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BRAKING PERFORMANCE OF A BOEING 727 AIRCRAFT TIRE ON GROOVED PORTLAND CEMENT CONCRETE SURFACES

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by
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ANA-430

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NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
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ABSTRACT

Although runway grooving is designed to improve traction under wet conditions, many runways remain ungrooved because of the high grooving costs. The objective of this study was to determine if grooving costs could be reduced through increased groove spacing (beyond spacings recommended by FAA Advisory Circular AC 150/5320-12), while still providing adequate traction. Wheel braking tests on Portland Cement Concrete surfaces, in which both the recommended and increased spacings had been incorporated, were performed, and the results are summarized. Estimates of cost savings made possible by the use of increased groove spacing are presented along with cost-performance tradeoff data.

BRAKING PERFORMANCE OF A BOEING 727 AIRCRAFT TIRE ON GROOVED PORTLAND CEMENT CONCRETE SURFACES

Introduction

The work described herein has been undertaken and accomplished in response to Request for RD&E Effort 9550-1 AAP-580-72-1, prepared by AAP-500. ARD-400 provided program direction under Request for End Item Support 082-431-01. ANA-400 provided test direction and data analysis, and ANA-200 data reduction, under NAFEC Program Document 08-459, Subprogram 082-431, Project 51. The Naval Air Engineering Center at Lakehurst, New Jersey, NAEC, provided test facility operation and data acquisition under FA74WAI-423 contract, funded by ARD-400. The author of this report is Hector Daiutolo, ANA-430, the NAFEC Program Manager.

Objective

The objective of the program has been to determine the lowest cost runway grooving configuration which has acceptable performance.

The results reported herein cover wheel braking tests performed on Portland Cement Concrete (PCC) surfaces. Program plans call for additional testing on asphaltic concrete surfaces as well as on other type surfaces, which exhibit cost saving potential, such as Porous Friction Course (asphaltic) and PCC with grooves applied in the plastic state.

Background

Runway grooving is known to improve traction and reduce hydroplaning under wet and flooded conditions. Regardless of this fact, only about 100 air carrier runways have been grooved. Approximately 650 runways have not been grooved; although more than 100 of these have received other types of surface treatment. There obviously exist deterrents to the use and acceptability of runway grooving. The most commonly cited are:

1. Cost
2. Question as to extent of improved traction.
3. Surface degradation.
4. Rubber buildup.
5. Tire damage.

Grooves are normally cut in runway surfaces using diamond tipped rotary saws. This method is applied to cured surfaces, and is the only available method for placing grooves in asphaltic concrete, the latter comprising about 80 percent of the air carrier runway surfaces. Its disadvantage is high cost. Grooves applied in the plastic state offer a cost saving, but are only applicable to Portland Cement Concrete and must await a surface overlay.

An FAA Advisory Circular, AC 150/5320-12, reference 1, recommends a runway grooving configuration of $\frac{1}{4} \times \frac{1}{4}$ inch square grooves cut transversely to the runway centerline and spaced at $1\frac{1}{4}$ inches center to center. This configuration was based on the results of NASA tests in which a $\frac{1}{4} \times \frac{1}{4}$ inch square groove spaced at 1 inch center to center, was found to be the most effective in improving traction and reducing hydroplaning under wet and flooded conditions.

In 1975, Edward Galura Sharf and Sons, of Washington, D. C., construction cost consultants, were contracted to examine the cost saving potential of decreased groove size and increased groove spacing. Grooving costs were sampled in the Northeastern, Midwestern, and Southwestern United States. Decreased groove size was found to offer little cost saving. Increased groove spacing offered significant cost savings.

The braking performance of aircraft tires on grooving configurations with increased spacings, however, remained an unknown, particularly at speeds above 100 knots. The runway grooving test facility, at NAEC, Lakehurst, N. J., was developed specifically to determine this braking performance.

The test facility also offers the capability of testing surface degradation, rubber buildup, and tire damage. However, to date, little effort has been expended in these areas since major emphasis was directed toward investigating the cost savings of increased groove spacing. It would be expected that with increased groove spacings, the deterrent effects of surface degradation, rubber buildup, and tire damage would be reduced.

Test Facility

The NAEC facility at test track no. 1 was developed jointly by the FAA and the U. S. Navy, and has the capability of simulating a jet transport tire-wheel assembly at touchdown and rollout. The setup at the launch end of the track is shown in Figure 1. A 4,000 lb. steel yoke, the dynamometer, housed the tire-wheel assembly, imparted the loading and braking to the

wheel, and contained the instrumentation system which measured the loading, angular motion, and linear motion of the wheel. The dynamometer was an adaptation of the NASA design. The dynamometer and tire-wheel assembly were contained in a 60,000-lb. dead load. The dead load was propelled to speeds between 70 and 150 knots by four J-48 jet engines, each capable of 6,000 lbs. of thrust. The dead load was arrested by a cable-fluid brake system at the far end of the mile long track. The steel structure for the overhead arrestment of the dead load is shown in Figure 2.

The loading was imparted to the wheel through two hydraulic cyclinders activated by pressurized nitrogen, Figures 3 and 4. The total vertical load was 35,000 lbs., the average landing load per tire for the Boeing 727-200 aircraft series. The tires were six groove 49 x 17, 26-ply rating, type VII, aircraft tires used on both the Boeing 727 and Boeing 747 aircraft, Figure 4. All tires were either newly recapped or totally worn recapped (wear extending into the plies) thereby covering the extremes of the effects of tire wear on wheel braking. Tire pressure was held at 140 p.s.i., the low end of the operational range, encouraging earlier hydroplaning with respect to speed or water depth.

Tire wear (and consequently tire grooving) was found to significantly affect wheel braking. Accordingly, the performance of a wide-groove tire was sampled. The tire was modified to the wide-groove condition by increasing the groove widths, on a standard tire, from 3/8 inch to 3/4 inch.

The braking system, Figure 5, was activated in the same manner as the loading system. Figure 5 also shows the port vertical and horizontal load links. The vertical load links, port and starboard, measured the load applied to the wheel; the horizontal load links, port and starboard, measured the braking force between the tire and the surface tested.

Figure 6 shows the test bed at the arrestment end of the track. The bed was a slab 200 feet long, 30 inches wide, and 5 inches thick, consisting of Portland Cement Concrete of 5,000 p.s.i. crushing strength, with a broomed surface finish. Dimensional tolerances of the surface were held to $\pm$ 1/8 inch from a perfectly horizontal plane for the full 200 feet. The bed was diked, by rubber strips, into four 45-foot test sections. The first 20 feet were sacrificed to insure that the tire was performing before it entered the test sections.

Portland Cement Concrete, rather than asphaltic concrete, was selected for the first test series in the program for the following reasons:

1. Groove cutting costs for PCC are higher and, consequently, the potential for cost savings per runway is greater.

2. Any concerns related to tire damage are generally expressed with respect to PCC surfaces.

3. The bulk of the NASA data related to tire braking performance and hydroplaning was obtained on PCC surfaces. Correlation with NASA results was considered important, particularly in the initial phases of the test program.

The Final Report, on this program, will examine the relationship between the NAFEC/NAEC test results and the NASA test results, references 2 and 3. Figure 7 shows the grooving machine developed by NAEC. It contained a single diamond tipped blade capable of cutting the $\frac{1}{4}$ in. x $\frac{1}{4}$ in. grooves to a tolerance of $\pm$ 1/64 in. Groove spacing was maintained to a tolerance of $\pm$ 1/32 in.

Test Procedures

In conducting the tests, the engines were first started and set at performance levels which would enable the dead load vehicle to enter the test bed at the desired speed. The system was then released at the launch end of the track. The tire was in contact with the ground (concrete surface), and was in a state of free roll supporting only the 4,000-lb. weight of the dynamometer for the full mile length of the track. Several hundred feet before the dead load reached the test bed, the pusher car was braked and separated from the dead load. About 150 ft. ahead of the test bed, the vertical load was applied to the wheel. Between 50 ft. and 20 ft. ahead of the test bed, depending on the speed of the test, the brakes were applied. The aircraft wheel thus entered the test sections at the desired speed, fully loaded and braked. Loading and brakes were released as the wheel left the test bed.

In testing the plain PCC surface, the tire engaged increased water depths at each successive 45-ft. test section. In testing the grooved surfaces, the water depth was held constant for each test, and the tire engaged increased groove spacings at each successive 45-ft. test section. The final 45-ft. section remained plain for the initial part of the PCC test series. For the latter part of the test series it was treated with the Klarcrete process. Klarcrete provides a reflex percussive cutting action which produces a roughened surface by enabling a thin upper layer of the PCC to flake off in tension by virtue of compressive rebound.

