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Evaluation of Two High-Speed Runway Exits

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September 1991
Interim Report
DOT/FAA/CT-TN91/36

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN91/36		

4. Title and Subtitle	5. Report Date
EVALUATION OF TWO HIGH-SPEED RUNWAY EXITS	September 1991
	6. Performing Organization Code
7. Author(s) Rick Marinelli	8. Performing Organization Report No. DOT/FAA/CT-TN91/36
9. Performing Organization Name and Address Federal Aviation Administraton Technical Center Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, NJ 08405	13. Type of Report and Period Covered Interim Report
	14. Sponsoring Agency Code ACD-110

15. Supplementary Notes

16. Abstract

This study evaluated the effect of proposed changes in runway exit geometry and lighting on runway occupancy time. Testing was conducted using a Boeing 727-200 simulator and a Boeing 727-100 aircraft. Subject pilots performed landings to runways equipped with the standard-design and the alternative-design exits. Exit speed was found to be affected most by pilot technique, with no advantage offered by the alternative design. Subjective evaluations by 12 pilots indicated a general preference for the standard-design exit.

17. Key Words	18. Distribution Statement
Runway Exits Airport Design Runway Occupancy Time	Document is on file at the Technical Center Library, Atlantic City International Airport, New Jersey 08405

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

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

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EXECUTIVE SUMMARY

This study evaluated the effect of an alternate-design, acute angle runway exit on runway occupancy time. The alternate-design exit, termed a "wide-throat" exit by its designers, differs from the FAA-standard acute angle exit in pavement geometry and lighting. Testing was conducted using a Boeing 727-200 simulator and a Boeing 727-100 aircraft. Twelve subject pilots performed landings to runways equipped with the two exits. Runway occupancy time and exit speed were recorded. Exit speeds were highly variable, indicating that results were strongly affected by pilot technique. Exit speed was found to be affected most by pilot technique, with no advantage offered by the alternative design. Actual runway exit speeds should be recorded to confirm this conclusion. Subjective evaluations by the subject pilots indicated a general preference for the standard-design exit. Deficiencies in the simulation of aircraft ground-handling require modifications to the simulator and additional testing.

INTRODUCTION

BACKGROUND.

Airport congestion and delays affect millions of air travelers in the United States every year. The rapid growth in demand for air travel combined with the almost unchanging number of air carrier runways indicates that the situation will become more severe in the future. One way to mitigate this problem is to allow more airplanes to use a runway in a given amount of time.

Only one aircraft can use, or "occupy," a runway at a time. The amount of time an aircraft has exclusive use of a runway is known as the runway occupancy time or (ROT). Barring other factors, a reduction in average ROT time will increase the capacity of a runway. One way to reduce ROT is to allow landing aircraft to maintain higher speeds while negotiating a runway exit. This is generally accomplished by the construction of FAA-standard long-length, spiral runway exits (figure 1). Alternative designs that may allow aircraft to turn off at even higher speeds have been proposed.

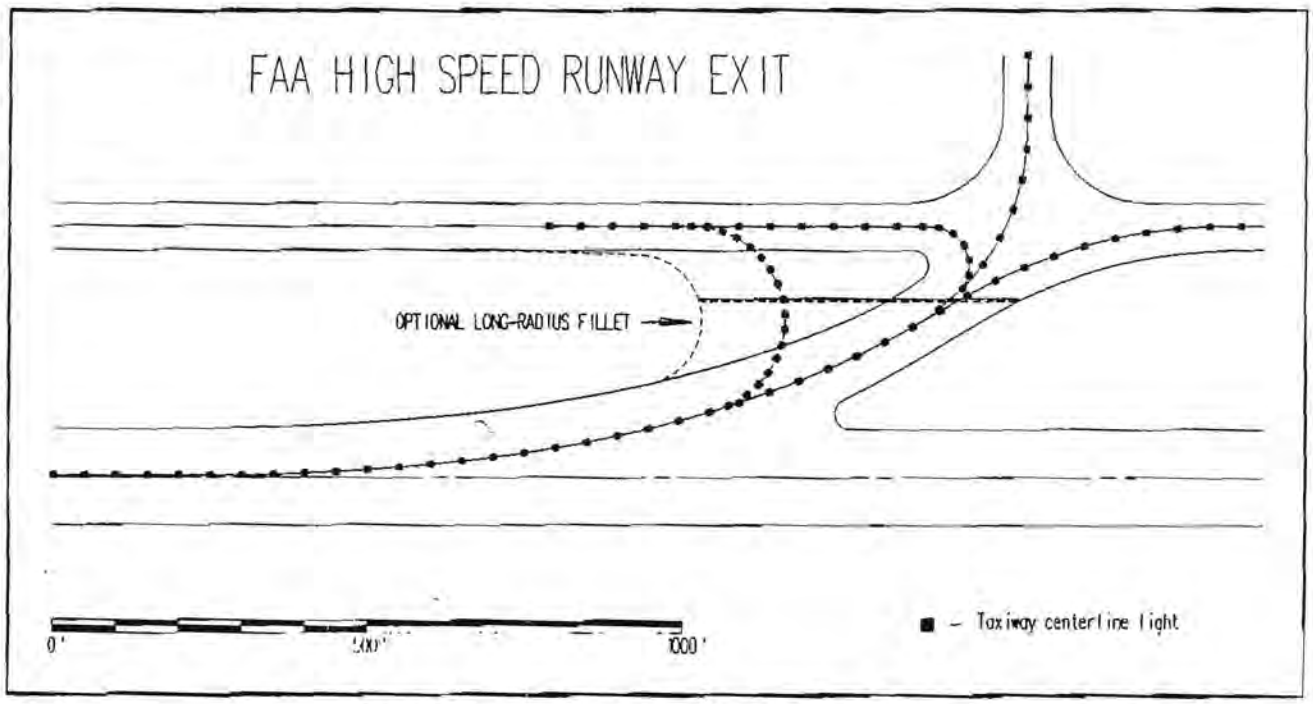


FIGURE 1. FAA HIGH-SPEED RUNWAY EXIT

OBJECTIVE.

Runway exits of an alternative design have been built at Miami International Airport, Orlando International Airport, and Baltimore-Washington International Airport. If runway exits of this design allow pilots to maintain higher exit speeds, runway occupancy time will decrease. This configuration, incorporating modifications to pavement geometry and in-pavement lighting, has been termed the "wide-throat" high-speed runway exit (figure 2). This

evaluation was conducted to determine if the installation of the alternative runway exit will result in a reduction in ROT.

