and Air Traffic Control (ATC) personnel training, and will utilize a No Transgression Zone (NTZ) monitored by Airport Surveillance Radar Model 9 (ASR-9). Prior to implementation of the RNP RNAV Z 28R approach, simulation and flight-testing were necessary to assess risk. The Flight Operations Simulation and Analysis Branch, AFS-440, modified its Airspace Simulation and Analysis tool (ASAT) software to perform various Monte Carlo simulations of the SFO RNAV Z 28R approach to assess collision risk. Nine different scenarios were modeled using the ASAT. None of the three scenarios that involved the placement of the MAP in the turn segment met the target level of safety. None of the three scenarios that involved the placement of the MAP at the start of the turn met the target level of safety. The three scenarios that involved placement of the MAP prior to the start of the turn met the target level of safety. The conclusion is that the MAP must be placed prior to the turn in order to meet the target level of safety.

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EXECUTIVE SUMMARY

The San Francisco International Airport (SFO) typically operates two pairs of closely spaced, intersecting parallel runways, one set for arrivals (28L and 28R) and one for departures (1L and 1R). The centerlines of runways 28L and 28R are approximately 750 feet apart, and dual stream arrivals are authorized only during visual meteorological conditions (VMC) with ceilings greater than 3,500 feet. Therefore, when visual approach weather requirements are not met, SFO tower is forced to reduce the 28L/R arrivals to a single runway or utilize staggered approaches to runways 28L and 28R. If arrivals are restricted to a single runway then arrival delays are increased. If parallel arrivals to runways 28L and 28R are staggered, departures from runways 1L and 1R are delayed.

Alaska Airlines proposed conducting a special Required Navigational Performance (RNP) Area Navigation (RNAV) approach procedure to SFO Runway 28R with simultaneous operation of the Instrument Landing System (ILS) approach to Runway 28L (figure 1). This has the potential to increase the airport arrival rate by allowing dual-stream simultaneous operations with weather conditions as low as 1,400 feet and 4 miles visibility. Since the approaching aircraft would be paired, departures from runways 1L and 1R would not be delayed. This "Special" procedure would require special aircraft, aircrew, and Air Traffic Control (ATC) personnel training, and would utilize a No Transgression Zone (NTZ) monitored by Airport Surveillance Radar Model 9 (ASR-9).

Alaska Airlines developed, demonstrated, and received FAA approval for the non-simultaneous operation of the SFO RNAV Z RWY 28R special approach procedure (figure 1). This RNAV Z approach has been operational for a number of months with prior (pre-flight) ATC approval and under certain weather conditions. Alaska Airlines has requested that this approach be approved for simultaneous operations. Alaska Airlines aircraft presently conduct similar company developed RNP RNAV approaches at several airports in Alaska, although under non-parallel/non-simultaneous conditions.

Prior to implementation of simultaneous operations for the RNAV Z approach, the FAA recognized the need to conduct a more detailed technical evaluation to comply with applicable provisions of FAA Order 8260.3B, ***United States Terminal Instrument Procedures*** (TERPS) Volume 3, and FAA Order 8260.49, ***Simultaneous Offset Instrument Approach*** (SOIA). This was essential to ensure that ATC personnel (using ASR-9 radar to detect aircraft excursions into the NTZ) would be able to maintain adequate aircraft separation and meet the target level of safety (TLS). *The target level of safety is the maximum allowable probability of collision.* An operation meets the target level of safety if the probability of collision during the operation is less than the target level of safety.

This RNP approach is unique because of the location of the missed approach point between waypoints LIKEU and HYKAI on the 20-degree converging path of RNAV Z 28R approach

toward traffic on the ILS to Runway 28L and the use of the ASR-9 radar. If an aircraft approaching runway 28L were to blunder at a 30-degree angle to runway 28L toward the aircraft approaching runway 28R while the RNP aircraft was between LIKEU and HYKAI, the blunder would be equivalent to a 50-degree blunder for parallel approach courses. Several studies were conducted by the FAA's Multiple Parallel Approach Program (MPAP) to investigate the probability of a collision caused by a 30-degree blunder during simultaneous independent parallel approaches. The studies concluded that simultaneous independent parallel approaches could be conducted if, among other requirements, a precision runway monitor (PRM) was used for runway spacing less than 4,300 feet. The question is whether an evasion maneuver can be performed such that the probability of a collision meets the target level of safety if a blunder equivalent to a 50-degree blunder should occur while ATC is using an ASR-9 radar for surveillance.

In collaboration with Alaska Airlines, industry, and pilot union officials, the Flight Operations Simulation and Analysis Branch, AFS-440, developed a test plan to collect objective RNP aircraft performance data, subjective aircrew data, and ATC procedural data. The first portion of the evaluation utilized the 0.11 RNP-capable Alaska Airlines B737-700, Level D flight simulator located at the Alaska Airlines Flight Training Facility in Seattle, Washington.

This test and data collection effort took place over 20 days during 4-hour-per-day simulator periods. Approximately 380 separate SFO RNAV Z 28R approaches were performed. After completing the test and data collection, AFS-440 used an extensive computer simulation and analysis to determine whether the approach met the TLS in a simultaneous operational environment.

AFS-440 modified its Airspace Simulation and Analysis tool (ASAT) software to perform various Monte Carlo simulations of the SFO RNAV Z 28R approach to assess collision risk. The AFS-440 team felt that a successful result of this risk evaluation would then lead AFS-440 to address the Air Traffic Control issues and procedures required to conduct simultaneous RNP runway 28R and ILS runway 28L approaches at SFO.

Nine different scenarios were modeled using the ASAT. All three scenarios that involved the placement of the MAP in the turn segment between HYKAI and LIKEU did not meet the target level of safety. In addition, all three scenarios that involved the placement of the MAP just prior to the turn at ZOMUK failed to meet the target level of safety. The three scenarios that involved placement of the MAP between TUNEY and ZOMUK met the target level of safety. The conclusion is that the MAP must be placed prior to the turn in order to meet the target level of safety. In this analysis, a MAP located 0.732 NM prior to ZOMUK resulted in all three RNP levels evaluated, meeting the target level of safety.

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1.0. INTRODUCTION

The San Francisco International Airport (SFO) typically operates two pairs of closely spaced, intersecting parallel runways, one set for arrivals (28L and 28R) and one for departures (1L and 1R). The centerlines of runways 28L and 28R are approximately 750 feet apart and dual stream arrivals are authorized only during visual meteorological conditions (VMC) with ceilings greater than 3,500 feet. Therefore, when visual approach weather requirements are not met, SFO tower is forced to reduce the 28L/R arrivals to a single runway or utilize staggered approaches to runways 28L and 28R. If arrivals are restricted to a single runway then arrivals are delayed. If parallel arrivals to runways 28L and 28R are staggered, departures from runways 1L and 1R are delayed

Alaska Airlines proposed conducting a special Required Navigational Performance (RNP) Area Navigation (RNAV) approach procedure to SFO Runway 28R with simultaneous operation of the Instrument Landing System (ILS) approach to Runway 28L (figure 1). This has the potential to increase the airport arrival rate by allowing dual-stream simultaneous operations with weather conditions as low as 1,400 feet and 4 miles visibility. Since the approaching aircraft would be paired, departures from runways 1L and 1R would not be delayed. This "Special" procedure would require special aircraft, aircrew, and Air Traffic Control (ATC) personnel training, and would utilize a No Transgression Zone (NTZ) monitored by Airport Surveillance Radar Model 9 (ASR-9). An NTZ is a critical area 2,000 feet wide, centered between two instrument approach paths and is shown pictorially on the surveillance radar monitor. If an aircraft enters the NTZ, the monitor controller is required to issue breakout instructions to any threatened aircraft on the adjacent approach.

Alaska Airlines developed, demonstrated, and received FAA approval for the non-simultaneous operation of the SFO RNAV Z RWY 28R special approach procedure (figure 1). This RNAV Z 28R approach has been operational for a number of months with prior (pre-flight) ATC approval and under certain weather conditions. Alaska Airlines has requested that this approach be approved for simultaneous operations. Alaska Airlines aircraft presently conduct similar company developed RNP RNAV approaches at several airports in Alaska, although under non-parallel/non-simultaneous conditions.

In order to reduce the possibility of overshooting the extended centerline of runway 28R, Alaska Airlines required their flight crews to use the runway 28R localizer. Thus, the localizer became required for the aircraft to execute the approach. The glideslope transmitter for runway 28R was turned off during the flight test. The Visual Approach Slope Indicator (VASI) was also illuminated and was used on final approach by some flight crews for vertical guidance instead of the electronic vertical path generated by the Flight Management System (FMS) and was required for the approach.

