NASA TECHNICAL NOTE

NASA TN D-6690

c. 1

NASA TN D-6690

INVESTIGATION OF AIRCRAFT TIRE DAMAGE RESULTING FROM TOUCHDOWN ON GROOVED RUNWAY SURFACES

by Thomas A. Byrdsong, John Locke McCarty, and Thomas J. Yager

Langley Research Center
Hampton, Va. 23365

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1972

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TN D-6690		
4. Title and Subtitle: INVESTIGATION OF AIRCRAFT TIRE DAMAGE RESULTING FROM TOUCHDOWN ON GROOVED RUNWAY SURFACES		5. Report Date: March 1972
		6. Performing Organization Code
7. Author(s): Thomas A. Byrdsong, John Locke McCarty, and Thomas J. Yager		8. Performing Organization Report No.: L-7883
9. Performing Organization Name and Address: NASA Langley Research Center, Hampton, Va. 23365		10. Work Unit No.: 133-61-12-01
		11. Contract or Grant No.
		13. Type of Report and Period Covered: Technical Note
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Simulated landing impact tests were conducted to study chevron-cutting damage to the tread of 49 × 17, type VII aircraft tires resulting from touchdown on grooved runway surfaces. The study, performed at the Langley landing-loads track, involved impacting new and retreaded tires at several inflation pressures, vertical loadings, and sink rates on concrete and asphalt surfaces having a variety of transversely grooved patterns at ground speeds up to approximately 110 knots.

The results of this study indicate that chevron cutting occurs at the spot on the tire which initially contacts the surface and that the damage is the result of the scrubbing action of the tire as it skids over the grooves prior to rotation. The extent of chevron cutting was found to be primarily a function of the airplane ground speed at touchdown – the higher the speed, the greater the damage. The studies further show that chevron-cutting damage is essentially independent of the grooving patterns generally considered for airport use but is dependent upon the nature of the surface finish. Tests with different tires of the same size also indicate that the tread rubber compounding significantly affects the extent of chevron-cutting damage.

17. Key Words (Suggested by Author(s))	18. Distribution Statement		
Aircraft tires Tire damage from landing on grooved runways	Unclassified – Unlimited		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	20	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

INVESTIGATION OF AIRCRAFT TIRE DAMAGE RESULTING FROM TOUCHDOWN ON GROOVED RUNWAY SURFACES

By Thomas A. Byrdsong, John Locke McCarty,
and Thomas J. Yager
Langley Research Center

SUMMARY

Simulated landing impact tests were conducted to study chevron-cutting damage to the tread of 49 × 17, type VII aircraft tires resulting from touchdown on grooved runway surfaces. The study, performed at the Langley landing-loads track, involved impacting new and retreaded tires at several inflation pressures, vertical loadings, and sink rates on concrete and asphalt surfaces having a variety of transversely grooved patterns at ground speeds up to approximately 110 knots.

The results of this study indicate that chevron cutting occurs at the spot on the tire which initially contacts the surface and that the damage is the result of the scrubbing action of the tire as it skids over the grooves prior to rotation. The extent of chevron cutting was found to be primarily a function of the airplane ground speed at touchdown – the higher the speed, the greater the damage. The studies further show that chevron-cutting damage is essentially independent of the grooving patterns generally considered for airport use but is dependent upon the nature of the surface finish. Tests with different tires of the same size also indicate that the tread rubber compounding significantly affects the extent of chevron-cutting damage.

INTRODUCTION

Runway grooving has proved to be an effective means for improving tire traction during airplane ground operations under adverse weather conditions. References 1 and 2, for example, cite many experiences of increased friction levels provided by pavement grooving under wet conditions. Hence, a number of military and civil airport runways have been transversely grooved to improve all-weather airplane ground performance. However, instances have been recorded (e.g., ref. 1) in which the tires of some airplanes have encountered tread damage in the form of chevron cuts resulting from touchdown on a grooved surface. Chevron cutting, so-called because of the general shape of the cuts in the damaged area, was also noted in reference 3 during tire spinup behavior tests on grooved surfaces at the Langley landing-loads track. Visual inspection of airplane tires at airports having grooved runways indicates that only high-performance airplanes equipped with large tires experience this type of damage. At the present time chevron cutting does not appear to be a detriment to tire service life because of the limited number of existing grooved runways. However, as more runways are grooved, chevron cutting may become a tire wear problem for some airplanes. In addition to safety, the problem is also one of economics, since tire replacement accounts for approximately half the overall landing-gear maintenance costs of present-day jet airplanes.

The primary factors which are believed to affect chevron cutting include the forward speed and sink rate of the aircraft at touchdown and those factors associated with the runway surface and the tire. In addition to the grooving pattern, the runway material composition (concrete and asphalt, as examples) and surface finish could also be influential. Tire parameters such as size, tread design, rubber compounding, and inflation pressure are also candidate factors. In an effort to isolate some of these many potential factors and to study their effects on tire chevron cutting, an experimental research program was undertaken at the Langley landing-loads track. The purpose of this paper is to present the results from that program, some preliminary results of which were published in reference 4.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units and converted to SI units.

F_Z nominal static vertical load on wheel

p tire inflation pressure

V_H forward ground speed at touchdown

V_V wheel vertical velocity (sink rate) at touchdown

APPARATUS AND TEST PROCEDURE

Tires

The test tires for this investigation were size 49 × 17, 26-ply-rating, type VII aircraft tires which are currently used on many large military and commercial transports and have a history of susceptibility to chevron cutting. Figure 1 is a photograph of the