Data Acquisition and Analysis

Tests were conducted such that the primary test variables were increased incrementally as the tests progressed. Speeds used were 70, 90, 110, 130 and 150 knots. Average water depths were 0.00, 0.01, 0.07, 0.15, 0.23, and 0.31 in. Water depths were controlled with the NASA water depth gage. Groove spacings tested were $1\frac{1}{4}$, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, and 4 in. Brake pressures

were varied depending on the traction capabilities of the tire and surfaces, under the water depth conditions tested. The intent was to hold wheel slips within an 8 percent to 30 percent range, where they produce the maximum range of traction levels, reference 4. Free roll represents 0 percent slip, locked wheel 100 percent slip.

A total of 190 tests were run in the PCC series. These tests generated 570 analog data traces. The most significant variable measured was the traction level, the horizontal force between the tire and the concrete surface divided by the vertical load on the wheel. The traction level, as well as the other items measured, was traced over the entire length of the test bed. The analog data were reduced to digital form and separated with respect to the parameter of tire wear (new vs. worn). The traction level data were then cross-plotted and curve fitted with respect to the primary test variables, speed, water depth, and groove spacing. These curves generated a parametric series of plots relating traction level to speed for varying groove spacings and water depths. These curves are presented in this report in Figures 9 to 14.

Summary of Results

Cost savings, provided by spacings increased beyond $1\frac{1}{4}$ inches, are presented in Figure 8. Tire braking performance is presented in Figures 9 to 14. Figures 11 to 14 are repeated in Figures 15 to 18, with the wide groove tire test results superimposed. The results and conclusions, based on the braking performance tests, pertain to the particular tire, wheel load, and concrete surfaces used in the tests.

The following items should be noted:

1. Tires

    a. All were recapped (the common operational condition).
    b. All were of the six groove type.
    c. Tire wear extended into the plies on the worn tire.
    d. Groove widths were doubled on the wide groove tire.
    e. The wide groove tire was in new condition.

2. Surfaces

    a. The term "grooved surfaces" encompasses all the groove spacings, $1\frac{1}{4}$ to 4 inches.
    b. The plain surface had a measured texture depth of 0.01 inch (reference 1 for method).

c. The Klarcrete treatment produced a roughened surface of 0.02 in. texture depth.
d. The plain and Klarcrete surfaces comprised the nongrooved surfaces.

3. Water Depths

a. All water depths are average water depths.
b. A water depth of 0.00 in. represents a saturated condition with water contained within the texture of the concrete surface.
c. Grooves were filled with water at all times.
d. A water depth of 0.25 in. represents the flooded condition.

4. Braking Performance

a. Braking performance is expressed by traction level which is the horizontal force between the tire and concrete surface, produced by braking, divided by the vertical load on the wheel.
b. Hydroplaning exists, in its complete form, as the traction level approaches zero, due either to the presence of water at sufficient depths (dynamic hydroplaning) or to a thin film of water acting as a lubricant (viscous hydroplaning). Viscous hydroplaning is recognized as being more characteristic of worn tire performance.

The results of the cost study are summarized as follows:

1. Percentage cost savings for cutting $\frac{1}{4}$ x $\frac{1}{4}$ in. square grooves at spacings increased beyond $1\frac{1}{4}$ in. are the same for both Portland Cement and asphaltic concrete, Figure 8.

2. Cost savings increase at a decreasing rate with increased groove spacing.

3. The variable cost range is 40 percent of the cost of cutting grooves at $1\frac{1}{4}$ spacing.

4. The cost saving for cutting grooves at 2 in. spacing is 15 percent, at 3 in. spacing 24 percent, and at 4 in. spacing 28 percent.

The results of the wheel braking tests are summarized as follows:

1. Traction levels encompassing all the variables tested, fell within a range of 0.37 to 0.00.

2. Traction levels on the grooved surfaces were consistently higher than those for the nongrooved surfaces, under the same conditions of tire wear.

3. Traction levels on the grooved surfaces decreased at a decreasing rate with increased water depth or increased speed.

4. Traction levels on the nongrooved surfaces decreased rapidly with increased water depth or increased speed.

5. Traction levels on the grooved surfaces decreased linearly with respect to increased groove spacing. The maximum rate of decrease was 0.02/in. under the new tire condition, and 0.04/in. (below 100 knots) to 0.03/in. (above 100 knots) under the worn tire condition.

6. The new tire produced higher traction levels than the worn tire on grooved surfaces, as well as nongrooved surfaces.

7. Grooved surfaces overcame the severe effects of tire wear on traction level. The worn tire produced traction levels on the nongrooved surfaces as low as 0.04 and 0.02 at 0.00 in. water depth, and approached a level of 0.00 at 0.05 in. water depth.

8. Grooved surfaces minimized the effects of tire wear on traction level at the extreme ends of the water depth range (0.00 in. and 0.25 in.).

9. Grooves in the surface increased traction levels to a greater extent than tire grooves for speeds above 130 knots at 0.02 in. water depth, down to speeds above 70 knots at 0.25 in. water depth.

10. Increased texture on the nongrooved surfaces (Klarcrete at 0.02 in. vs. plain at 0.01 in.) produced higher traction levels with the worn tire but lower traction levels with the new tire.

11. The wide groove tire increased the traction level of the plain surface at water depths of 0.10 in. to 0.25 in.

12. The wide groove tire elevated the traction level of the grooved surface with 4 in. spacing to the level of the grooved surface with 3 in. spacing at water depths of 0.10 in. to 0.25 in.

Conclusions

1. The $\frac{1}{4}$ x $\frac{1}{4}$ in. square grooves cut in Portland Cement Concrete surfaces at 3 in. spacing, in lieu of $1\frac{1}{4}$ in. spacing, offer the most promising cost-performance tradeoff possibility for the following reasons:

a. Cost savings at 3 in. groove spacing are significant (24 percent).

b. Groove spacings extended beyond 3 in. provide consistent traction level reduction at a rapidly diminishing cost return.

c. Grooving at 3 in. spacing provides significant traction levels under conditions of tire wear and water depth most frequently encountered (intermediate tire wear at low water depths).

d. Grooving at 3 in. spacing offers the same general traction performance characteristics as grooving at $1\frac{1}{4}$ in. spacing (shape and slope of the traction level--speed curves).

e. Grooving at 3 in. spacing still tends to resist total hydroplaning (0.00 traction level) at extreme conditions of tire wear, water depth, and speed. Nongrooved surfaces produced total hydroplaning, even with a new tire, at speeds as low as 78 knots under extreme water depth conditions (0.25 in. water depth).

2. Based on the results of the wide groove tire tests, it is evident that tire groove patterns of the types commonly in use, may not necessarily represent the optimum for braking performance on either grooved or nongrooved surfaces, under intermediate to extreme water depth conditions.

For further information regarding the subject test program, Charles R. Grisel, the NAFEC Project Manager, FTS 346-2629, or Hector Daiutolo, the NAFEC Program Manager, FTS 346-2283, may be contacted.

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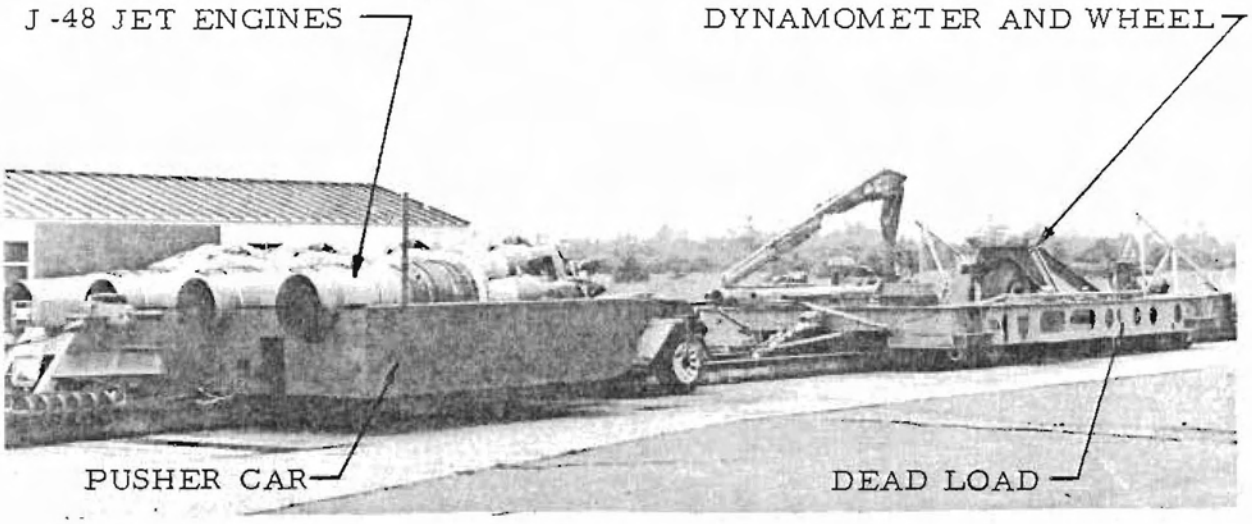

