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INVESTIGATION OF THE EFFECTS OF RUNWAY GROOVES ON WHEEL SPIN-UP AND TIRE DEGRADATION

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APRIL 1971

FINAL REPORT

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Washington D. C., 20590

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16. Abstract

Tests were conducted at three airports having different runway groove configurations. The objective of these tests was to determine if grooves change the rate of wheel spin-up and if they produce cuts in the tires of the test aircraft. Although no evidence of tire cutting was observed, it was found that the wheel spin-up rate for the test aircraft was increased by the runway grooves. The extent of the increase was influenced by the width of the grooves.

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INTRODUCTION

Purpose

The primary purpose of this phase of the project was to compare aircraft wheel spin-up rates produced by landing on dry ungrooved runways with those produced by landing on runways with grooves of various configurations. A secondary purpose was to determine if the test aircraft's tires suffered any cutting due to landing on grooved runways.

Background

The grooving of runways at several commercial airports may have caused some operational problems. Several air carriers have reported chevron cutting on their jet aircraft tires. Chevron cuts are shallow cuts on the tire tread which are thought to be caused by higher tire loads believed to be produced by landing on grooved runway surfaces. These cuts occur more often on recapped tires rather than new tires. Faster wheel spin-up rates infer higher horizontal landing gear loads.

Description of Equipment:

Aircraft - A Convair T-29, Figure 1, the military designation of a Convair 240, was the aircraft used to conduct these tests. The maximum gross weight of this aircraft is 42,000 pounds. Each main landing gear truck consists of two wheels in juxtaposition, mounting tires, size 34 x 9.9 inflated to 95 pounds per square inch pressure. The main landing gear tires, Figure 2, were the five-rib type normally used by this aircraft, and unless they were in excellent condition, newly recapped tires were installed prior to each series of tests. Recapped tires were used for these tests because the airlines had experienced tire cutting with this type of tire.

Instrumentation - Wheel rotational velocity was determined by use of 90-toothed ring gears which were affixed to one wheel of the left and right main landing gear assemblies. A magnetic transducer was attached to each main strut, Figure 3, in close proximity to the teeth of the ring gear, to indicate wheel rotation. The self-generating magnetic transducer produced an electrical signal which was proportional to a change in magnetic flux. The resultant signals were recorded by an analog tape recorder. In addition, vertical sensing