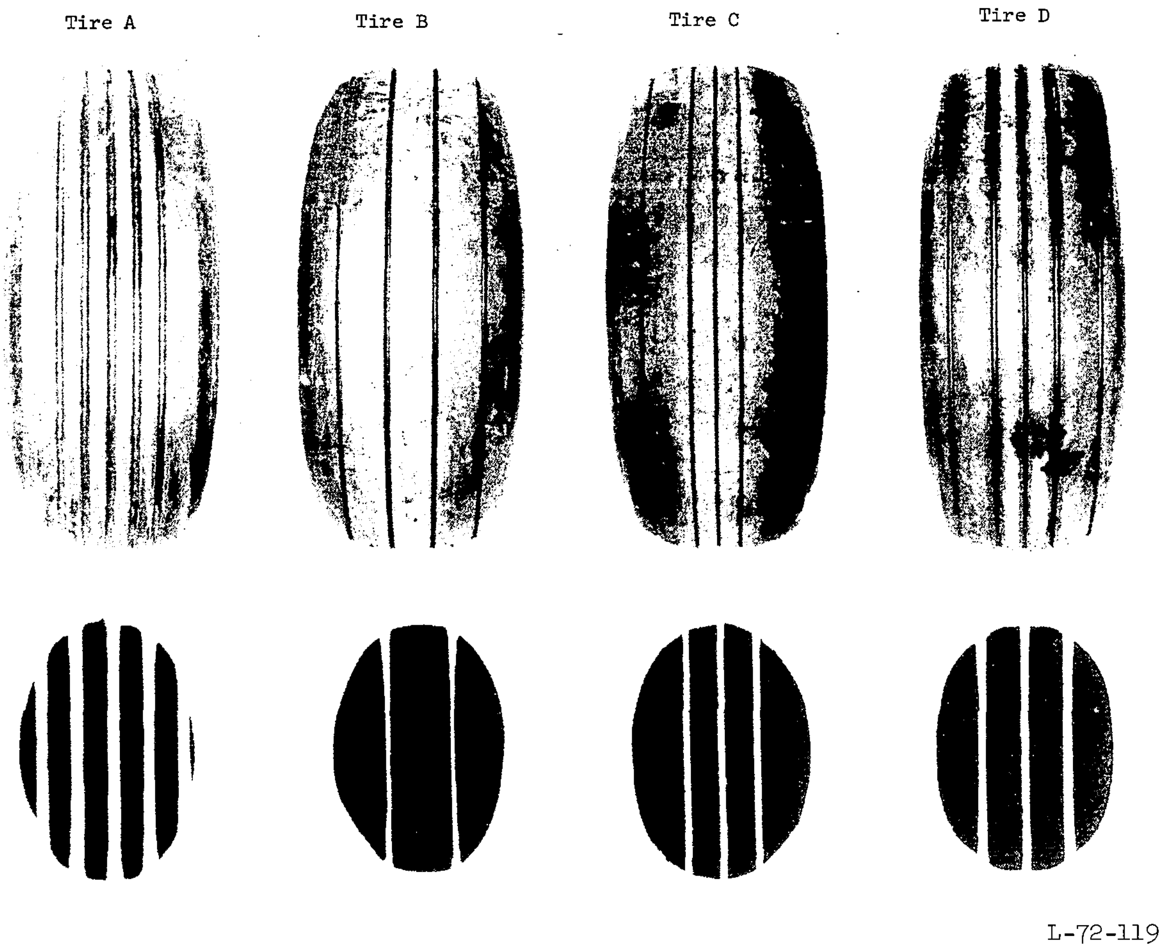
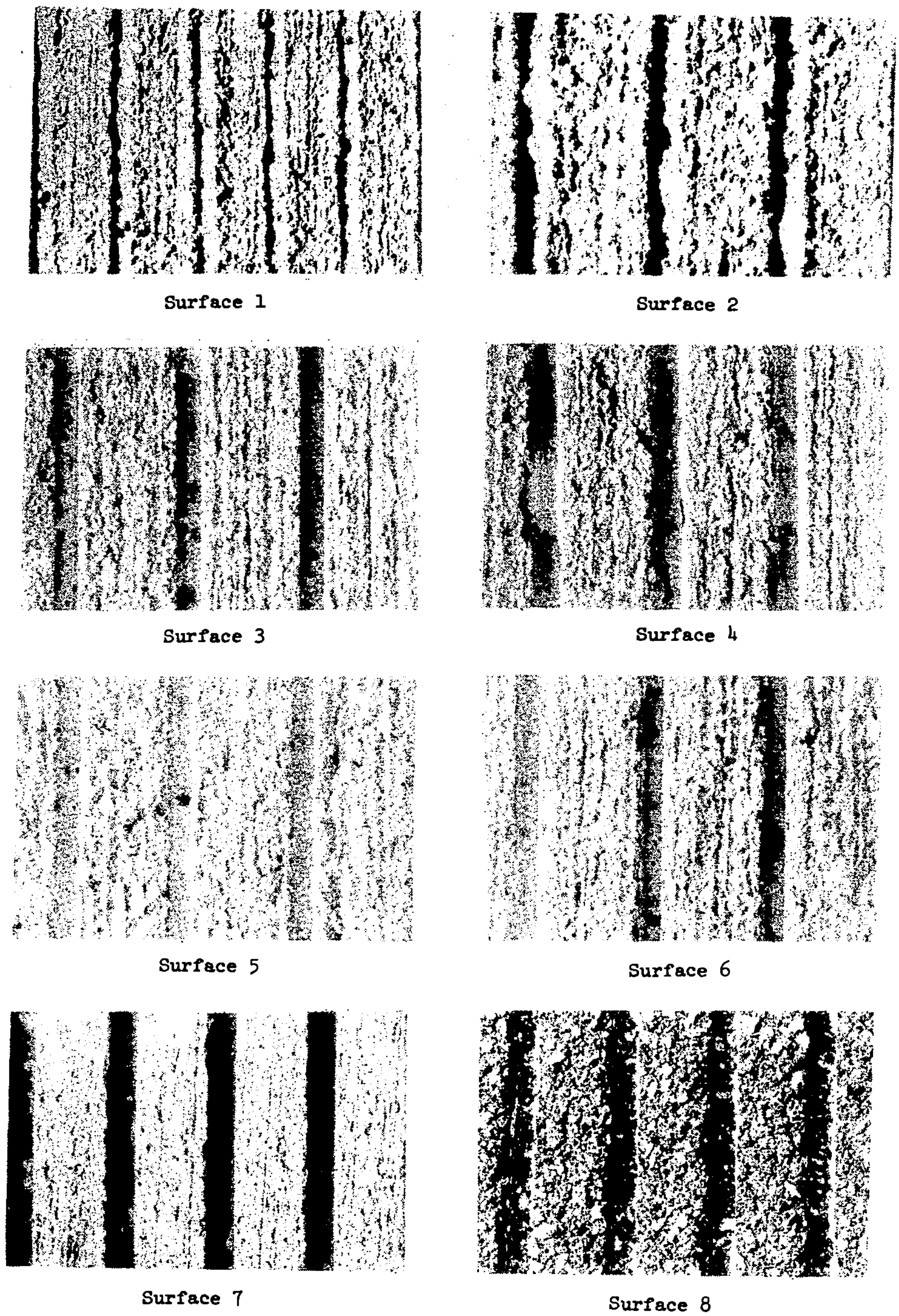


Figure 1.- Test tires and footprints under vertical loading of 66.7 kN (15 000 lb).

four basic tires and their respective footprints under a static vertical loading of 66.7 kN (15 000 lb). Pertinent characteristics of these tires are listed in table I, together with the measured net bearing pressures under most of the test inflation pressures. Tires A, B, and C were retreaded tires; tire A was equipped with a tread having five evenly spaced wide grooves, and tires B and C, retreaded by the same manufacturer, had four evenly spaced and five unevenly spaced narrow grooves, respectively. Tire D was a new tire of five unevenly spaced narrow grooves. The tire designated as C' in the table was the result of modifying the tread pattern of a tire C to approximate the tread pattern in the center section of the footprint of tire A.

Test Surfaces

Tire damage data were obtained from the eight grooved test sections shown in figure 2 and described in table II, which duplicated surfaces and grooving patterns generally



L-72-120

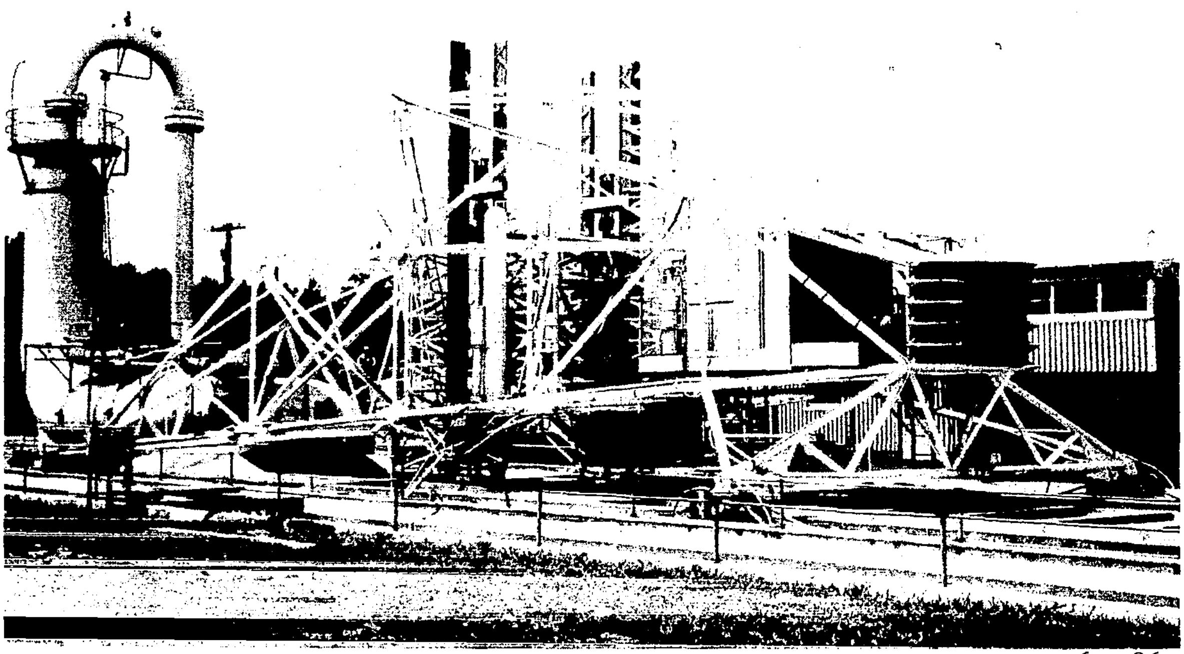
Figure 2.- Test surfaces.