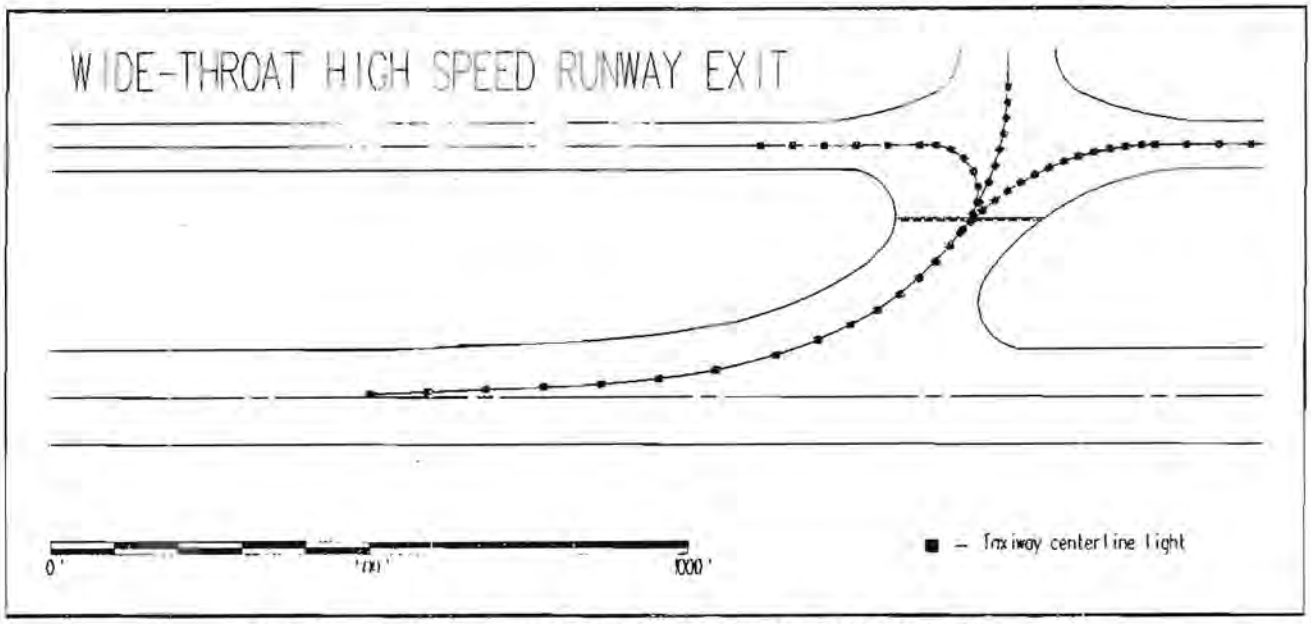


FIGURE 2. WIDE-THROAT HIGH-SPEED RUNWAY EXIT

SCOPE.

This study was performed to evaluate the effect of proposed changes in runway exit geometry and lighting on runway occupancy time. This was accomplished by measuring runway exit speeds and runway occupancy times corresponding to the use of each exit, using a Boeing 727-200 simulator and a Boeing 727-100 aircraft. Subject pilots included FAA Technical Center test pilots and active commercial airline pilots.

TEST PROCEDURE

PHASE I SIMULATOR TESTS.

Runway 17 at Orlando International Airport was modeled on the Boeing 727-200 simulator at the FAA Aeronautical Center in Oklahoma City, Oklahoma. The first exit centerline light was located at a point 5500 feet from the runway threshold. The exit centerline thus crossed the runway hold line approximately 6000 feet from the runway threshold. The same runway was then modeled substituting the standard exit for the actual exit. The standard exit was located such that the exit centerline crossed the runway hold line at the same distance from runway threshold.

Tests were conducted with the simulator set to three different aircraft landing weights; minimum, maximum, and mid-range. Approach speeds corresponded to landing weights as noted in the operating manual for the

Boeing-727-200. Tests were conducted under night conditions; the simulator does not simulate daylight conditions. All exits were to the left of the pilot. Winds were set to calm.

Landing Weight	Aircraft Groundspeed
110,000 Lbs.	115 Knots
125,000 Lbs.	135 Knots
140,000 Lbs.	145 Knots

Parameters recorded included the following:

Heading
Groundspeed
XYZ coordinates relative to runway threshold
XYZ speeds
XYZ accelerations
Wheels on ground

The test plan called for each pilot to execute three landings to each exit under each of the three aircraft configurations. Subject pilots were allowed as much practice as needed to become familiar with the simulator and the two exits.

PHASE II SIMULATOR TESTS.

Runway exits were to be located at varying distances from runway threshold. This would determine if the alternative-design exit would allow a reduction in ROT by permitting installation of the runway exit closer to the runway threshold. This phase was not performed (see Discussion).

PHASE III FULL-SCALE TESTS.

Full-scale tests were performed to compare the accelerations and landing gear loads recorded in simulator testing to those found using an actual aircraft. These tests were conducted with the FAA Technical Center's Boeing 727-100 equipped with an Automated Airborne Data Collection System. The data collection system recorded the following aircraft parameters:

Heading
Ground speed
XYZ accelerations

Also recorded were event signals activated by the cockpit observer. Event signals were triggered at threshold crossing and runway clearance. Landing weights and wind velocities were recorded manually.

Tests were conducted at Orlando International Airport (MCO) (figure 3), where runway 17-35 is equipped with the alternative-design exit; and Washington-Dulles International Airport (IAD) (figure 4), where runways are equipped with FAA-standard exits. At MCO, pilots were instructed to use the first exit whenever possible. On IAD runways, the second exit is nearest in location to the first runway exit at MCO. Pilots were instructed to use the second exit even if it was possible to turn off safely at the first exit.

The test plan called for each pilot to execute three daylight and three night landings to each exit. Exit turns were to be to the left whenever possible.

GENERAL.

The purpose of the project was explained to subject pilots. To simulate a condition in which the runway was in use at maximum capacity, pilots were instructed to proceed as if requested by air traffic controllers to "expedite clearing the runway." They were to assume the aircraft was carrying passengers and to avoid extraordinary maneuvers.

To eliminate bias, runway exits were identified to pilots by nondescriptive terms (Exit 1 and Exit 2). The order of the tests was varied among pilots.

Pilots were asked to complete a questionnaire after completion of tests. The questionnaire allowed for a subjective evaluation of the two exits. A subjective evaluation of the in-pavement lighting of each exit was performed by FAA Technical Center airport lighting engineers who are also licensed pilots.

EVALUATION PROCEDURE

SIMULATOR TESTS.

The position of the aircraft with respect to the runway threshold and centerline was recorded by the simulator computer every 0.5 seconds. Also recorded was the yaw angle of the aircraft. From this information, along with knowledge of the aircraft's physical characteristics, the position of the wing-tip and elevator was calculated. When both of these points are beyond the runway edge line (75 feet from centerline), the aircraft is considered clear of the runway. (While an aircraft in this position would be struck by the wing of a Boeing 747 rolling down the centerline of the runway, this is the definition used in airport capacity studies.) The time between the aircraft crossing the runway threshold and the time it is clear is the runway occupancy time.

