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# LOW PRESSURE TYPE EXPANDABLE AIRCRAFT TIRE CHARACTERISTICS

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# FOREWORD

The research work in this report was performed in-house in the Air Force Flight Dynamics Laboratory's Landing Gear Test Facility by the Mechanical Branch, Vehicle Equipment Division, Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base, Ohio. This research is part of a continuing effort to obtain high flotation ground contacting elements which will permit aircraft operation on bare soil, low strength runways, and rough fields. The Project Number is 1369, "Mechanical Subsystems for Aerospace Vehicles," and the Task Number is 136903, "Launching and Alighting Systems for Ground Contact." The research was conducted from May 1965 to July 1966 by Paul M. Wagner, Project Engineer and experimental testing was performed by Shade Campbell. The program was under the direct supervision of Mr. Aivars V. Petersons, Alighting Gear Technical Manager.

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This technical report has been reviewed and is approved.

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ABSTRACT

Type III (low pressure) expandable aircraft tires of the 9.50-16 and 23.00-20 sizes were investigated. These tires with their 30 to 50 percent outside diameter expansion capabilities were subjected to simulated landing taxi and taxi takeoff conditions. Results indicate that the load capacity and life of the expandable tires are equivalent to standard tires of the same size. Takeoff speeds on the order of 200 MPH were obtained on tires of both sizes.

One 9.50-16 expandable tire with sidewall convolutions successfully completed 60 simulated C-141 main tire missions and 110 taxi camber cycles in accordance with C-141 nose landing gear tire requirements. Two 23.00-20 expandable tires, one with sidewall convolutions and the other with tread convolutions, successfully completed 200 landing cycles in accordance with procedures outlined in MIL-T-5041D. One 23.00-20 expandable tire (with sidewall convolutions) successfully completed 80 taxi takeoff and 100 landing taxi cycles and one aborted takeoff cycle. The simulated conditions for this tire were derived from estimated operating characteristics of a heavy cargo type of aircraft. Another 23.00-20 sidewall convoluted expandable tire successfully completed 18 taxi takeoff cycles at takeoff speeds of 200 MPH.

The tread convoluted (Design I) expandable tire displayed excellent foldability during tire inflation and deflation. After a number of folding operations, the sidewall convoluted (Design II) expandable tire in a nonrotational state would experience lateral shifting. However, a symmetrical folding procedure was obtained on a Design II expandable tire at peripheral tire speeds as low as 30 MPH.

The Design II expandable tire has the most promising fold from an expansion capability standpoint. In the 23.00-20 expandable tire size, the Design I offered an expansion of 33 percent compared to the Design II expansion of 50 percent in outside diameter.

A landing at 120 MPH was accomplished on a folded (deflated) Design II expandable tire indicating that the expandable tire has operational potential even after battle damage.

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# SECTION I

# INTRODUCTION

This report presents preliminary design criteria on type III, low pressure expandable tires based on data obtained from an AFFDL in-house experimental program. The type III expandable tire is capable of folding after takeoff for minimum stowage, and upon gear extension will inflate to a standard aircraft tire size. The purpose of the AFFDL investigation was to evaluate and to obtain performance data for further design improvements on type III expandable tires.

Experimental evaluations were conducted on expandable tires fabricated by the B. F. Goodrich Company and delivered under Contracts AF33(615)-2010 and AF33(615)-2382. Under Contract AF33(615)-2010, a feasibility study was conducted on the most promising expandable tire concepts. Work under this contract proved that the expandable tire concept is feasible for application to aircraft tires and an expansion of about 30 percent is readily obtainable in the 9.50-16 size tire, 24.7 and 32.2 inches being the folded and expanded diameters respectively. One 9.50-16/12 PR expandable tire of the sidewall convoluted design, the most promising design, was fabricated and delivered to the AFFDL for dynamic test.

Effort on the expandable tire was continued under Contract AF33(615)-2382. The objective of this program was to establish an expandable tire concept capable of operation on cargo type of aircraft such as the C-5A. A number of expandable tires, sizes 9.50-16 and 23.00-20, were delivered periodically to AFFDL for evaluation. As the tires were progressively tested, AFFDL furnished the test results along with suggested improvements to the contractor. This information was used for the design of the remaining tires. The 23.00-20/16 PR expandable tire of the convoluted sidewall design exhibited an expansion of 50 percent, having a folded and expanded outside diameter of 39.50 and 59.44 inches respectively.

This report includes the data obtained from the evaluation of the tires delivered under these contracts.

# SECTION II

# GENERAL DISCUSSION

## DESCRIPTION OF EXPANDABLE TIRE DESIGNS

Design I has circumferential convolution cured into the tread area, as illustrated in Figures 4 and 50. During inflation the tire tread unfolds, thereby increasing the outside diameter, and takes on the appearance of an inflated conventional tire.

Design II has circumferential convolution cured into the sidewalls of the tire, as illustrated in Figures 1, 2, 3, and 9. The sidewall of the tire unfolds during inflation and the outside diameter increases.

Early in the initial contractual program, it became apparent that the Design II expandable tire offered more advantages than the Design I expandable tire. Thus, only one Design I tire, size 23.00-20, was delivered to the AFFDL. In the 23.00-20 expandable tire size, Design II offered an expansion of 50 percent compared to a Design I expansion of only 33 percent in outside diameter.

The tires investigated and discussed in this report are listed in Table I.

## ADVANTAGES AND DISADVANTAGES

Runway length and strength have been generally associated with aircraft size and weight. Small light aircraft have had short low strength field capability and large heavy aircraft have required long high strength runways. However, the trends in recent years in the design and requirements for future aircraft have been toward short takeoff and landing capabilities and operations out of lower strength airfields, with higher cargo capacities for transport aircraft. The higher cargo capacities of many future aircraft will require multiple landing gear assemblies with significantly larger tires spaced farther apart to provide the high flotation required. Thus, gear cavities will extend beyond the body structure, thereby incurring a weight penalty as a result of utilizing pods and a drag penalty due to the increase in frontal area. These penalties have already been incurred in several of the existing large cargo aircraft. Gears stowed in the body structure, as opposed to pod stowage, would reduce cargo capacities. Landing gears equipped with expandable tires with their 30 to 50 percent outside diameter expansion capability are extremely attractive for use on aircraft requiring a high flotation gear design.

The successful application of expandable tires on landing gear systems will result in improved aircraft performance. Improved aircraft performance can be achieved because: (a) reduced stowage volume requirements permit more efficient fuselage design and/or (b) the tires expansion characteristics upgrade the flotation capability of the aircraft. Theoretically, such a tire if incorporated on a four wheel bogie gear could decrease the gear stowage volume by 50 percent, or from a ground flotation standpoint could increase the number of passes on a CBR 6 soil by a factor of 10. Besides the apparent advantages mentioned, the convoluted sidewall (Design II) expandable tire has the inherent capability of emergency operation in a folded (deflated) condition. This capability is discussed in further detail in the Performance Characteristics section of this report.

Use of the expandable tire produces an advantage through the requirement for in-flight inflation and deflation during gear extension and retraction. With an in-flight tire pressure adjustment system, the tire pressure can be varied to correspond to various aircraft gross weight conditions and landing surfaces. With a variable pressure capability, a higher tire deflection could be selected. These additional features further increase the ground flotation capability of the aircraft and extend the life of theater-of-operations type of airfields.

The innovation of an expandable tire inflation-deflation system offers many advantages; but disadvantages exist in the inflation-deflation system from a weight and complexity standpoint.

In a cost effectiveness study, the merits of the expandable tire must be given a fair appraisal. Tradeoffs conducted should include the advantages associated with the expandable tire versus the added weight and complexity of inflation-deflation system.

## SECTION III

## STATIC AND DIMENSIONAL CHARACTERISTICS

This section presents static and dimensional data on the type III expandable tire expansion, load-deflection, contact area, and deflation time characteristics. Interchangeability with standard wheels and the 23.00-20 type III expandable tire hydroburst is discussed in this section.

### DIMENSIONAL GROWTH

Extensive measurements were taken on the 9.50-16 and 23.00-20 type III expandable tires. Dimensional growth due to variable inflation pressure, rotation, and usage are discussed for both of the tire sizes investigated.

#### Growth Due to Variable Tire Inflation

The 9.50-16 type III sidewall expandable tire (Number 8), with a folded outside diameter of 24.8 inches, offered a 30-percent expansion capability upon inflation to 140 PSI. Outside diameter expansion characteristics for the first expandable tire of this size delivered for evaluation are shown in Figure 5. Variations in outside diameter and section width due to an increase in inflation pressure are plotted in Figure 6 for 9.50-16 Expandable Tire Number 4.

The tread convoluted (Design I) 23.00-20 type III expandable tire, when expanded to its rated inflation pressure from the folded shape, offered a 33-percent increase in the outside diameter dimension.

The sidewall convoluted (Design II) 23.00-20 expandable tire offers a 50-percent expansion when inflated to a pressure of 90 PSI from the folded position. Variations in outside diameter due to an increase in inflation pressure are plotted in Figure 7 for the best designed tire (Number L-6) of the 23.00-20 size. Tire outside diameter and section width versus inflation pressures up to 35 PSI are plotted in Figure 8 for the 23.00-20 Expandable Tire, Number L-4. Profile data was obtained on an unloaded tire (Number L-6) at various inflation pressures. A section profile of the 23.00-20 expandable tire is shown in Figure 9 for both the expanded shape at 115 PSI inflation pressure and the folded shape. Dimensional data is presented in Table II for the sidewall convolute expandable tire at inflation pressures of 50, 75, 90, and 115 PSI. Figure 10 shows the location of the various tire dimensions.

Centrifugal Growth

A centrifugal growth investigation was conducted on a 9.50-16 (Number 2) and a 23.00-20 (Number L-6) type III expandable tire, both of the sidewall (Design II) shape. The purpose of this investigation was to provide tradeoff data indicating the expandable tire centrifugal growth at various tire inflation pressures and rotating speeds during gear retraction. The AFFDL Centrifugal Tire Growth Machine was used in the spin-up investigation.

Results on the 9.50-16 expandable tire at a 50 PSI inflation pressure revealed radial growths of 0.50 and 0.75 inches at peripheral speeds of 100 and 150 MPH respectively. Centrifugal growth profiles of the 9.50-16 expandable tire are shown in Figure 11 for a non-inflated tire, and Figure 12 for a 50 PSI inflated tire. Figure 13 presents a plot of the radial growth versus the spin-up velocity for the 9.50-16 expandable tire.

The 23.00-20 expandable tire was investigated at non-inflated, 50 and 75 PSI inflation pressures under various spin-up speeds. Figures 14, 15, and 16 depict the centrifugal growth profile for the 23.00-20 expandable tire. Centrifugal growth characteristics for the 23.00-20 expandable tire are plotted in Figure 17.