considered for airport runway use. The test surfaces consisted of sections of transverse-brush-finish concrete (surfaces 1 to 6), a section of float-finish concrete (surface 7), and a section of small-aggregate asphalt (surface 8). The grooving patterns are defined by the spacing of the groove center lines, the groove width, and the groove depth and consist of rectangular and triangular grooves, with and without rounded troughs and corners. All grooves were in the transverse direction (i.e., perpendicular to the direction of travel) and were formed by two techniques: combed, in which the surface was raked or combed while in the plastic state, and sawed, the technique generally employed in grooving runways and roads. It is of interest to note in figure 2 that the grooves obtained from the combing technique are less uniform, particularly in depth, than those sawed, since the rake, unlike a saw blade, tends to ride over the random aggregate in the concrete mix. Thus, it appears that sawed grooves provide better runway drainage than combed grooves.

With the exception of two tests, one in which surface 7 was dampened and one in which it was flooded to a depth of 0.63 cm (1/4 in.), all testing was performed on dry surfaces to provide the highest tire-damage potential.

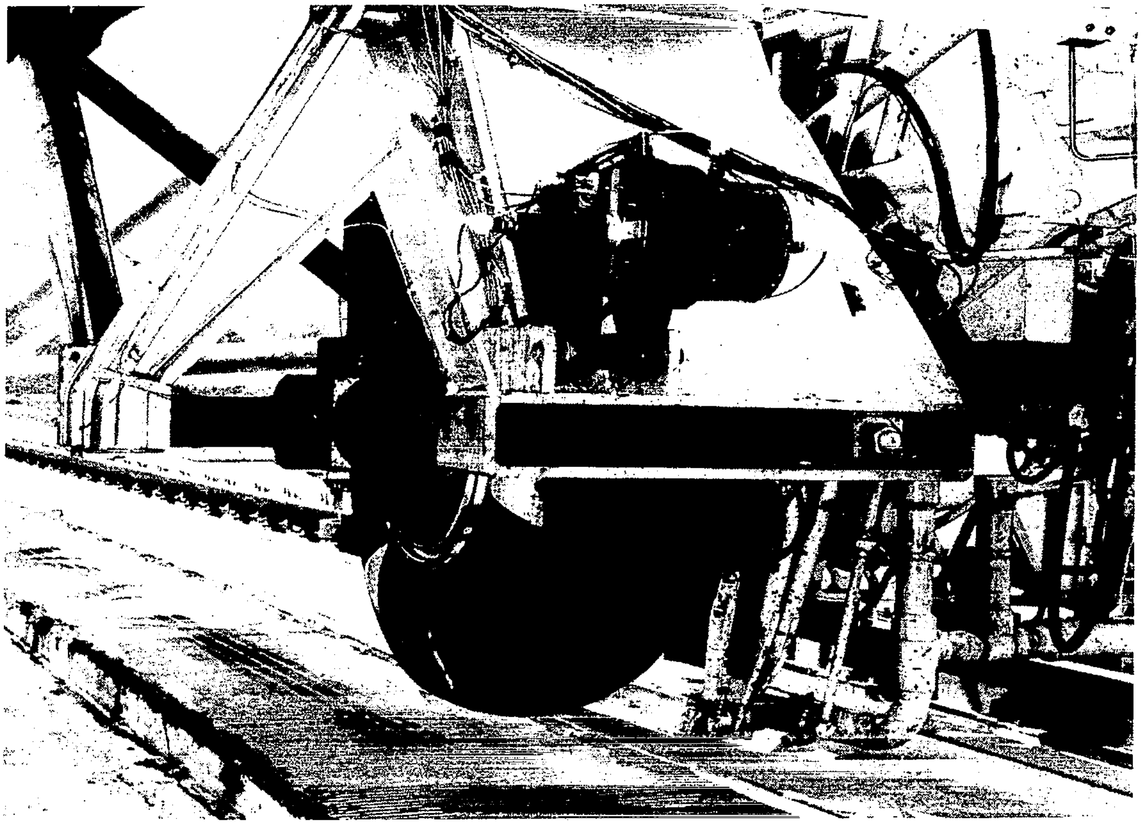
Test Facility

The investigation was conducted at the Langley landing-loads track and utilized the main test carriage. A description of this facility and its operation is given in reference 5. Figure 3 is a photograph of the carriage with the test wheel assembly, and figure 4 is a closeup view of the wheel and shows details of the instrumented dynamometer (of the type



L-69-5860

Figure 3.- Test carriage at Langley landing-loads track prior to launch.



L-69-5862

Figure 4.- Closeup of test tire showing load dynamometer.

described in ref. 5), which supports the wheel and measures the various axle loadings. The dynamometer is attached to a drop-test fixture which, during a test, was released to simulate an aircraft touchdown on a preselected test surface. The simulation was not entirely complete, however, since there was no wing lift and no strut system linking the wheel to the drop-test fixture.

Wheel response during touchdown was monitored by recording the outputs from the vertical- and drag-load beams in the dynamometer and a dc generator which yielded the instantaneous wheel angular velocity. These outputs, together with signals which described the carriage ground speed and wheel vertical velocity at touchdown, were transmitted to an oscillograph onboard the carriage.

Test Procedure

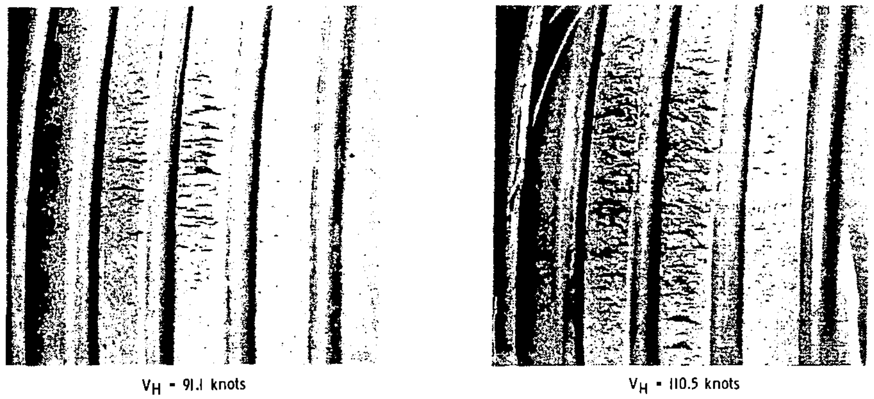
The testing technique involved propelling the carriage to the preselected ground speed, releasing the drop-test fixture to permit the tire to impact the desired test surface, and recording the tire response. After each test, the tire was examined and the tread damage, if any, was measured. Table III lists the various test conditions together with the corresponding tread-damage results. These conditions include not only those in direct support of this study but those of other published (ref. 3) and unpublished tests conducted at this facility, in which chevron cutting was observed. In addition to the different test surfaces and tires, these conditions included variations in the tire inflation pressure, the wheel ground speed and sink rate at touchdown, and the gross vertical loading on the wheel. The tires were tested at the rated inflation pressure of 117 N/cm^2 (170 lb/in^2) and at under- and over-inflation pressures of 69 N/cm^2 (100 lb/in^2) and 145 N/cm^2 (210 lb/in^2), respectively. In general, the range of ground speeds for each tire and test surface extended from approximately 110 knots, the maximum available test speed, down to the speed where no tire tread damage was evident. For those tests directly in support of this study, the drop-test fixture was equipped to apply a nominal static vertical loading of 66.7 kN (15 000 lb) on the wheel and was positioned in the carriage to provide a nominal sink rate of 0.76 m/sec (2.5 ft/sec). Other studies, which involved some tests on surface 7 and both tests on surface 8, were performed with a nominal static vertical loading of 155.7 kN (35 000 lb) on the wheel and a nominal sink rate of 0.46 m/sec (1.5 ft/sec).