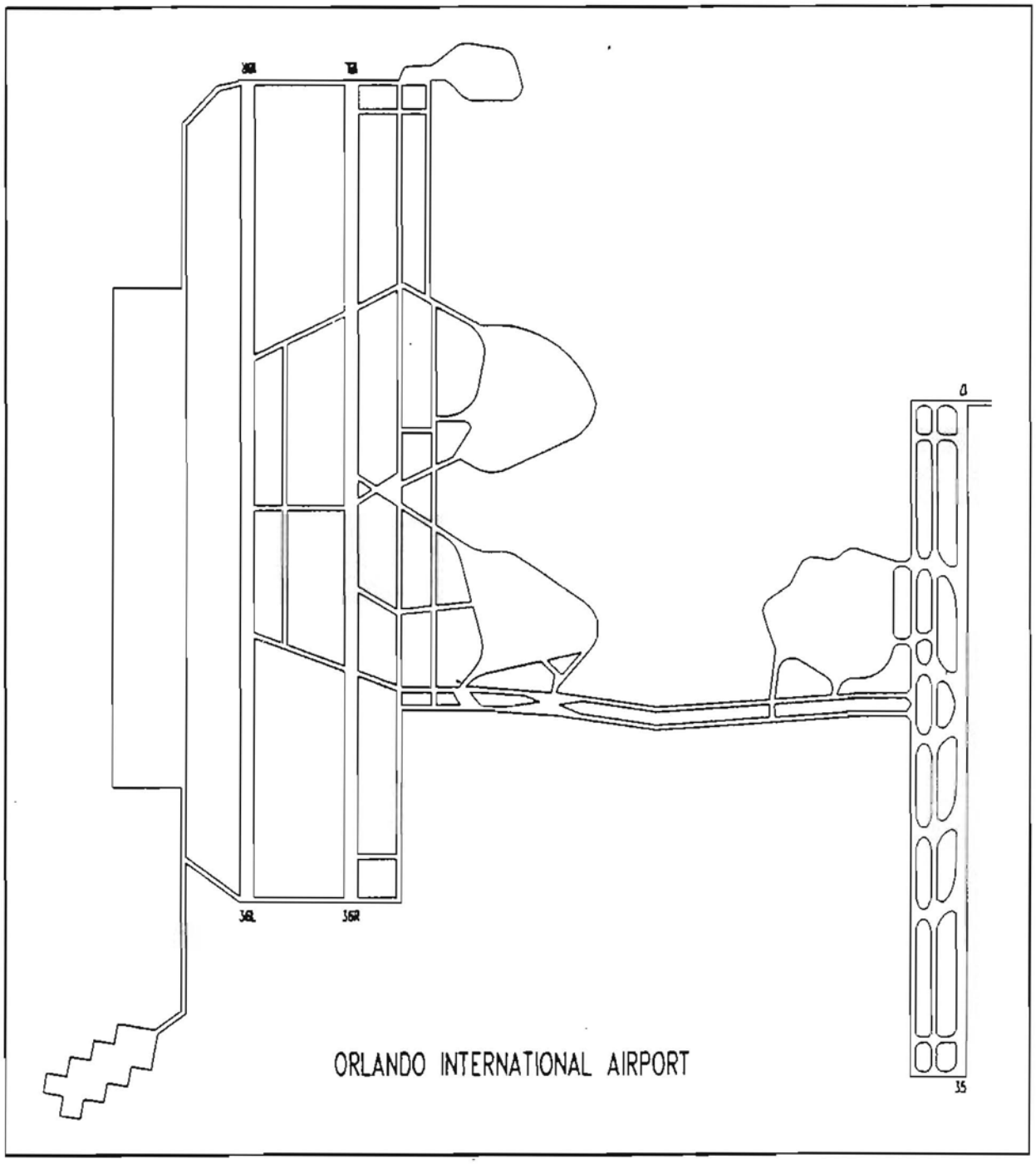


FIGURE 3. ORLANDO INTERNATIONAL AIRPORT

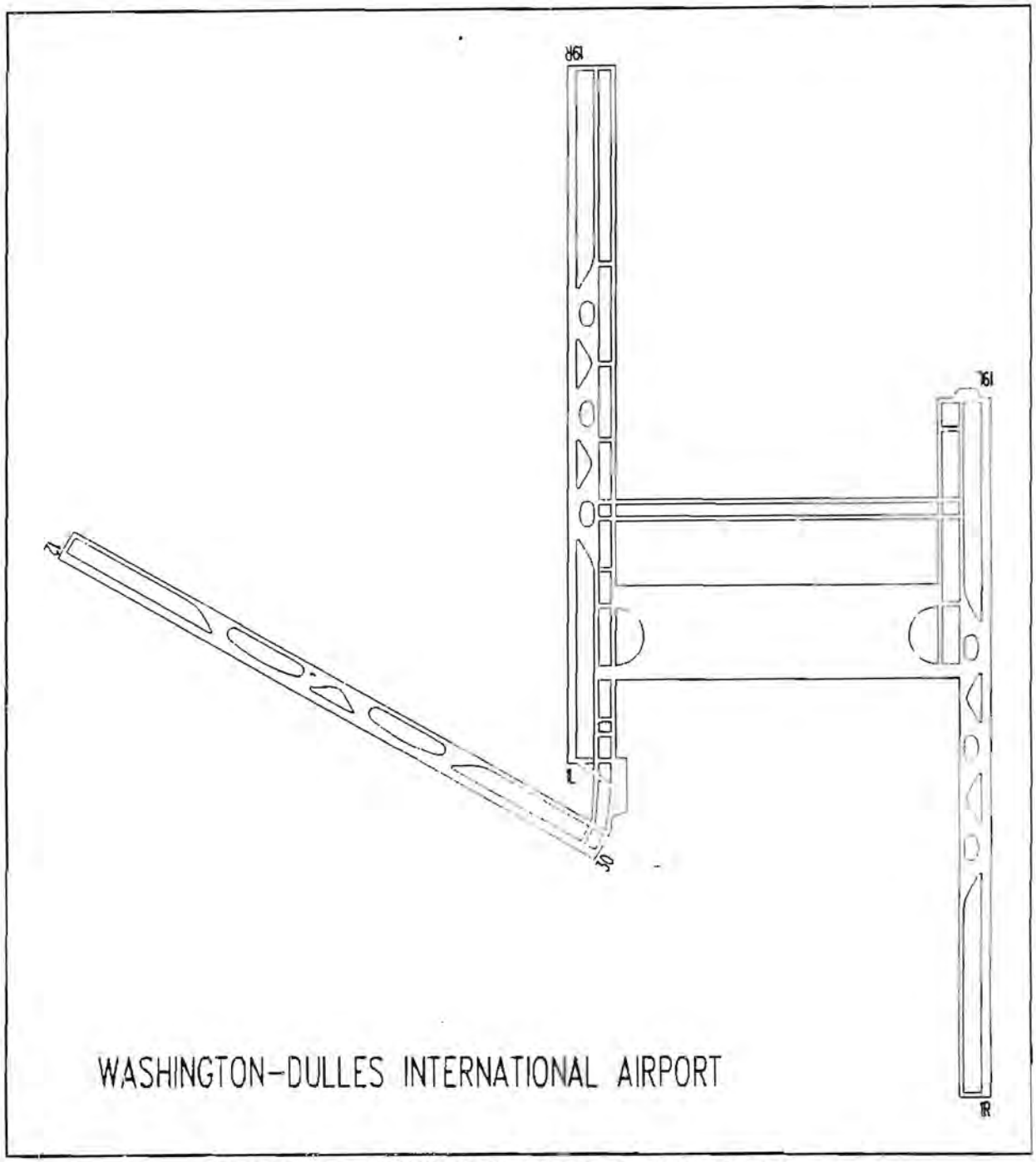


FIGURE 4. WASHINGTON-DULLES INTERNATIONAL

Computer software was written to allow superimposing of the ground track of the aircraft over a diagram of the runway exits. Runway occupancy time was determined by computing the time between crossing of the runway threshold and runway clearance. The groundspeed of the aircraft was displayed at 5-second intervals. Plotting the route of the aircraft provided a visual indication of the accuracy of the pilot in following the taxiway centerline (figure 5).

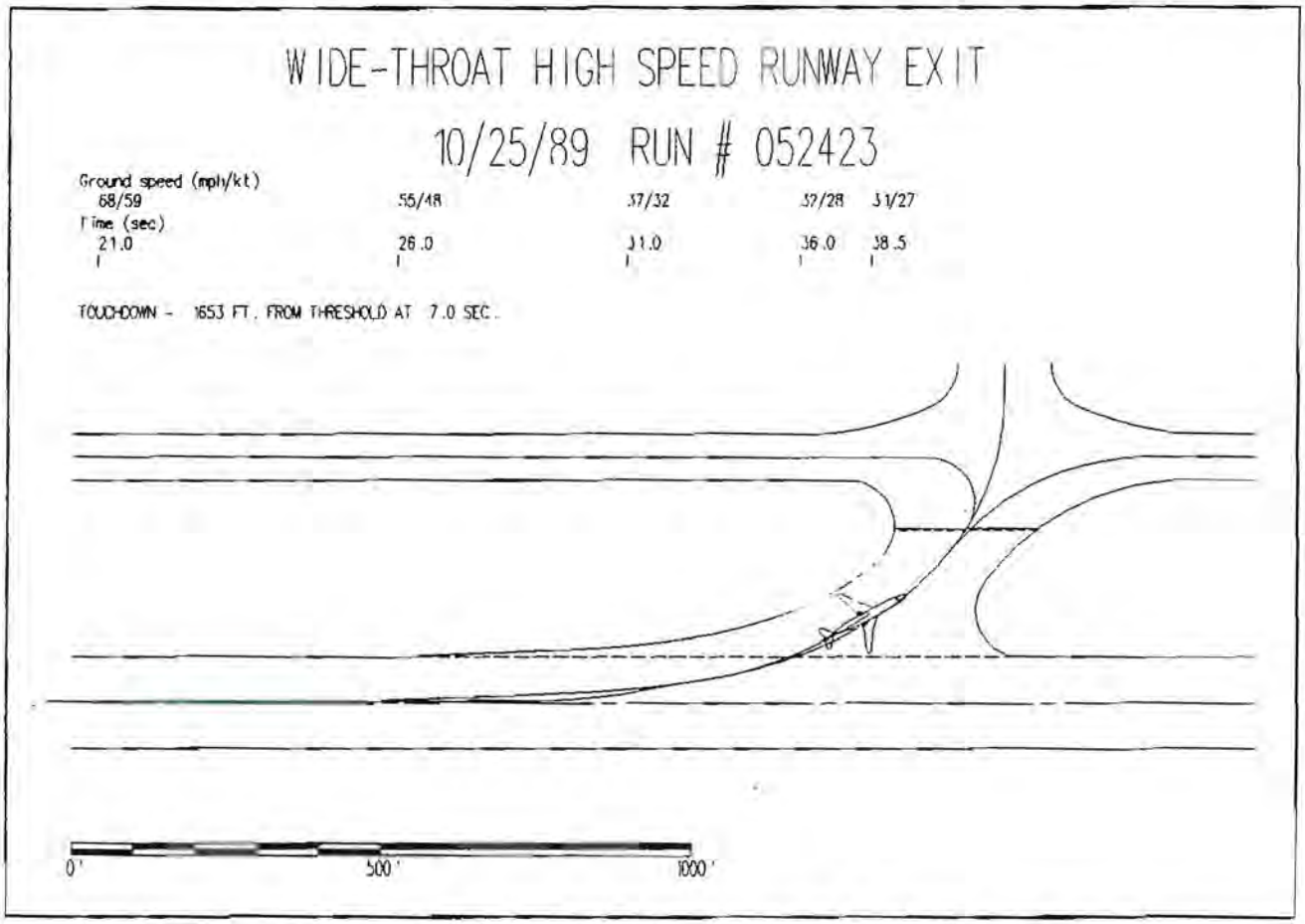


FIGURE 5. SAMPLE PLOT - SIMULATOR TESTS

Runway occupancy times and exit speeds were related to aircraft landing weight and compared for the two exits. Accelerations were plotted versus time for comparison with full-scale tests.

FULL-SCALE TESTS.

Similar precision in calculating the position of the aircraft was not possible in full-scale tests because of limitations of the data collection system. Event signals were triggered by the cockpit observer upon crossing the runway threshold and again at the point where, in his judgement, the aircraft was clear of the runway edge line. To reduce error, the same observer was used throughout the testing.

Runway occupancy times and exit speeds were related to aircraft landing weight and compared for the two exits. Accelerations were plotted versus time for comparison with simulator tests.

DISCUSSION

OCCUPANCY TIME.

There are many factors that may affect runway occupancy time. Some of these factors are:

Exit Speed	Aircraft Weight
Exit Location	Wind Velocity
Exit Design	Runway Condition
Touchdown Point	Gate Location
Aircraft Type	Pilot Technique

Several of these factors are interrelated. For instance, runway occupancy time is affected by exit design because exit design affects exit speed. Since other factors do affect runway occupancy time, the efficiency of a particular runway exit is best evaluated by measuring the speed at which the exit is used.

It was desirable to eliminate, as far as possible, the effects of factors other than exit design. Caution was exercised, however, to exclude only those factors that are not influenced by exit design. These factors include wind velocity, runway condition, touchdown point, and gate location.

Exit location is related to exit design only in the sense that an exit allowing higher exit speeds may be located closer to the runway threshold. This relation was to be addressed in Phase II testing and will be discussed later. Runway exit design may have a different effect on the exit speeds of different aircraft types. The availability of a Boeing 727 simulator and aircraft, however, made this the aircraft of choice for this evaluation. The results should be representative for narrow-body transport aircraft.