Centrifugal growth results point out the fact that proper sequencing of tire deflation, in-flight braking, and gear retraction are important and time sensitive. In-flight braking is required to allow the expandable tire to deflate to its folded shape prior to stowage. Without in-flight braking, centrifugal growth results indicate radial growths at the tread center on the order of 3 inches will occur on non-inflated 9.50-16 expandable tires when rotating at 100 MPH peripheral speeds. By extrapolation of the 23.00-20 expandable tire centrifugal growth profile, as shown in Figure 14(d) at a peripheral speed of 60 MPH and non-inflated, a radial growth of 5 inches will occur at the maximum shoulder dimension. Clearance allowances between the walls of the wheel well and the rotating tire would be excessive, thus detracting from the expandable tires' advantage of providing a reduced stowage volume.

Growth Due To Usage

Dimensions on 9.50-16 and 23.00-20 expandable tires which had undergone simulated takeoff and/or landing cycles are presented in Table III through IX to indicate the trend in tire growth due to usage. All tire crown dimensions for tires numbered 2, 3, 6, 8, and L-2 were recorded at the completion of a taxi takeoff cycle at the maximum test inflation pressure. Dimensions will fluctuate during the dynamic evaluation of the tire. This fluctuation can be attributed to the variance in initial and peak tire temperatures and the time-recovery characteristics of the tire.

The expanded outside diameter is not a critical dimension when compensated for the expandable tire's service growth but serves as a comparison with existing growth factors for standard aircraft tires. The appropriate tire service growth factor as referenced in the Tire and Rim Association Yearbook for a type III aircraft tire is 1.04 and 2.08 for the width and height respectively.

The expandable tire's folded (deflated) outside diameter is the critical dimension when compensated for growth, since this dimension will determine the allowable clearance between the tire and the adjacent parts of the stowage compartment. The folded section width will not be a critical dimension if allowance for a service growth is made, since this dimension does not exceed the wheel width dimension. Since the tires investigated were laboratory evaluated, the usage growth data summarized in Table X serves only as an indication of possible expandable tire service growth. The symbols and subscripts used in this summary are identical to those used in the Tire and Rim Association Yearbook with the exception of additional subscripts for the purpose of identifying an expanded or folded condition. The following symbols, with subscripts, apply only to this subsection:

| | |
|---|---|
| $D$ | Rim ledge diameter |
| $D_{OE}$ | Maximum expanded outside diameter (new, after 12-hour minimum stretch, and runs at test inflation pressure) |
| $D_{GE}$ | Maximum expanded grown outside diameter (used, after completion of dynamometer runs, and runs at test inflation pressure) |
| $D_{OF}$ | Maximum folded outside diameter (new, after 12-hour minimum stretch, and in a non-inflated condition) |
| $D_{GF}$ | Maximum folded grown outside diameter (used, after completion of dynamometer runs, and in a non-inflated condition) |
| $H_E$ | Maximum expanded section height (new tire) |
| $H_F$ | Maximum folded section height (new tire) |
| $W_E$ | Maximum expanded cross-sectional width (new tire) |
| $W_{GE}$ | Maximum expanded grown sectional width (used tire) |
| $G_{HE}$ | Expanded height growth factor |
| $G_{HF}$ | Folded height growth factor |
| $G_{WE}$ | Expanded width growth factor |

The maximum expanded section height for the expandable tire in the new condition is given by:

$$H_E = \frac{D_{OE} - D}{2} \qquad (1)$$

The maximum folded section height for the expandable tire in the new condition is given by:

$$H_F = \frac{D_{OF} - D}{2} \qquad (2)$$

The growth factors for the expandable tire's expanded height, $G_{HE}$, and expanded width, $G_{WE}$, are given by:

$$G_{HE} = \frac{D_{GE} - D}{H_E} \qquad (3)$$

$$G_{WE} = \frac{W_{GE}}{W_E} \qquad (4)$$

and the growth factor for the expandable tire's folded height, $G_{HF}$, is given by:

$$G_{HF} = \frac{D_{GE} - D}{H_F} \qquad (5)$$

Calculated growth factors presented in Table X on expandable tires in the inflated condition are in line with the growth factors presented by the Tire and Rim Association. Growth factors obtained from folded dimensions on expandable tires are higher than those obtained from inflated dimensions. When compensating for service growth on folded expandable tires, the existing type III height growth factor should be increased by 10 percent.

## LOAD-DEFLECTION DATA

Load-deflection relationships were determined for the 9.50-16 and 23.00-20 type III expandable tires with sidewall convolutions. All load-deflection data was obtained from new tires. Figure 18 presents the load-deflection characteristics for the 9.50-16 expandable tire (Number 1) at inflation pressures of 30, 50, 65, and 80 PSI. Inches deflection is plotted against load in Figure 19 for the sidewall convoluted 23.00-20 expandable tire (Number L-2) of first design. Percent deflections are also shown, and were based on the tire's outside diameter at the inflation pressure recorded. Four inflation pressure curves, one representing rated inflation pressure and the other three representing less than the rated inflation pressure, were plotted at inflation pressures of 55, 65, 75, and 85 PSI.

The load-deflection characteristics for the 23.00-20 expandable tire (Number L-6) with additional sidewall stiffness is presented in Figure 20. Load-deflection curves indicate that this tire, with additional rubber incorporated into the sidewalls, was slightly less flexible than tire (Number L-2) of the first design.

## TIRE CONTACT AREA

Tire contact area prints were obtained for the 9.50-16 and 23.00-20 expandable tires under various static loads and various inflation pressures. Prints of the 9.50-16 expandable tire (Number 2) with four circumferential grooves are presented in Figures 21 and 22. The 9.50-16 expandable tire at 140 PSI produced gross contact areas of 50.7 and 90.5 square inches under 5,000 and 10,000 pound loads respectively.

Contact area prints of a 23.00-20 expandable tire (Number L-6) with six circumferential grooves are shown in Figure 23 through 29. Prints were obtained on the tire at inflation pressures of 50, 75, and 90 PSI under various static loads. A summary of tire contact area data for the 23.00-20 expandable tire is presented in Table II.

The gross contact area was determined by placing a one-inch square grid over the print and counting the number of squares within the contact area. The total area of the print, including the spaces between the tread ribs shown on the print, is defined as the gross contact area of the tire. All tire contact area data was obtained on new tires loaded against a flat surface.

## INFLATION-DEFLATION TIME CHARACTERISTICS

Expanding and folding the 9.50-16 expanable tire required excessive inflation and deflation times on the order of three minutes when using standard valves. Due to the excessive time required to inflate and deflate the 9.50-16 expandable tire, it became necessary to provide a quick inflation-deflation system for the 23.00-20 expandable tire. This system allowed for a comparison of inflation and deflation time characteristics between a tread convoluted (Design I) and a sidewall convoluted (Design II) expandable tire of the same size.

Installed on the AFFDL variable inertia 120-inch dynamometer, as shown in Figure 51a, the quick inflation-deflation system consisted of the following:

(a) A 49 by 17 wheel was modified with two 3/4-inch fittings spaced 180 degrees apart on the outboard wheel valve. These fittings replaced the standard wheel valve.

(b) A rotating seal, one inch in size (a one-inch pipe thread at air inlet), was mounted on the carriage mandrel (axle) using an adapter.

(c) Lines from the fittings to the rotating seal were 3/4 -inch tubing. An air passage was provided through the hollow mandrel from the rotating seal to the inboard side of the mandrel. Lines 12 feet in length, from the inboard side of the mandrel, lead to manually operated valves for air supply and release.

A comparison of the contained-air pressure changes during deflation between a Design I and a Design II expandable tire is illustrated in Figure 30. Both the tread convolute and the sidewall convolute 23.00-20 expandable tires were deflated from an initial contained-air pressure of 90 PSI. The deflation time for the tread convolute expandable tire is over 75 percent longer than the sidewall convolute expandable tire when using the same deflation system. Table XI lists the various deflation times for changes in initial inflation pressures, rotational tire speed conditions, and landing cycles for the tread convolute 23.00-20 expandable tire.

As could be expected, the deflation time for the tread convolute 23.00-20 expandable tire increased by the following amounts:

(a) Approximately 8 percent with an increase in initial inflation pressure from 50 to 90 PSI.

(b) Approximately 11 percent when the tire's peripheral speed was increased from

30 to 95 MPH. After ten low speed and ten high speed landing cycles the tire's static deflation time of 73 seconds was increased by 25 percent when the tire was deflated at 95 MPH.

(c) Fifteen percent after completion of an additional 100 landing cycles on the tire at 90 PSI inflation pressure and rotation at peripheral speeds of 30 MPH.

## INTERCHANGEABILITY WITH STANDARD WHEELS

A requirement in the contractual program specified that the expandable tires should fit readily and exhibit ease of mounting on standard aircraft wheels. All 9.50-16 and 23.00-20 expandable tires fabricated and delivered by the contractor met this requirement. Earlier 9.50-16 expandable tires displayed some bead seating problems when severe shifting of the tire occurred during deflation. An improved bead seat interference fit was incorporated in later designs of the 9.50-16 expandable tire, eliminating further unseating occurrences.

The 9.50-16 expandable tires were mounted on either 9.50-16 or 32 by 8.8 wheels having a width between flanges of 7.00 inches and a 16-inch ledge diameter. The 32 by 8.8 wheels were modified for tubeless tire mounting. The 23.00-20 expandable tires were mounted on 49 by 17 wheels having rim dimensions of 13.25, 20.0, and 1.75 inches for the width between flanges, ledge diameter, and flange height respectively.

## BURST PRESSURE

A 23.00-20 sidewall convoluted expandable tire (Number L-1) was subjected to a hydrostatic burst test. The tires burst at 350 PSI. The failure was a V-shaped diagonal break through all plies in the tire's crown and extended over to one sidewall and into the convoluted fold. A photograph of the failed tire is shown in Figure 31. When a safety factor of four as determined in MIL-T-5041D for the type III, low pressure tire is used, the 23.00-20 expandable tire can be loaded at a rated inflation pressure of 85 PSI.

# SECTION IV

# DYNAMIC PERFORMANCE CHARACTERISTICS

This section presents data on the dynamic performance characteristics, requirements, and results of the operational capability, carcass fatigue life, foldability, flatspot recovery, and deflated operational evaluations on type III expandable tires.

## OPERATIONAL CAPABILITIES

Simulated taxi takeoff and landing taxi cycles were conducted on type III expandable tires of the 9.50-16 and 23.00-20 sizes. The purpose of performing these dynamic evaluations was to establish the tires' operational characteristics and to provide resulting data which would be useful in the progressive refinement of a type III expandable tire.