FIGURE 1. TEST SYSTEM AT LAUNCH END OF TRACK

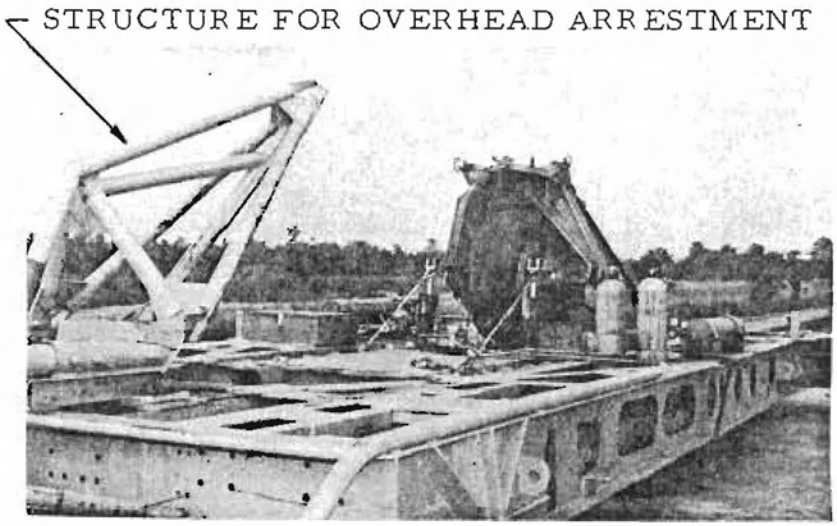

FIGURE 2. DYNAMOMETER IN RAISED POSITION

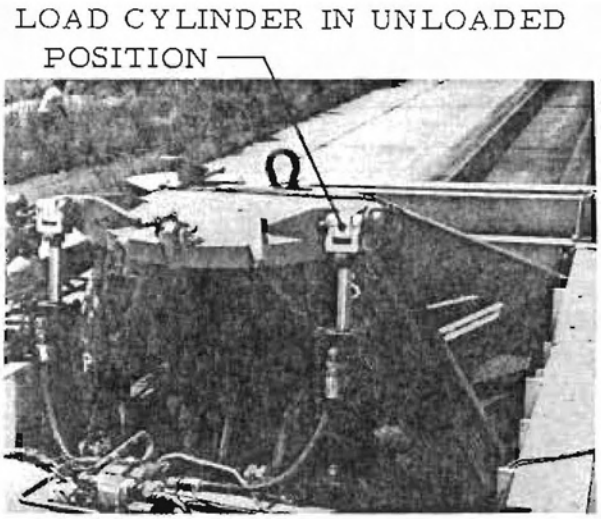

FIGURE 3. DYNAMOMETER IN POSITION WITH TIRE CONTACTING CONCRETE SURFACE

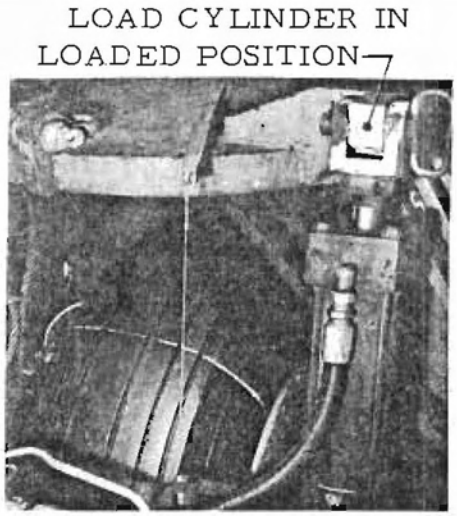

FIGURE 4. DETAIL OF 49 x 17, TYPE 7 JET AIRCRAFT TIRE UNDER B 727 LANDING LOAD

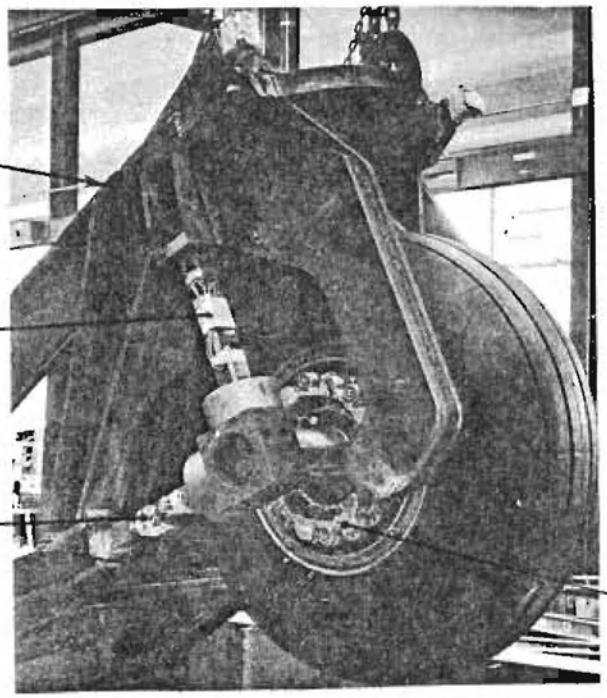

FIGURE 5. DETAIL OF BRAKE AND LOAD LINKS

FOUR 45 FOOT TEST SECTIONS

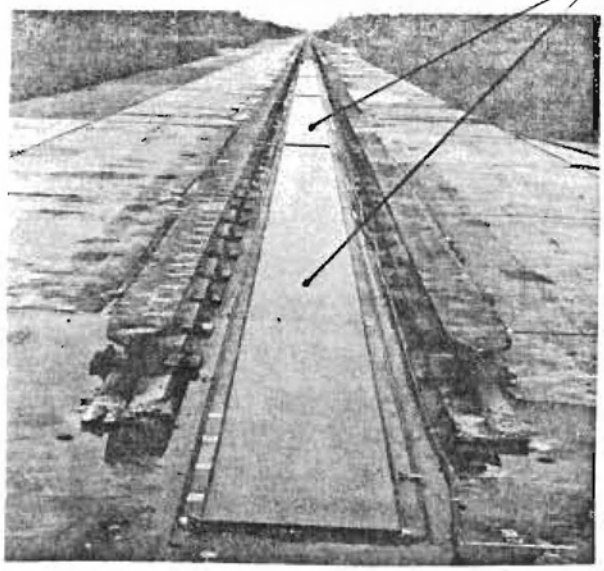

FIGURE 6. PORTLAND CEMENT CONCRETE TEST BED IN FLOODED CONDITION

GROOVES AT 3 IN. SPACING

PLAIN SURFACE BROOMED FINISH

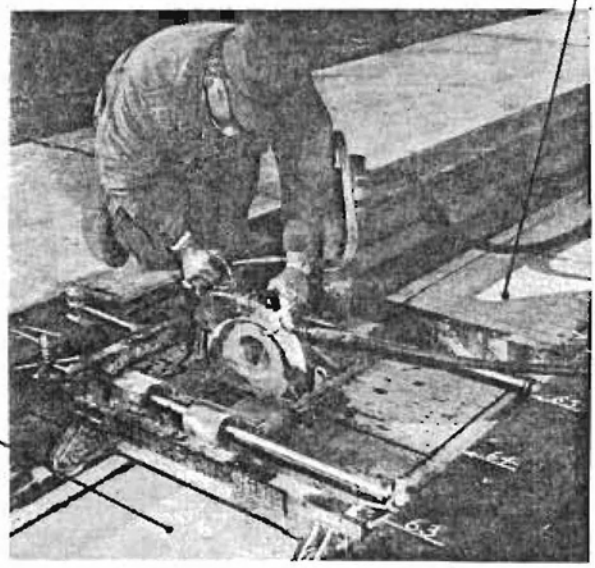

FIGURE 7. GROOVING MACHINE CUTTING $\frac{1}{4}$ IN. x $\frac{1}{4}$ IN. SQUARE GROOVES

REFERENCES

1. Anon, Advisory Circular, "Methods for the Design, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces," AC No. 150/5320-12, DOT/FAA, June 30, 1975.

2. Byrdsong, T. A. and Yager, T. J., "Some Effects of Grooved Runway Configurations on Aircraft Tire Braking Traction under Flooded Runway Conditions," NASA TN D-7215, April 1973.