Prior to implementation of simultaneous operations for the RNAV Z 28R approach, the FAA recognized the need to conduct a more detailed technical evaluation in order to evaluate collision risk with applicable provisions of FAA Order 8260.3B, ***United States Terminal Instrument Procedures (TERPS)*** Volume 3, and FAA Order 8260.49, ***Simultaneous Offset Instrument Approach*** (SOIA).

This was essential to ensure that ATC personnel (using ASR-9 radar to detect aircraft excursions into the NTZ) would be able to maintain adequate aircraft separation and meet the target level of safety (TLS). ***The target level of safety is the maximum allowable probability of collision.*** An operation meets the target level of safety if the probability of collision during the operation is less than the target level of safety.

This RNP approach is unique because of the location of the missed approach point between waypoints LIKEU and HYKAI on the 20-degree converging path of RNAV Z 28R approach toward traffic on the ILS to Runway 28L and the use of the ASR-9 radar. If an aircraft approaching runway 28L were to blunder at a 30-degree angle to runway 28L toward the aircraft approaching runway 28R while the RNP aircraft was between LIKEU and HYKAI, the blunder would be equivalent to a 50-degree blunder for parallel approach courses. A blunder in this case is defined as an aircraft on the runway 28L, ILS approach, turning toward an adjacent aircraft on RWY 28R, during instrument meteorological conditions (IMC), and entering the NTZ.

Several studies were conducted by the FAA's Multiple Parallel Approach Program (MPAP) to investigate the probability of a collision caused by a 30-degree blunder during simultaneous independent parallel approaches. The studies concluded that simultaneous independent parallel approaches could be conducted if, among other requirements, a precision runway monitor (PRM) was used for runway center line spacing less than 4,300 feet. The question is whether an evasion maneuver can be performed such that the probability of a collision meets the target level of safety if a blunder equivalent to a 50-degree blunder should occur while ATC is using an ASR-9 radar for surveillance.

In collaboration with Alaska Airlines, industry, and pilot union officials, the Flight Operations Simulation and Analysis Branch, AFS-440, developed a test plan to collect objective RNP aircraft performance data, subjective aircrew data, and ATC procedural data. The data were collected using an Alaska Airlines B737-700, Level D flight simulator, located at the Alaska Airlines Flight Training Facility in Seattle, Washington. The test and data collection effort required 20 days and produced approximately 380 separate SFO RNAV Z 28R approaches. After completing the test and data collection, AFS-440 modified its Airspace Simulation and Analysis Tool (ASAT) software to perform various Monte Carlo simulations of the SFO RNAV Z 28R approach to assess collision risk. Data from the flight test were used as input in the Monte Carlo simulations.

In a risk analysis of this nature, a TLS is established and the analysis determines an estimate of the risk associated with the operation. If the risk associated with the operation is less than or equal to the TLS, then the operation is considered to be a safe operation.

If the risk associated with the operation is more than the TLS, then the operation is considered unsafe. The risk of an unsafe operation must be reduced to a level less than the TLS in order for the operation to be approved.

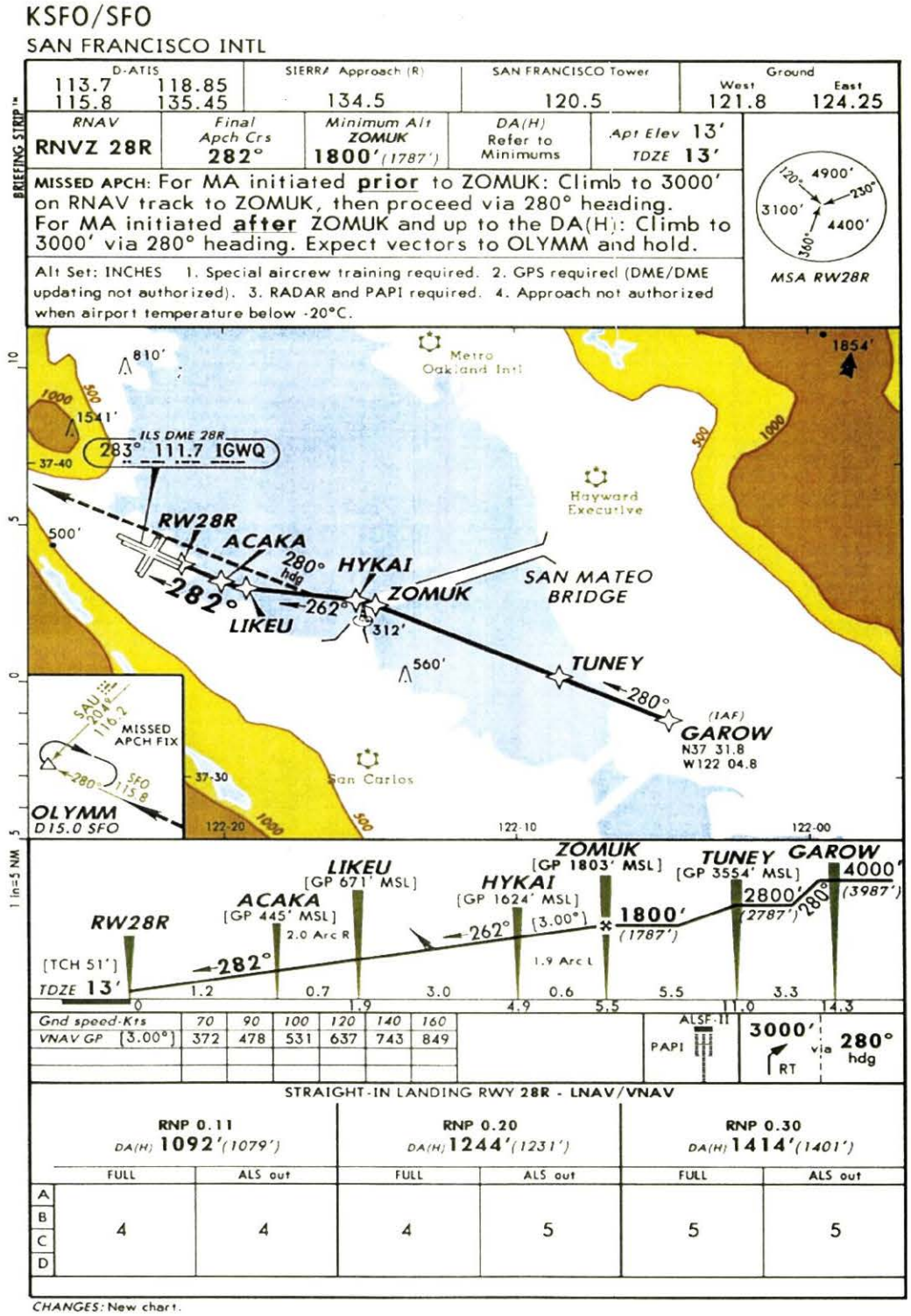

Figure 1. RNP Approach Chart for San Francisco

2.0. FLIGHT SIMULATOR SCENARIO/TEST PLAN OVERVIEW

In order to perform a Monte Carlo simulation to estimate the collision risk, it was necessary to obtain a sufficient quantity of input data such as pilot reaction times and aircraft flight characteristics such as roll rates and climb rates under various flight conditions. These data were obtained from a real-time simulation using flight simulators and line pilots. Eighteen RNAV Z 28R approach flight scenarios were designed and programmed into the Alaska Airlines Level-D, B-737-700 flight simulator. All were easily selected and initiated at the discretion of AFS-440 test personnel. The scenarios were designed to examine the effects of variables deemed appropriate for flight operation at SFO. Weather conditions included four 15-knot crosswinds from separate quadrants and four ceiling and visibility weather conditions. Procedural conditions included three database approach paths, visual landing segments, missed approaches due to poor weather, four ATC-initiated missed approaches termed "Breakout," one induced navigation system malfunction, and 100 foot-high altimeter error.

Of the 18 scenarios, three approaches were conducted without a simulator-induced navigational error and four were conducted with the approach course shifted laterally to the right by 668 feet (the maximum error associated with a 0.11RNP). A navigational error resulting in a position 0.11RNP left of course would be of greatest concern because of the proximity of parallel traffic on the 28L ILS. Therefore, the remaining eleven scenarios were programmed with the approach course shifted laterally to the left by 668 feet.

Twenty, 4-hour simulator periods were scheduled at the Alaska Airlines Flight Training facility that would yield data from approximately 360 approaches. Forty Alaska Airline flight crew personnel from all experience levels were selected and scheduled, including: senior management and check airmen, line Captains/First Officers, and junior First Officers. Some of the junior first officers were in their first year of flying the B-737-700.

To add more realism to the scenarios, the simulation included realistic ATC communication, designed in cooperation with the FAA's Western Pacific Region. Simulated radio traffic provided ATC instructions to the Alaska test flight crew during the final approach. For added realism, simulated radio transmissions from other random aircraft, were provided on the same frequency.