Test tire Number 1, a 9.50-16 type III tubeless expandable tire having a 12-ply rating, was built using a bladderless cure closed mold. To determine the speed capability of this tire, simulated taxi takeoff cycles were conducted in 10 or 20 MPH increments, starting at 100 MPH, until tire failure was encountered. Tread separation occurred on the inboard shoulder during the third 180 MPH taxi takeoff cycle. The 9.50-16 tire, inflated at 130 PSI, completed 25 simulated taxi takeoff cycles at a 10,000-pound load for various takeoff speeds ranging between 100 and 180 MPH. Each cycle consisted of a 10,000-foot taxi roll on the tire at 30 MPH under full load prior to takeoff. Taxi takeoff cycles were conducted on the dynamometer in the following sequence: four cycles to 100 MPH; and three cycles each to 120, 130, 140, 150, 160, 170, and 180 MPH.

An improved 9.50-16 type III tubeless expandable tire with a 12-ply rating was molded by the contractor in the folded shape and was bladderless cured. The dynamic performance requirements for this 9.50-16 expandable tire, designated as tire number 2, was selected with capabilities relatively comparable to those of the C-141 aircraft tire. The load profile parallels the C-141 main tire taxi takeoff and landing taxi cycles at loads proportional to this expandable tires size, ply rating, and rated inflation pressure. The speed profile for the number 2 expandable tire is identical to the C-141 main tire taxi takeoff and landing taxi conditions. Refer to Figure 32 for the taxi takeoff profile and to Figure 33 for the landing taxi profile for the Number 2.

Initially, the tire was loaded at 10,000 pounds on the flywheel at 140-PSI inflation pressure for a 2.2-inch tire deflection at 32-percent deflection. Under identical load and pressure, a corresponding flat plate deflection of 28.3 percent, 1.95-inches tire deflection, was obtained. Tire deflections were based on an inflated outside diameter of 32.13 inches and a standing height of 6.89 inches.

During the 46th mission, the tire folded and remained in a shifted position causing one of the tire beads to unseat. To complete the remaining missions, silicone rubber was coated on the wheels' bead ledge to maintain a tight bead seat interference fit. The tire successfully completed 60 simulated C-141 missions (60 taxi takeoff and 60 landing taxi cycles). A summary is given in Table XII on the dynamic conditions and results of tire Number 2. The tire was sectioned at the completion of the test, and revealed that a ply separation had occurred in the middle plies starting from one inch above the beads and extending up to the convoluted fold.

Based upon the results of tire Number two, a 9.50-16 type III tubeless expandable tire was constructed by the contractor which incorporated an increased interference fit on the bead diameter. This tire, designated as tire Number 3, a 12-ply rating tire, had a 11,000-pound rated load at a 140-PSI test inflation pressure. This tire was subjected to simulated taxi takeoff and landing taxi cycles identical to those of tire Number 2, except for the load increase. For taxi takeoff and landing taxi profiles, refer to Figure 34 and 33 respectively.

A rolling radius of 13.75 inches was obtained when the tire at 34-percent deflection and 140-PSI inflation pressure was loaded at 11,000 pounds against the flywheel surface. Tread chunking occurred on the inboard shoulder, 3 inches in length, during the 58th simulated mission. Figure 35 shows the tread separation in both the folded and inflated position after the 58th mission. The remaining simulated missions were conducted on the tread separated tire.

Tread chunking progressed during the 60th simulated mission. Separation of the shoulder tread did not impair the tire's operational capability during the final two simulated missions. The tire successfully completed 60 simulated C-141 missions. Total tread separation after the completion of the 60 simulated missions is shown in Figure 36 for the tire in both the folded and inflated positions. A summary of the dynamic conditions and results on tire Number 3 is given in Table XIII.

A 9.50-16 expandable tire, identical in construction to tire Number 2, was subjected to a flatspot taxi runout prior to conducting simulated taxi takeoff cycles on the tire. Refer to the Flatsport Recovery subsection of this report for a detailed discussion on the long-time park and taxi runout investigation. This tire, designated as tire Number 5, was subjected to the same speed, distance, load, and time spectrum as tire Number 3. A blowout occurred on the 9th taxi takeoff cycle in the inboard sidewall between the head and the convoluted fold. A section through the blowout area was taken from the tire and is shown in Figure 37. This section revealed that a ply separation was present in both lower sidewalls. The ply separation occurred in the middle plys similar to tire Number 2 of identical tire construction.

An explanation for this tire's early failure is that an excessive taxi runout of five miles, continuously, was conducted on the tire. This is a stringent taxi runout condition and results of this investigation suggest that further taxi runouts be conducted at multiple 10,000-foot distance taxi cycles.

To fully evaluate the operational capabilities of a 9.50-16 type III tubeless expandable tire, tire Number 6 was selected for a full simulated C-141 performance spectrum. This included not only the 60 missions conducted in previous evaluations, but an additional 110 taxi camber cycles. Taxi camber cycles parallel the C-141 nose tire conditions with the exception that the tire was loaded at 11,000 pounds. Tire Number 6 was identical in tire construction to that of tire Number 2. To avoid the tire bead from unseating during the folding procedure, it was necessary to increase the wheel's bead ledge diameter. The wheel's bead ledge was wrapped with electrical friction tape, providing the required interference fit.

Taxi takeoff and landing taxi profiles used for tire Number 6 are shown in Figure 34 and 33 respectively. The following sequence of cycles was conducted to obtain a complete performance spectrum: (1) 110 taxi camber cycles; and (2) 10 taxi takeoff and 10 landing taxi cycles, alternately, until a total of 60 cycles each were accomplished. Groove cracking occurred on the outboard side of the tread, three inches in length after 110 taxi camber, 30 taxi takeoff, and 30 landing taxi cycles. At completion of all cycles, groove cracking had progressed to five inches in length.

Tire Number 6 successfully completed 60 simulated C-141 main tire missions (60 taxi takeoff and 60 landing taxi cycles) and 110 camber cycles (55 outboard and 55 inboard) in accordance with C-141 nose tire requirements. A summary of the dynamic conditions and results on tire Number 6 is given in Table XIV. The tire was sectioned, indicating a ply separation in both lower sidewalls and in one side of the tread shoulder, as shown in Figure 38. The sidewall separation occurred in the middle plies, an area of high shear stress, similar to the Number 2 tire separation.

A 9.50-16 type III tubeless expandable tire, designated as tire Number 7, was constructed with fabric-reinforced tread. Based upon successful takeoff speeds on the order of 200 MPH on previous expandable tires, tire Number 7 was subjected to simulated KC-135 taxi takeoff cycles. This represented a 25-MPH increase in takeoff speeds over the previous 200-MPH takeoff conditions. The simulated taxi takeoff condition conducted on tire Number 7 is as follows; The tire was landed against a stationary flywheel at a 11,000-pound load. The flywheel was then accelerated to 30 MPH and maintained at this velocity until a taxi roll distance of 10,000 feet had been covered. The flywheel was then decelerated to zero MPH, and immediately accelerated at 4 ft/sec/sec average (simulating takeoff) to 225 MPH. During the acceleration, the load was maintained at 11,000 pounds for the first 20 seconds, and then decreased linearly with time to 6,600 pounds in 75 seconds after acceleration starts, then reduced to zero load after a total roll distance of 13,600 feet had been covered in approximately 82.5 seconds.

Tire Number 7 failed on the third taxi takeoff cycle with tread separation, two inches on circumference, in the center rib. Results of this evaluation indicate that additional work is required in order to increase the maximum operating speeds above 200 MPH for the expandable tire.

Tire Number 8 featured an increased interference fit on the bead diameter and additional rubber built in between the middle plies in the sidewall area. Additional rubber between the middle plies was incorporated in an attempt to resolve the ply separation problem experienced with tires Number 2, 5, and 6. This 9.50-16 expandable tire was subjected to the C-141 simulated taxi takeoff and landing taxi cycles used in previous runs. For the simulated taxi takeoff and landing taxi profiles, refer to Figures 34 and 33 respectively.

Slight cord fraying in the outboard convolute fold was noticed after the third mission and is shown in Figure 39. After the sixth taxi takeoff cycle, inspection revealed a blister on the inboard sidewall, shown in Figure 40, just below the convolute fold. Tire number eight successfully completed 21 taxi takeoff and 21 landing taxi cycles before a malfunction in the machine's load-programming controls caused tire failure. No lift-off simulation occurred since the load did not decay as programmed, thus causing excessive tire tread separation. A summary is given in Table XV on the dynamic conditions and results for tire Number 8.

A 23.00-20 type III tubeless expandable tire, with a 16-ply rating, was subjected to simulated taxi takeoff conditions that were derived from estimated operating characteristics of a heavy cargo type of aircraft. Speed and load variations plotted against time are represented for the takeoff condition in Figure 41. This tire, designated as number L-2, successfully completed 18 taxi takeoff cycles. The tire remained in the shifted position after the fifth cycle as described in the Foldability subsection of this report. The dynamic evaluation was terminated after the 18th taxi takeoff cycle, when it became difficult to force the tire back into its folded shape. Inspection revealed that broken cords existed on the outer layer of the convoluted fold. The tire was sectioned and revealed no ply separations, indicating a structurally sound tire. Table XVI presents a summary of dynamic conditions and results on number L-2, 23.00-20 expandable tire.

The estimated operating characteristics were updated for the maximum gross weight takeoff configuration and for the design weight landing configuration of a heavy cargo type of aircraft. A 23.00-20 expandable tire, designated as number L-6, was subjected to these revised load and speed spectrums as outlined in the taxi takeoff, landing taxi, and aborted takeoff profiles, Figures 42, 43, and 44 respectively. A rolling radius of 23.38 inches was obtained when the tire at 34.8-percent deflection and 75-PSI inflation pressure was loaded at 31,000 pounds against a flat plate. To obtain the same percent deflection on the flywheel surface under identical loading, the inflation pressure was increased to 90 PSI, resulting in a rolling radius of 23.50 inches. The tire's outside diameters at inflation pressures of 75 and 90 PSI are 59.28 and 59.50 inches respectively.

The sequence of simulated taxi takeoff and landing taxi cycles conducted on tire number L-6 were alternated between 10 and 25 cycles. A simulated aborted takeoff was conducted on the 140th cycle (64 taxi takeoff and 75 landing taxi cycles). The tire was deflated immediately after completion of each takeoff cycle. Prior to each taxi takeoff cycle, the tire was inflated to 90 PSI. A quick inflation-deflation system described in the Inflation-Deflation Time Characteristics subsection was used to deflate and inflate the tire.

Tire Number L-6 successfully completed 80 taxi takeoff and 100 landing taxi cycles, and one aborted takeoff cycle. The dynamic evaluation was terminated due to tread chunking in the center rib, cord fraying on the outboard shoulder, and excessive shifting during the folding procedure. At completion of the test, a total radial runout of 0.150 inches was measured off the outboard tread rib. On the outboard side, the high spot was located 90 degrees clockwise from the tread chunking location. Location of the tread chunking area with respect to the tire's high spot indicates that the tire was continuously landed at the same location where the tread chunking occurred. Table XIX summarizes the dynamic conditions and results on the Number L-6, 23.00-20 expandable tire.