3. Anon, "Pavement Grooving and Traction Studies," NASA SP-5073, 1969.

4. Horne, W. B. and Leland, T. J.W., "Influence of Tire Tread Pattern and Runway Surface Condition on Braking Friction and Rolling Resistance of a Modern Aircraft Tire," NASA TN D 1376, September 1962.

EFFECT OF INCREASED SPACING ON GROOVE CUTTING COSTS FOR PORTLAND CEMENT AND ASPHALTIC CONCRETE SURFACES

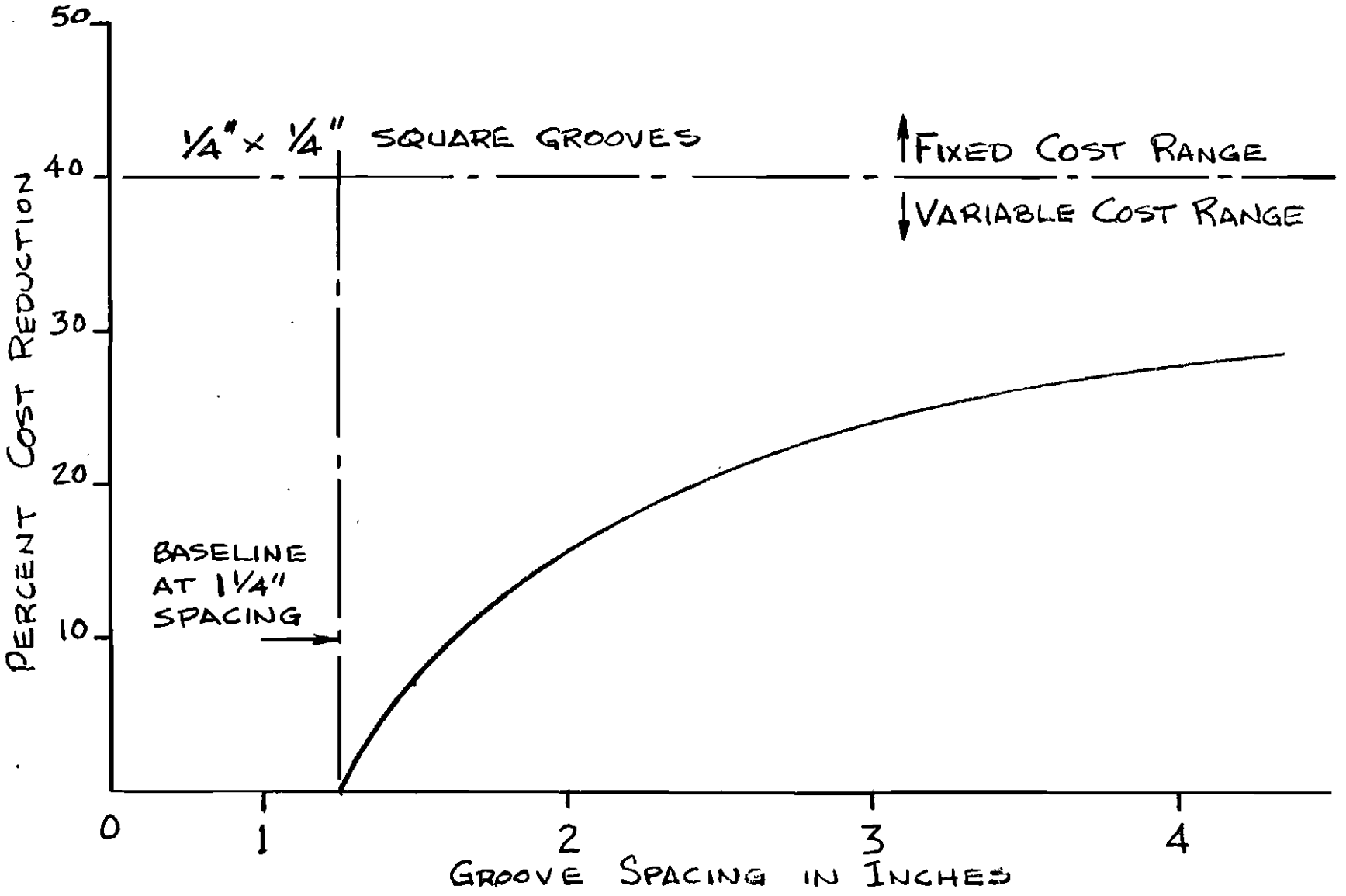

FIG. 8

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.00 INCHES (WET)