The critical factor to be considered is pilot technique. A runway exit may allow a higher exit speed; but in order to be effective, the design of the exit must induce the pilot of the aircraft to use that higher speed. For this reason, subjective opinions of the 12 pilots and observation of their techniques were considered fundamental to this evaluation.

Early in the test program, it became apparent that the number of landings required of each pilot was excessive. While a greater number of landings provide more data points for statistical significance, the number of planned landings per pilot (24) was found to cause fatigue. For this reason, the number of landings per pilot was reduced. The total number of landings per pilot varied; some pilots experienced fatigue earlier than others.

The pilots were asked to use a particular exit and to exit the runway as rapidly as possible, considering passenger comfort, tire scrubbing, etc. Each pilot then began the exit maneuver at the maximum speed he felt was prudent. The point at which the aircraft had turned 5 degrees from the runway heading was then taken as the initial exit speed for data analysis.

A pattern in the techniques of the various pilots was observed. While some touched down earlier, or decelerated more quickly, or turned at higher speeds than others, all seemed to complete the landing in three stages. Initially, the aircraft was flown to the touchdown point. This first stage ended when all landing gear were firmly on the runway. During the second stage, the aircraft was decelerated to taxi speed. Finally, and only after the second stage was completed, the pilot started looking for the runway exit. In several instances, additional power was applied to comply with the request to exit as rapidly as possible. The wide variation in exit speeds used by various pilots shows that the runway exit speed was more a function of pilot technique than exit design.

Most pilots felt that the ground steering of the simulator was not sufficiently realistic. This is considered to be a serious deficiency for an evaluation of runway exits. Phase II testing, which also requires the use of the simulator, will be postponed until the ground handling characteristics of the simulator have been improved. Conclusions drawn from Phase I testing are based on data collected with the simulator and must be subject to further tests.

Phase III tests, involving the use of the Technical Center's instrumented B-727 aircraft, were originally intended to validate the acceleration data obtained from simulator tests. After the deficiencies in ground handling capabilities of the simulator were apparent, it was decided to conduct equivalent tests using the aircraft. While this type of testing assured maximum realism, the lack of control over aircraft weight, wind velocity, and runway choice made direct comparison of test results impracticable. Full-scale tests were adequate, however, to reinforce the observation that high-speed runway exits are not used at design speeds. Pilot techniques were similar to those observed in the simulator.

LIGHTING.

The standard exit provides roughly 950 feet of centerline lighting prior to the point where the exit centerline crosses the runway edge line, and 1400 feet prior to the point at which it crosses the hold line. These lengths for the alternative design exit are roughly 650 and 900 feet, respectively. During low-visibility conditions, the additional lighting provided by the standard exit gives a pilot several seconds extra notice of the location of the exit.

The lighting of the standard exit begins with a segment parallel to the runway centerline and transitions smoothly to the spiral portion. The lighting of the alternative design exit starts at an angle of 8 degrees to the runway centerline. The pilot thus cannot strictly follow a series of lights throughout the rollout and exit, but must begin the exit turn prior to the onset of exit lights.

The uniform spacing of the standard exit lighting provides a pilot with a visual cue by which to gauge speed and deceleration. As the aircraft slows, lights pass under the cockpit at lower frequency. The gradually decreasing spacing of the alternative design exit lighting will tend to pass under the cockpit at a more uniform rate, or possibly at a higher rate, as the aircraft decelerates. This could induce a perception of reduction in deceleration or even a feeling of acceleration under certain conditions. Subject pilots were asked to provide comments on the lighting of the two exits.

PAVEMENT AREA.

Another factor to be considered when designing a runway exit is cost. Generally, an exit requiring less pavement will cost less to build. When compared to the standard exit with the optional long-radius fillet, the alternative design exit requires less pavement. When the standard exit is not equipped with the long-radius fillet, it requires less pavement than the alternative design exit. Actual pavement areas are shown in figure 6.

RESULTS

Pilots showed some consistency in the speed at which each used a runway exit (figure 7). There was, however, very high variability in results among pilots. Initial exit speeds ranged from 22 to 65 knots. Average initial exit speeds were roughly 40 knots. This speed is well below the speed for which the exits are designed to be used (65 knots). In several instances, pilots that exited at higher speeds indicated that they normally would have continued rolling to the next exit.

Aircraft weight had an effect on runway occupancy time because of differences in initial approach speed (figure 8). Exit speeds, however, were relatively independent of aircraft weight (figure 9). The high variability of the exit speed data suggests that the averages are not statistically significant. The variability itself, however, is significant in that it shows that pilot technique is the factor which influences exit speed the most.