In addition to monitoring the wheel loadings, which were recorded by the oscillograph, further tire-response information during the simulated touchdowns was provided by photographic coverage of each landing impact to complement the recorded data. The extent of tread damage was determined from an examination of the tire after each test.

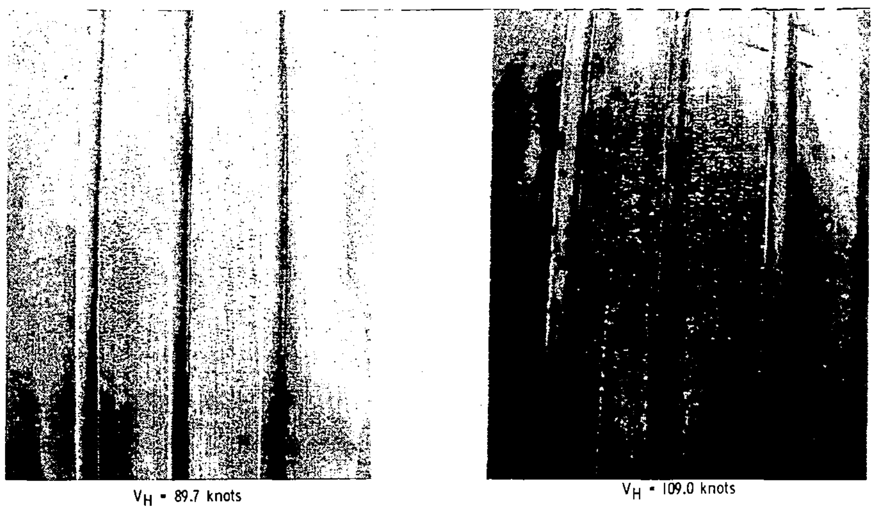
RESULTS AND DISCUSSION

Photographs which illustrate chevron-cutting tire tread damage are given in figure 5 for two of the test tires employed in this study. These photographs show the nature of the superficial cuts which can result from landing impacts on grooved runway surfaces. It was revealed from high-speed photographic coverage of the tires during touchdown that chevron cutting occurs at the spot on the tire which initially contacts the surface, and it appears that the damage is the result of the shearing action in the tire-pavement interface as the tire skids over the grooves. Chevron cutting was observed to cease when the tire begins to rotate. Thus, the larger and heavier the tire, the greater the inertia and the corresponding force necessary to induce rotation. This fact helps to explain why the smaller tires of fighter-type airplanes are not generally susceptible to chevron cutting.

In view of differences in the extent of tread damage for various test conditions, as noted in figure 5, it was necessary to develop a means for describing the damage that would permit an evaluation of the results on a comparative basis. The means selected was to measure the damaged volume, which is defined as the product of the damaged area of the tire tread and the maximum cut depth. Although damaged volume was somewhat arbitrarily selected, some rationale does exist for its use to describe the extent of the damage. Shallow cuts dispersed over a large area, for example, may be no more



(a) Tire A.



L-72-121

(b) Tire D.

Figure 5.- Chevron-cutting tread damage.

detrimental to the tire than localized deeper cuts having a similar damaged volume. Similarly, several deep cuts, which in themselves may not significantly contribute to reduced tire service life, would yield a small damaged volume because of the small tread area involved. For these tests, in which the touchdown horizontal velocity was limited to approximately 110 knots, the maximum cut depths which generally extended over a large percentage of the total damaged area never exceeded 0.48 cm (3/16 in.) in the tread ribs of tire A or 0.24 cm (3/32 in.) in the ribs of tire D. The damaged volumes for the various test conditions are included in table III and are used in the subsequent sections to illustrate the influence of certain test, tire, and surface parameters considered to affect chevron cutting.

Effect of Test Parameters

The test parameters are those which define the touchdown condition of an aircraft and consist of the horizontal ground speed, the sink rate, and the gross loading per wheel. The effect of each of these parameters on the extent of chevron cutting can be obtained by referring to table III. It is readily apparent from the data of the table and from the photographs of figure 5 that the ground speed at touchdown is a primary governing factor. The test results indicate that for each tire-surface combination there is a ground speed below which no tire chevron cutting could be detected and above which the extent of the damage generally increased (increased damaged volumes) with increased speed.

Because of bearing friction in the drop-test fixture, the sink rate, or vertical velocity, of the wheel at touchdown varied from the nominal; however, there is no discernible trend to support any conclusion relative to the influence of sink rate on tire chevron-cutting damage, at least over the range of sink rates provided by these tests. Similarly, the effect of wheel gross vertical loading appears to be of secondary importance. An analysis of the wheel loadings during touchdown revealed that the vertical loading when the wheel began to rotate – and when chevron cutting apparently ceased – was generally within the range between 8.9 and 17.8 kN (2000 and 4000 lb), well below the nominal static vertical loadings. In support of this analysis, it was observed (fig. 5) that the tread damage, in general, was restricted to the center ribs and this would imply that the tires were lightly loaded when the damage occurred.

Effect of Tire Parameters

Inflation pressure.- The nominal tire inflation pressures for this study were 117 and 145 N/cm^2 (170 and 210 lb/in^2); however, several additional tests were conducted on surface 7 with tires A and D underinflated at 69 N/cm^2 (100 lb/in^2) to establish the effect of inflation pressure on chevron cutting. The results from these tests together with the results obtained at the nominal pressures are presented in figure 6, where the measured damaged volume is plotted as a function of the ground speed at touchdown. The scatter associated with the data in this figure and in subsequent figures for each inflation pressure may be attributed to possible inaccuracies in measurements of the damaged volume (particularly cut depths, which were more difficult to obtain) and to variations in each runway test surface resulting from the grooving process and from repeated touchdowns in the same area. The figure shows that differences in the damaged volumes associated with the two higher inflation pressures appear to fall within the scatter of the data such that the extent of tire damage is essentially independent of these two test pressures. However, the limited data at 69 N/cm^2 (100 lb/in^2) do indicate that the tires are less susceptible to chevron cutting at low inflation pressures.