### Temperature Increase Due To Ground Operations

The temperature versus time data obtained from the simulated missions indicate that the bead and contained-air temperatures of expandable tires are neither critical nor in excesss of temperatures previously recorded on standard tires. Peak temperatures recorded at the completion of the taxi takeoff cycles ranged between 150 and 267 degrees Fahrenheit in the most critical area which is located above the tire bead. Initial temperatures in the bead area prior to the taxi takeoff cycle ranged between 80° and 117°F. The peak bead temperature of 267°F was recorded after the 38th takeoff cycle. The initial bead temperature prior to the 38th takeoff cycle was 101°F. The maximum tire taxi load and the speed reached during this takeoff cycle were 11,000 pounds and 200 MPH respectively. A typical taxi takeoff cycle temperature versus time curve is plotted in Figure 45 for both the bead and contained-air temperatures. A bead temperature versus time plot is presented in Figure 46 for a typical landing cycle.

## CARCASS FATIGUE LIFE

A fatigue durability type of evaluation was conducted in accordance with procedures outlined in Military Specification MIL-T-5041D. The purpose of this evaluation was to determine the carcass fatigue life properties of the 23.00-20 type III expandable tire for both Designs I and II. The quick inflation-deflation system described in the Inflation-Deflation Time Characteristics subsection was used to deflate and inflate the tires between each cycle.

Tire Number L-3, a 23.00-20 type III tubeless expandable tire with sidewall convolutions (Design II) successfully completed 200 MIL-T-5041D landing cycles. Slight cord fraying on the inboard convolute fold was noticed after 29 low speed and 25 high speed landing cycles. Cord fraying had progressed during the remainder of the test as shown in Figure 47. Table XVII presents a summary of test conditions and results on the 23.00-20 expandable tire, tire Number L-3.

A 23.00-20 expandable tire with tread convolutions, designated as tire Number L-5, was subjected to the same test conditions as the Number L-3, sidewall convoluted expandable tire. Minor flow cracks in the tread shoulder were evident when the tire was in the new condition. These flow cracks were intermittent for 14 inches at one location and continuous for nine inches at the other location on the tread shoulder circumference approximately 120 degrees apart. Initial flow cracks and progression of these flow cracks are shown in Figures 48 and 49. The Number L-5 tire successfully completed 200 MIL-T-5041D landing cycles with excessive tread chunking in the tread shoulder area. A summary of test conditions and results on the tread convoluted expandable tire is presented in Table XVIII.

## FOLDABILITY

Expandable tires of the 9.50-16 and 23.00-20 size were deflated and inflated between each taxi takeoff, landing taxi or MIL-T-5041D specified landing cycles, to determine the tires' folding capability. The tires were deflated to the folded position after the completion of a cycle, and prior to the next cycle, they were inflated to the tires' test inflation pressure.

Design I Foldability

The tread convoluted expandable tire exhibited excellent foldability during tire deflation and inflation between cycles. The Design I expandable tire, tire Number L-5, is shown in Figure 4 and 50 at folded, partially inflated, and fully inflated shapes. This tire has symmetrical folding and unfolding characteristics, and possessed none of the lateral shifting of the Design II, sidewall convoluted expandable tire.

Design II Foldability

All Design II sidewall convoluted expandable tires investigated experienced the same problem from the start, that of lateral instability during the folding and expanding procedure. This problem occurred in a nonrotational state when the crown of the tire folded and expanded unsymmetrically with the centerline of the wheel. One convolution unfolds first during inflation, causing the crown of the tire to shift axially as illustrated in Figure 51. During deflation, one convolution folds first, causing the crown of the tire to shift axially outboard as illustrated in Figure 52.

After a number of test cycles, a nonrotating tire would fail to return to its folded shape. The tire would deflate, but would remain in a shifted position. The tires always inflated to the expanded shape, but would experience lateral shifting.

A 23.00-20 size tire, tire Number L-3, displayed excellent symmetry during the tire's deflation at rotational speeds of 30 MPH or greater. This symmetrical folding can be attributed to centrifugal force acting on the tire's periphery. This force restrained the tread from contracting radially inward until the convoluted sidewalls had sufficient time to fold. This tire was mounted on a 49 by 17 wheel having a quick inflation-deflation system as described in the Inflation-Deflation Time Characteristics subsection of this report. The inability of the tire to center itself at speeds below 30 MPH, indicates that additional stiffness must be incorporated into the tire sidewalls in order to obtain symmetrical folding. Table XX presents a summary of the foldability results obtained on sidewall convoluted, Design II, expandable tires.

Lateral instability of the sidewall convoluted (Design II) expandable tire during inflation or deflation is not considered to be a serious problem to the operating capability of the tire. Results of the dynamic and static investigations indicate that several solutions to the problem are available. The most promising solution is to stiffen the tire sidewall by the addition of molded rubber stiffners. Considerations in alleviating this problem are twofold; first, the tire's deflation time is increased due to the lateral shifting, and second, it is probable that the shifted tire will interfere with adjacent gear structure or components.

FLATSPOT RECOVERY

The purpose of this investigation was to evaluate the expandable tire's flatspot recovery characteristics after simulated aircraft long time parking. A 9.50-16 expandable tire, tire Number 5, was installed in the AFFDL Number 3 Drop Test Tower for the long-time park evaluation. With the tire in a folded (deflated) position, a static load of 11,000 pounds was applied on the tire for a duration of 720 hours. At the completion of this flatspot time period, the tire-wheel assembly was installed on the AFFDL 120-Inch High Speed Dynamometer.

A 40-MPH simulated taxi runout was conducted on the inflated (140 PSI) flatspot tire at a load of 11,000 pounds for a distance of five miles. Due to the flatspot on the tire, a 650-pound load differential existed at the beginning of the taxi roll. Within 15 seconds from the start of the taxi run, the load differential had reduced to within 150 pounds, as shown in Figure 53. The rate of decay in the differential load is consistent with standard tire performance during a flatspot taxi runout. The results of this investigation substantiate the fact that aircraft can be parked for reasonable periods of time with the expandable tire in a folded (deflated) position.

FOLDED, BATTLE-DAMAGED OPERATION

Expandable tires with sidewall convolutions (Design II) fold inward toward the centerline of the wheel when deflated. When a load is applied to the deflated tire, a cross section at this point would show that the tire's folded sidewalls take on the density of a solid tire. Thus, this quasi-solid tire prevents wheel contact with the ground and keeps the wheel rims from cutting the tire.

To demonstrate the expandable tire's capability to withstand a landing cycle in the folded, battle-damaged condition, a simulated landing taxi cycle was conducted on a 9.50-16 expandable tire with sidewall convolutions. Tire Number one which had already completed 25 simulated taxi takeoff cycles at various takeoff speeds ranging between 100 and 180 MPH was selected for this investigation. This tire in the folded position was landed against the flywheel rotating at a peripheral speed of 120 MPH. The load was increased linearly with time during the initial five seconds after landing from 0 to 8000 pounds. The flywheel was decelerated at an average of 8 ft/sec/sec from 120 MPH to zero MPH. Without removing the load from the folded tire, the flywheel speed was increased to 40 MPH and the tire was rolled for an additional distance of 1000 feet. Poor air retention was evident when the tire was inflated after completing this landing cycle. The tire and wheel were disassembled and inspected. The wheel "0" ring seal was broken, an insignificant matter since air retention at the juncture of the wheel halves is not required during a folded tire landing cycle. Nondestructive inspection of the wheel revealed no defects due to the folded tire landing procedure. Results of this investigation indicate that the expandable tire has, at least a one time usage, battle-damaged operational potential.

# SECTION V

# CONCLUSIONS

The following overall conclusions are formulated from the results of this investigation:

(a) Expansion Capability - The Design II expandable tire offers the most promising fold from an expansion standpoint.

(1) The tread convoluted (Design I) 23.00-20 expandable tire (Number L-5) offered a 33 percent expansion, with a folded outside diameter of 43.94 inches and an expanded diameter of 58.55 inches.

(2) The sidewall convoluted (Design II) 9.50-16 expandable tire, (Number 8) with a folded outside diameter of 24.81 inches, offered a 30-percent expansion capability upon inflation.

(3) A 50-percent expansion was obtained on the sidewall convoluted (Design II) 23.00-20 expandable tire (Number L-6), when expanded from a folded outside diameter of 39.50 inches to an expanded diameter of 59.44 inches.

(b) Dynamic Performance - Considerable success has been achieved in the expandable tire's dynamic performance capability. Results indicate that the load capacity and life of the expandable tire are equivalent to the standard tire of the same size. Speed capability of the expandable tires investigated has exceeded the speed ratings of standard type III (low pressure) tires.

(c) Foldability - The Design I expandable tire exhibits excellent foldability during tire inflation and deflation. The Design II expandable tire in a nonrotational state experiences lateral shifting during inflation or deflation. However, a symmetrical folding procedure will occur on the Design II expandable tire at peripheral tires speeds as low as 30 MPH. Progressive refinements incorporated into the Design II expandable tire have improved upon its folding characteristics.

(d) A 75-percent increase in deflation time was recorded for the Design I 23.00-20 expandable tire. In comparison with a Design II fold, the longer folding time and the decrease in percent expansion for the Design I fold detract from its excellent folding qualities.

TABLE I

TYPE III TUBELESS EXPANDABLE TIRE DESCRIPTION SUMMARY

| TIRE NO. | TIRE SIZE | PR | FOLD | CONSTRUCTION | INVESTIGATIONS CONDUCTED |
|---|---|---|---|---|---|
| 1 | 9.50-16 | 12 | Sidewall | Fabricated by using a bladderless cure in a closed mold. | Load-deflection, dynamic simulation |
| 2 | 9.50-16 | 12 | Sidewall | First design under Contract AF33(615)-2382, Bladderless cured. | Centrifugal growth, dynamic simulation |
| 3 | 9.50-16 | 12 | Sidewall | Increased interference fit on the bead diameter. | Dynamic simulation |
| 4 | 9.50-16 | 12 | Sidewall | Same construction as tire No. 2. | Used for display |
| 5 | 9.50-16 | 12 | Sidewall | Same construction as tire No. 2. | Flatspot recovery |
| 6 | 9.50-16 | 12 | Sidewall | Same construction as tire No. 2. | Dynamic simulation |
| 7 | 9.50-16 | 12 | Sidewall | Fabric-reinforced tread. | Dynamic simulation |
| 8 | 9.50-16 | 12 | Sidewall | Increased interference fit on bead diameter and additional inter-ply rubber in sidewall area. | Dynamic simulation |
| L-1 | 23.00-20 | 16 | Sidewall | First design of 23.00-20 size. | Hydrostatic burst |
| L-2 | 23.00-20 | 16 | Sidewall | Same construction as tire L-1. | Load-deflection, dynamic simulation |
| L-3 | 23.00-20 | 16 | Sidewall | Same construction as tire L-1. | Carcass fatigue |
| L-4 | 23.00-20 | 16 | Sidewall | Same construction as tire L-1. | Used for display |
| L-5 | 23.00-20 | 16 | Tread | First design of tread convolute. | Carcass fatigue |
| L-6 | 23.00-20 | 16 | Sidewall | Addition of sidewall stiffners. | Centrifugal growth, load deflection, dynamic simulation |

NOTE: 1. Dynamic Simulation - Tires were subjected to programmed load and speeds, simulating aircraft landing, takeoff and/or taxi conditions.