A visual representation of parallel traffic on the RWY 28L ILS was developed and programmed. When the test aircraft descended below the clouds (nominally 1,400 feet), the ILS 28L traffic was programmed to appear well within visual range of the test aircraft (at the 10 O'clock position). To ensure the same relative position on each approach and to compensate for speed vagaries, the adjacent ILS 28L traffic was programmed to begin its approach just prior to the time when the test aircraft would enter visual meteorological conditions.

The one approach that was designed with a 100-foot barometric error equated to a track displacement toward the threshold of approximately 2,000 feet.

Some approaches would require the flight crew to execute a missed approach, while other approaches were terminated prematurely when ATC issued a "breakout" instruction that simulated an ATC monitor controller's response to a "blunder" by the aircraft on the ILS 28L approach.

All RNAV approaches were designed to be flown with the autopilot/flight director in the "ON" position to the 0.11RNP approach minimums of 1,092 feet MSL. At that point, all approaches were flown manually to touchdown. The two pilots alternated approaches similar to actual airline operations. Alaska Airlines officials elected to use the 28R localizer for additional course information during the final approach segment (FAS). The intent of the design mix was to achieve realistic data pertaining to flight crew reaction time, aircraft navigation performance, and ATC communications.

AFS-440 test personnel were not concerned with flight crew adherence to Alaska Airlines' flight operation manual (FOM). Flight crews were provided a "pre-flight" briefing that clearly stated that the primary purpose of the simulated flight test was to collect RNP performance data. Also, the nature and latency of flight crew reaction was considered critical during certain times in the data collection. These events were captured by the AFS-440 Test Director (TD) when applicable. This was accomplished by pressing an "event marker" on the simulator control panel at the same time that ATC issued a breakout, thereby "time-stamping" that event to the objective data stream. These actions, along with 31 other aircraft data sets were captured, recorded on 3½-inch "floppy" disks, and transferred via the Internet to AFS-440 in Oklahoma City using the file transfer protocol (FTP) process.

3.0. SIMULATOR VALIDATION

AFS-440 personnel from Oklahoma City visited the Alaska Airlines Training Center to inspect the simulator and evaluate the data collection and test scenario programming and presentation before the simulator flight test began. The simulator navigational and visual databases were checked to verify accuracy and continuity. Data were taken by positioning the simulator at each end of runway 28R to determine the accuracy of the x, y, and z data points with relation to the visual picture. Preliminary runs were done to capture data that were both recorded on site and transmitted to AFS-440 in Oklahoma City. During this period, each test scenario, with its appropriate weather, wind, and navigation tracks, was programmed into the simulator and could be individually selected by run number by the AFS-440 TD. Test personnel also practiced each "run" and determined the order of the 18 scenarios.

4.0. DATA COLLECTION

Prior to each session, AFS-440 test personnel made an initial briefing to welcome the crews and to explain the purpose and intent of the data collection. The AFS-440 briefing is presented in appendix 4. Alaska Airlines technical pilots then provided a detailed briefing of the RNP RNAV Z RWY 28R approach and cockpit procedures to be used during the data collection, focusing on the Flight Management System and cockpit requirements. Some of the flight crew were familiar with the approach and/or had previously flown the actual non-simultaneous version of it at SFO.

Data collection began as the RNP aircraft (flight simulator) was released from "flight freeze" by the TD, approximately 2 miles outside of TUNEY intersection at 2,800 feet MSL, cleared for the approach, with the autopilot-ON. Data collection continued until landing rollout or aircraft established on missed approach procedure heading and altitude.

Three FAA test personnel were onboard for each session, serving in the following positions: Test Director, Air Traffic Controller, and Human Factors Engineer/Observer. The TD logged all approaches and noted all simulator anomalies.

Scripted ATC radio transmissions were simulated throughout the approach. The transmissions began immediately after the simulator (the test aircraft) was released from flight freeze. The controller notified the RNP test aircraft of traffic on the 28L ILS approach, and requested that the test aircraft report when the traffic was "in-sight." Communications with other aircraft on the approach to 28R were simulated. If the scenario called for test aircraft to enter VMC, i.e., clear of the clouds, the test aircraft was able to report that the ILS 28L traffic was in sight. In some scenarios, the 28L aircraft was not made visible and the test aircraft was forced to execute a missed approach. In some other scenarios, ATC would issue "breakout" instructions.

A "breakout" is a mandatory compliance, ATC-issued instruction that directs an aircraft away from an adjacent aircraft entering the NTZ. During the simulation, ATC directed the RNP aircraft to execute an immediate 60-degree right turn and climb to an altitude of 3,000 feet. This portion of the data collection was used to simulate and collect data during the test aircraft's avoidance maneuver of an aircraft "blundering" off the 28L ILS. Pilot and aircraft reaction times were recorded and were used to calculate the overall blunder response time. The simulated ATC acted from a script and did not use a radar display. Only pilot reaction times were obtained from the real-time simulation.

When the test aircraft reported "traffic in sight," ATC issued a "maintain visual separation" clearance with the parallel ILS 28L traffic. When this transmission was acknowledged, the 28R aircraft was instructed to contact the tower. The flight crew had approximately 25 seconds to report the traffic in sight, receive a visual separation clearance, acknowledge that clearance, and receive and acknowledge a frequency change to the local controller before reaching the 28R missed approach point (MAP) located about 3.3 NM from the runway threshold.

To further evaluate the communication dynamics of the approach, ATC communications to other aircraft were occasionally issued after the test aircraft exited the clouds in a manner that prevented the 28R aircraft from immediately transmitting, further decreasing the time available to receive the required transmissions before the 28R aircraft reached the MAP.

After the aircraft contacted the simulated tower controller, a landing clearance was issued. Other tower transmissions to arriving and departing aircraft were simulated based on the assumption that a single local control frequency was being used (standard for the SFO tower operation). In a similar manner, ATC tower communications to other aircraft were occasionally simulated so that contact with the local controller was delayed until the aircraft was well inside the 28R MAP.

In the flight simulator, crews were given a short human factors questionnaire after each approach. At the conclusion of the entire 4-hour data collection session, the crews were given a more detailed questionnaire and participated in a short, informal debrief with the FAA test personnel. During these sessions, crews were free to express their opinions and make suggestions or comments to FAA test conductors. These post-flight comment periods provided valuable subjective data regarding the communication procedure and the flight crews overall impressions about the proposed approach.

5.0. HUMAN FACTORS ANALYSIS

The Human Factors/Engineering Psychology analysis involved the collection of both subjective and objective data. Subjective performance measures included a post-run questionnaire given after each approach and a post-test questionnaire administered after each respective crew completed the entire simulation.

A multi-dimensional rating procedure was used, geared toward capturing subjective measures of crew sense of realism, perceived comfort level, and perceived level of both individual and crew workload. Given the intrusive nature of any data-gathering procedure of this type, the number of questions was minimized to reduce the time required to complete the questionnaire. A single-page, 6-question form was used. Pilots normally took from 1-3 minutes to complete their responses. Objective crew performance measures were taken as well. This was accomplished through simple observation of pilot/crew performance. Observers were unobtrusively positioned directly behind the pilot stations in the simulator. All flight scenarios were carefully scripted. During those periods in a given flight sequence, when a pilot/crew might be required to perform a task out of the norm, one that was neither expected nor planned, both primary and secondary task completions were monitored. Specifically, during periods of TD-induced heightened activity or workload, reaction times, latency of task completion, or task shedding may have taken place. Those events were observed and recorded.

5.1. SUBJECTIVE QUESTIONNAIRE RESPONSES

Three hundred sixty separate approaches were conducted using 20 different crews. The crews were a mix of management pilots, instructor pilots, and line pilots. Each crew was given two blunder scenarios, requiring them to "breakout" at the appropriate ATC direction.

After each run, both the Pilot-Flying (PF) and Pilot-Not-Flying (PNF) were given a six-question subjective questionnaire (720 total questionnaires). Figures 2 through 7 are graphs illustrating the number of responses by the PF and PNF. The mode or most frequent response to the six questions tended to be "Easy 3" or "Low workload 3." The mode of question 4 that dealt with the comfort of executing a missed approach was a somewhat higher "Moderate 1." A small number of pilots (between 6 and 15) responded "Difficult or Uncomfortable" or "High Workload 1" to every question. A smaller number of pilots (between 0 and 6) responded "Difficult or Uncomfortable" or "High Workload 2" to every question. There were no responses indicating a "Difficult or Uncomfortable" or "High Workload 3."