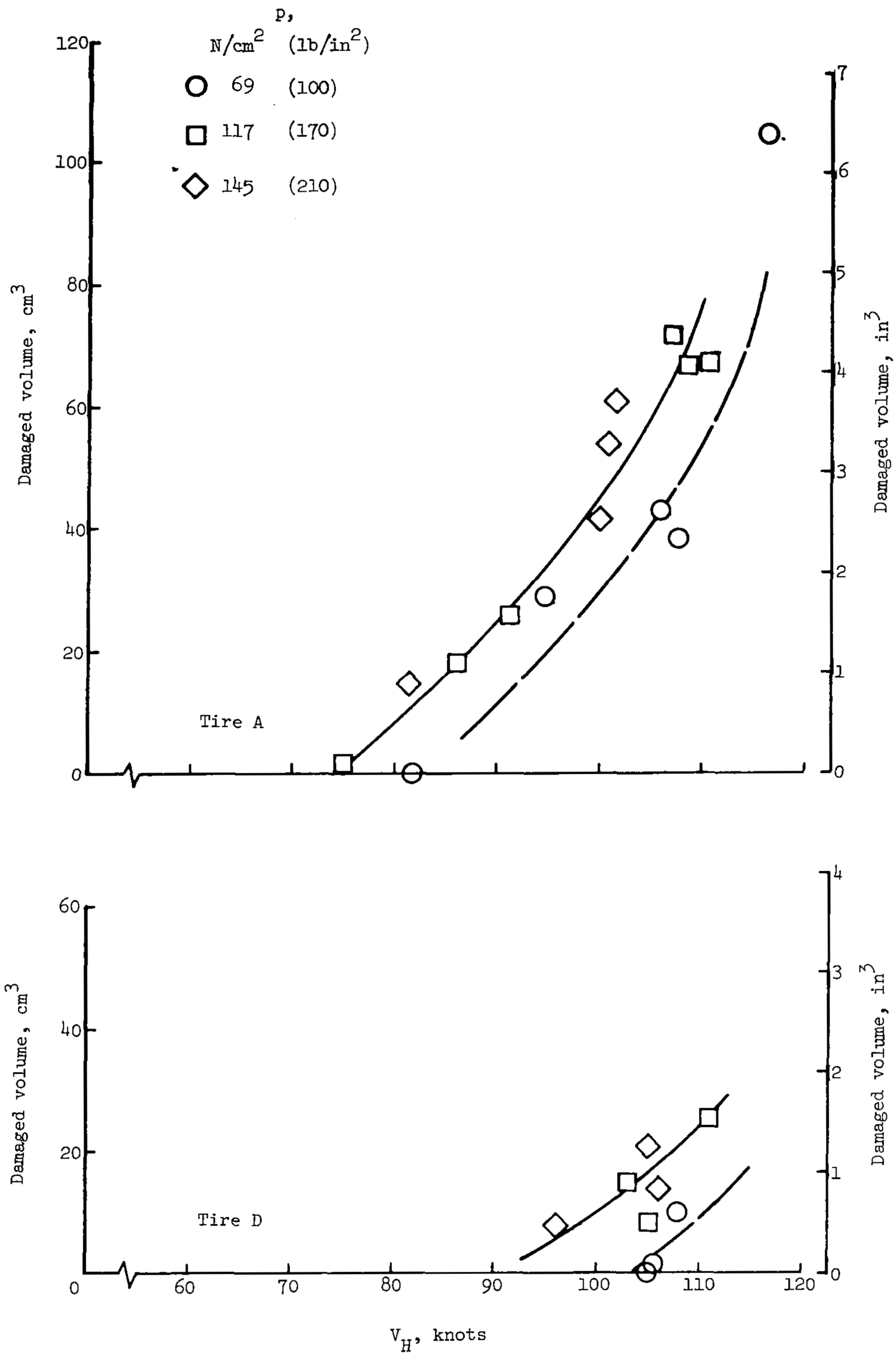


Figure 6.- Effect of tire inflation pressure on chevron-cutting damage. Surface 7.

Tire differences.- It is readily apparent from figure 6 that the damaged volumes of tire A are greater than those of tire D at corresponding touchdown velocities and tire inflation pressures. However, the effects of tire differences are better illustrated in figure 7, which combines the data from tires A and D and also includes the data from tire C. No data from tire B were obtained on this surface (surface 7) since earlier tests with that tire on surfaces 1 and 2 indicated damage results which were not significantly different from those for tires A and D. Figure 7 shows that tire A incurred chevron

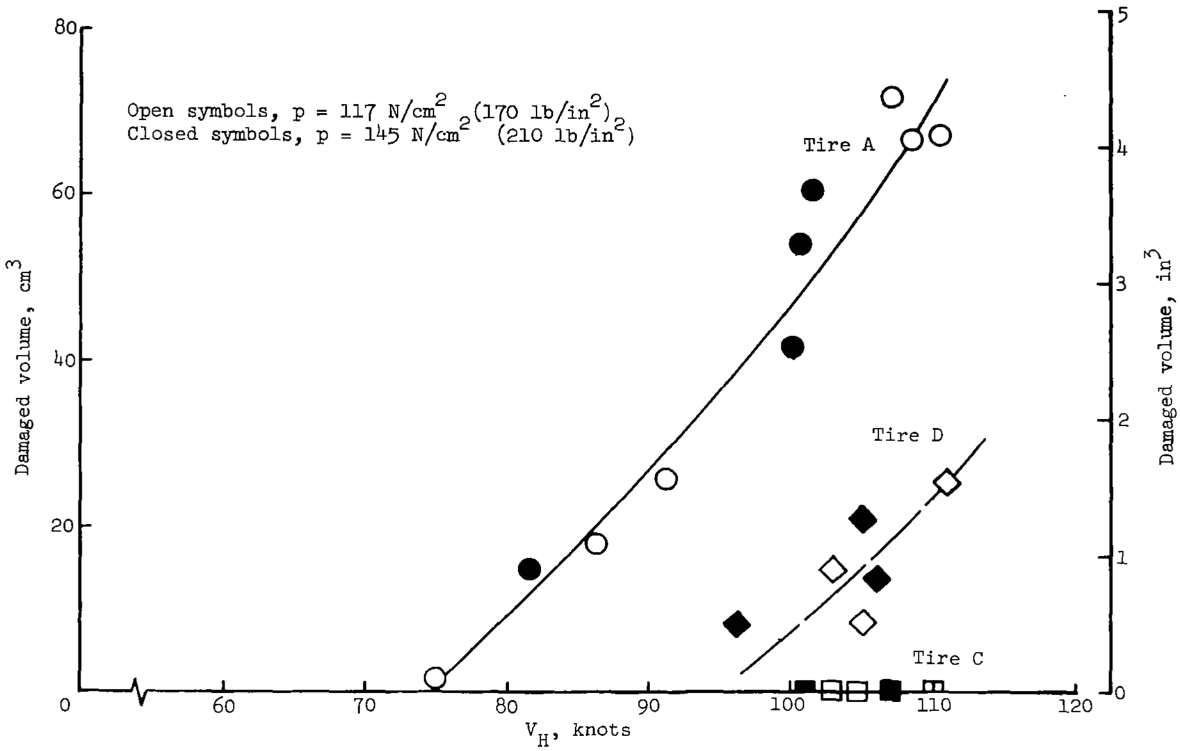


Figure 7.- Effect of tire differences on chevron-cutting damage. Surface 7.

cutting at touchdown velocities as low as 75 knots, that tire D was not susceptible to cutting below approximately 95 knots, and that tire C showed no evidence of chevron cutting up to the maximum test speed available with the facility. The data of this figure are for surface 7. The limited data for surfaces 1 and 2, as provided in table III, show similar trends for these tires.