2. Carcass Fatigue - Tires were subjected to dynamic landings in accordance with procedures outlined in MIL-T-5041D.

TABLE II

SUMMARY OF PROFILE AND CONTACT AREA PRINT DATA ON 23.00-20 EXPANDABLE TIRE, NUMBER L-6

| INFLATION PRESSURE (PSI) | PROFILE DATA* | | | | | CONTACT AREA PRINT DATA | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A OUTSIDE DIAMETER (INCHES) | B SECTION WIDTH (INCHES) | C SHOULDER DIAMETER (INCHES) | D SHOULDER WIDTH (INCHES) | E STANDING HEIGHT (INCHES) | STATIC LOAD (LBS) | DEFLECTION (INCHES) | PERCENT DEFLECTION | GROSS CONTACT AREA (SQ IN) | CONTACT AREA PRINT |
| 50 | 58.00 | 20.81 | 51.94 | 14.50 | 17.25 | 20,500 | 5.98 | 34.7 | 370.5 | Fig. 23 |
| | | | | | | 24,000 | 6.83 | 39.6 | 416.0 | Fig. 24 |
| | | | | | | 27,000 | 7.51 | 43.5 | 445.1 | Fig. 25 |
| 75 | 59.06 | 20.83 | 53.06 | 14.63 | 17.78 | 31,000 | 6.19 | 34.8 | 380.3 | Fig. 26 |
| | | | | | | 35,600 | 6.90 | 38.8 | 418.3 | Fig. 27 |
| | | | | | | 41,400 | 7.78 | 43.8 | 456.9 | Fig. 28 |
| 90 | 59.44 | 20.88 | 53.28 | 14.88 | 17.97 | 39,000 | 6.39 | 35.6 | 406.4 | Fig. 29 |
| 115 | 59.75 | 20.94 | 54.00 | 14.88 | 18.13 | - | - | - | - | - |

NOTE: Above data obtained after 12-hour minimum stretch.

* Refer to Figures 9 and 10 for section profiles. Folded outside diameter, dimension AA, is 39.50 in.

TABLE III

DIMENSIONS ON 9.50-16 EXPANDABLE TIRE, NUMBER 2

| CONDITION | INFLATED DIMENSIONS AT 140 PSI INFLATION PRESSURE | | FOLDED DIMENSIONS | |
|---|---|---|---|---|
| | MAX. OUTSIDE DIAMETER (INCHES) | REMARKS | MAX. O.D. AT CENTER TREAD (INCHES) | REMARKS |
| After 12-Hour Minimum Stretch | 32.13 | 8.88-Inch Section Width | 25.17 | |
| After 6 Missions | 32.53 | See Note 3 Below | 25.42 | See Note 3 Below |
| After 8 Missions | 32.53 | See Note 3 Below | 25.31 | See Note 1 Below |
| After 10 Missions | 32.63 | See Note 2 Below | 25.63 | See Note 2 Below |
| After 11 Missions | 32.56 | See Note 3 Below | 25.56 | See Note 1 Below |
| After 12 Missions | 32.56 | See Note 3 Below | 25.77 | See Note 2 Below |
| After 20 Missions | 32.56 | See Note 3 Below | 25.56 | See Note 1 Below |
| After 21 Missions | 32.56 | See Note 3 Below | 25.77 | See Note 2 Below |
| After 23 Missions | 32.73 | See Note 2 Below | 25.61 | See Note 1 Below |
| After 24 Missions | 32.47 | See Note 1 Below | 25.88 | See Note 2 Below |
| After 25 Missions | 32.77 | See Note 2 Below | 25.73 | See Note 3 Below |
| After 30 Missions | 32.44 | See Note 1 Below | 25.83<br>25.69 | See Note 2 Below<br>See Note 1 Below |
| After 36 Missions | 32.75 | See Note 2 Below | 26.00<br>25.75 | See Note 2 Below<br>See Note 1 Below |
| After 45 Missions | 32.56 | See Note 3 Below | 26.00 | See Note 2 Below |
| After 47 Missions | 32.64 | See Note 3 Below | 26.06 | See Note 2 Below |
| After 56 Missions | 32.56 | See Note 3 Below | 26.25 | See Note 2 Below |
| After 60 Missions | 32.63 | See Note 3 Below | 26.13 | See Note 3 Below |

NOTE

1. Dimensions taken after tire was allowed to cool down to room temperature.
2. Dimensions taken within 15 minutes after completion of cycle.
3. Dimensions taken between mission cycles with limited cool-down time.

TABLE IV

DIMENSIONS ON 9.50-16 EXPANDABLE TIRE, NUMBER 3

| CONDITION | INFLATED DIMENSIONS AT 140 PSI INFLATION PRESSURE: MAX. OUTSIDE DIAMETER (INCHES) | INFLATED DIMENSIONS AT 140 PSI INFLATION PRESSURE: REMARKS | FOLDED DIMENSIONS: MAX. O.D. AT CENTER TREAD (INCHES) | FOLDED DIMENSIONS: REMARKS |
|---|---|---|---|---|
| After 12-Hour Minimum Stretch | 32.27 | | 24.95 | 7.31-Inch Folded Section Width |
| After 1 Mission | 32.45 | See Note 3 Below | 25.11 | See Note 1 Below |
| After 2 Missions | 32.58 | See Note 2 Below | 25.44 | See Note 3 Below |
| After 3 Missions | 32.45 | See Note 3 Below | 25.56 | See Note 2 Below |
| After 8 Missions | 32.56 | See Note 3 Below | 25.67 | See Note 2 Below |
| After 14 Missions | 32.58 | See Note 3 Below | 25.58 | See Note 1 Below |
| After 17 Missions | 32.70 | See Note 2 Below | 25.70 | See Note 3 Below |
| After 18 Missions | 32.41 | See Note 1 Below | 25.63 | See Note 1 Below |
| After 19 Missions | 32.41 | See Note 1 Below | 25.94 | See Note 2 Below |
| After 25 Missions | 32.47 | See Note 1 Below | 25.80 | See Note 3 Below |
| After 31 Missions | 32.53 | See Note 3 Below | 25.80 | See Note 3 Below |
| After 38 Missions | 32.45 | See Note 1 Below | 25.83 | See Note 3 Below |
| After 44 Missions | 32.84 | See Note 2 Below | 25.84 | See Note 3 Below |
| After 46 Missions | 32.51 | See Note 3 Below | 26.03 | See Note 2 Below |
| After 48 Missions | 32.58 | See Note 3 Below | 25.91 | See Note 1 Below |
| After 50 Missions | 32.89<br>32.58 | See Note 2 Below<br>See Note 3 Below | 26.06 | See Note 3 Below |
| After 52 Missions | 32.54 | See Note 3 Below | 26.20<br>26.00 | See Note 2 Below<br>See Note 1 Below |
| After 56 Missions | 32.88 | See Note 2 Below | 26.17 | See Note 3 Below |
| After 58 Missions | 32.63 | See Note 3 Below | 26.25 | See Note 2 Below |
| After 60 Missions | 32.50 | See Note 1 Below | 26.06 | See Note 1 Below |

NOTE

1. Dimensions taken after tire was allowed to cool down to room temperature.
2. Dimensions taken within 15 minutes after completion of cycle.
3. Dimensions taken between mission cycles with limited cool-down time.

TABLE V

DIMENSIONS ON 9.50-16 EXPANDABLE TIRE, NUMBER 6

| CONDITION | INFLATED DIMENSIONS | | |
|---|---|---|---|
| | INFLATION PRESSURE (PSI) | MAX. OUTSIDE DIAMETER (INCHES) | MAX. SECTION WIDTH (INCHES) |
| After 12-Hour Minimum Stretch | 140 | 32.45 | 8.80 |
| After 110 Camber Cycles | 130 | 32.30 | 8.63 |
| After 10 TTO and 5 LT Cycles | 140 | 32.56 | 9.00 |
| After Completion of all Cycles | 140 | 32.77 | 9.13 |

TABLE VI

DIMENSIONS ON 9.50-16 EXPANDABLE TIRE, NUMBER 8

| CONDITION | INFLATED DIMENSIONS | | FOLDED OUTSIDE DIAMETER (INCHES) | REMARKS |
|---|---|---|---|---|
| | INFLATION PRESSURE (PSI) | MAX. OUTSIDE DIAMETER (INCHES) | | |
| After 12-Hour Minimum Stretch | 140 | 32.19 | 24.81 | See Note 1. Maximum Section Width is 8.63 Inches at 140-PSI Inflation Pressure. |
| After First Mission | 140 | 32.31 | 24.84 | See Note 1. |
| After Third Mission | 140 | 32.56 | 25.56 | See Note 2. Bead Temperature Peaked at 242°F. |
| | | - | 25.39 | See Note 1. |
| After Sixth Mission | 140 | 32.41 | 25.48 | See Note 1. |
| After 19th Mission | 140 | 32.58 | 25.86 | See Note 2. Bead Temperature Peaked at 258°F. |
| After 20th Mission | 140 | 32.63 | 26.00 | See Note 2. Bead Temperature Peaked at 267°F. |

NOTE

1. Dimensions taken at ambient temperature.
2. Dimensions taken within 15 minutes after completion of cycle.

TABLE VII

DIMENSIONS ON 23.00-20 EXPANDABLE TIRE, NUMBER L-2

| CONDITION | INFLATED DIMENSIONS | | | | FOLDED DIMENSIONS (NON-INFLATED) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | INFLATION PRESSURE (PSI) | O.D. MAX.(1) (INCHES) | TIRE STANDING HEIGHT(2) (INCHES) | CROSS SECTION MAX. (INCHES) | O.D. AT OUTBOARD TREAD (INCHES) | O.D. AT CENTER TREAD (INCHES) | O.D. AT INBOARD TREAD (INCHES) | C.S. ABOVE CONVOLUTED FOLD (INCHES) | C.S. BELOW CONVOLUTED FOLD (INCHES) |
| After 12-Hour Minimum Stretch | 55 | 56.88 | 16.69 | | | | | | |
| | 65 | 57.31 | 16.91 | | | | | | |
| | 75 | 57.67 | 17.07 | 20.64 | | | | | |
| | 85 | 58.00 | 17.25 | 20.56 | | | | | |
| After 2 Mile Break-in | 90 | | | | 39.56 | 38.83 | 39.50 | 15.00 | 15.39 |
| After 1st T-T-O Cycle | 90 | 58.44 | | | 39.83 | 38.97 | 39.73 | | |
| After 2nd T-T-O Cycle | 90 | | | | 41.88 | 40.33 | 41.27 | | |
| After 3rd T-T-O Cycle | 90 | 58.94 | | | | | | | |
| After 4th T-T-O Cycle | 90 | 59.11 | | | 40.75 | 39.25 | 40.56 | | |
| After 6th T-T-O Cycle | 90 | 59.17 | | | (3) 41.75 | (3) 40.81 | (3) 41.25 | | |
| After 7th T-T-O Cycle | 90 | 59.31 | | | 41.25 | 40.31 | 41.25 | | |
| After 10th T-T-O Cycle | 90 | 59.44 | | | | | | | |
| After 17th T-T-O Cycle | 90 | 59.56 | | | | | | | |

(1) Maximum O.D. at center of tread when inflated.