5.2. OBJECTIVE OBSERVATIONS

Generally, pilots had no difficulty performing this approach in all its phases. In addition, pilots (Captain/First Officer non-specific) responded timely and properly to ATC "breakout" instructions. During times of ATC-induced increased cockpit activity (i.e. during "breakout" or go-around maneuvers), pilot workload increased marginally. That is to say, during those times, pilots were simply required to do more things within the scope of their duties to safely maneuver the aircraft. Tasks such as these that are not specifically monitored for the purpose of this test are termed "Secondary." That does not imply that they are any less important than any other task, just not major observation tasks for this test. Those tasks included, but may not be limited to: disengaging the autopilot, tuning aircraft navaids and/or radios, and verbally responding to ATC instructions. Those tasks that are specifically required for maneuvering the aircraft away from other aircraft are termed "primary" for the purposes of this test.

As part of the evaluation, we observed various pilot techniques and procedures. Standard company operational procedures were normally employed but appeared to vary with different flight crews. For example, when an "RNP Unable" malfunction was induced during the final approach phase, approximately 20 percent of the flight crews attempted to continue the approach by selecting a greater RNP value in the FMS, which required the crew to select a higher missed approach altitude. The simulator sessions were primarily concerned with data collection and not company operational procedures. However, the majority of the flight crews immediately executed a missed approach at the first indication of the malfunction. Note: all approaches of this type eventually resulted in a missed approach due to poor ceiling and visibility conditions.

5.3. PILOT COMMENTS/DEBRIEFING REMARKS

After each crew completed all 18 approaches, a short debriefing to gather crew comments, concerns, and recommendations was conducted. Approximately 75 percent of all crews felt that workload did increase during the time they made the turn to final approach, acquired the parallel traffic on Runway 28L, maintained visual contact with the intended point of landing, and made the appropriate radio call to Approach Control. They did state, however, that this increased workload was not so high that it in any way impaired the crew's ability to perform the approach.

When pilots are aware that another aircraft is on a parallel approach to their own, they will change their scanning pattern during head-outside versus head-inside transitions. Again, this presented no appreciable increase or change in cognitive workload. Some pilots did note that upon visually acquiring the parallel traffic, their perceived level of comfort increased. At that point, pilot visual acquisition remains outside the cockpit and visual scanning workload may actually decrease.

An equally small number of pilots noted that their level of anxiety increased slightly during the 20-degree converging turn towards final, until they had visual acquisition of that aircraft at which time it subsided. A small number of pilots commented that there might be a tendency, during a breakout sequence, to climb first when, in fact, it is more important to turn first.

Both objective and subjective data indicate that comfort level increased greatly with each successive run. Concurrently, a few of the test pilots that have actually flown this approach at San Francisco (without parallel traffic on 28 L) felt completely comfortable during the testing scenario, perhaps more comfortable than those pilots who were flying the scenario for the first time. Crews almost universally agreed that a call indicating "traffic in sight" was not necessary. They preferred to switch frequencies from Approach Control and contact SFO Tower, without having to make the additional call.

Given that blunders and potential breakouts are a relatively rare occurrence, the first of such simulated events might be more representative of how a crew reacts. The "Hawthorne" (testing) effect could very well pre-warn and pre-arm the crews to any subsequent "breakout" scenarios after the first one.

6.0. DATA ANALYSIS

The data analysis team retrieved the data sets from the Alaska Airlines Training Center during July, August, and September 2003 for analysis. The task of the analysis team was to use the test data to assess the safety of the RNP 0.11 approach to San Francisco International Airport runway 28R with adjacent traffic approaching runway 28L under ILS guidance.

In order to assess the safety of this approach, the team performed the following tasks. First, the team categorized the data in order to examine the variables relevant to the performance of the aircraft system during the test scenarios.

Second, the team analyzed the variables in order to use them in high-speed computer simulations of the scenarios. Third, the team set up and ran the high-speed computer simulations of the scenarios to determine what proportion of those runs resulted in potential collisions. Finally, the team analyzed the risk by comparing those proportions to the accepted Target Level of Safety to complete the safety assessment.