FIG. 1 CONVAIR T-29 TEST AIRCRAFT

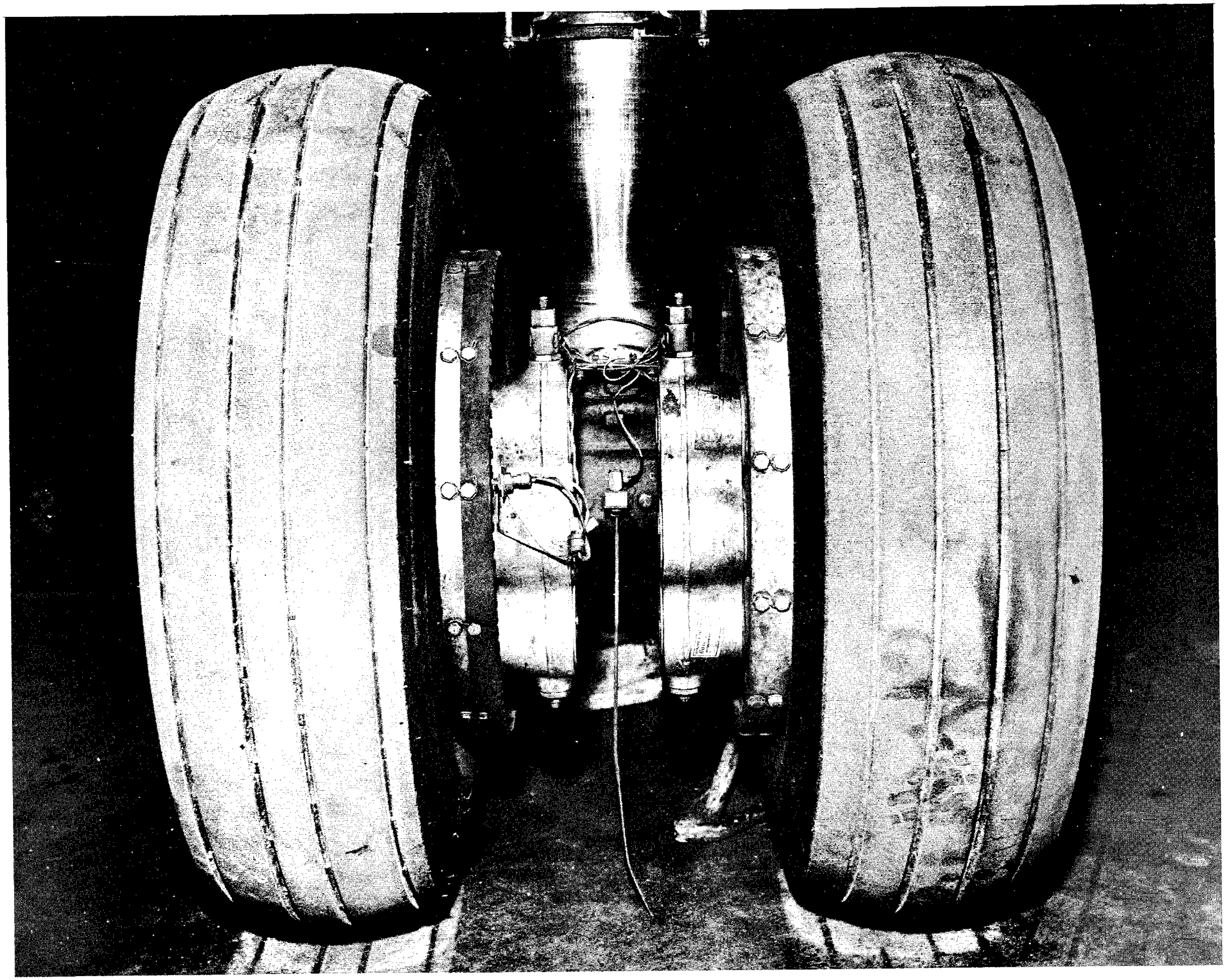


FIG. 2 MAIN LANDING GEAR AND TIRES

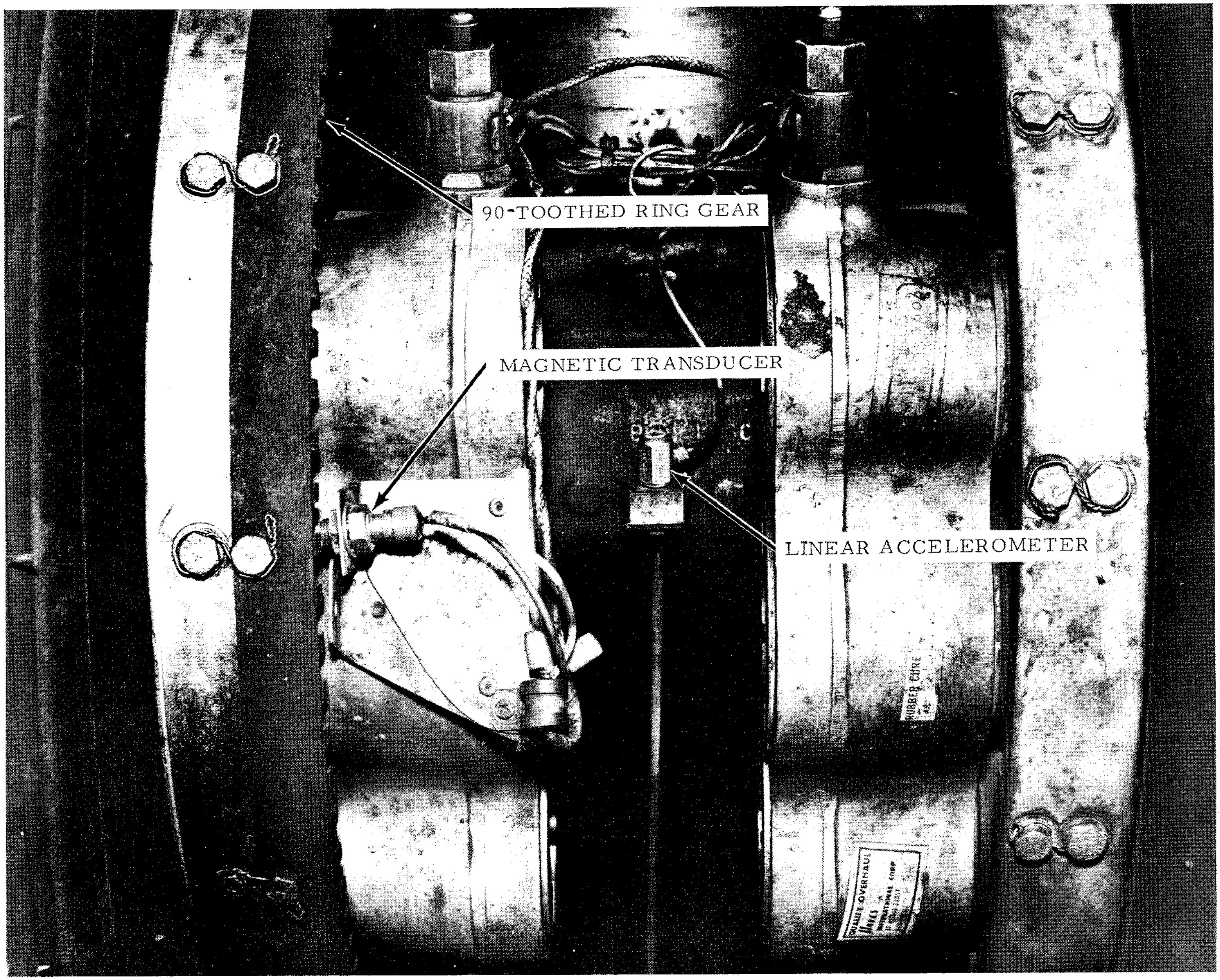


FIG. 3 WHEEL ROTATION AND TOUCHDOWN INSTRUMENTATION

Description of Runways and Grooves: Aircraft landing tests were conducted at three airports having different runway groove configurations as shown in Figures 4, 5, and 6. These three different groove patterns were tested to determine their relative effect on wheel spin-up rates. In addition, an ungrooved runway having the most similar surface to the grooved runway at the airport was used to provide the ungrooved runway spin-up rates.

Runway 4R-22L at John F. Kennedy International Airport (JFK) is a concrete runway having a groove configuration as shown in Figure 4. The other runway used to measure ungrooved accelerations was Runway 13L-31R which is also a concrete runway of similar surface appearance.

The grooved Runway 5-23 at Kanawha Airport (Charleston, West Virginia) was originally constructed of asphaltic concrete; however, the 60-foot-wide center section was replaced with a concrete inlay which was then grooved. The groove configuration of this runway is shown in Figure 5. Runway 14-32, the ungrooved runway, is comprised of asphaltic concrete.

The groove configuration of Runway 18-36 at Washington National Airport is shown in Figure 6. This runway and Runway 15-33, used to obtain the ungrooved runway test data, are both constructed of asphaltic concrete.

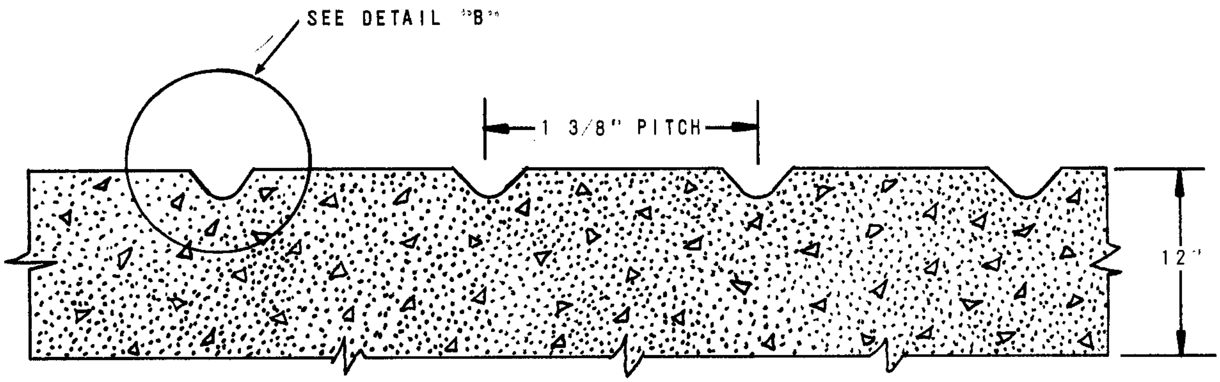
DISCUSSION

Spin-up Tests

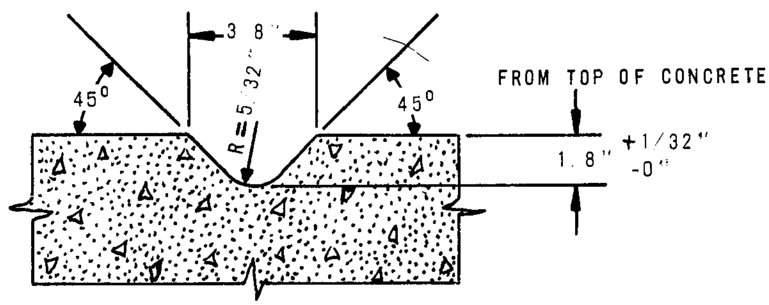
To measure and record the aircraft's wheel speeds for comparative purposes, landings were made on the dry grooved runway and on the most similar dry ungrooved runway available on the same airport.