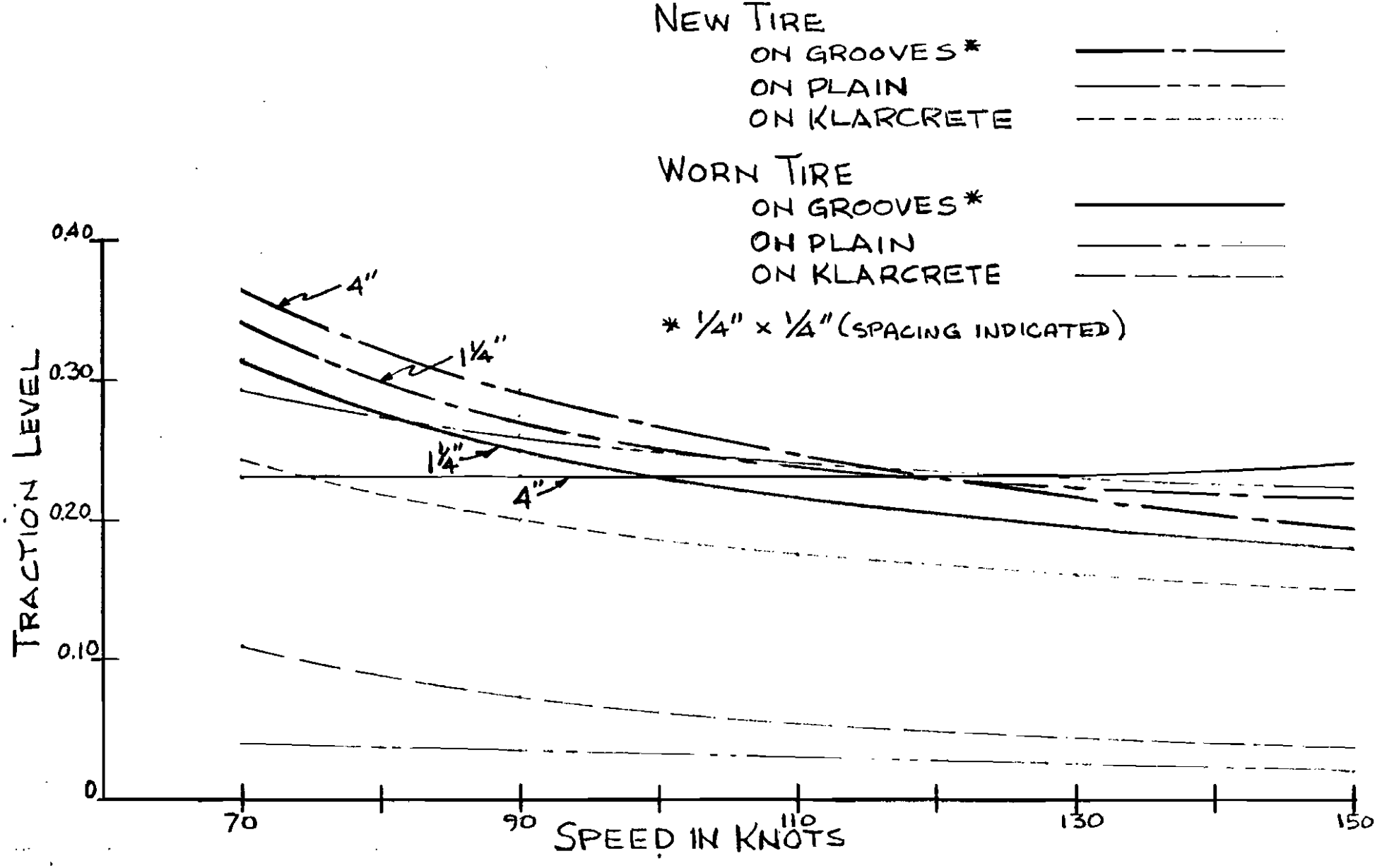

FIG. 9

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.02 INCHES

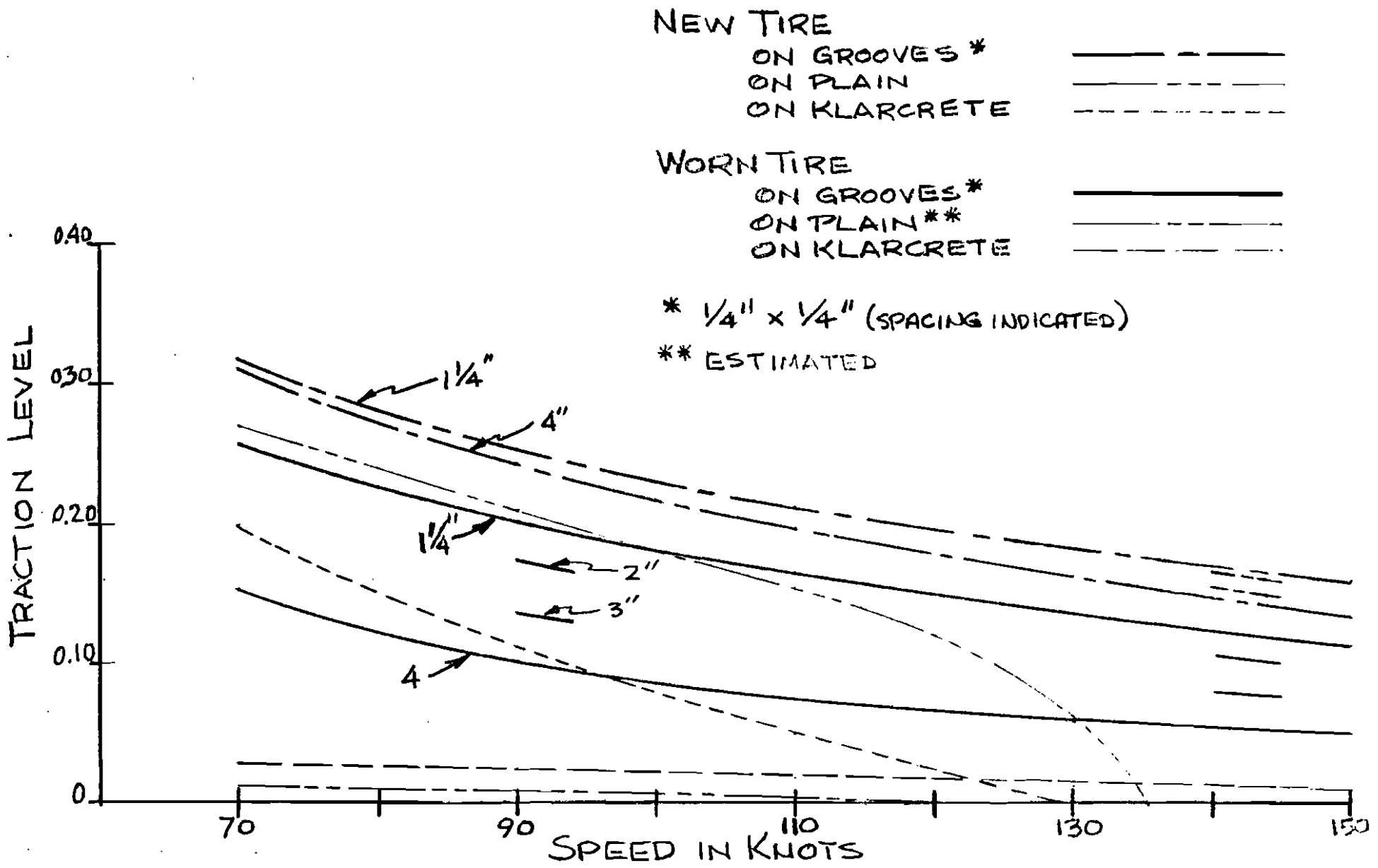

FIG. 10

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.05 INCHES

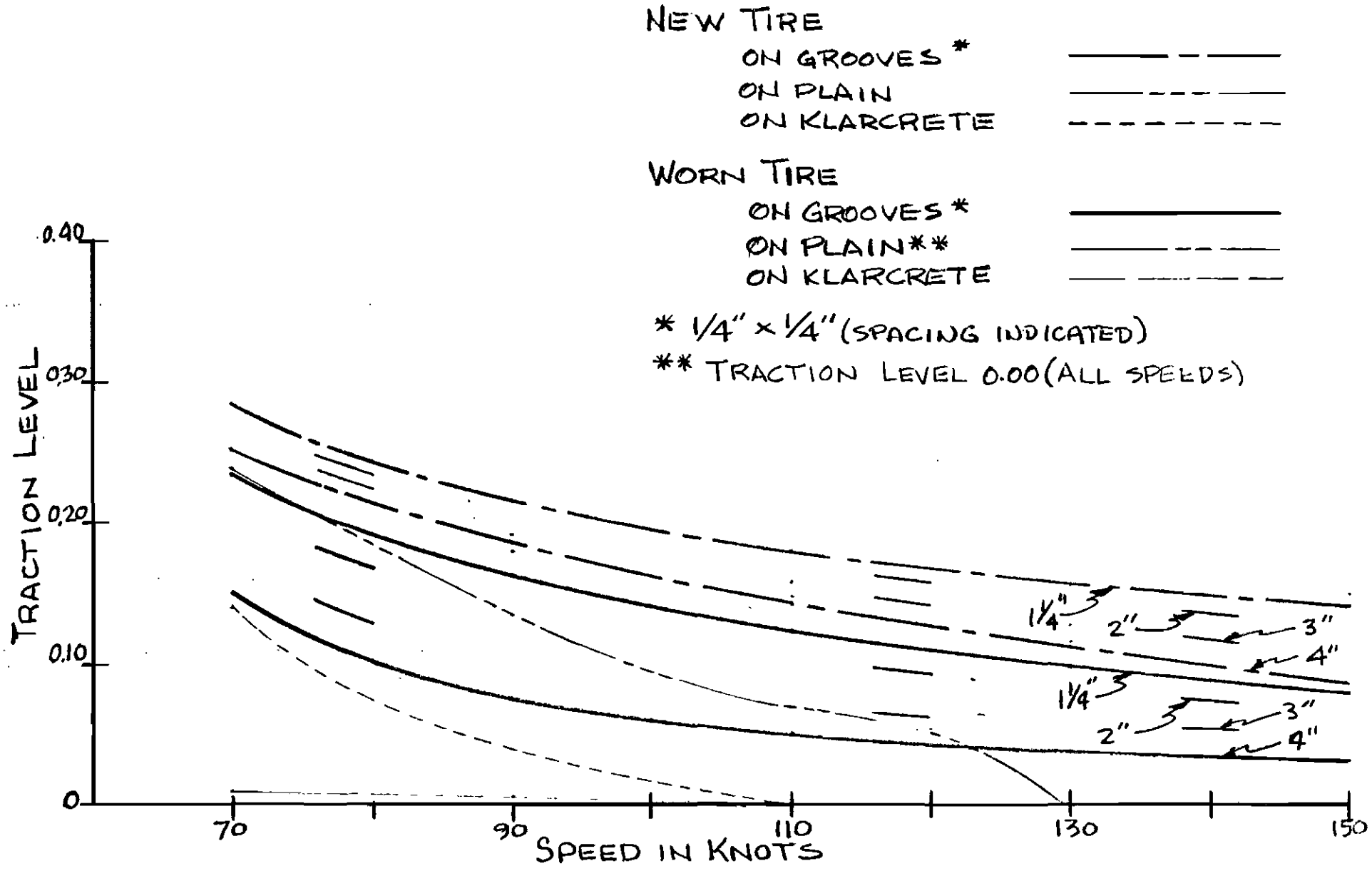

FIG. 11

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.10 INCHES