(2) Based on a wheel flange radius of 11.75 inches.

(3) Dimension taken within five minutes after completion of cycle.

TABLE VIII

DIMENSIONS ON 23.00-20 EXPANDABLE TIRE, NUMBER L-3

| CONDITION | INFLATED DIMENSIONS AT 85-PSI INFLATION PRESSURE | | FOLDED DIMENSIONS (NON-INFLATED) | |
|---|---|---|---|---|
| | MAX. OUTSIDE DIAMETER (INCHES) | REMARKS | MAX. O.D. AT CENTER TREAD (INCHES) | REMARKS |
| After 12-Hour Minimum Stretch | 57.81 | 20.56-Inch Section Width | 39.08 | |
| After 7 Low Speed Cycles | 58.08 | See Note 1 Below | 39.25 | See Note 1 Below |
| After 9 Low Speed Cycles | 58.25 | See Note 2 Below | 39.56 | See Note 2 Below |
| After 19 Low Speed Cycles | 58.30 | See Note 2 Below | 39.63 | See Note 2 Below |
| After 21 Low Speed Cycles | 58.17 | See Note 1 Below | 39.63 | See Note 2 Below |
| After 25 Low & 2 High Speed Cycles | 58.28 | See Note 1 Below | 39.42 | See Note 1 Below |
| After 25 Low & 5 High Speed Cycles | 58.47 | See Note 2 Below | 39.87 | See Note 2 Below |
| After 25 Low & 9 High Speed Cycles | 58.34 | See Note 1 Below | 39.60 | See Note 1 Below |
| After 25 Low & 15 High Speed Cycles | 58.53 | See Note 2 Below | 39.75 | See Note 2 Below |
| After 25 Low & 16 High Speed Cycles | 58.41 | See Note 1 Below | 39.65 | See Note 1 Below |
| After 25 Low & 24 High Speed Cycles | 58.45 | See Note 1 Below | 39.66 | See Note 1 Below |
| After 25 Low & 25 High Speed Cycles | 59.63 | See Note 2 Below | 39.86 | See Note 2 Below |
| After 42 Low & 25 High Speed Cycles | 58.61 | See Note 2 Below | 39.56 | See Note 1 Below |
| After 50 Low & 35 High Speed Cycles | 58.72 | See Note 2 Below | 39.81 | See Note 2 Below |
| After 50 Low & 50 High Speed Cycles | 58.50 | See Note 1 Below | 39.92 | See Note 2 Below |
| After 60 Low & 50 High Speed Cycles | 58.53 | See Note 1 Below | 39.96 | See Note 2 Below |
| After 77 Low & 51 High Speed Cycles | 58.50 | See Note 1 Below | 39.75 | See Note 1 Below |
| After 77 Low & 65 High Speed Cycles | 58.81 | See Note 2 Below | 39.94 | See Note 2 Below |
| After 86 Low & 100 Hi Speed Cycles | 58.54 | See Note 1 Below | 39.97 | See Note 2 Below |
| After 87 Low and 100 Hi Speed Cycles | 58.91 | See Note 2 Below | 40.13 | See Note 2 Below |

NOTE
1. Dimensions taken after tire was allowed to cool down to room temperature.
2. Dimensions taken within five minutes after completion of cycle.

TABLE IX

DIMENSIONS ON 23.00-20 EXPANDABLE TIRE, NUMBER L-5

| CONDITION | INFLATED DIMENSIONS AT 90-PSI INFLATION PRESSURE | | | FOLDED DIMENSIONS (NON-INFLATED) | | |
|---|---|---|---|---|---|---|
| | MAX. OUTSIDE DIAMETER (INCHES) | MAX. CROSS SECTION (INCHES) | REMARKS | MAX. O.D. AT CENTER TREAD (INCHES) | MAX. CROSS SECTION (INCHES) | REMARKS |
| After 12-Hour Min. Stretch | 58.55 | 20.88 | 17.5 Inch Shoulder Cross Section | 43.94 | 17.50 | |
| After 18th Cycle (10 Low & 8 High Speed Cycles) | 58.81 | 20.88 | See Note 1 Below | 44.33 | 17.75 | See Note 1 Below |
| After 28th Cycle (18 Low & 10 High Speed Cycles) | 58.97 | 20.88 | See Note 1 Below | 44.22 | 17.88 | See Note 1 Below |
| After 38th Cycle (25 Low & 13 High Speed Cycles) | 59.13 | 20.97 | See Note 1 Below | 44.38 | 17.38 | See Note 1 Below |
| After 68th Cycle (43 Low & 25 High Speed Cycles) | 59.47 | 20.97 | See Note 2 Below | 44.44 | 17.63 | See Note 2 Below |
| After 108th Cycle (58 Low & 50 High Speed Cycles) | 59.44 | 21.06 | See Note 2 Below | 44.39 | 17.50 | See Note 2 Below |
| After 113th Cycle (63 Low & 50 High Speed Cycles) | 58.94 | 21.00 | See Note 1 Below | 44.31 | 17.50 | See Note 1 Below |
| After 124th Cycle (74 Low & 50 High Speed Cycles) | 59.00 | 20.88 | See Note 1 Below | 44.30 | 17.50 | See Note 1 Below |
| After 126th Cycle (75 Low & 51 High Speed Cycles) | 59.44 | 21.00 | See Note 2 Below | 44.44 | 17.50 | See Note 2 Below |
| After 154th Cycle (79 Low & 75 High Speed Cycles) | 59.13 | 21.00 | See Note 1 Below | 44.38 | 17.50 | See Note 1 Below |
| After 181st Cycle (100 Low & 81 High Speed Cycles) | 59.06 | 21.00 | See Note 1 Below | 44.50 | 17.50 | See Note 1 Below |
| After 200th Cycle (100 Low & 100 High Speed Cycles) | 59.50 | 21.13 | See Note 2 Below | 44.69 | 17.56 | See Note 2 Below |
| | 59.20 | 21.00 | See Note 1 Below | 44.56 | 17.50 | See Note 1 Below |

NOTE

1. Dimensions taken after tire was allowed to cool down to room temperature.
2. Dimensions taken within five minutes after completion of cycle.

TABLE X

SUMMARY OF DATA ON DIMENSIONAL GROWTH DUE TO USAGE

| TIRE SIZE* | TIRE NO.*** | EXPANDED DIMENSIONS** | | | | | FOLDED DIMENSIONS** | | | CALCULATED GROWTH USAGE FACTORS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $D_{OE}$ | $H_E$ | $W_E$ | $D_{GE}$ | $W_{GE}$ | $D_{OF}$ | $H_F$ | $D_{GF}$ | $G_{HE}$ | $G_{WE}$ | $G_{HF}$ |
| 9.50-16 | 2 | 32.13 | 8.07 | - | 32.77 | - | 25.17 | 4.59 | 26.25 | 2.08 | - | 2.23 |
| 9.50-16 | 3 | 32.27 | 8.14 | - | 32.89 | - | 24.95 | 4.48 | 26.25 | 2.07 | - | 2.29 |
| 9.50-16 | 6 | 32.45 | 8.23 | 8.80 | 32.77 | 9.13 | - | - | - | 2.04 | 1.04 | - |
| 9.50-16 | 8 | 32.19 | 8.10 | - | 32.63 | - | 24.81 | 4.41 | 26.00 | 2.05 | - | 2.27 |
| 23.00-20 | L-2 | 58.10 | 19.05 | - | 59.56 | - | 39.56 | 9.78 | 41.75 | 2.08 | - | 2.22 |
| 23.00-20 | L-3 | 57.81 | 18.96 | - | 58.91 | - | 39.08 | 9.56 | 40.13 | 2.05 | - | 2.11 |
| 23.00-20 | L-5 | 58.55 | 19.28 | 20.88 | 59.50 | 21.13 | 43.94 | 11.97 | 44.56 | 2.05 | 1.01 | 2.05 |

* Tire Size: Rim Ledge Diameter, D, for the 9.50-16 tire is 16 inches, and 20 inches for the 23.00-20 tire.
** Refer to the description of symbols listed in the dimensional growth section of this report. All dimensions are in inches.
*** Tire Number:
- a. Tires No. 2 and 3 completed 60 simulated missions (60 taxi takeoff and 60 landing taxi cycles).
- b. Tire No. 6 completed 60 simulated missions and 110 camber taxi cycles.
- c. Tire No. 8 completed 21 simulated missions.
- d. Tire No. L-2 completed 18 simulated taxi takeoff cycles.
- e. Tires No. L-3 and L-5 completed 200 landing cycles in accordance with procedures outlined in MIL-T-504ID.

TABLE XI

SUMMARY OF DEFLATION TIME FOR THE
TREAD CONVOLUTE 23.00-20 EXPANDABLE TIRE

| PERIPHERAL TIRE SPEED (MPH) | LANDING CYCLE LOW/HIGH | INITIAL INFLATION PRESSURE (PSI) | DEFLATION TIME (SECONDS) |
|---|---|---|---|
| 30 | After 9/0 | 90 | 75 |
| 95 | After 10/10 | 90 | 91 |
| Static | After 10/10 | 90 | 73 |
| 30 | After 11/10 | 90 | 82 |
| 30 | After 12/10 | 90 | 82 |
| Static | After 12/10 | 90 | 73 |
| Static | After 12/10 | 50 | 68 |
| Static | After 12/10 | 75 | 71 |
| 30 | After 59/50 | 90 | 86 |
| Static | After 59/50* | 90 | 81 |

* Prior to the landing cycle the tire was inflated within 73 seconds.