Touchdown speeds for the entire series of tests varied from 90 to 100 knots. The landing weights of the test aircraft varied from 41,000 to 39,000 pounds depending on fuel load.

As the landing weights and touchdown speeds varied approximately 5 and 10 percent respectively, test landings were made alternately on the grooved and ungrooved runways, wherever possible, to hold the effect of these variations to a minimum.



TYPICAL SURFACE SECTION A-A



DETAIL - "B"

FIG. 4 JOHN F. KENNEDY AIRPORT GROOVE CONFIGURATION

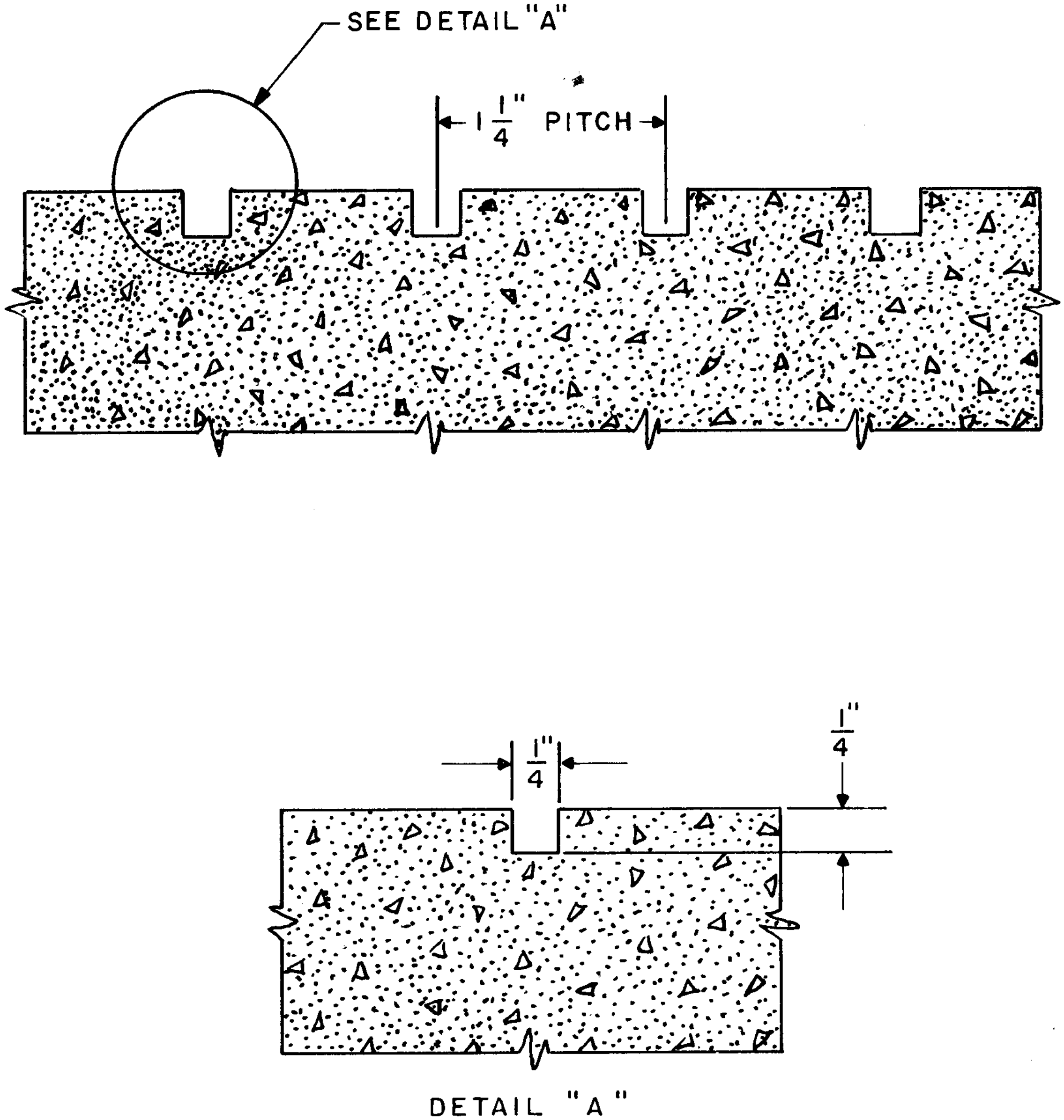
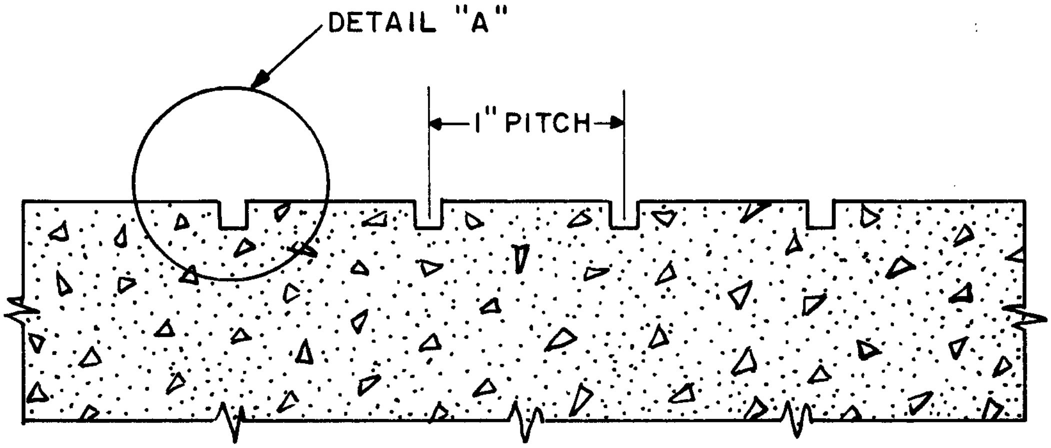
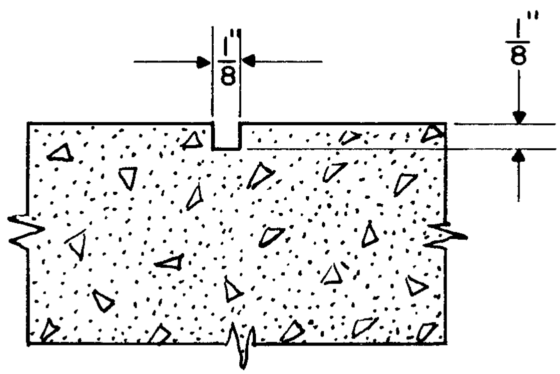


FIG. 5 CHARLESTON AIRPORT GROOVE CONFIGURATION





DETAIL "A"

FIG. 6 WASHINGTON NATIONAL AIRPORT GROOVE CONFIGURATION

JFK Airport: Twelve landing test runs were conducted at this airport on November 25-26, 1969. Due to airport traffic, alternate landings on each runway could not be accomplished. Six consecutive landings were first made on ungrooved Runway 13L-31R, followed by six landings on grooved Runway 4R-22L. Hard braking was applied during the rollout on each of the last three landings. This was done to induce higher tire loads in an attempt to produce tire cutting which reportedly occurs during hard braking periods as well as during touchdown.