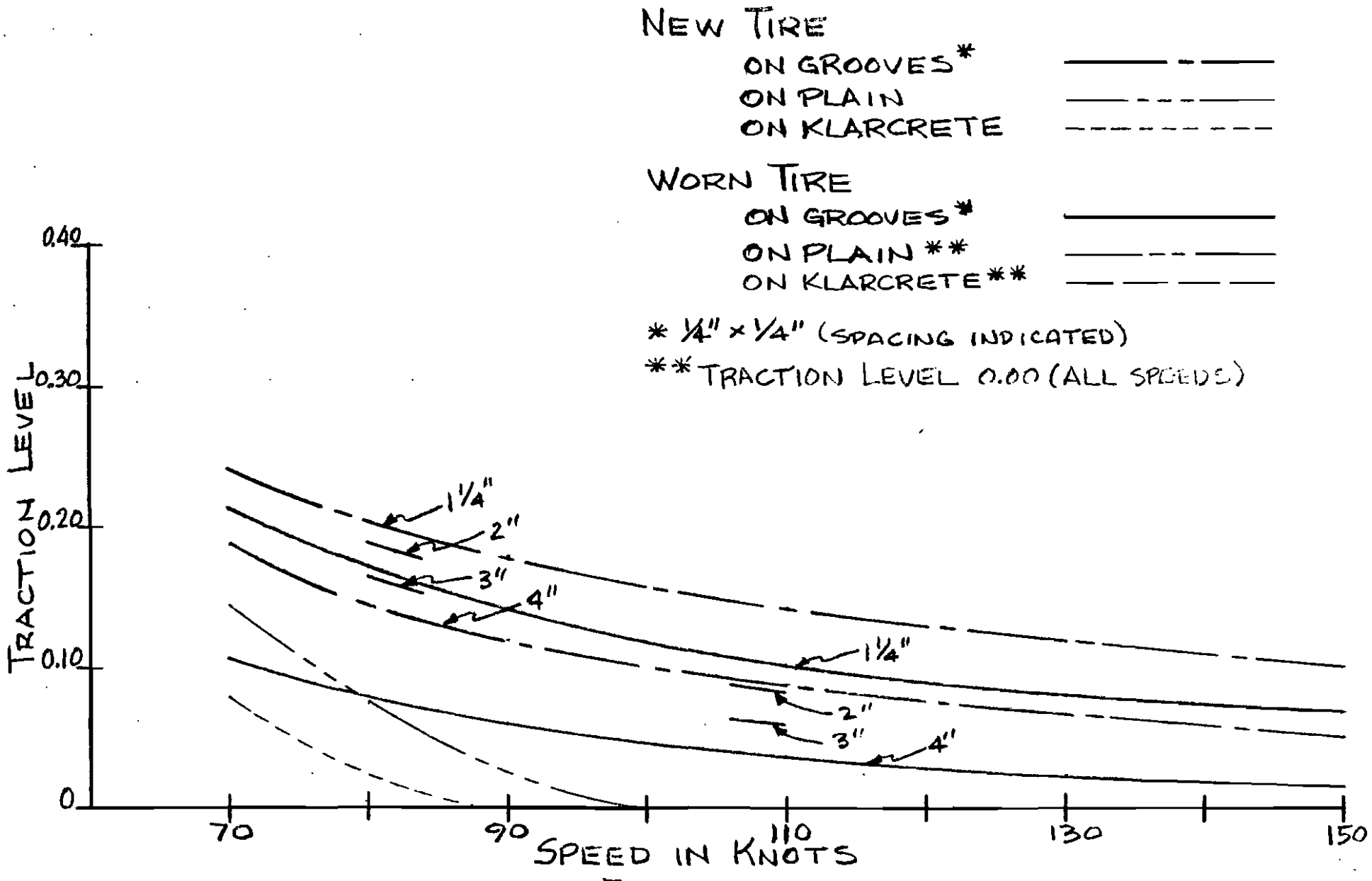

FIG. 12

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.15 INCHES

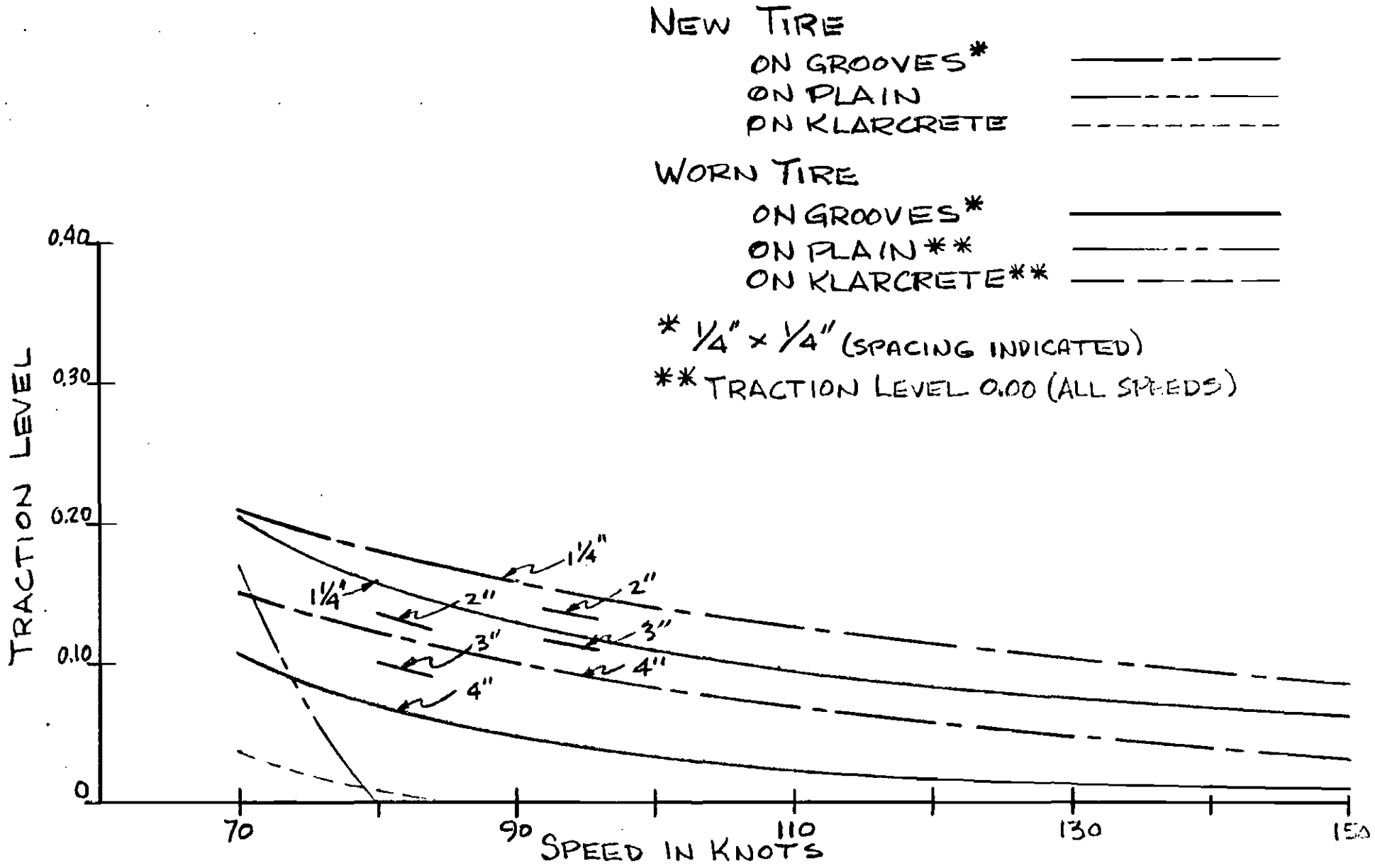

FIG. 13

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.25 INCHES

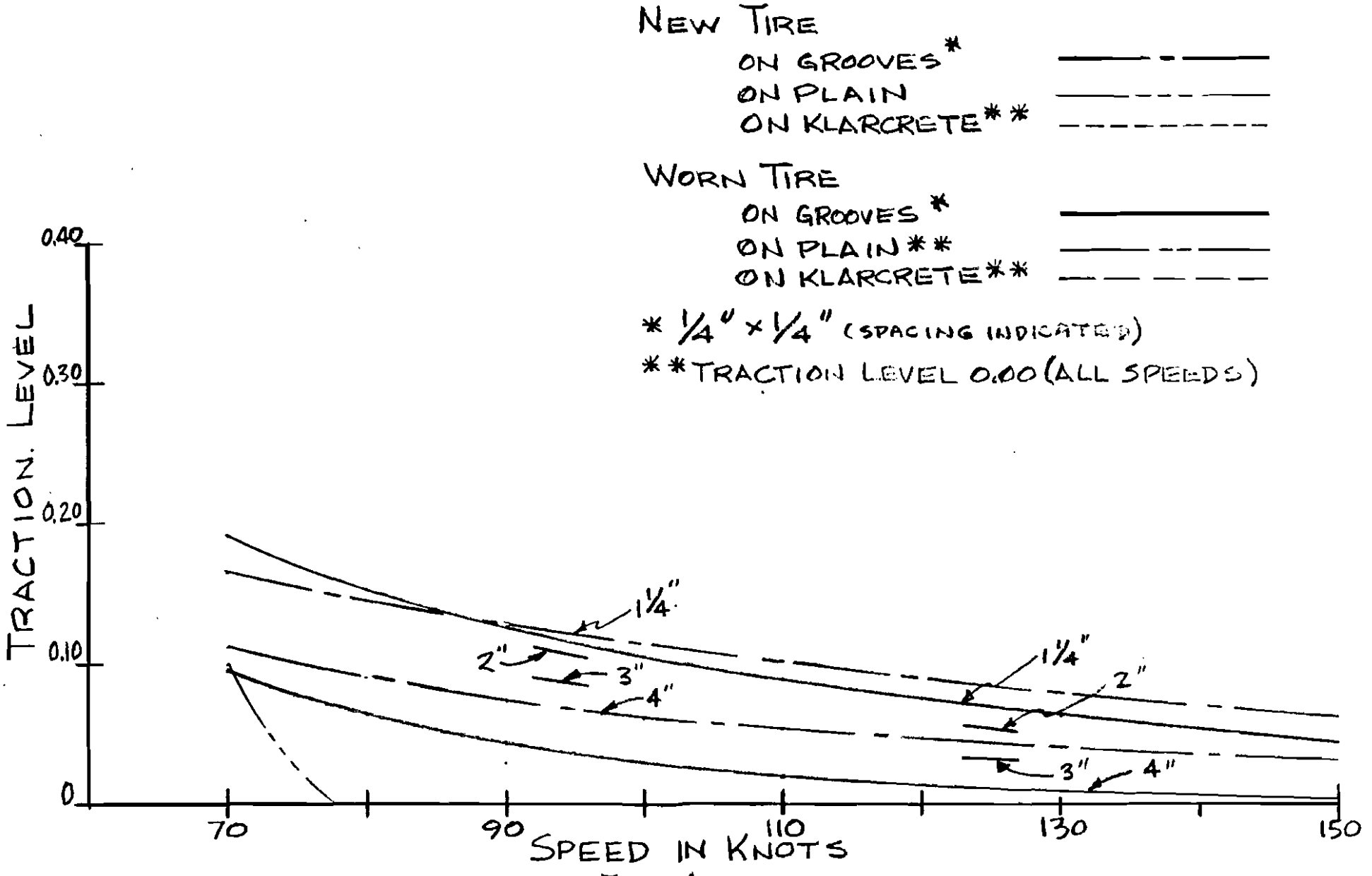

FIG. 14