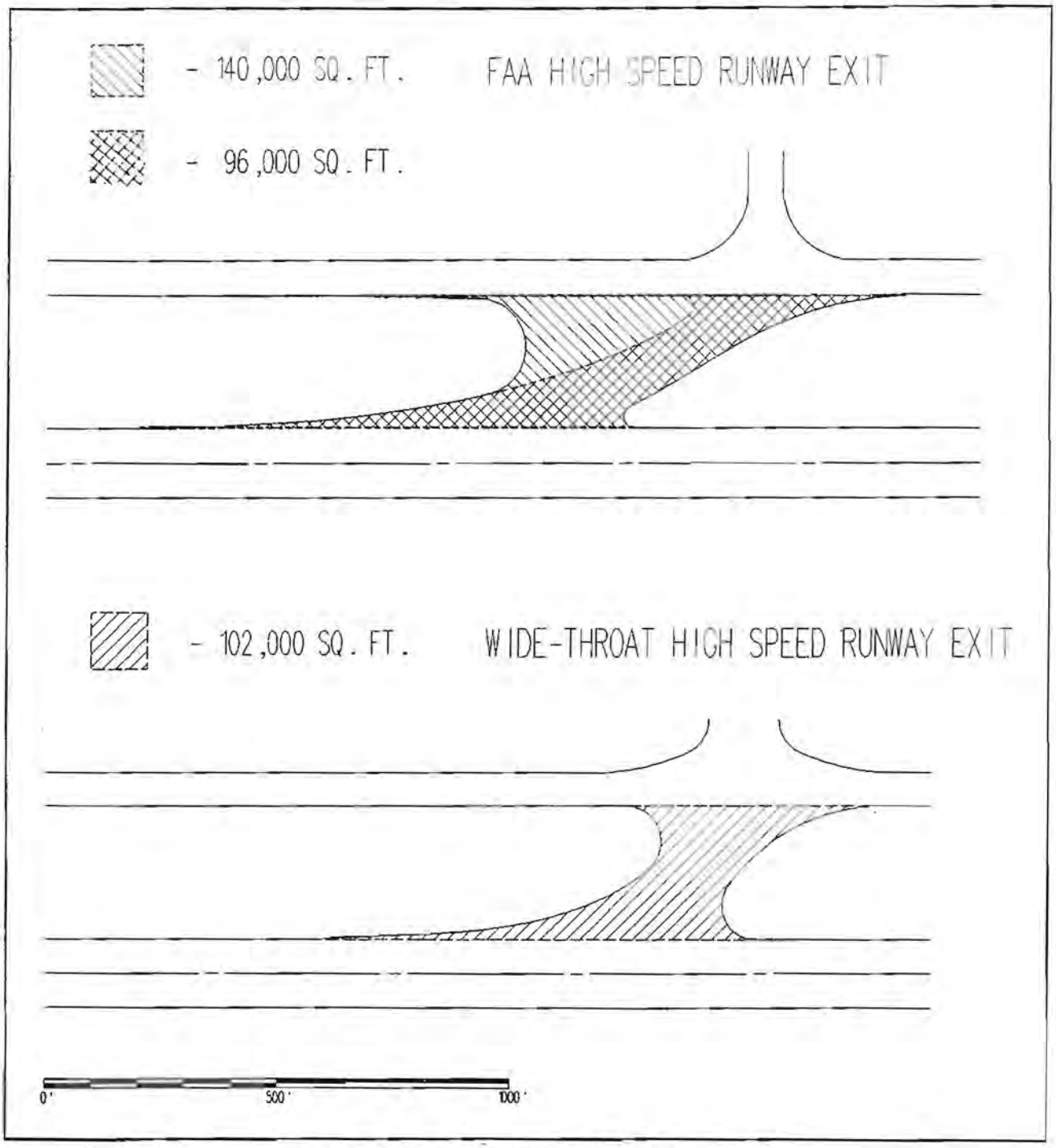
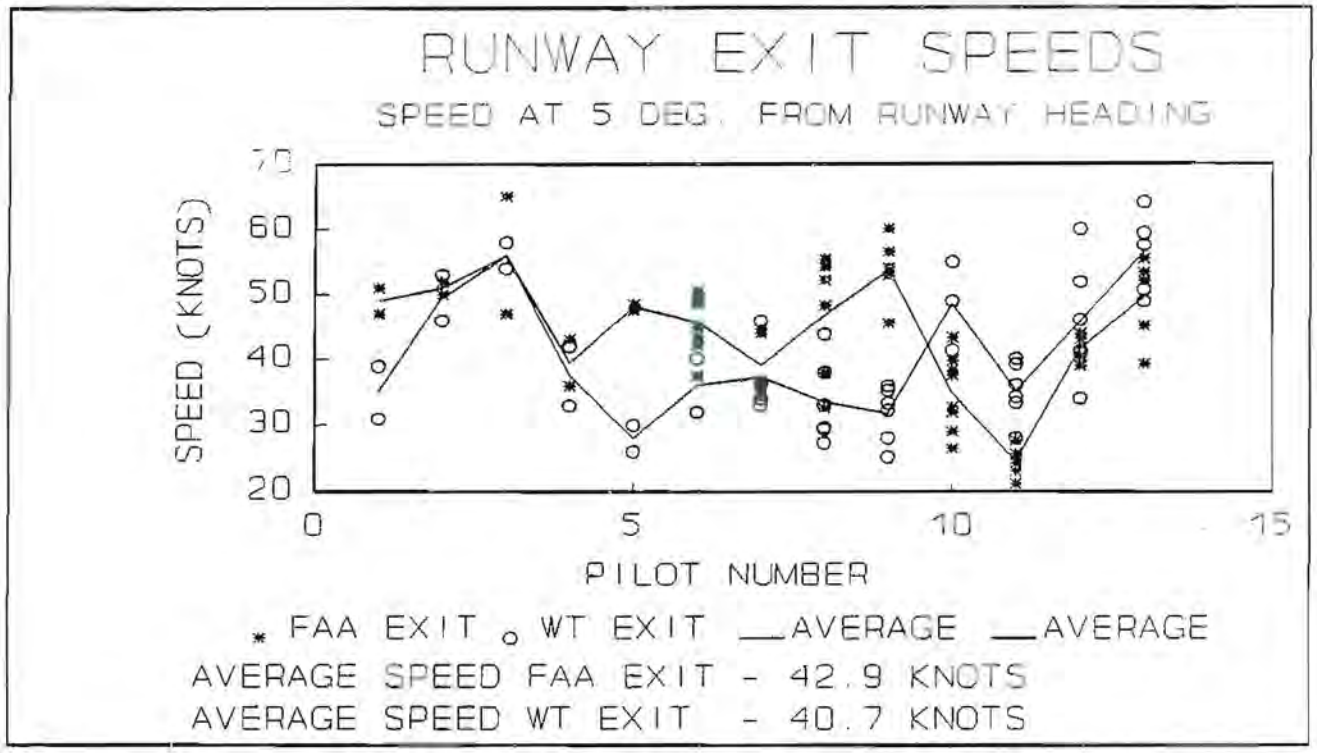