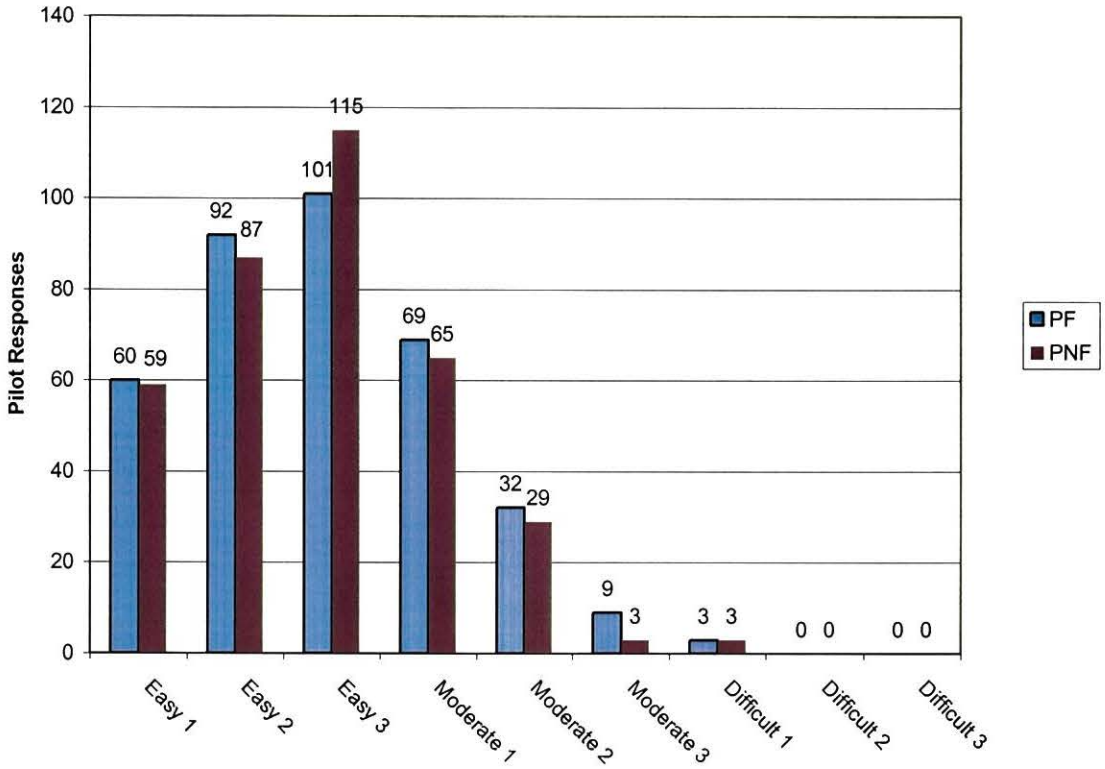

Figure 2. Question 1 – Compared to Other Approaches your Company Performs

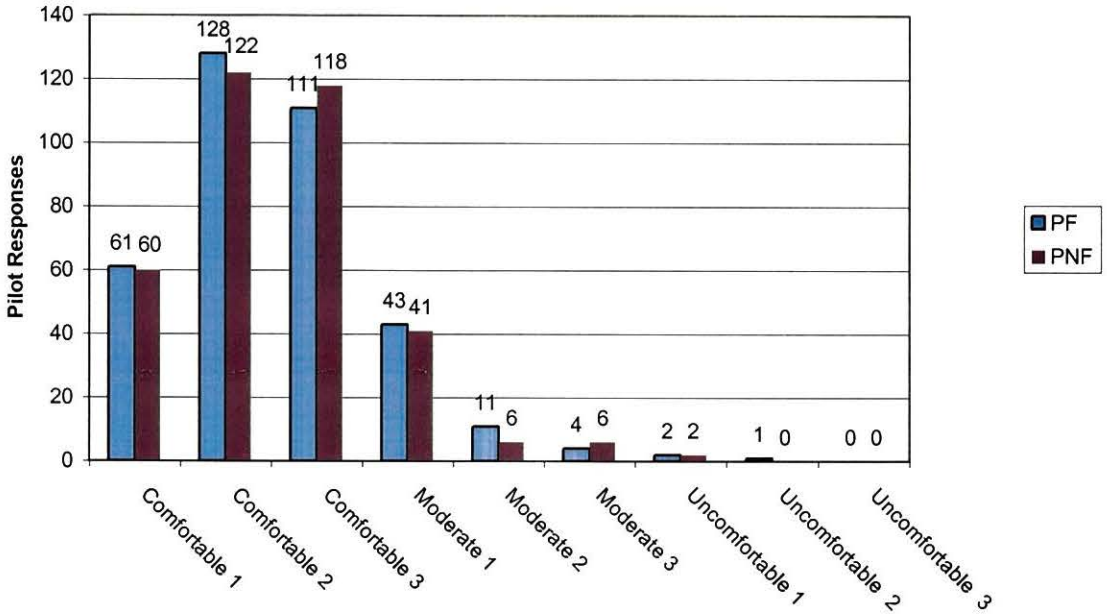

Figure 3. Question 2 - Level of Comfort During IMC Segment

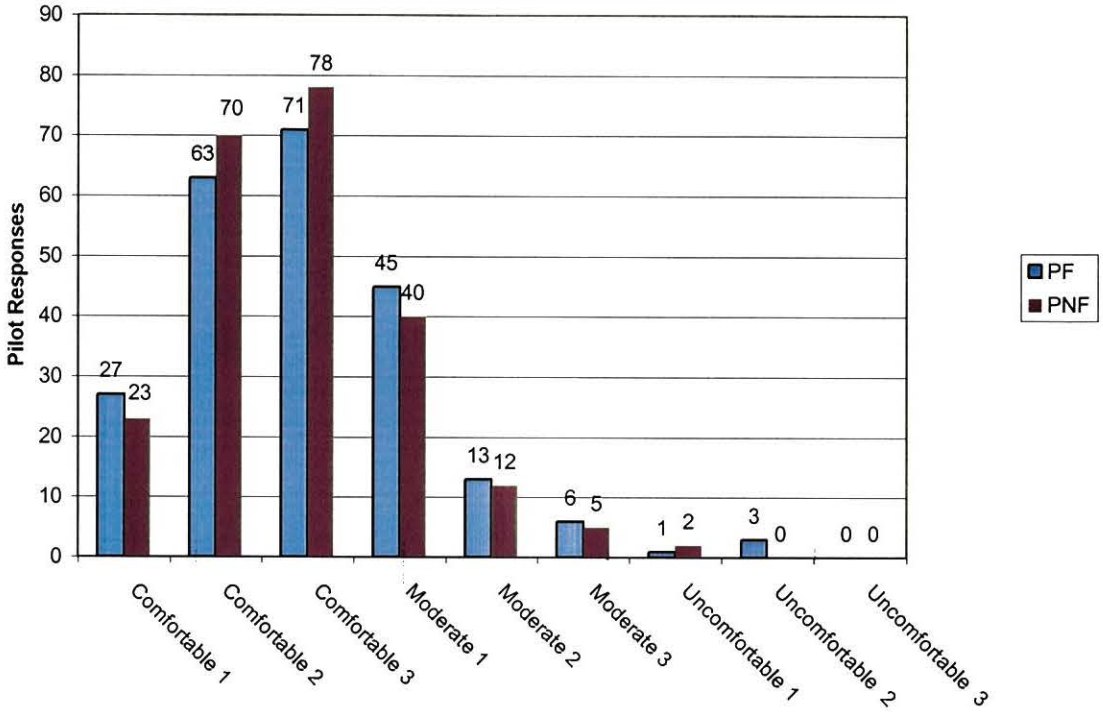

Figure 4. Question 3 - Level of Comfort Transitioning from IMC to Visual

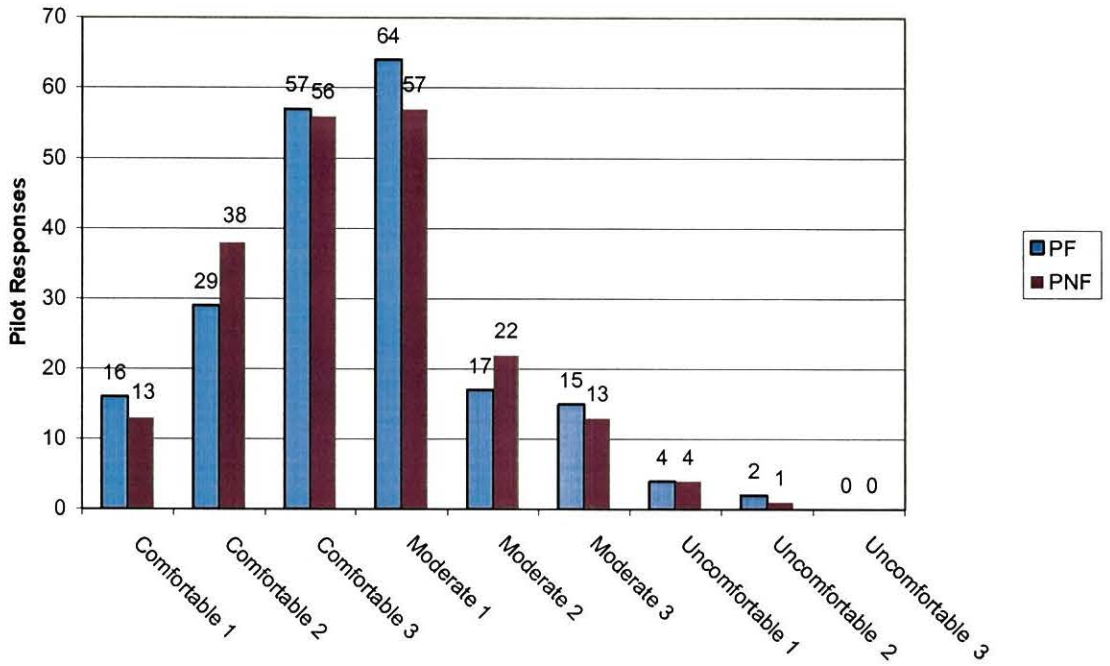

Figure 5. Question 4 - Level of Comfort Executing Missed Approach

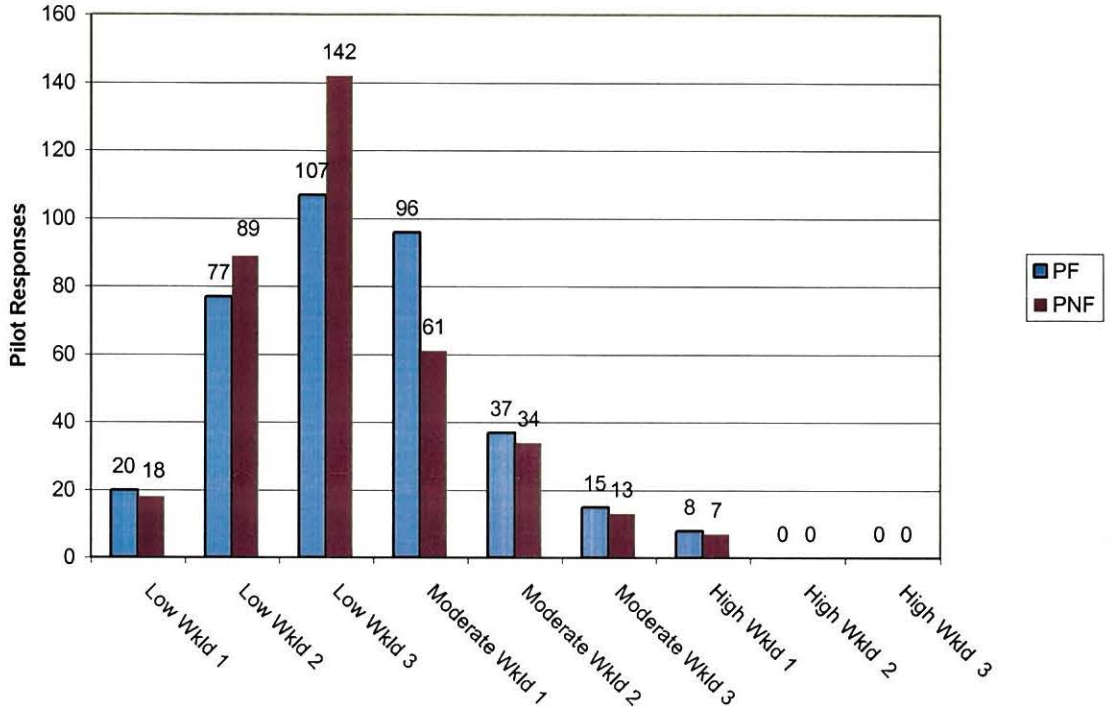

Figure 6. Question 5 - Perceived Individual Workload

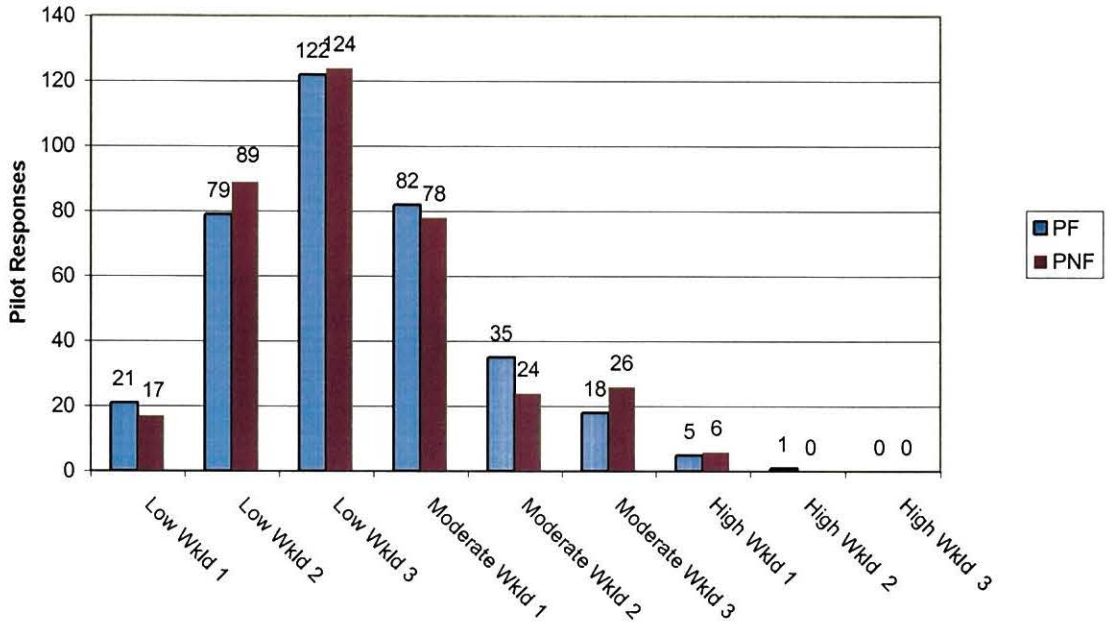

Figure 7. Question 6 - Perceived Crew Workload

6.1. DATA VARIABLES

The analysis team examined the following 31 variables from the test data for each run:

1. Crew number
2. Simulator x coordinate (longitudinal position)
3. Simulator y coordinate (lateral position)
4. Simulator z coordinate (vertical position)
5. Lateral deviation from nominal track
6. Vertical deviation from nominal track
7. Indicated air speed (IAS)
8. Bank
9. Pitch
10. Yaw
11. Magnetic heading
12. Magnetic heading variation
13. Vertical speed
14. Wind direction
15. Wind speed
16. Flap position
17. Brake
18. Gear positions (nose, left, and right)
19. Aileron
20. Elevator
21. Rudder
22. Radio altimeter
23. Pilot
24. VNAV on
25. LNAV on
26. RNP unable
27. Event marker (air traffic controller mike keyed)
28. Latitude
29. Longitude
30. Time
31. ATC response time

Of these variables, the x-y-z coordinates, lateral and vertical deviations from nominal track, and time could be used to determine pilot response times. Also, the bank angle, roll rate, rate of climb, rate of change of climb, and approach IAS could be used along with environmental variables such as wind direction and speed as parameters in the high-speed computer simulation. (Note that roll rate, rate of climb, and rate of change of climb are variables derived from the data.)

6.2. VARIABLE ANALYSIS

The analysis team focused on the critical variables that determine response time and aircraft performance during the evasion maneuver to avoid the blundering aircraft. The team calculated pilot response times from the data in addition to aircraft performance variables.

- ATC: The controller responded immediately once the aircraft was displayed inside the NTZ. This was determined based upon when the next radar scan picked up the blundering aircraft and the radar processing delay time.