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.05 INCHES

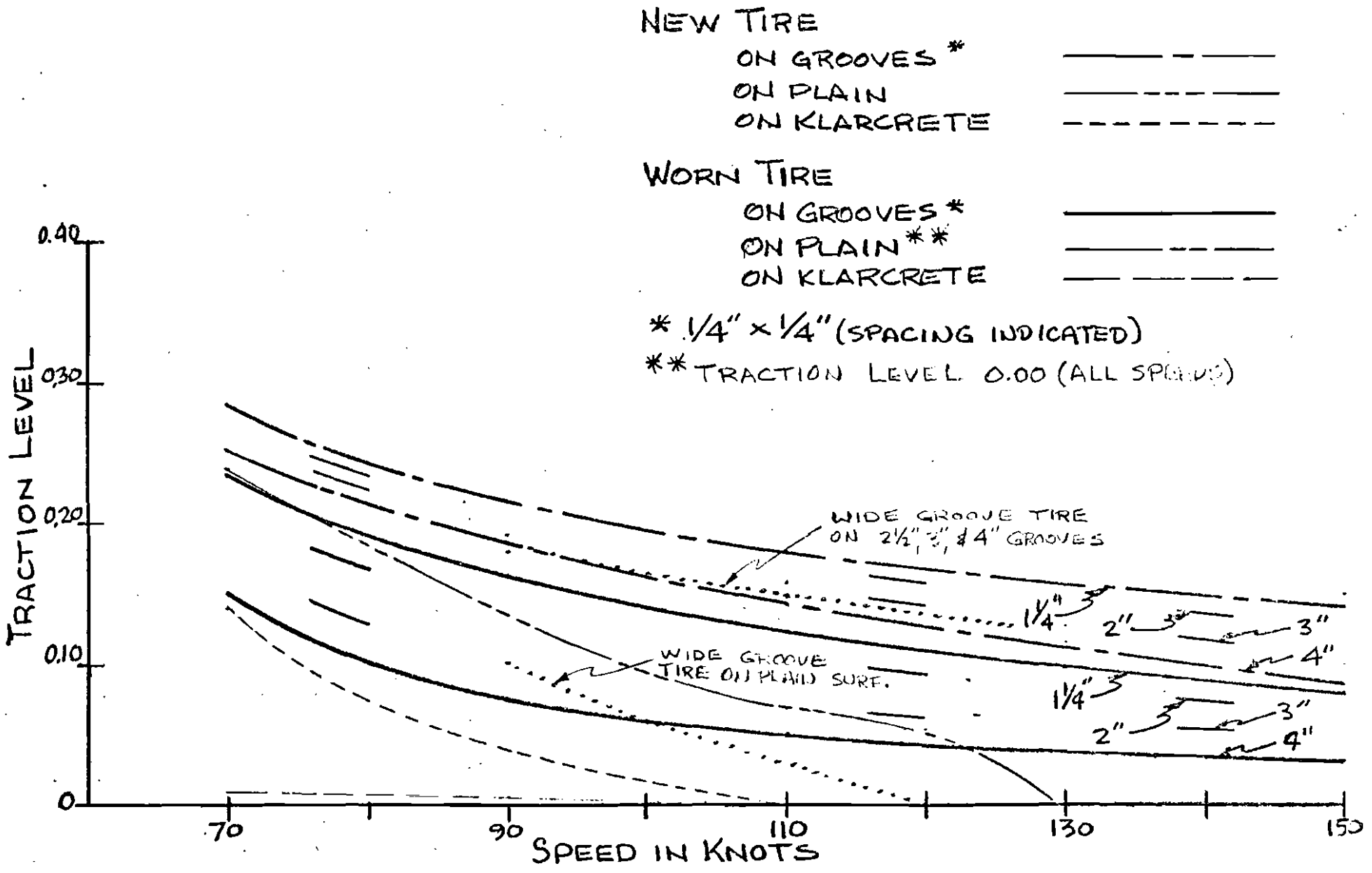

FIG. 15

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.10 INCHES

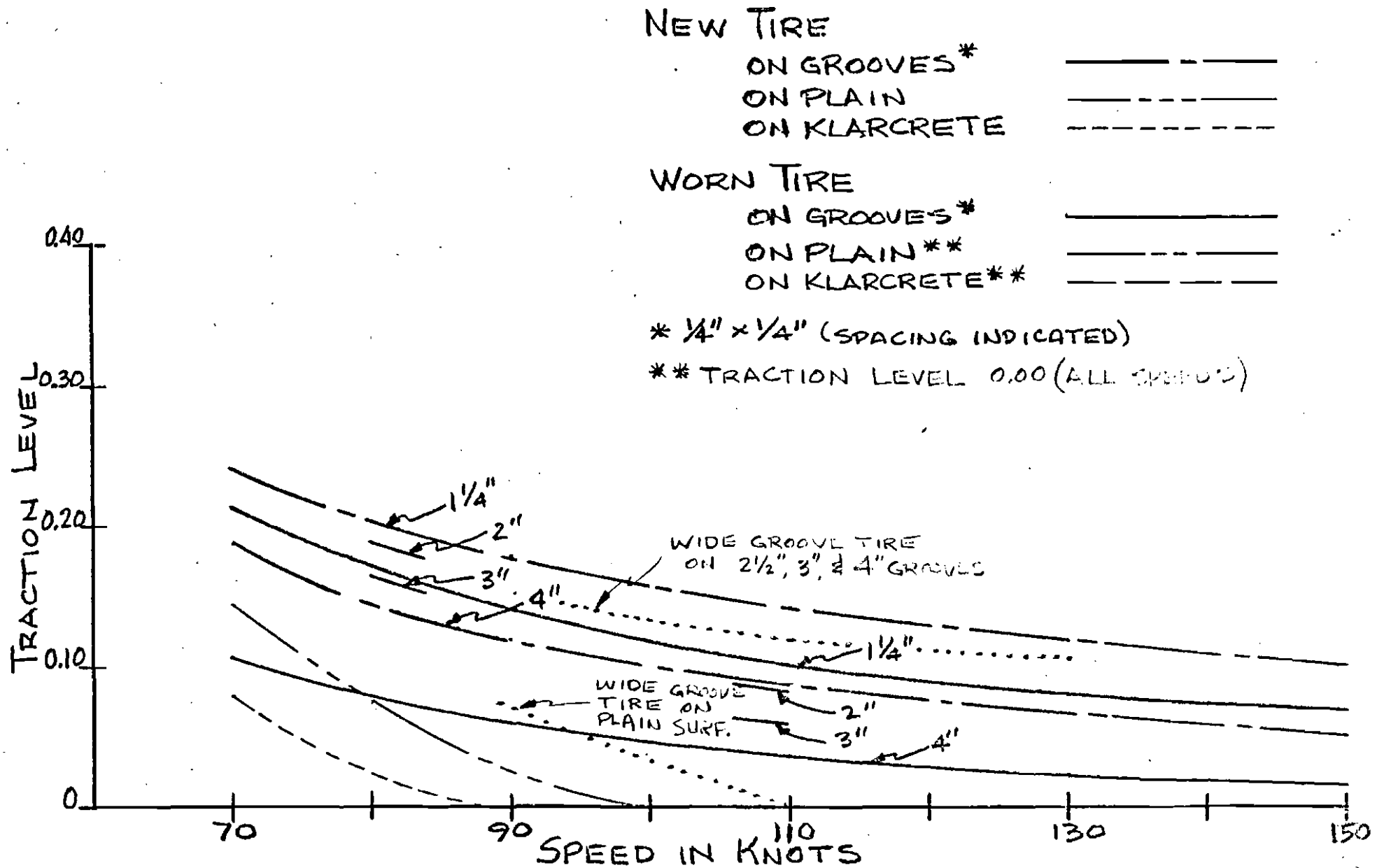

FIG. 16

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE
AVERAGE WATER DEPTH 0.15 INCHES