FIGURE 6. PAVEMENT REQUIREMENTS



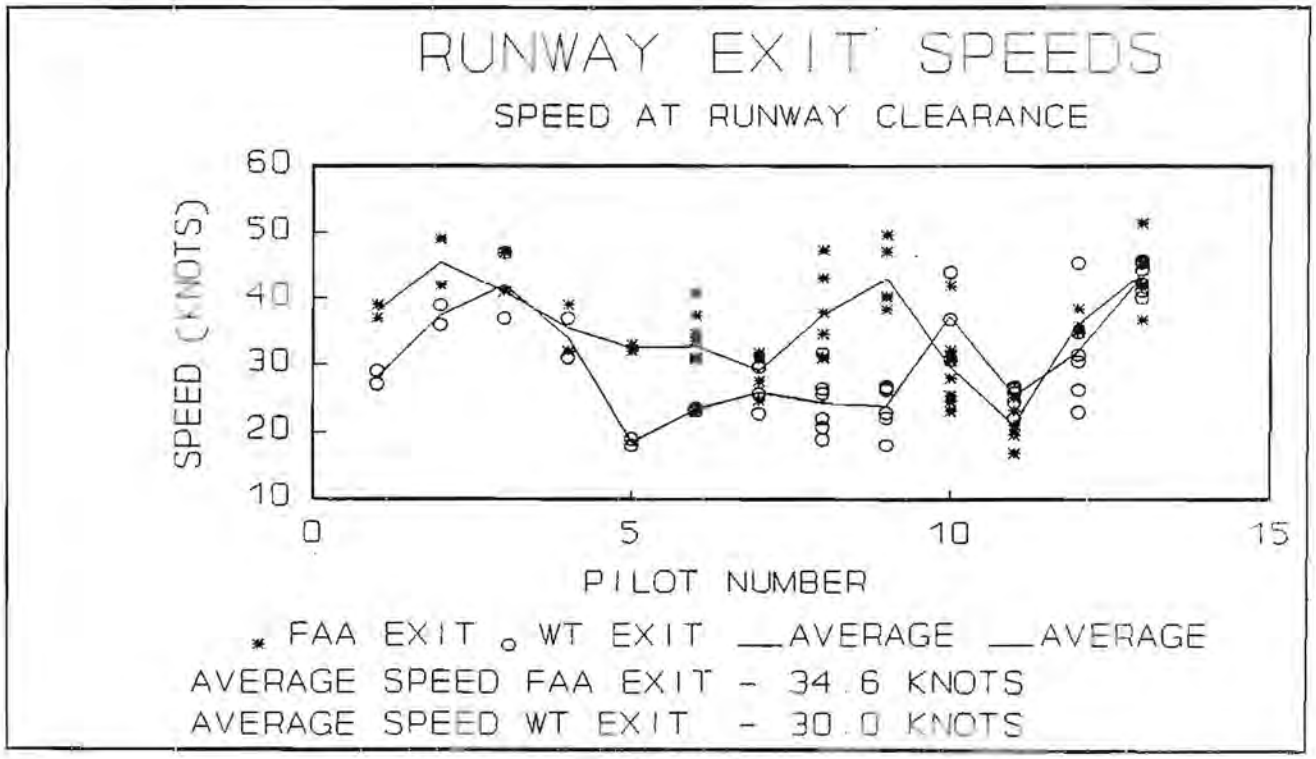


FIGURE 7. RUNWAY EXIT SPEEDS

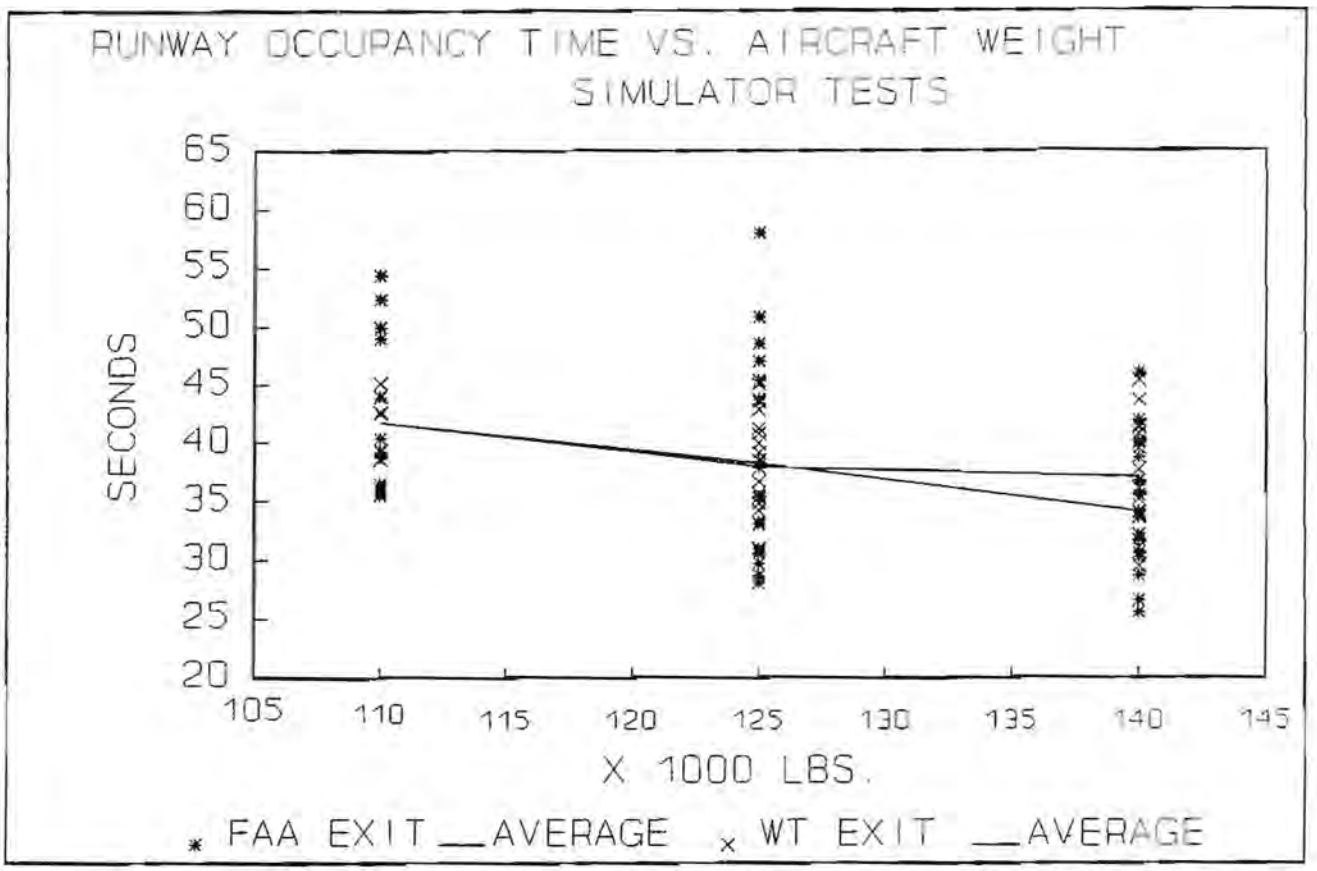
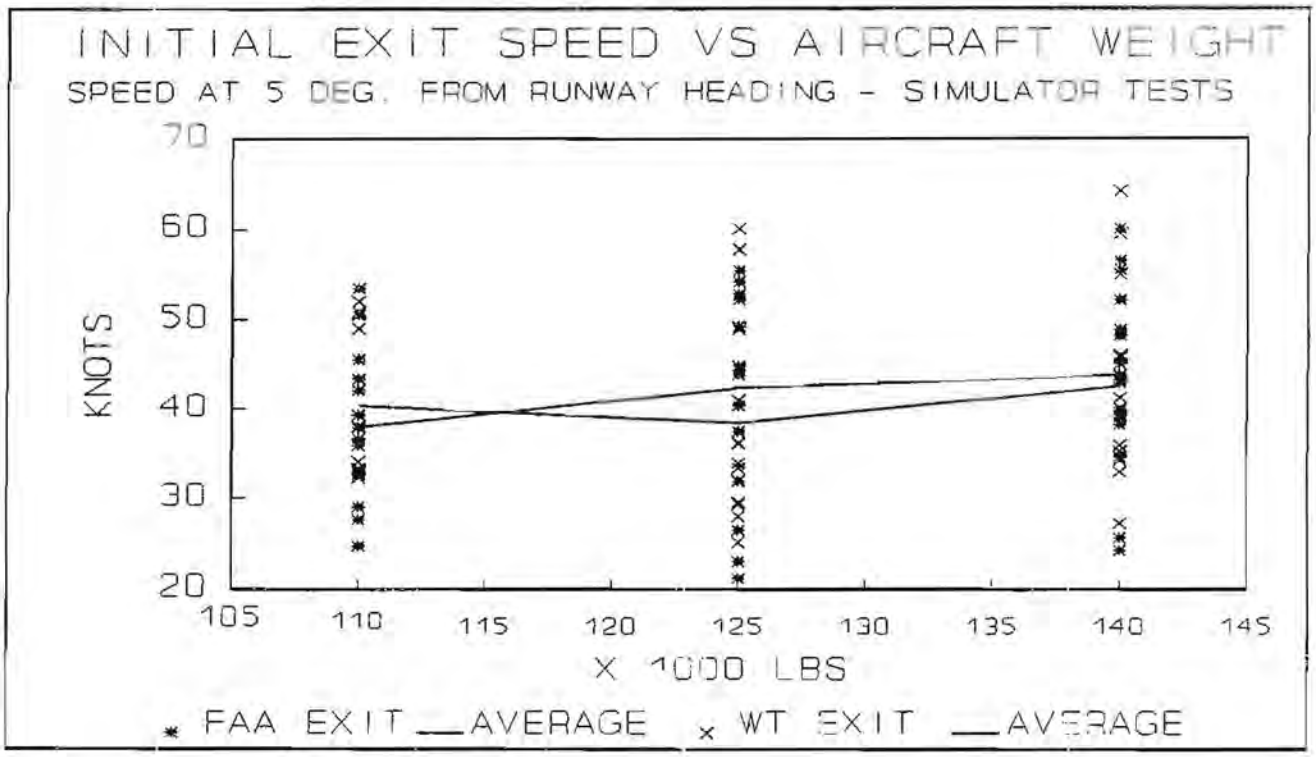