Differences in the damage levels between tires A and C may be partly explained by differences in their respective tread patterns. As noted in table I, the tread pattern influences the net bearing pressure in the tire footprint, and the pressure associated with tire C is much less than that associated with tire A. In an effort to examine the effects of bearing pressure on chevron cutting, the tread of tire C was modified to resemble tire A and to provide a comparable net bearing pressure. The resulting tire, tire C', had seven grooves, but the outer two grooves, as for tire C (fig. 1), did not contribute to the footprint even at the larger wheel loading. The results of landing impact tests with this tire on surface 7 are included in table III and indicate that some chevron cutting did occur but that the extent of the damage was considerably less than that of tire A at similar ground speeds. It should be pointed out that the chevron cutting of tire C' was limited to the edges of the ribs in the tread and could possibly be associated with localized weak spots in the ribs, which resulted from the tread-modification process. Thus, on the basis of these tests, it is difficult to establish what influence tire tread pattern, and hence bearing pressure, has on the susceptibility of a tire to chevron cutting.

The compounding of the tire tread rubber may be another factor contributing to differences in the susceptibility of tires to chevron cutting. The rubber compound in the tread of the tires of this study is unknown; however, certain evidence exists which suggests possible differences. For example, Shore hardness numbers, which serve to define the resistance of a material to local penetration, were obtained for the tread of the test tires, and the average value for each tire is presented in table I. These numbers do suggest possible differences in the tread rubber inasmuch as they differ for each tire; the tread of tire C offers the least resistance to penetration and tire D the greatest resistance. Further evidence suggesting differences in rubber compounding was obtained from observations of the nature of the cuts in the damaged area of the test tires. As an example, figure 5 illustrates differences in the failure modes of tires A and D, where the damage of tire A is characterized by a gouged appearance and that of tire D shows distinct cuts in the tire tread with no apparent rubber removed.

Effect of Runway Surface Parameters

The effects of various runway surface parameters on tire chevron cutting are best illustrated by the data from tire A, since that tire was found to be the most susceptible to this type of damage. These parameters include the grooving pattern and the surface finish and wetness condition. The contribution of each of these parameters to chevron cutting is discussed separately in the paragraphs which follow.

Grooving pattern.- Figure 8 summarizes the results of chevron-cutting damage as a function of ground speed for tire A on transverse-brush-finish concrete having groove patterns described by surfaces 1 to 6 in table II. Data are presented for tire inflation pressures of 117 and 145 N/cm^2 (170 and 210 lb/in^2). The figure shows that the extent of chevron cutting is essentially independent of the grooving patterns tested, which included variations in the groove dimensions and configuration, in addition to the grooving technique. No chevron cutting was observed below approximately 85 knots on these surfaces, and, typical of all tire-surface combinations, the magnitude of the damaged volume is shown in the figure to increase with touchdown velocity and to be independent of the two inflation pressures within the scatter of the data.

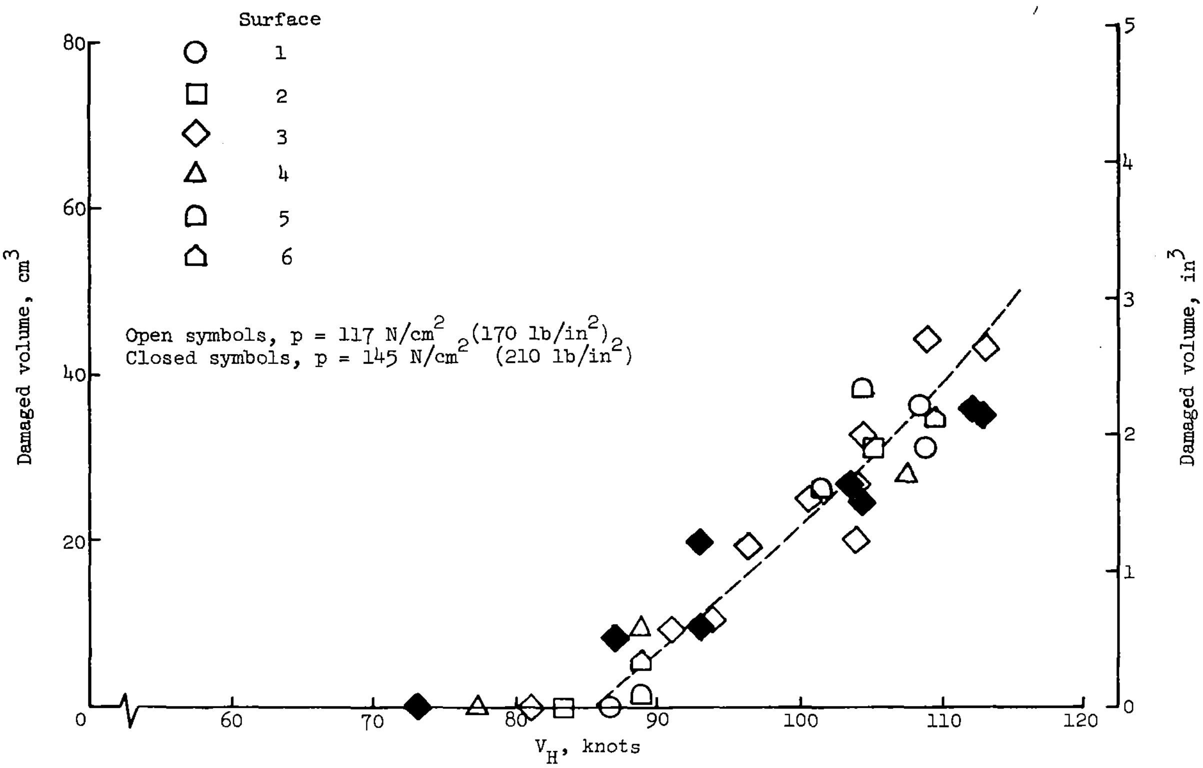


Figure 8.- Effect of grooving pattern on chevron-cutting damage. Tire A; brush-finish concrete.

Surface finish.- The effect of surface finish on chevron cutting is illustrated in figure 9, which includes the results of tests, again obtained with tire A, conducted on the transverse-brush-finish concrete (surfaces 1 to 6), on the float-finish concrete (surface 7), and on the asphalt (surface 8). Presented in the figure are data for surfaces 7 and 8, which have the same grooving pattern, and the curve from figure 8 which fairs the data for the brush-finish concrete surfaces having different patterns. The figure shows that the grooved transverse-brush-finish concrete is less damaging to the tire than the grooved float-finish concrete. The lower damage levels associated with the grooved brush-finish surfaces may be attributed to the edges of the grooves, which parallel the brush marks and hence are less distinct and more rounded than those in the float-finish concrete (fig. 2). This assumption helps to explain the even lower damage levels obtained on the grooved asphalt, which was observed (fig. 2) to have more rounded grooves than either of the concrete finishes. It should be pointed out that from the limited tests with tire D on surfaces 1, 2, and 7 (table III), the low damage levels associated with that tire show little distinction between the two concrete surface finishes. However, it does appear on the basis of the overall test results that tires are least susceptible to chevron cutting on asphalt surfaces, and a transverse brush finish for concrete surfaces would provide better tire wear, while possibly improving runway drainage.