Charleston, West Virginia (Kanawha County Airport): Sixteen landing tests were conducted at this airport on March 11, 1970. Seven wheel spin-up test landings took place on the grooved runway, and six on the ungrooved runway. The first, second and alternate landings thereafter, were made on the grooved runway until seven landings were made on this runway. The third, and subsequent alternate landings, were made on the ungrooved runway until six were made on this runway. These thirteen landings provided wheel spin-up data and tire cutting information. Three additional landings, all hard braked to a full stop, were conducted on the grooved runway for the sole purpose of inducing high tire loads and possible tire cuts.

Washington National Airport: On December 10, 1969, thirteen test landings were made at this airport, five of which were on the ungrooved runway and eight on the grooved runway. The procedure of landing alternately on the grooved and ungrooved runways was performed at this airport. Ten landings were conducted for wheel spin-up and tire cutting data. Three additional landings were made on the grooved runway at near maximum gross weight, and each landing was braked to a full stop in an effort to induce high tire loads and possible tire cuts.

Tire Cutting Tests

Prior to departing to a given airport for test purposes, the aircraft's tires were inspected. Tires which were not in excellent condition were replaced with newly recapped tires. Before and after a series of landings were made at a given airport, the tires were visually inspected for chevron cuts.

A visual inspection of the tires was made after completing the first six landings on the ungrooved runway at JFK Airport. The tires were inspected again at the completion of the six landings on the grooved runway.

At Charleston Airport, where the alternate grooved and ungrooved landing method was used, tire inspections were conducted at the completion of Landing No. 8 and at the end of the tests (Landing No. 16).

At Washington Airport, tire inspections were made at the completion of the 10 alternate grooved and ungrooved landings and at the completion of the following three hard braked landings.

SUMMARY OF RESULTS

Spin-up Tests

The test data were reduced to oscillogram format to facilitate analysis. The total wheel spin-up time was measured from the instant of touchdown, as indicated by the accelerometer, to a point where the number of signals produced by the rotating ring gear became constant with respect to time. This indicated the wheels had reached constant velocity. Prior to reaching constant velocity, the change in the number of signals per unit time was the measure of the wheel spin-up rate. In most of the landings, one wheel usually touched down before the other, resulting in two different wheel spin-up times. These spin-up times were averaged for each landing. The spin-up times were then averaged for all the landings on the grooved runway, and for all the landings on the ungrooved runway for each airport. These data, compiled for each airport tested, are presented in Tables 1, 2, and 3. A comparison of the wheel spin-up times between the grooved and ungrooved runways for each airport is shown in Table 4.

The 3/8-inch-rounded V-shaped groove configuration at JFK Airport produced wheel spin-up times which averaged approximately 37 milliseconds less than the average spin-up time produced by the ungrooved runway.

The 1/4-inch-square groove at the Charleston Airport produced wheel spin-up time averaging approximately 23 milliseconds less than the spin-up times obtained on the ungrooved runway.

The 1/8-inch-square groove configuration at Washington Airport produced wheel spin-up times averaging approximately 17 milliseconds less than the spin-up times obtained on the ungrooved runway.

TABLE 1. - JFK INTERNATIONAL AIRPORT

Wheel Spin-up Time for Landings on Ungrooved Runway 13L-31R

Landing No.	Left Wheel Spin-up Time milliseconds	Right Wheel Spin-up Time milliseconds		Average Left and Right Wheels milliseconds
1	212.5	238		225
2	175	137		156
3	188	162		175
4	200	150		175
5	213	175		194
6	187	125		156
			Avg.	180

Wheel Spin-up Time for Landings on Grooved Runway 4R-22L

Landing No.	Left Wheel Spin-up Time milliseconds	Right Wheel Spin-up Time milliseconds		Average Left and Right Wheels milliseconds
7	187	187		188
8	100	112		106
9	175	163		169
10	162	138		150
11	100	112		106
12	150	125		138
			Avg.	143

TABLE 2. - CHARLESTON AIRPORT

Wheel Spin-up Time for Landings on Ungrooved Runway 14-32

Landing No.	Left Wheel Spin-up Time milliseconds	Right Wheel Spin-up Time milliseconds	Average Left and Right Wheels milliseconds
3	162	138	150
5	162	112	138
7	125	113	119
9	175	225	200
11	162	188	175
13	163	175	169
		Avg.	158

Wheel Spin-up Time for Landings on Grooved Runway 5-23

Landing No.	Left Wheel Spin-up Time milliseconds	Right Wheel Spin-up Time milliseconds	Average Left and Right Wheels milliseconds
1	175	113	144
2	188	150	169
4	125	113	119
6	137	125	131
8	138	150	144
10	125	113	119
12	125	113	119
		Avg.	135

TABLE 3. - WASHINGTON NATIONAL AIRPORT

Wheel Spin-up Time for Landings on Ungrooved Runway 15-33

Landing No.	Left Wheel Spin-up Time milliseconds	Right Wheel Spin-up Time milliseconds	Average Left and Right Time milliseconds
1	150	200	175
3	137	237	188
5	113	175	144
7	137	175	156
9	137	225	181
		Avg.	169

Wheel Spin-up Time for Landings on Grooved Runway 18-36

Landing No.	Left Wheel Spin-up Time milliseconds	Right Wheel Spin-up Time milliseconds	Average Left and Right Time milliseconds
2	200	162	181
4	162	150	156
6	137	137	138
8	162	150	156
10	125	137	131
		Avg.	152

TABLE 4. - COMPARISON BY AIRPORT OF AVERAGE WHEEL SPIN-UP TIME

Airport	Spin-up Time For Ungrooved Runways milliseconds	Spin-up Time* For Grooved Runways milliseconds	Difference In Spin-up Time milliseconds	Percent Decrease in Wheel Spin-up Time
JFK	180	143	37	21
Charleston	158	135	23	14
Washington	169	152	17	10

In comparing the wheel spin-up times of the three airports, shown in Table 4, it was found that the average wheel spin-up times for the ungrooved runway at Charleston Airport were 11 and 22 milliseconds less than for the ungrooved runways at Washington and JFK Airports, respectively.