TABLE XII

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 9.50-16 EXPANDABLE TIRE, NUMBER 2

| | | | REMARKS |
|---|---|---|---|
| Size 9.50-16 Tubeless Expandable Tire<br>Ply Rating 12 Type III<br>Test Date 21 May - 22 June 65 | | | |
| DIMENSIONS | | | 1. See Table III |
| **TAXI TAKEOFF** | | | 2. See Fig. 32 for taxi takeoff profile. |
| Flywheel O.D. .............. | In. | 84 | |
| Test Inflation ............. | PSI | 140 | 3. See Fig. 33 for landing taxi profile. |
| Acceleration ............... | $Ft/Sec^2$ | 9 | |
| Initial Contained-Air Temperature Range ........ | °F | 80-110 | 4. Tire in good condition, no blemishes, at the completion of 60 simulated missions. |
| Peak Contained-Air Temperature Range ........ | °F | 150-170 | |
| Initial Bead Temp. Range ... | °F | 80-115 | |
| Peak Bead Temp. Range ...... | °F | 150-210 | |
| Number of T-T-O Cycles ..... | | 60 | |
| **LANDING TAXI** | | | |
| Flywheel O.D. .............. | In. | 84 | |
| Test Inflation ............. | PSI | 130 | |
| Deceleration Rate .......... | $Ft/Sec^2$ | 8 | |
| Initial Contained-Air Temperature Range ........ | °F | 80-115 | |
| Peak Contained-Air Temperature Range ......... | °F | 150-160 | |
| Initial Bead Temp. Range ... | °F | 82-128 | |
| Peak Bead Temp. Range ...... | °F | 140-189 | |
| Number of LT Cycles ........ | | 60 | |

FINAL RESULTS: Tire successfully completed 60 simulated C-141 missions (60 taxi takeoff and 60 landing taxi cycles). A total distance of 312.4 miles was accumulated on the tire.

TABLE XIII

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 9.50-16 EXPANDABLE TIRE, NUMBER 3

| | | | REMARKS |
|---|---|---|---|
| Size 9.50-16 Tubeless Expandable Tire<br>Ply Rating 12 Type III<br>Test Date 15 July - 28 July 1965 | | | |
| DIMENSIONS | | | 1. See Table IV |
| **TAXI TAKEOFF** | | | 2. See Fig. 34 for taxi takeoff profile. |
| Flywheel O.D. .............. | In. | 84 | 3. See Fig. 33 for landing taxi profile. |
| Test Inflation ............. | PSI | 140 | |
| Acceleration ............... | Ft/Sec/Sec | 9 | |
| Initial Bead Temp. Range ... | °F | 80-110 | 4. Inspection revealed a slight blister on inboard shoulder after 56 simulated missions. Blister was not noticeable when the tire was deflated to its folded position. |
| Peak Bead Temp. Range ...... | °F | 198-252 | |
| Number of T-T-O Cycles ..... | | 60 | |
| **LANDING TAXI** | | | |
| Flywheel O.D. .............. | In. | 84 | |
| Test Inflation ............. | PSI | 130 | |
| Deceleration Rate .......... | Ft/Sec/Sec | 8 | |
| Initial Bead Temp. Range ... | °F | 84-115 | 5. Tread chunking occurred on inboard shoulder, 3 inches in length, during the 58th simulated mission. |
| Peak Bead Temp. Range ...... | °F | 172-220 | |
| Number of LT Cycles ........ | | 60 | 6. Additional tread chunking, 3 inches in length, occurred during the 60th simulated mission. |
| FINAL RESULTS: Tire successfully completed 60 simulated C-141 missions (60 taxi takeoff and 60 landing taxi cycles). A total distance of 311.3 miles was accumulated on the tire. | | | |

TABLE XIV

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 9.50-16 EXPANDABLE TIRE, NUMBER 6

| Size 9.50-16 Tubeless Expandable Tire with Convoluted Sidewalls<br>Ply Rating 12 Type III<br>Test Date 13 September - 29 December 1965 | | | REMARKS |
|---|---|---|---|
| DIMENSIONS | | | 1. See Table V. |
| **TAXI TAKEOFF** | | | 2. See Fig. 34 for taxi takeoff profile. |
| Flywheel O.D. | In. | 84 | |
| Test Inflation | PSI | 140 | |
| Acceleration | FT/Sec/Sec | 9 | 3. See Fig. 33 for landing taxi profile. |
| Peak Contained-Air Temperature Range | °F | 135-200 | |
| Peak Bead Temp. Range | °F | 175-240 | 4. Blistering on tire tread after 110 camber, 10 TTO, and 5 LT cycles. |
| Number T-T-O Cycles | | 60 | |
| **LANDING TAXI** | | | |
| Flywheel O.D. | In. | 84 | 5. Groove cracking on outboard side of tread, 3 inches in length, after 110 camber, 30 TTO, and 30 LT cycles. |
| Test Inflation | PSI | 140 | |
| Deceleration Rate | Ft/Sec/Sec | 8 | |
| Peak Contained-Air Temperature Range | °F | 120-178 | |
| Peak Bead Temp. Range | °F | 160-184 | |
| Number LT Cycles | | 60 | 6. Inspection after 110 camber, 40 TTO, and 32 LT cycles revealed groove cracking on outboard side of tread progressed to 4 inches in length. |
| **CAMBER TAXI** | | | |
| Flywheel O.D. | In. | 120 | |
| Tire Load | Lb. | 11,000 | |
| Test Inflation | PSI | 140 | |
| Speed | MPH | 40 | |
| Camber Angle | Deg. | 6 | |
| Distance/Roll | Ft. | 1,900 | |
| Number of Camber Cycles | | 55 O.B., 55 I.B. | 7. At completion of all cycles, groove cracking on O.B. tread progressed to 5 inches in length. |

FINAL RESULTS: Tire successfully completed 60 simulated C-141 main tire missions (60 taxi takeoff and 60 landing taxi cycles) and 110 camber cycles (55 outboard and 55 inboard) in accordance with C-141 nose tire requirements. A total distance of 344.6 miles (41 mile camber and 303.6 mile TTO and LT) was accumulated on the tire.

TABLE XV

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 9.50-16 EXPANDABLE TIRE, NUMBER 8

| Size 9.50-16 Tubeless Expandable Tire with Convoluted Sidewalls<br>Ply Rating 12 Type III<br>Test Date 4 August - 10 August 1965 | | | REMARKS |
|---|---|---|---|
| DIMENSIONS | | | 1. See Table VI |
| TAXI TAKEOFF | | | 2. See Fig. 34 for T-T-O Profile. |
| Flywheel O.D. .............. | In. | 84 | |
| Test Inflation ............. | PSI | 140 | 3. See Fig. 33 for LT Profile. |
| Acceleration ............... | Ft/Sec/Sec | 9 | |
| Initial Contained-Air Temperature Range ........ | °F | 80-108 | 4. Slight cord fraying in convolute fold on outboard side after 3rd mission. |
| Peak Contained-Air Temperature Range ........ | °F | 148-170 | |
| Initial Bead Temp. Range ... | °F | 80-117 | |
| Peak Bead Temp. Range ...... | °F | 240-267 | |
| Number of T-T-O Cycles ..... | | 21 | 5. Blister on lower convolute shoulder, inboard side, after 11th cycle. |
| LANDING TAXI | | | |
| Flywheel O.D. .............. | In. | 84 | 6. No decay in load on 43rd cycle, tire stripped tread. |
| Test Inflation ............. | PSI | 130 | |
| Deceleration Rate .......... | Ft/Sec/Sec | 8 | |
| Initial Contained-Air Temperature Range ........ | °F | 82-105 | |
| Peak Contained-Air Temperature Range ........ | °F | 140-165 | |
| Initial Bead Temp. Range ... | °F | 82-115 | |
| Peak Bead Temp. Range ...... | °F | 196-248 | |
| Number of LT Cycles ........ | | 21 | |

FINAL RESULTS: Test terminated due to dynamometer malfunction in the machine's load-programming controls, causing tire failure. Tire successfully completed 21 taxi takeoff and 21 landing taxi cycles for a total accumulated distance of 109.6 miles.

TABLE XVI

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 23.00-20 EXPANDABLE TIRE, NUMBER L-2

| | | REMARKS |
|---|---|---|
| Size 23.00-20 Expandable Tire<br>Ply Rating 16 Type III<br>Test Date 1 June - 1 July 65 | | 1. See Fig. 19 for load-deflection curves. |
| DIMENSIONS | | 2. See Table VII |
| TAXI BREAK-IN<br>Flywheel O.D. .............. In.<br>Test Inflation ............. PSI<br>Taxi Speed ................. MPH | <br>120<br>90<br>20 | 3. First taxi run at 20,000 lbs load for a distance of 10,560 ft.<br>4. Second taxi run at 30,000 lbs load for a distance of 5,280 ft. |
| TAXI TAKEOFF<br>Flywheel O.D. .............. In.<br>Test Inflation ............. PSI<br>Number of TTO Cycles .......<br>Initial Contained Air Temperature Range ........ °F<br>Peak Contained Air Temperature Range ........ °F<br>Initial Bead Temp. Range ... °F<br>Peak Bead Temp. Range ...... °F | <br>120<br>90<br>18<br>76-86<br>158-166<br>82-100<br>207-214 | 5. See Fig. 41 for TTO profile.<br>6. Lateral instability occurred after 1st cycle.<br>7. Tire failed to return to its molded shape after 5th cycle. |

RESULTS: Test terminated after 18th TTO cycle with an accumulated mileage of 72 miles on the tire.

TABLE XVII

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 23.00-20 EXPANDABLE TIRE, NUMBER L-3

| | | | REMARKS |
|---|---|---|---|
| Size 23.00-20 Tubeless Expandable Tire with Sidewall Convolutions<br>Ply Rating 16 Type III<br>Test Date 23 August - 25 September 1965 | | | |
| DIMENSIONS | | | 1. See Table VII. |
| MIL-T-5041D TEST | | | 2. Tire failed to return to its molded shape after 6th low speed cycle. |
| Flywheel O.D. .......... In. | 120 | | |
| Inertia Equivalent ..... Lbs | 13,630 | | |
| Tire Load (Constant) ... Lbs | 31,000 | | |
| Test Inflation ......... PSI | 85 | | 3. Slight cord fraying in convolute fold located on inboard side after 29 low and 25 high speed cycles. |
| Speed Range ............ MPH | 84.5-33 | 120-98 | |
| KE absorbed by Tire Per Cycle ....... Ft/Lb | $2.75 \times 10^6$ | $2.16 \times 10^6$ | 4. Inspection revealed cord fraying on inboard fold progressing after 75 low and 67 high speed cycles. |
| Ave. Stop Time ......... Sec | 75 | 24 | |
| Number of Cycles ....... | 100 | 100 | 5. Excessive cord fraying on inboard convolute fold at completion of test. |
| RESULTS: Tire successfully completed 200 cycles in accordance with procedures outlined in MIL SPEC MIL-T-5041D. Total mileage of 200.3 miles was accumulated on the tire. | | | |

TABLE XVIII

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 23.00-20 EXPANDABLE TIRE, NUMBER L-5