- Pilot: The pilot responded to ATC instruction by performing an evasion maneuver that consisted of a simultaneous turn and climb. This was determined by comparing the Event Marker (when the ATC mike was keyed) with the changes in aircraft IAS, position, and aileron configuration. Along with the other data, the critical statistical data used to simulate the flight path of the evading aircraft consisted of the following items (all gathered at the Alaska Airlines flight simulator facility):
    - Bank angle
    - Bank rate
    - Rate of climb
    - Rate of change of rate of climb
    - Approach IAS
    - Combined ATC + Pilot response time

The statistical coefficients describing this data are listed in Table A1 of Appendix 1.

In addition to the test data, the analysis team used the following parameter assumptions for the ATC function:

1. ASR-9 radar with a scanning rate of one revolution every 4.8 Seconds and data latency of 90° (= 4.8 × 90 / 360 = 1.2 Seconds).
2. The controller responded immediately once the aircraft was displayed inside the NTZ.

6.3. OPERATIONAL SET UP AND COMPUTER SIMULATION

Based on the response time, aircraft performance, and environmental data above, the analysis team set up and ran high-speed computer simulations using the ASAT. The study is focused on the segment from ZOMUK, the precision final approach fix (PFAF), to the missed approach point (MAP), determined by decision altitude, between LIKEU and HYKAI, because of the 20-degree converging course. The decision altitude is determined by the RNP value. The decision altitude for RNP 0.11 is 1,092 feet. The decision altitude for RNP 0.2 is 1,244 feet,

and the decision altitude for RNP 0.3 is 1,414 feet. Figure 8 is a screen capture of the ASAT graphics that illustrate the simulation of the RNP approach as proposed by Alaska Airlines. The parallelogram shaped area between the two approaches (shown in black) is the No Transgression Zone.

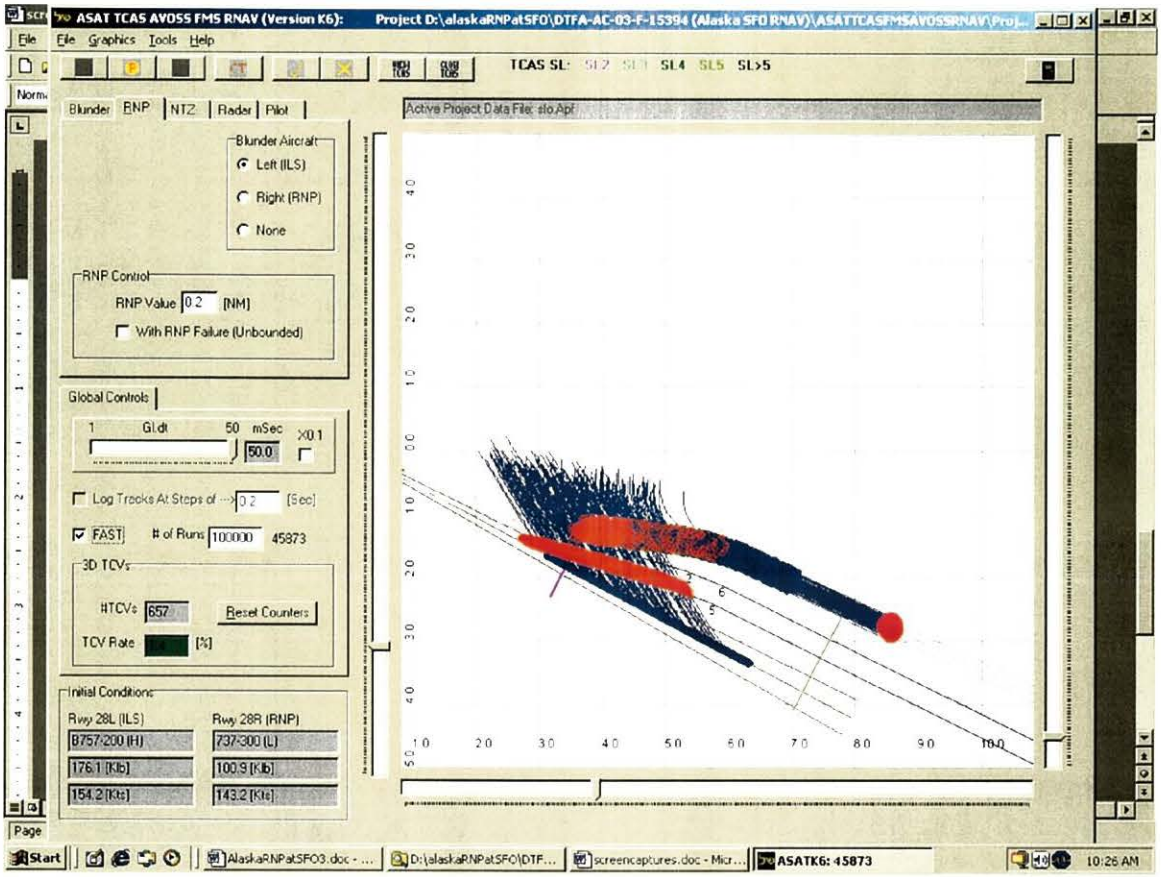

Figure 8. Screen Capture of ASAT Simulation Graphics Showing RNP 0.2

The ASAT modeled a commonly used "blunder scenario," where the aircraft on 28L makes a 30-degree right turn toward the RNP aircraft and does not thereafter alter heading. The blundering aircraft was randomly placed between the abeam point from the MAP of the RNP approach and the abeam point of the PFAF of the RNP approach. The points abeam of the MAP varied because of the different decision altitudes associated with the three different RNP values. After the blundering aircraft was randomly located, the RNP aircraft was randomly placed within a segment, starting abeam the blundering aircraft to as much as one nautical mile in trail of the blundering aircraft. Table 1 summarizes the abeam distances along the ILS approach to runway 28L that defined the random placement of the blundering aircraft.