When comparing the grooved runways of each airport, it was found that the average wheel spin-up times obtained at Charleston Airport were 8 and 17 milliseconds lower than those obtained on the grooved runways at JFK and Washington Airports, respectively.

In all cases, however, the average wheel spin-up times for the grooved runways were less than for the comparable ungrooved runways. The shorter spin-up times produced by the dry grooved runways infer higher angular accelerations of the aircraft's wheels and thus higher horizontal forces acting on the tires and the landing gear system.

Analysis of the wheel velocity versus time graphs, Appendix A, indicates that the slope of the curves (which is the measure of angular acceleration of the wheel) is, in more cases, steeper for grooved runway landings than for the ungrooved runway landings. The wider grooves of JFK and Charleston Airports tended to produce steeper slopes while the narrow grooves of Washington National Airport did not appreciably change the slopes of the curves from the grooved runway landings over the ungrooved runway landings.

It is also noted that both curves (grooved and ungrooved) have basically similar slopes at the very beginning of wheel rotation after which the curves would diverge. This similar portion of the curve is thought to be the result of tire deformation (carcass stiffness constant) which precedes and is included in the initial rotation of the wheel.

It is apparent that the dry friction characteristics of grooved runway surfaces will affect the wheel spin-up rate during landing. To better measure the effect of runway grooves on the wheel spin-up rate, tests could be conducted on the same runway immediately before and after the runway is grooved so that a direct comparison could be made. Differences in the coefficient of friction of the ungrooved runway surface may mask the effect of the grooves. The coefficient of friction of the runway surface does influence wheel spin-up as shown by the differences in the wheel spin-up times of the ungrooved runways of the three airports.

The following facts must be considered in assessing the test results:

1. The runways tested at JFK and Washington National Airports were of similar materials, while the two runways used for tests at Charleston Airport were of dissimilar materials. The difference between the coefficients of friction of each runway surface, which influences wheel spin-up, was not measured, and therefore was not taken into account in computing wheel spin-up time.

2. No evidence of tire cutting either due to touchdown or hard braking on runway grooves was found in this entire series of tests, and may be due in part to tire pressure, which is approximately two-thirds that of jet transports.

3. The wheel spin-up results are in terms of "time," without factoring for differences between the aircraft weight and speed during landings.

CONCLUSIONS

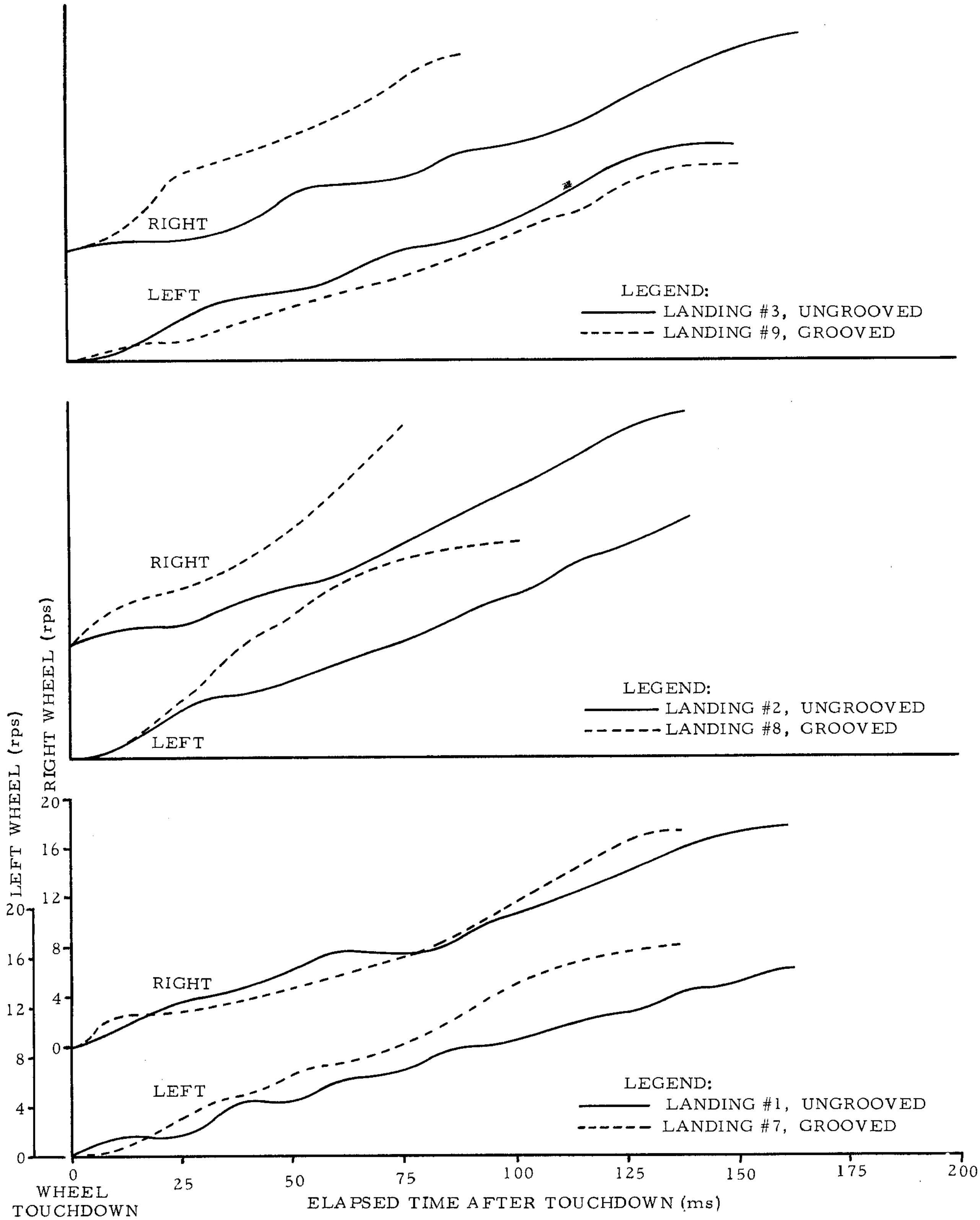
Based upon an analysis of the results of these tests, it is concluded that:

1. Landing on dry grooved runways can cause the aircraft's wheels to spin-up faster than when landing on dry ungrooved runways.