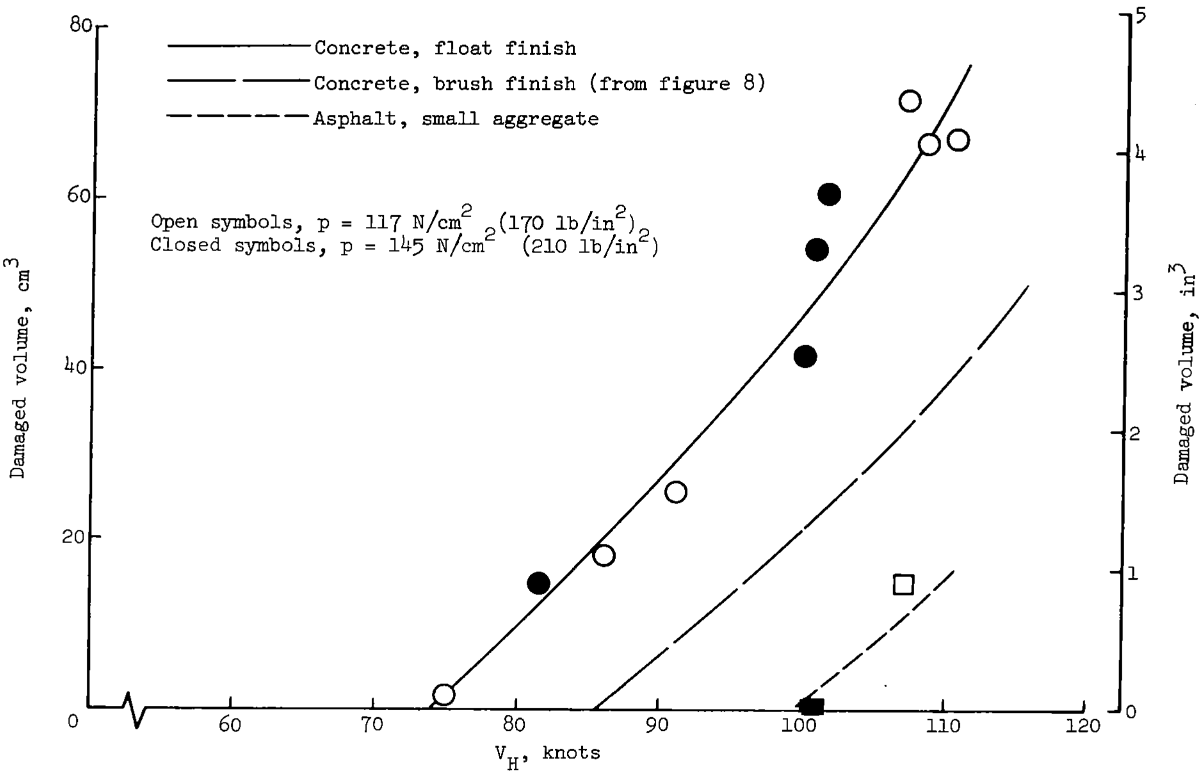
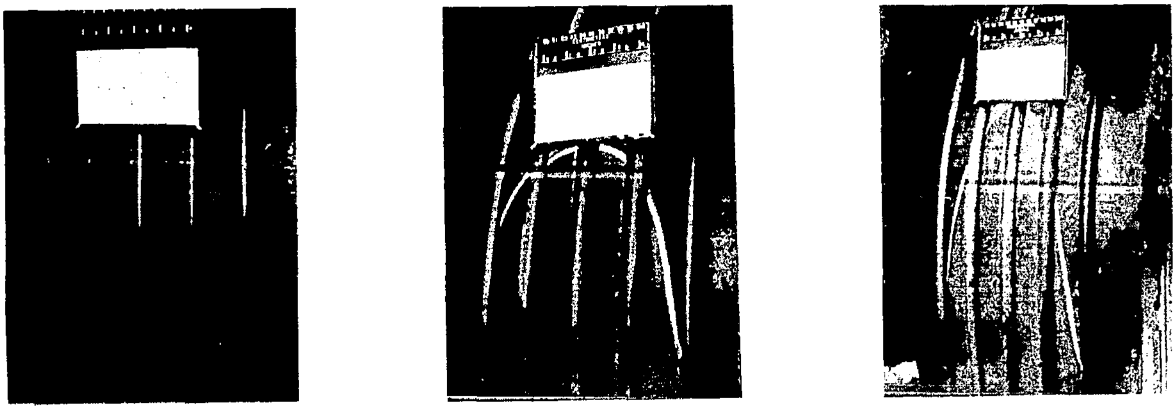


Figure 9.- Effect of surface finish of grooved surface on chevron-cutting damage. Tire A.

Wetness condition.- One series of tests was performed with tire A on surface 7 under dry, damp, and flooded conditions at essentially the same ground speed to examine the effect of surface wetness condition on chevron cutting. The results from these limited tests are identified in table III and indicate that the presence of water apparently serves as a lubricant since the extent of tread damage decreased with increased surface wetness.

Effect of Wheel Prerotation on Tire Damage at Touchdown

Since it was observed that chevron cutting resulted from the scrubbing action of the tire as it skids over the grooved surface prior to rotation, one series of tests was conducted to ascertain if prerotation of the wheel prior to touchdown would eliminate this tread damage. Tire A was selected for these tests because of its high susceptibility to cutting. Wheel prerotation was provided by winding a length of rope about the tire circumference and anchoring one end to the ground so that when the carriage was launched the wheel was spun up. The length of the winding governed the wheel prerotation speed, which was monitored throughout the tests by use of the dc generator. The results of three tests, conducted at a nominal forward ground speed of 100 knots on surface 3, are shown in figure 10 for no prerotation and for prerotation in which the tire circumferential



No prerotation **4.7% prerotation** **11% prerotation**

L-72-122

Figure 10.- Effect of prerotation on tire chevron cutting. $V_H \approx 100$ knots.

speed at touchdown approximated 4.7 and 11 percent of the carriage ground speed. The figure shows that at 4.7-percent prerotation the tire incurred only slight damage, whereas at 11 percent, no tread damage was evident. Although these limited tests indicate that the extent of chevron cutting can be reduced or altogether avoided by wheel prerotation, insufficient data were obtained to establish the minimum prerotation required to eliminate chevron cutting. Conceivably, this required prerotation may be less than that necessary to reduce the relative speed between the tire and the ground to the velocity threshold for chevron cutting noted in figures 6 to 9 for the different tires and grooved surfaces.

CONCLUSIONS

Simulated landing impact tests were performed with several 49 × 17, type VII, aircraft tires on a variety of grooved runway surfaces to study the effects of certain test, tire, and surface parameters on chevron-cutting tire tread damage. The results of these tests suggest the following conclusions:

1. Chevron cutting was observed to occur at the spot on the tire which initially contacts the surface, and the damage appears to be the result of the scrubbing action of the tire as it skids over the grooves prior to rotation.

2. The ground speed at touchdown is a primary variable affecting chevron cutting; for each combination of tire and grooved surface, there is a ground speed below which no chevron cutting occurs and above which the extent of the damage increases with increased speed. The effect of sink rate and tire gross loading, at least within the framework of these tests, appears to be negligible.

3. Chevron cutting is generally less pronounced at low tire inflation pressures.

4. Different tires of the same size can differ in their susceptibility to chevron cutting. The susceptibility appears to be affected significantly by the composition of the rubber in the tire tread and only slightly by the tire tread patterns.

5. Chevron-cutting damage is essentially independent of the grooving patterns generally considered for airport use but is dependent upon the nature of the surface finish. Grooved transverse-brush-finish concrete is less damaging to tires than grooved float-finish concrete because the edges of the grooves in the brush-finish concrete are less distinct and more rounded than those in the float-finish concrete. The results from limited tests on grooved asphalt, having even more rounded grooves, indicate lower damage levels than on either of the concrete surfaces.

6. Tire tread damage decreases with increased surface wetness condition, apparently as a result of the lubricating action of the water in the tire-pavement interface.

7. Providing the wheel with prerotation prior to touchdown is one approach for either reducing or eliminating chevron-cutting damage.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 2, 1972.