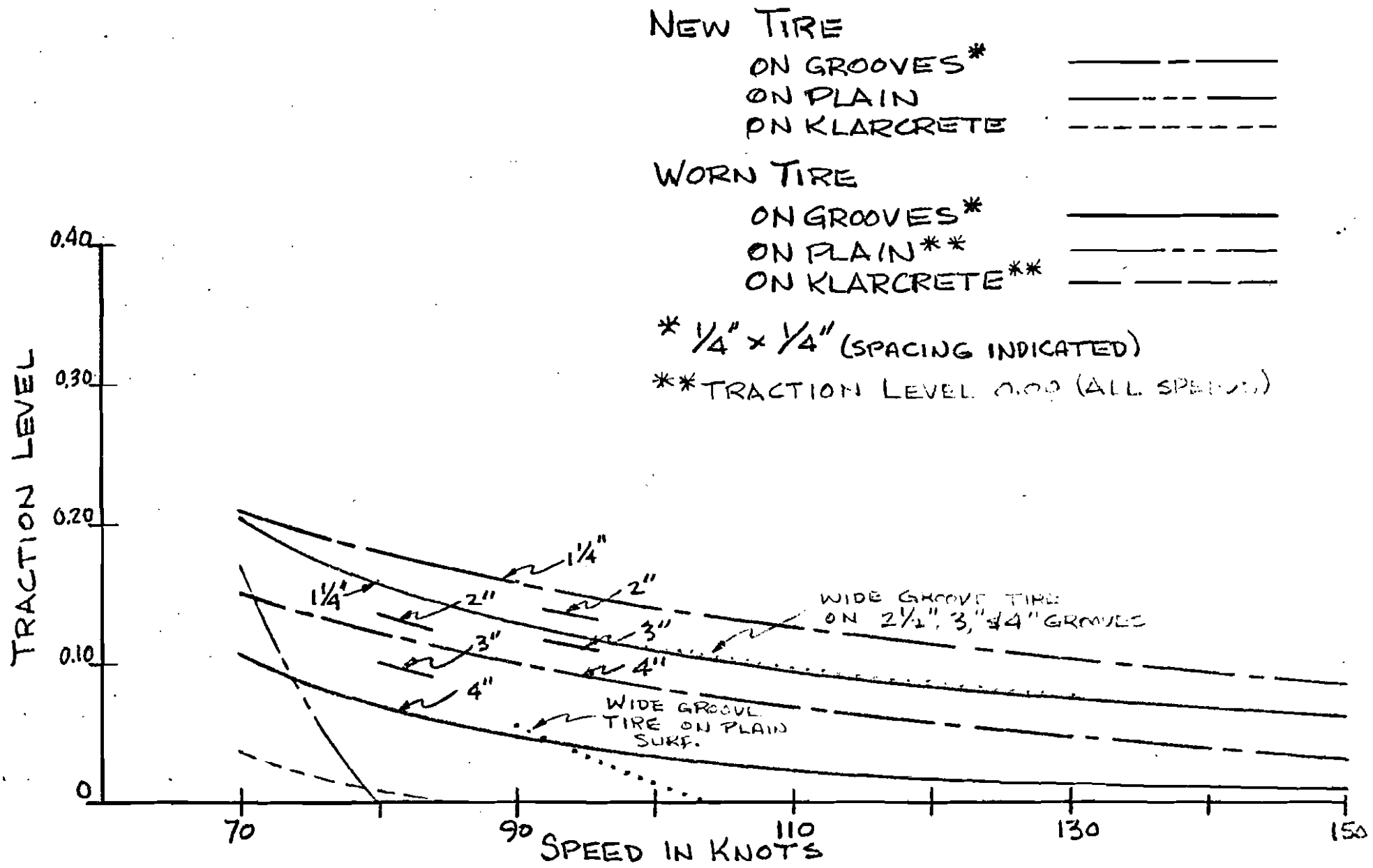

FIG. 17

BRAKING PERFORMANCE OF A 49×17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE AVERAGE WATER DEPTH 0.25 INCHES

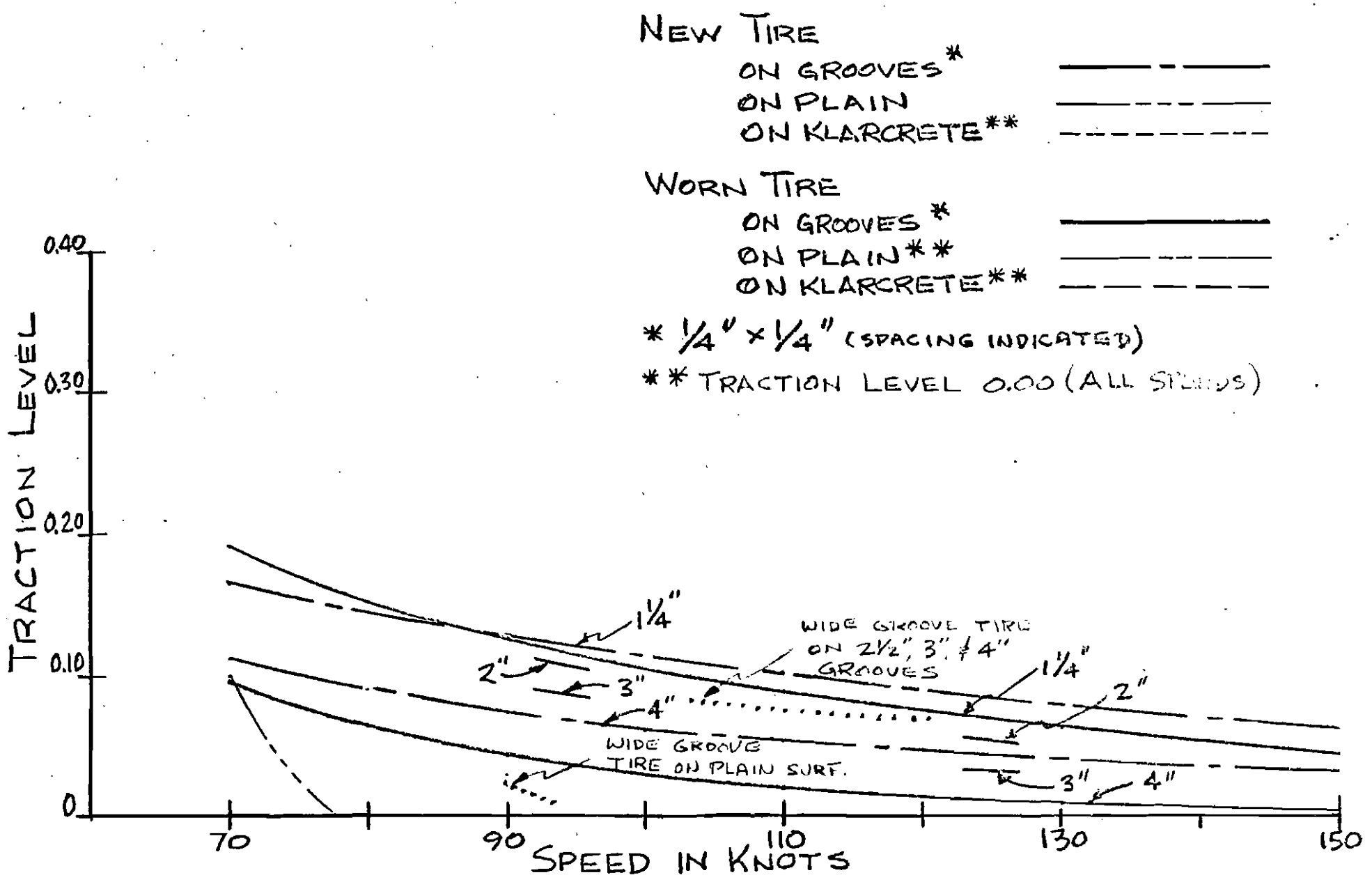

FIG. 18