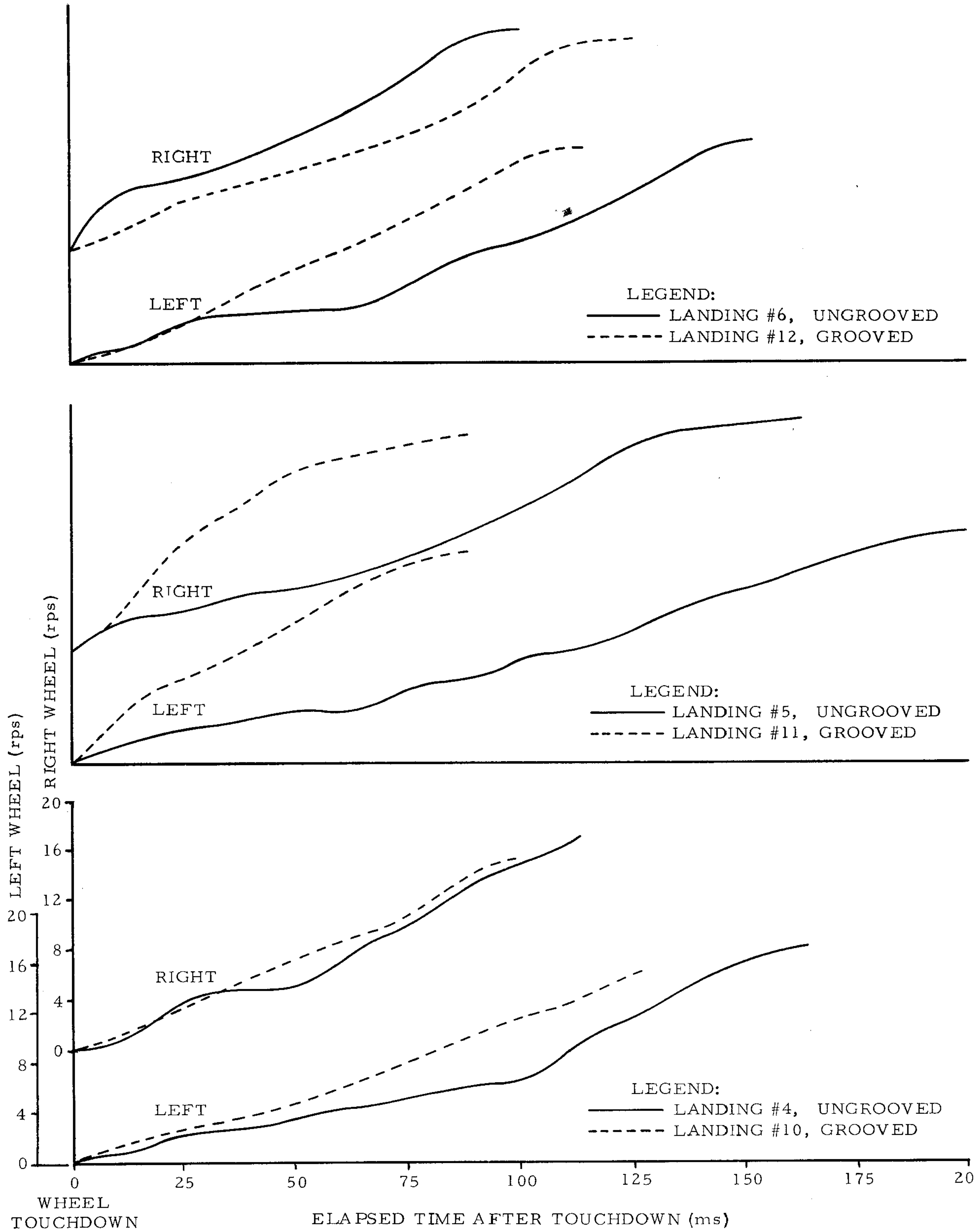
2. Within the limits of these tests, the wider grooves produce the shorter wheel spin-up times, and hence higher wheel accelerations.