REFERENCES

1. Anon.: Pavement Grooving and Traction Studies. NASA SP-5073, 1969.

2. Yager, Thomas J.; Phillips, W. Pelham; Horne, Walter B.; and Sparks, Howard C. (With appendix D by R. W. Sugg): A Comparison of Aircraft and Ground Vehicle Stopping Performance on Dry, Wet, Flooded, Slush-, Snow-, and Ice-Covered Runways. NASA TN D-6098, 1970.

3. McCarty, John Locke: Effects of Runway Grooving on Aircraft Tire Spin-Up Behavior. NASA TM X-2345, 1971.

4. Anon.: NASA Aircraft Safety and Operating Problems. Vol. I. NASA SP-270, 1971.

5. Joyner, Upshur T.; Horne, Walter B.; and Leland, Trafford J. W.: Investigations on the Ground Performance of Aircraft Relating to Wet Runway Braking and Slush Drag. AGARD Rep. 429, Jan. 1963.

TABLE I.- CHARACTERISTICS OF TEST TIRES

Tire	Tread		Test inflation pressure		Net bearing pressure (a)	
	Description	Shore hardness number	N/cm^2	lb/in^2	N/cm^2	lb/in^2
A	Five grooves, retread	66	69 117 145	100 170 210	105 145 256	153 210 372
B	Four grooves, retread	58	117	170	110	159
C	Five grooves, retread	55	69 117 145	100 170 210	--- 107 132	--- 155 192
C'	Seven grooves, retread	55	117	170	143	208
D	Five grooves, new tread	69	69 117 145	100 170 210	--- 114 ---	--- 165 ---

[a] Static vertical loading = 66.7 kN (15 000 lb).

TABLE II.- GROOVED RUNWAY TEST SECTIONS

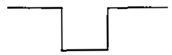
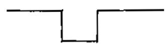
Surface	Material and finish	Grooving pattern: Configuration	Grooving pattern: Dimensions, cm	Grooving pattern: Dimensions, in.	Grooving technique
1	Concrete, brush		1.9 by 0.3 by 0.3	$\frac{3}{4}$ by $\frac{1}{8}$ by $\frac{1}{8}$	Combed
2			3.2 by 0.6 by 0.6	$1\frac{1}{4}$ by $\frac{1}{4}$ by $\frac{1}{4}$	
3					Sawed
4					
5					
6			3.2 by 0.5 by 0.5	$1\frac{1}{4}$ by $\frac{3}{16}$ by $\frac{3}{16}$	
7	Concrete, float		2.5 by 0.6 by 0.6	1 by $\frac{1}{4}$ by $\frac{1}{4}$	
8	Asphalt, small aggregate				

TABLE III. - SUMMARY OF TEST CONDITIONS AND RESULTS

Surface	Tire	p		V_H, knots	V_V		F_Z		Damaged volume	
		N/cm^2	lb/in^2		m/sec	ft/sec	kN	lb	cm^3	in^3
1	A	117	170	86.6	0.67	2.19	66.7	15 000	0	0
				108.4	.77	2.53			36.1	2.2
				108.8	.77	2.53			31.1	1.9
	B			89.5	.75	2.45			1.6	.1
				90	.78	2.57			3.9	.24
				108.5	.78	2.57			23.1	1.41
	C			104.2	.84	2.77			0	0
	D			65.7	.78	2.56			0	0
				89.7	.75	2.45			4.1	.25
				109.5	.73	2.38			21.5	1.31
2	A	117	170	83.4	0.74	2.42	66.7	15 000	0	0
				105.1	.78	2.56			31.1	1.9
	B			89.2	.70	2.31			0	0
	C			111	.80	2.63			1.6	.1
	D			109	.84	2.74			24.9	1.52
3	A	117	170	81.1	0.70	2.31	66.7	15 000	0	0
				90.9	.74	2.42			9.3	.57
				93.8	.71	2.32			10.5	.64
				96.3	.71	2.32			19.3	1.18
				100.7	.71	2.32			24.9	1.52
				103.9	.75	2.45			26.7	1.63
				104	.75	2.45			20	1.22
				104.5	.73	2.38			32.8	2.0
				109	.64	2.11			44.3	2.7
				113.1	.73	2.38			43.1	2.63
		145	210	73.2	.70	2.29			0	0
				87	.75	2.47			8.2	.5
				93	.73	2.38			19.7	1.2
				93	.70	2.30			9.7	.59
				103.9	.74	2.42			26.9	1.64
				104.4	.73	2.38			24.6	1.5
				112.2	.69	2.25			35.7	2.18
				112.8	.73	2.38			35.2	2.15
	C	117	170	104.5	.74	2.42			0	0
				112.5	.73	2.38				
		145	210	103	.72	2.35				
				111.7	.74	2.42				
4	A	117	170	77.2	0.72	2.35	66.7	15 000	0	0
				88.8	.73	2.38			9.5	.58
				107.6	.73	2.38			27.9	1.7
	C			104.5	.68	2.22			0	0
5	A	117	170	88.8	0.73	2.38	66.7	15 000	1.6	0.1
				101.6	.80	2.64			26.2	1.6
				104.5	.74	2.42			38.4	2.34
	C			103.6	.73	2.38			0	0

TABLE III.- SUMMARY OF TEST CONDITIONS AND RESULTS – Concluded

Surface	Tire	p, N/cm^2	p, lb/in^2	V_H, knots	V_V, m/sec	V_V, ft/sec	F_Z, kN	F_Z, lb	Damaged volume, cm^3	Damaged volume, in^3
6	A	117	170	88.8	0.75	2.45	66.7	15 000	5.6	0.34
				109.5	.72	2.35			34.4	2.1
	C			98.7	.74	2.42			0	0
7	A	69	100	81.7	0.80	2.61	66.7	15 000	0	0
				94.7	.80	2.64			28.8	1.76
				106	.48	1.57	155.7	35 000	42.9	2.62
				107.6	.52	1.72			38.4	2.34
				116.2	.80	2.64	66.7	15 000	103.5	6.32
		117	170	74.9	.80	2.64			1.6	.1
				86.1	.76	2.48			18	1.1
				91.1	.85	2.78			25.6	1.56
				107	.53	1.74	155.7	35 000	71.6	4.37
				108.4	.35	1.15			66.5	4.06
				110.5	.76	2.48	66.7	15 000	67.2	4.1
[a]7				110.2	.77	2.52			52.4	3.2
[b]7				110.9	.71	2.32			20	1.22
7		145	210	81.5	.56	1.83	155.7	35 000	14.8	.9
				100	.52	1.72			41.6	2.54
				100.6	.51	1.67			54.1	3.3
				101.4	.52	1.72			60.6	3.7
	C	69	100	104.2	.52	1.72			0	0
		117	170	103	.46	1.51				
				104.1	.66	2.16	66.7	15 000		
				110	.65	2.14				
		145	210	101	.41	1.35	155.7	35 000		
				107	.49	1.62				
	C'	117	170	91	.78	2.57	66.7	15 000		
				98.6	.78	2.57			11.5	.7
				113.2	.68	2.22			16.4	1.0
	D	69	100	105	.77	2.54	155.7	35 000	0	0
				105.6	.43	1.40			1.6	.1
				107.7	.56	1.83			9.8	.6
		117	170	103	.49	1.62			14.8	.9
				105	.76	2.50			8.2	.5
				110.9	.57	1.87			25.4	1.55
		145	210	96	.49	1.62			8	.49
				105	.89	2.92			20.8	1.27
				106	.49	1.62			13.8	.84
8	A	117	170	107	0.48	1.58	155.7	35 000	14.8	0.9
		145	210	100.7	.44	1.43			0	0

[a] Damp.

[b] Flooded to a depth of 0.63 cm (1/4 in.).

NASA-Langley, 1972 —— 2 L-7883

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546