FIGURE 8. RUNWAY OCCUPANCY TIME VS. AIRCRAFT WEIGHT - SIMULATOR TESTS

Pilots tended to maintain a higher speed through the standard exit than the alternative-design exit. The tighter spiral of the alternative-design exit centerline apparently requires greater deceleration in the turn. The low number of tests conducted with the B-727 aircraft and the noted deficiencies in steering characteristics of the simulator, however, do not support a conclusion based on the data.

Questionnaires were completed by 12 active airline pilots. Figure 10 is a summary of responses to the questionnaire. Numbers indicate the number of pilots checking a particular response. The subjective evaluations indicated a general preference for the standard-design exit.



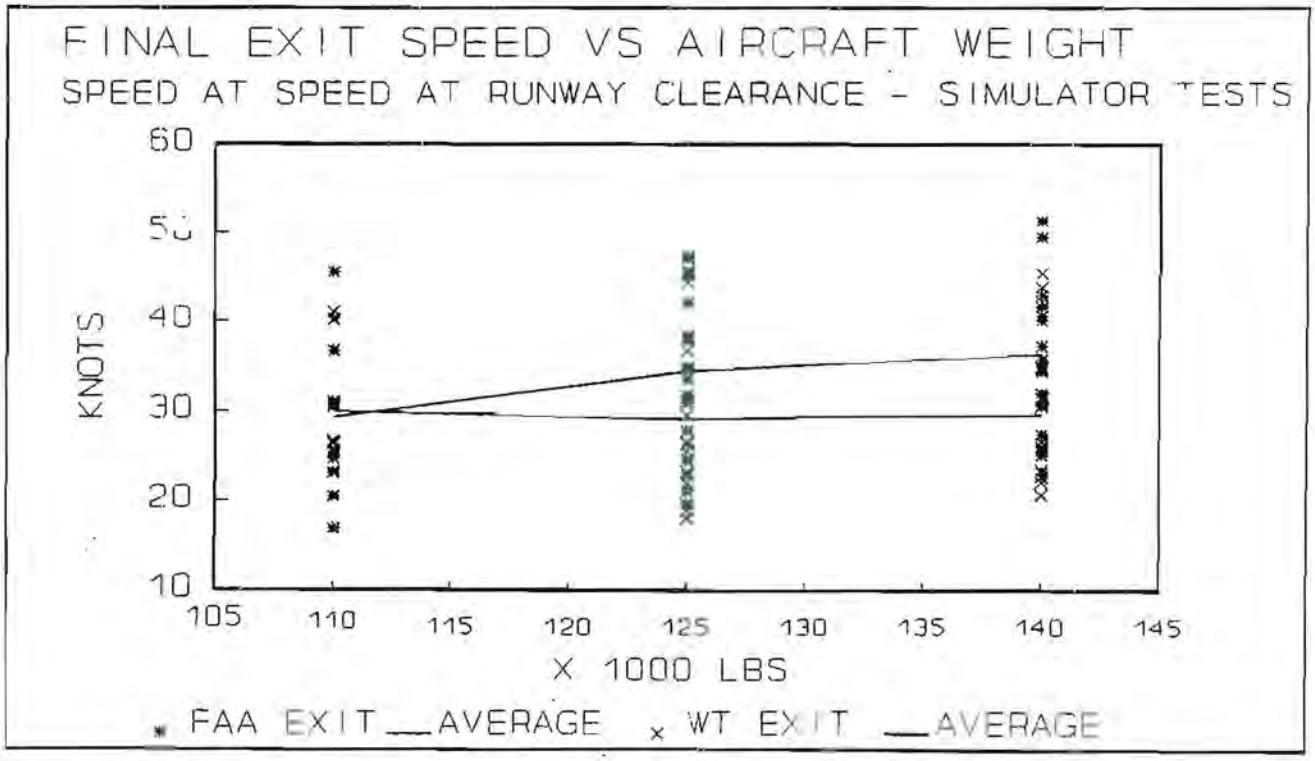


FIGURE 9. EXIT SPEEDS VS. AIRCRAFT WEIGHT - SIMULATOR TESTS

HIGH SPEED RUNWAY EXIT EVALUATION
PILOT QUESTIONNAIRE

1. Do you feel that the design of one of the exits enabled you to exit the runway at higher speed? Which?*

Standard 7 Alternative 1 Same 4

2. What do you consider the limiting parameter in runway exit speed? (one multiple response)

Configuration of the exit	3
Location of the exit	3
Handling capability of the aircraft	5
Tire scrubbing	___
Passenger comfort	2
Urgency (gate time, ATC request)	___
Other _____	

3. Do you feel that the handling of the simulator was realistic?

Yes 1 No 5

If not, what were the deficiencies? _____

Steering too sensitive (5)

4. Compare the adequacy of the in-pavement lighting of the two exits.

Standard Better 5 Alternative Better 0 Same 3

5. Please provide any comments on the designs of the two runway exits.

Comments indicated a general preference for the standard design exit.

*In the actual questionnaire, the exits were designated "Exit No. 1 and "Exit No. 2."

FIGURE 10. SUMMARY OF PILOT QUESTIONNAIRES

CONCLUSIONS

The results of the study presented in this report warrant a number of conclusions regarding high-speed runway exits and requirements for future research.

1. Pilot technique is the most important factor affecting exit speed.

2. The alternative-design exit does not offer an operational improvement over the standard-design exit.

3. The subject pilots preferred the standard-design exit.

4. The ground-handling characteristics of the B-727 simulator should be improved to allow valid evaluations of exit designs.

5. A study should be conducted to record actual speeds of aircraft using the standard-design exit and the alternative-design exit.

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