APPENDIX A

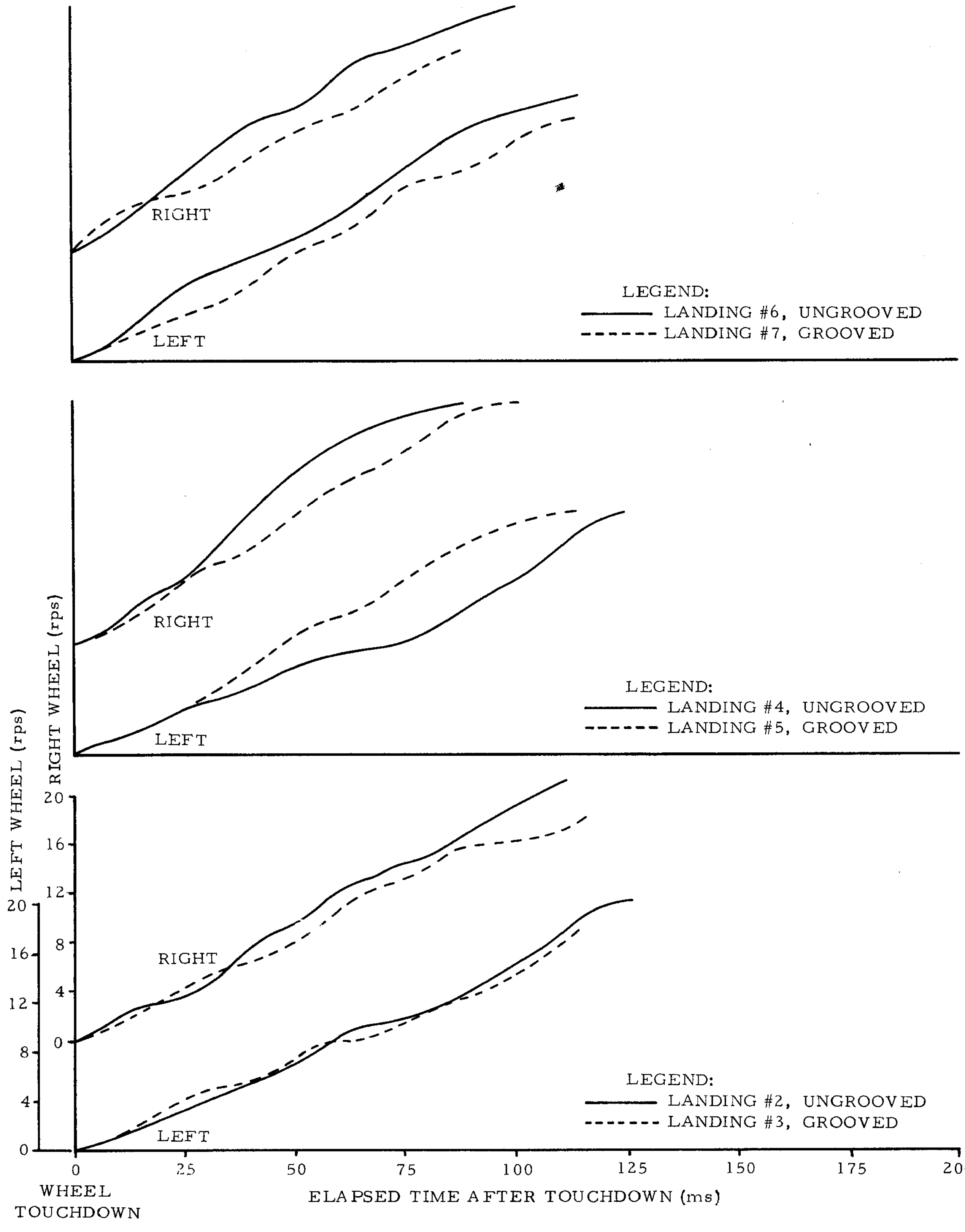
Wheel Velocity vs. Time Graphs


RIGHT
LEFT
LEGEND:
LANDING #3, UNGROOVED
LANDING #9, GROOVED
RIGHT
LEFT
LEGEND:
LANDING #2, UNGROOVED
LANDING #8, GROOVED
RIGHT WHEEL (rps)
LEFT WHEEL (rps)
20
16
12
8
4
0
RIGHT
LEFT
LEGEND:
LANDING #1, UNGROOVED
LANDING #7, GROOVED
0
WHEEL
TOUCHDOWN
25
50
75
100
125
150
175
200
ELAPSED TIME AFTER TOUCHDOWN (ms)

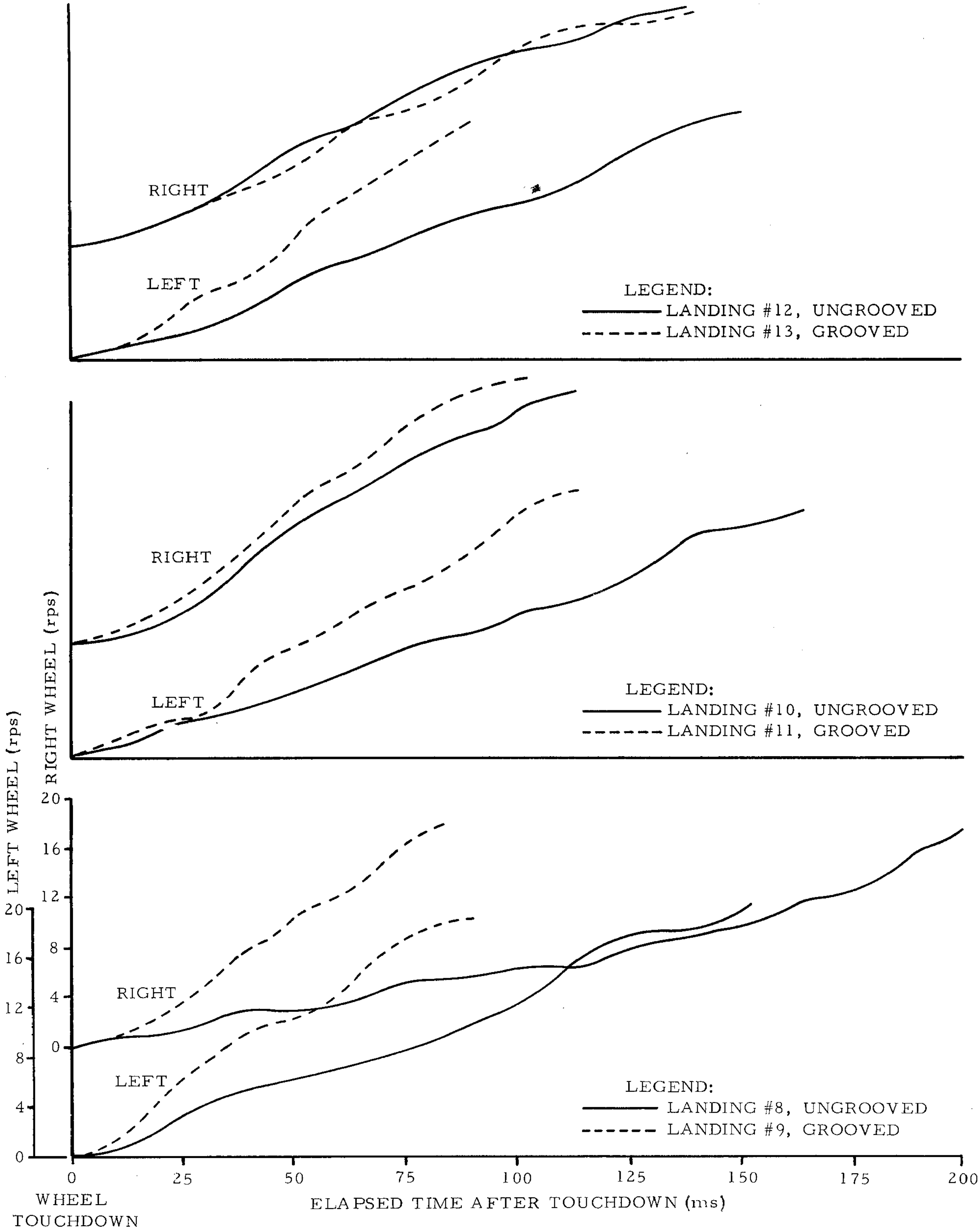
JFK AIRPORT


RIGHT
LEFT
LEGEND:
LANDING #6, UNGROOVED
LANDING #12, GROOVED
RIGHT
LEFT
LEGEND:
LANDING #5, UNGROOVED
LANDING #11, GROOVED
RIGHT WHEEL (rps)
LEFT WHEEL (rps)
20
16
12
8
4
0
RIGHT
LEFT
LEGEND:
LANDING #4, UNGROOVED
LANDING #10, GROOVED
0
25
50
75
100
125
150
175
200
WHEEL TOUCHDOWN
ELAPSED TIME AFTER TOUCHDOWN (ms)