RNP	Abeam MAP RWY28R Distance from TH RWY28L	Abeam PFAF Distance from TH RWY28L
0.11	3.144 NM	5.297 NM
0.2	3.592 NM	5.297 NM
0.3	4.235 NM	5.297 NM

Table 1. Abeam Distances from Threshold of the Blundering Aircraft

Pilot and aircraft reaction times were extracted from the data obtained during the real-time simulator testing. Since controller reaction time was not available from the real-time simulation, the controller reaction time was assumed to be essentially "zero' or immediate, once the blundering aircraft entered the NTZ.

The ASAT performed each of the three possible scenarios 100,000 times. For each run, the ASAT would select values from distributions of the response time, aircraft performance, and environmental variables determined from the test data and based on the distribution values described in Appendix 1. The team used the following assumptions about these aircraft.

6.3.1. RNP Aircraft Approaching Runway 28R

- In all runs, a Boeing B737 was selected.
- Approach IAS was selected from a given distribution (see Table A1).
- An RNP value of 0.11, 0.2, or 0.3 NM was modeled by randomizing a distance (normal distribution) and an angle (uniform distribution) and computing the North and East shift values for all waypoints for each run.
- The distribution was bounded to 95 percent (1.96 σ) and aircraft system failures such as engine out were not considered.
- The evasion maneuver was performed using a combined turn and climb.
- The aircraft was randomly placed within a pre-determined range from the abeam point of the blundering aircraft approaching 28L.

6.3.2. ILS Aircraft Approaching Runway 28L

- Aircraft types were selected from a traffic mix.
- In all runs, the aircraft executed a 30° blunder to the right.
- The blunders were initiated at the distances from the threshold of runway 28L corresponding to the RNP value as shown in table 1.

- The blundering aircraft did not return to its localizer course, but continued through the approach course for runway 28R.

6.4. TARGET LEVEL OF SAFETY

The target level of safety for multiple parallel approaches was determined by the FAA's Multiple Parallel Approach Program (MPAP). Historic accident data were examined to determine rates at which accidents could occur and not increase the current overall approach accident rate. The TLS was found to be 4×10^{-8}, or one accident per 25 million approaches.

The MPAP conducted real-time and Monte Carlo simulations to determine the probability that two aircrafts' centers of gravity closest point of approach (CPA) would be less than 500 feet following a blunder by one of the affected aircraft. If the CPA of the two centers of gravity was less than 500-feet, a test criterion violation (TCV) was said to have occurred. Although in reality, the occurrence of a TCV does not guarantee a collision will occur; a TCV was treated as a collision.

The MPAP real-time and Monte Carlo simulations were conducted "at-risk." In an at-risk simulation, the two aircraft are positioned such that during a blunder a TCV will occur without timely intervention by the controller and prompt reaction by the pilot of the evading aircraft. Blunders were initiated at random positions along the glide path from the final approach fix to the missed approach point. The in-trail distance between aircraft flying the same glide path was assumed to be 3.0 NM. This assumption meant that in actual operations the evading aircraft would be located within a ±1.5 NM range of the abeam position of blundering aircraft at the start of the blunder and the probability of an at-risk alignment would only be 0.06. The MPAP determined that dual parallel approaches would meet the TLS with simulated aircraft positioned at-risk and at random from the FAF to the MAP if the TCV rate did not exceed 6.8 percent.

This study was focused on the turn segment from ZOMUK to the missed approach point located between HYKAI and LIKEU. The evading aircraft was not placed at-risk as in the MPAP simulations. Therefore, the acceptable TCV rate must be adjusted to reflect the 0.06 probability of being at-risk. This is done by multiplying the 6.8 percent TCV rate by 0.06. The resulting maximum acceptable TCV rate to meet the target level of safety is 0.4 percent. Therefore, to meet the target level of safety, the TCV rate must not be greater than 0.4 percent.

The TCV rates obtained from the simulation are produced by a random process and successive replications of the simulation will result in somewhat different rates. A range of possible variation of the TCV rate can be found by computing a confidence interval from the observed rate. The derivation of the confidence intervals is explained in Appendix 2. Ninety nine percent confidence intervals for the TCV rates were computed to diminish the uncertainty of the TCV rates. The probability that the actual TCV rate is contained by the ninety nine percent confidence interval is 0.99. If the upper limit of the ninety nine percent confidence interval is greater than the observed

TCV rate, then the TCV rate may exceed the target level of safety. Therefore, in order to meet the target level of safety, the upper bound of the confidence interval must be less than 0.4 percent.

6.5. RISK ANALYSIS

The simulations of the three scenarios were performed 100,000 times each. The resulting TCV rates are summarized in table 2. Each of the lower bounds of the confidence intervals is greater than the maximum allowable TCV rate. For convenience, the maximum allowable TCV rates are also listed in the tables. Since none of the upper bounds of the confidence intervals is less than 0.4 percent, the conclusion is that none of the three scenarios meets the target level of safety.

RNP	Max Allowable TCV Rate	Observed TCV Rate	Lower Bound 99% Confidence Interval	Upper Bound 99% Confidence Interval	Meets TLS?
0.11 NM	0.4%	1.5%	1.36%	1.55%	No
0.2 NM	0.4%	1.4%	1.31%	1.50%	No
0.3 NM	0.4%	1.5%	1.43%	1.63%	No

Table 2. TCV Rates and Confidence Intervals with MAP between LIKEU and HYKAI

6.5.1. Risk Analysis with MAP Located at ZOMUK

In the original RNP approach proposed by Alaska Airlines, the MAPs for each RNP level, 0.11, 0.2, and 0.3, were located in the turn segment from HYKAI to ACAKA. The analysis above indicated that the target level of safety is not met when the MAP is located in the turn segment. Additional scenarios were designed in which the MAP was located on the segment from TUNEY to ZOMUK, with the MAP located nearest ZOMUK. In the first group of three scenarios, the MAP point was set to coincide with ZOMUK. In this case, it was found that in a significant number of runs the evading aircraft entered the turn segment before the evasion maneuver command was issued by ATC. The result was that the target level of safety was not met using any of the three RNP values. The results of the three simulations are summarized in table 3.

RNP	Max Allowable TCV Rate	Observed TCV Rate	Lower Bound 99% Confidence Interval	Upper Bound 99% Confidence Interval	Meets TLS?
0.11 NM	0.4%	0.4%	0.35%	0.46%	No
0.2 NM	0.4%	0.47%	0.42%	0.53%	No
0.3 NM	0.4%	0.6%	0.55%	0.68%	No

Table 3. TCV Rates and Confidence Intervals with MAP at ZOMUK

6.5.2. Risk Analysis with MAP Located Between ZOMUK and TUNEY

In this group of three scenarios, the MAP was placed 0.732 NM from ZOMUK between ZOMUK and TUNEY. The simulation indicated that the target level of safety was met for each of the three RNP levels. The results are summarized in table 4.

RNP	Max Allowable TCV Rate	Observed TCV Rate	Lower Bound 99% Confidence Interval	Upper Bound 99% Confidence Interval	Meets TLS?
0.11 NM	0.4%	0.18%	0.14%	0.21%	Yes
0.2 NM	0.4%	0.2%	0.17%	0.24%	Yes
0.3 NM	0.4%	0.3%	0.26%	0.36%	Yes

Table 4. TCV Rates and Confidence Intervals with MAP between ZOMUK and TUNEY

7.0. CONCLUSION

Table 2 shows that the RNP approach proposed by Alaska Airlines does not meet the target level of safety for any of the RNP values. The course defined by the waypoints HYKAI and LIKEU converges with the ILS course to runway 28L at a 20-degree angle. The simulated blunders were directed from the ILS course toward traffic on the RNP approach at a 30-degree angle. The result is an effective 50-degree blunder angle. The combination of pilot reaction time, controller reaction time, and aircraft flight dynamics does not reliably provide for the successful resolution of blunders from the ILS approach to runway 28L toward the RNP approach on 28R.

Table 3 indicates that the target level of safety is not met if the MAP coincides with ZOMUK. In this case, some blunders could occur when the RNP aircraft is very near the MAP. The result is that the RNP aircraft could enter the turn segment before an evasion maneuver command is issued by ATC.

Table 4 indicates that the target level of safety is met if the MAP is located 0.732 NM from ZOMUK between ZOMUK and TUNEY. In this case, the RNP aircraft could not enter the turn segment before an evasion maneuver command is issued by ATC.

The results of the simulation indicate that the MAP cannot be located such that the evading aircraft flying the RNP approach to runway 28R can enter the turn segment prior to action by ATC. The resultant 50-degree blunder angle cannot be reliably resolved by the combined actions of ATC and the pilot.

APPENDIX 1.

Table A-1 describes some of the parameters used in the ASAT simulation.