JFK AIRPORT



CHARLESTON AIRPORT



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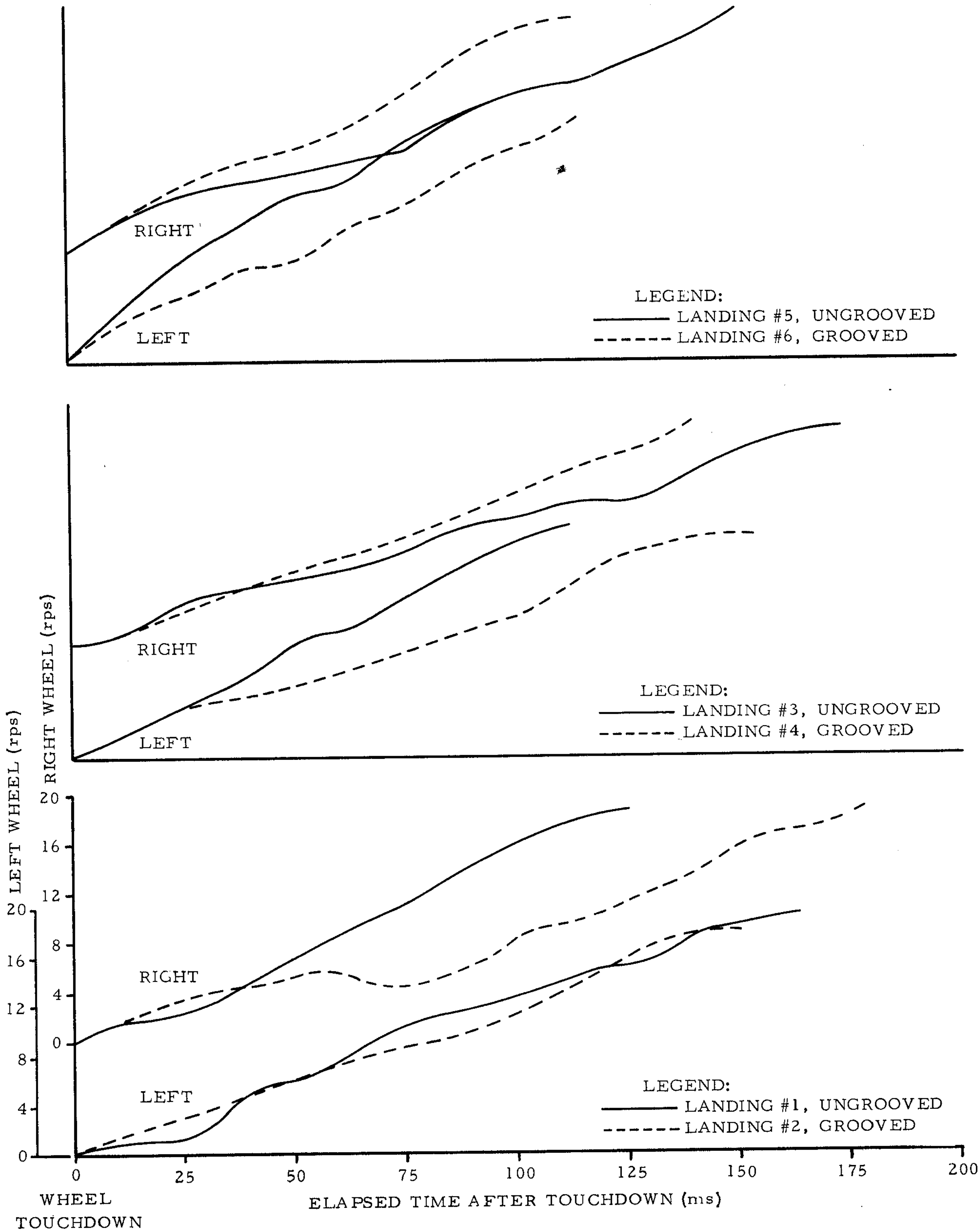
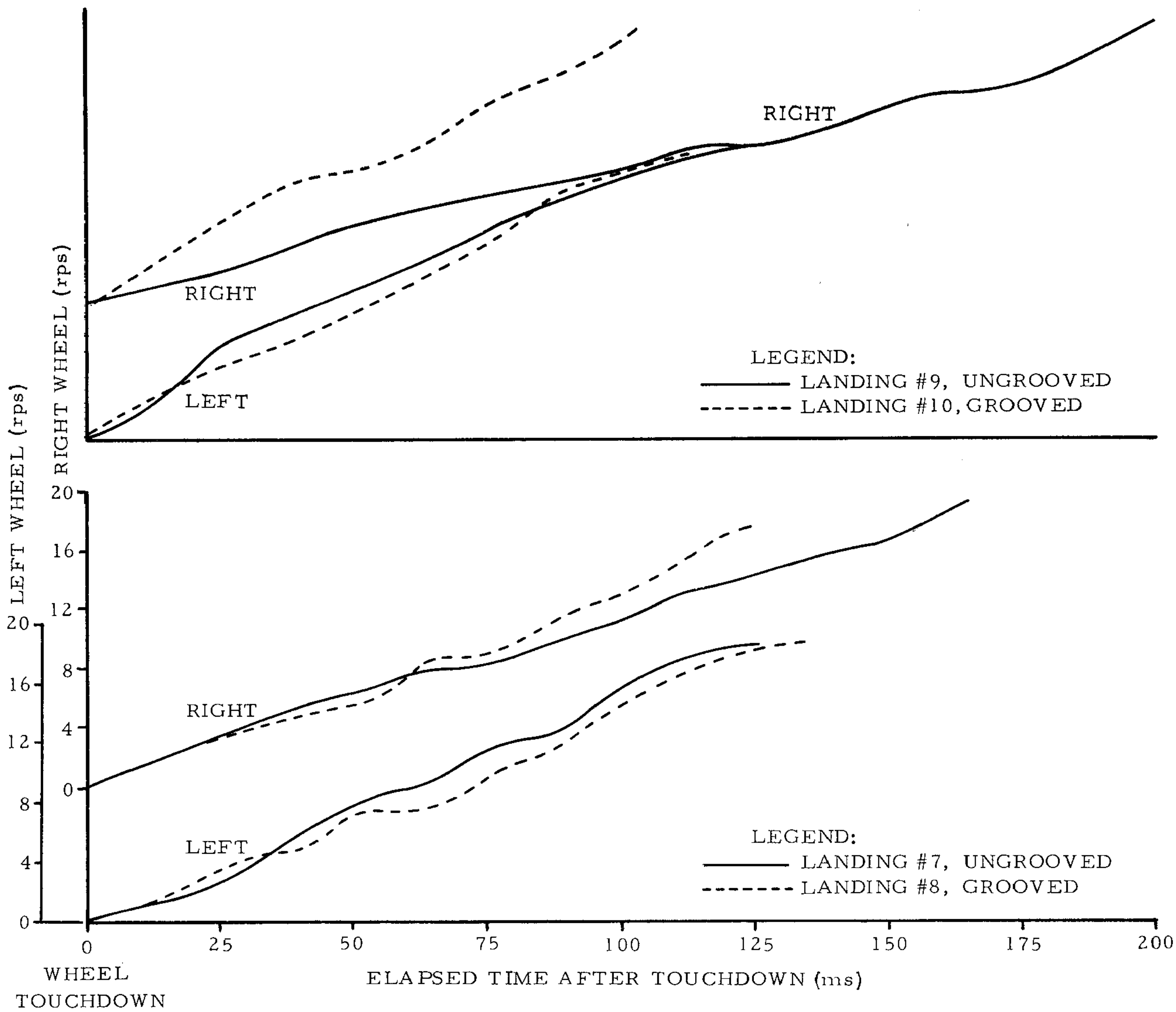


WASHINGTON NATIONAL AIRPORT



WASHINGTON NATIONAL AIRPORT