Variable [Units]	Mean	Minimum	Maximum	Standard Deviation
Nominal Bank Angle [Deg]	24.99	19.00	32.00	3.71
Nominal Climb Rate [FPM]	1779.05	850.00	3300.00	560.24
Bank Rate [Deg/Sec]	3.91	1.05	7.25	1.62
ROC rate [Ft/Sec/Sec]	251.34	99.50	483.33	97.41
Overall Response Time[Sec]	2.74	0.53	9.06	1.48
Approach IAS [KIAS]	143.69	141.97	152.78	1.86

Table A-1. Parameter Values Used in the ASAT Simulation

The analysis used these parameters along with other values captured during the testing to model the behavior of the aircraft in the ASAT simulations.

APPENDIX 2.

This appendix describes the derivation of the confidence interval for the TCV rate in section 6.5.

The TCV rate may be modeled as a Bernoulli process. In a Bernoulli process there are only two outcomes usually called "success" and "failure." In this case, a simulated run with no TCV could be called a success and a simulated run with a TCV could be called a failure. If p is the probability of a failure during one simulated flight and $(1 - p)$ is the probability of a success during the same simulated flight, then the probability of having exactly x failures during n simulated runs is given by:

$$P(X = x) = C_{n,x} p^x (1-p)^{n-x},$$

where $C_{n,x}$ is the number of combinations of n things chosen x at a time.

Sometimes in an experiment such as flipping a coin or rolling a die, the value of p is known from the physical aspects of the experiment. However, in the scenarios investigated in this report, the value of p is unknown and we are using the TCV rate to estimate the value of p. The TCV rate is simply the ratio of TCVs to the number of runs. In the case of the RNP 0.11 scenario proposed by Alaska Airlines, the TCV rate is the ratio of 1,452 TCVs to 100,000 runs or 1.452 percent TCVs. Therefore, our estimate of the actual probability p is $p = 0.01452$.

If we ran another 100,000 runs then we expect the estimated value of p to be somewhat different from the first value, $p = 0.01452$. Therefore, we could ask the question "How accurate is our estimate of the true value of p?" The Bernoulli model gives an answer to that question in terms of a confidence interval, in this case a 99 percent confidence interval.

The probability that the actual probability p lies within a 99 percent confidence interval is 0.99. This means that if the experiment was performed 100 times we would expect to get 100 different TCV rates. Since a confidence interval is computed from the rate obtained from the experiment, we would expect to compute 100 different confidence intervals. Ninety-nine of the confidence intervals would be expected to contain the true or actual TCV rate.

To develop the confidence interval for the TCV rate we observed we must calculate the lower bound and the upper bound of the confidence interval. The lower bound is calculated from the formula:

$$\sum_{y=0}^{k} C_{n,y} p^y (1-p)^{n-y} = 0.005,$$

where k is the number of TCVs (1452 in this case), n is the number of runs (100,000 here), and p is the confidence interval lower bound that we seek. Solving this numerically for p, we get p = 0.0136 (or 1.36 percent).

The upper bound is calculated from a similar formula:

$$\sum_{y=k}^{n} C_{n,y} q^{y} (1-q)^{n-y} = 0.005,$$

where q is the confidence interval upper bound that we seek. Solving this numerically for q, we get q = 0.0155 (or 1.55 percent).

Combining the two confidence bounds, we can say that the probability is 0.99 that the true value of p is between 0.0136 and 0.0155.

APPENDIX 3.

This appendix summarizes the flight scenarios used in the flight test segment of the study.

Prior to each flight simulator approach, the crew was handed a sheet representing the current report of the Automated Terminal Information Service (ATIS). Four different ATIS reports were used in the simulation. They were designated Alpha 1, Alpha 2, Alpha 3, and Alpha 4. The ATIS reports are as follows.

ALPHA – 1

CEILING	1,400 FT
VISIBILITY	4 SM
WIND	215°/15 KT
ALTIMETER	29.92 IN
TEMPERATURE	32
DEW POINT	27

SIMULTANEOUS APPROACHES IN
PROGRESS TO RUNWAY 28L
ILS 28R GLIDESLOPE OTS

ALPHA – 2

CEILING	1,400 FT
VISIBILITY	4 SM
WIND	305°/15 KT
ALTIMETER	29.92 IN
TEMPERATURE	32
DEW POINT	27

SIMULTANEOUS APPROACHES IN
PROGRESS TO RUNWAY 28L
ILS 28R GLIDESLOPE OTS

ALPHA – 3

CEILING	1,400 FT
VISIBILITY	4 SM
WIND	125°/15 KT
ALTIMETER	29.92 IN
TEMPERATURE	32
DEW POINT	27

SIMULTANEOUS APPROACHES IN
PROGRESS TO RUNWAY 28L
ILS 28R GLIDESLOPE OTS

ALPHA – 4

CEILING	1,400 FT
VISIBILITY	4 SM
WIND	035°/15 KT
ALTIMETER	29.92 IN
TEMPERATURE	32
DEW POINT	27

SIMULTANEOUS APPROACHES IN
PROGRESS TO RUNWAY 28L
ILS 28R GLIDESLOPE OTS

Table A-2 summarizes the test flight scenarios. The RNP level for each scenario was 0.11 NM. In fifteen of the scenarios, a simulated navigation system error (NSE) was induced by shifting the missed approach point left or right to the RNP limit 0.11 NM. A transponder code was included to indicate the scenario number. In four of the scenarios, the simulated weather was lowered to 0 ceiling and 0 visibility to force a missed approach. All runs were provided with a dusk visual scene and a 5 percent turbulence level.

Scenario Number	Shifted NSE	Normal or Unable RNP	Transponder Code	Crew WX	Sim WX	Event
1	0	Normal	1210	Alpha 2	Alpha	Landing
2	0	Normal	1310	Alpha 3	Alpha	Landing
3	0	Normal	1410	Alpha 4	Alpha	Landing
4	0.11L	Normal	2310	Alpha 3	Alpha	Landing
5	0.11L	Normal	2410	Alpha 4	Alpha	Landing
6	0.11L	+Vert Bias**	4422	Alpha 4	Alpha	Landing
7	0.11R	Normal	3310	Alpha 3	Alpha	Landing
8	0.11R	Normal	3410	Alpha 4	Alpha	Landing
9	0.11L	Normal	2140	Alpha 1	0/0	Missed
10	0.11L	Normal	2340	Alpha 3	0/0	Missed
11	0.11L	Normal	2440	Alpha 4	0/0	Missed
12	0.11R	Normal	3340	Alpha 3	0/0	Missed
13	0.11R	Normal	3440	Alpha 4	0/0	Missed
14	0.11L	Normal	2360	Alpha 3	Alpha	Break Out
15	0.11L	Normal	2460	Alpha 4	Alpha	Break Out
16	0.11L	Unable RNP*	2371	Alpha 3	Alpha	Missed
17	0.11L	Unable RNP*	2471	Alpha 4	Alpha	Missed
18	0.11L	+Vert Bias**	4450	Alpha 4	0/0	Missed

Table A-2. Test Flight Scenarios

* Unable RNP fault to occur at 1,600 FT MSL.

** Runs require simulator altimeter system reset to 30.02 IN altimeter setting.

APPENDIX 4.

PILOT BRIEFING

Good morning/afternoon/evening, I am _____, from the FAA Flight Procedure Standards Branch, Oklahoma City, OK. I will be serving as the TD for this simulator period.

With greater emphasis on improving efficiency within the National Airspace Systems, the FAA is evaluating several flight procedures that may result in greater capacity at many of our more congested airports.

Today you will fly the SFO RNP RNAV 28R approach down to RNP.11 minimums. Your initial position will be inbound approximately 2-3 miles outside of TUNEY, direct TUNEY and cleared for the approach. Please fly the approach with the HUD off, Autopilot/Flight Director engaged, or as your company flight procedures direct. In support of this evaluation, the manufacturer at the request of Alaska Airlines has altered the FMC database.

Weight and fuel will be frozen at the maximum landing weight of 129,200 pounds. Altimeter setting will be 29.92" Hg and the surface temperature will be 90° F/32° C. The simulator will be released with appropriate speed and flaps for the aircraft and with the gear up. All checklists (except for final landing checklist) are presumed to be completed. You should verify that the aircraft configuration agrees with these conditions. ATIS information will be provided before each run. The visual scene selected for this evaluation is Dusk.

This IS NOT an Airman examination. This session IS a no-jeopardy evaluation from the perspective of the pilot. We are here to evaluate the safety aspects of this approach procedure. You may observe us taking notes or discussing various issues, this is in regard to the approach procedure and will in no way evaluate any performance factors.

Please complete the questionnaires that will be provided after each run and upon completion of the simulator session. They are intended to capture your thoughts concerning various dimensions of the approach and are designed to be as non-intrusive as possible.

What are your questions, if any, at this time?