Size 23.00-20 Tubeless Expandable Tire, with Tread Convolutions

Ply Rating 16 | Serial Number 16E-808-10 | Tire Weight 199 Lbs

Test Date 21 January 1966 - 24 February 1966

| | | | REMARKS |
|---|---|---|---|
| DIMENSIONS | | | 1. See Table IX. |
| MIL-T-5041D TEST<br>Flywheel O.D. 120 In.<br>Inertia Equivalent 13,630 Lbs<br>Tire Load 31,000 Lbs<br>Test Inflation 90 PSI | | | 2. Rolling Radius of 23.5 inches.<br>3. Tread flow cracks in new tire, intermittent for 14 inches, continuous for 9 inches. |
| Speed Range MPH | 84.5-33 | 120-98 | 4. Tread Chunking |
| KE Absorbed by Tire per Cycle Ft-Lb | $2.75 \times 10^6$ | $2.16 \times 10^6$ | a. Tread chunking, ½ in. x ¼ in. in IB shoulder on 15th cycle. |
| Average Stop Time Sec | 75 | 24 | b. Three areas of tread separation 120° apart on IB shoulder on 18th cycle. |
| Number of Cycles | 100 | 100 | |
| FINAL RESULTS: Tire successfully completed 200 cycles in accordance with procedures outlined in MIL-SPEC MIL-T-5041D. Total milage of 194.8 miles was accumulated on the tire. | | | c. Tread chunking at completion of test: 120° apart on IB shoulder, 16 in. x 2 in. x ¼ in., 19 in. x 2 in. x ¼ in., 17 in. x 2 in. x ¼ in. 120° apart on OB shoulder: 8 in. x ¼ in. x ¼ in., 21 in. x ¼ in. x ¼ in. |

TABLE XIX

SUMMARY OF DYNAMIC CONDITIONS AND RESULTS
ON 23.00-20 EXPANDABLE TIRE, NUMBER L-6

Size 23.00-20 Tubeless Expandable Tire, with Sidewall Convolutions

Ply Rating 16    Type III    Tire Weight 180 Lbs.

Test Date 9 June 1966 - 28 June 1966

DIMENSIONS

| Condition | Inflated Dimensions at 90-PSI Inflated Pressure: Max. Outside Diameter (Inches) | Max. Cross Section (Inches) | Folded Dimensions: Outside Diameter (Inches) Outboard Tread | Center Tread | Inboard Tread | C.S. Above Convoluted Fold (Inches) |
|---|---|---|---|---|---|---|
| After 12-Hour Minimum Stretch | 59.44 | 20.88 | | | | |
| After Break-In | 59.50 | 20.75 | 39.81 | 39.39 | 39.78 | |
| After 10 TTO & 5 LT Cycles | 60.00- | 21.00 | 40.56 | 39.81 | 40.44 | |
| After 50 TTO & 45 LT Cycles | 60.17 | 21.00 | 40.98 | 40.36 | 40.97 | 14.89 |
| After 60 TTO & 45 LT Cycles | 60.58 | 21.28 | 41.05 | 40.38 | 41.13 | |
| After 75 TTO, 75 LT, and 1 RTO cycles | 60.63 | 21.22 | 41.38 | 40.42 | 41.36 | 14.94 |
| After 80 TTO, 100 LT, and 1 RTO Cycles | 60.62 | 21.86 | 41.97 | 41.16 | 42.00 | 15.14 |

NOTE: Dimensions taken between cycles with limited cool-down time.

BREAK-IN

Flywheel O.D. 120 Inches    Distance 2 Miles    Speed 40 MPH

Tire Load (Constant) 31,000 Lbs    Inflation Pressure 80 PSI

TABLE XIX (Continued)

| | |
|---|---|
| **TAXI TAKEOFF** | |
| Flywheel O.D. ...... In. | 120 |
| Test Inflation ..... PSI | 90 |
| Taxi Speed ......... MPH | 40 |
| Max. Load .......... Lbs | 31,000 |
| Takeoff Distance ... Ft. | 11,250 |
| Number of Cycles ... | 80 |
| **LANDING TAXI** | |
| Flywheel O.D. ...... In. | 120 |
| Test Inflation ..... PSI | 80 |
| Taxi Speed ......... MPH | 40 |
| Max. Load .......... Lbs | 26,400 |
| Landing Distance ... Ft. | 3,360 |
| Number of Cycles ... | 100 |
| **ABORTED TAKEOFF** | |
| Flywheel O.D. ...... In. | 120 |
| Test Inflation ..... PSI | 90 |
| Taxi Speed ......... MPH | 40 |
| Max. Load .......... Lbs | 30,500 |
| Aborted Takeoff Distance ......... Ft. | 18,640 |
| Number of Cycles ... | 1 |

REMARKS: This tire successfully completed 80 taxi takeoff and 100 landing taxi cycles and one aborted takeoff cycle. These simulated conditions were derived from estimated operating characteristics of a heavy cargo type of aircraft. A total distance of 683 miles was accumulated on the tire.

REMARKS

1. See TTO profile, Fig. 42.
2. See Fig. 43 for landing taxi profile.
3. See Fig. 44 for aborted takeoff profile.
4. Inspection after 19 TTO and 10 LT cycles revealed reversion of rubber in center tread rib. Continuous for 7 inches and intermittent for 4 inches.
5. Reversion of rubber in center tread rib progressed to:
   a) 12 in. after 40 TTO and 45 LT cycles.
   b) 15 in. after 50 TTO and 45 LT cycles.
   c) 25 in. after 60 TTO and 62 LT cycles.
   d) 22 in. continuous and intermittent at 3 3/4, 4 1/2, and 2 1/2 inches at completion of dynamic runs.
6. Tread chunking occurred in center rib, 3 1/2 x 1", after 80 TTO, 100 LT, and 1 abort cycles.
7. After 75 TTO, 100 LT, and 1 aborted TO, inspection revealed cord fraying, approximately 15 inches along the circumference of the outboard shoulder.
8. At completion of test, a total radial runout of 0.150 inches was measured off the outboard tread rib. On outboard side, high spot was located 90 degrees clockwise from tread chunking location.

TABLE XX

SUMMARY OF RESULTS ON FOLDABILITY OF SIDEWALL CONVOLUTED (DESIGN II) EXPANDABLE TIRES

| Tire Size | Tire No. | Results |
|---|---|---|
| 9.50-16 | 2 | Lateral instability always occurred during inflation and deflation of tire. No tire rotation during deflation. |
| 9.50-16 | 3 | Always shifted during inflation and deflation. Failed to return to folded shape after 60 missions. Beads stayed seated. No tire rotation during deflation. |
| 9.50-16 | 6 | Always shifted, failed to return after 110 camber and 10 taxi takeoff cycles. No tire rotation during deflation. |
| 9.50-16 | 8 | Always shifted but returned to its folded shape. No tire rotation during deflation. |
| 23.00-20 | L-2 | Failed to return to folded shape after fifth taxi takeoff cycle. Tire was not rotating during the folding procedure. |
| 23.00-20 | L-3 | Failed to return after sixth low speed MIL-T-5041D landing cycle, under nonrotational conditions. Excellent symmetry during folding procedure when tire was rotating at low (30 MPH) peripheral speeds. |
| 23.00-20 | L-6 | Shifting occurred during deflation with a nonrotating tire from the onset. While rotating, tire displayed excellent symmetry for 75 deflations before shifting occurred. |

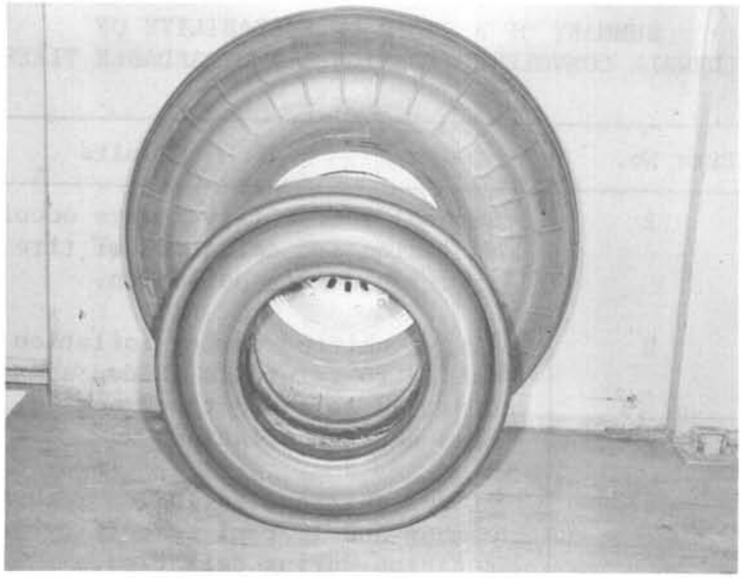
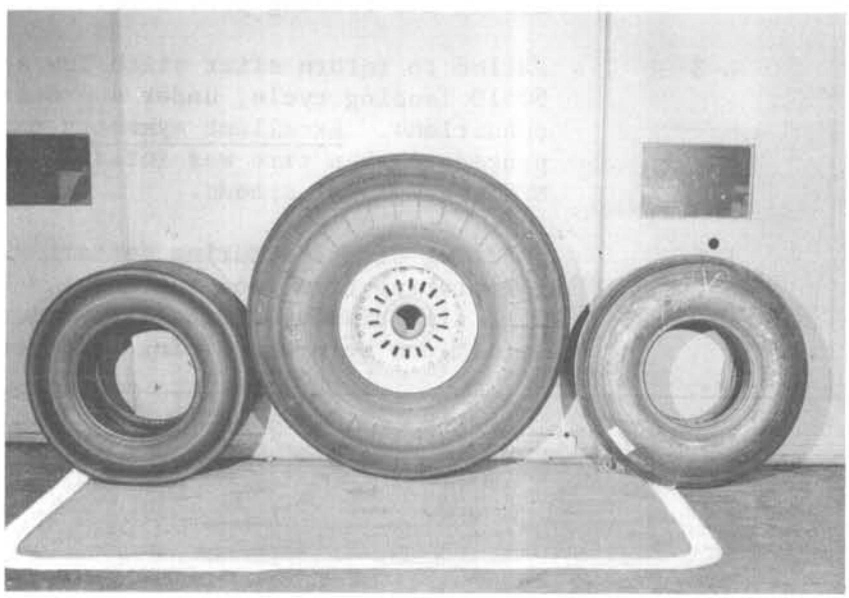


FIGURE 1. Comparison of 23.00-20 Expandable Tire in Folded (Deflated) Shape, Foreground; and in Fully Expanded Shape, Background



(a) (b) (c)

FIGURE 2. Comparison of Tires with Identical Rim Dimensions: (a) 23.00-20 Expandable Tire in Folded Shape, (b) 23.00-20 Expandable Tire Inflated, and (c) Standard AF Stock Tire, Size 44 x 16

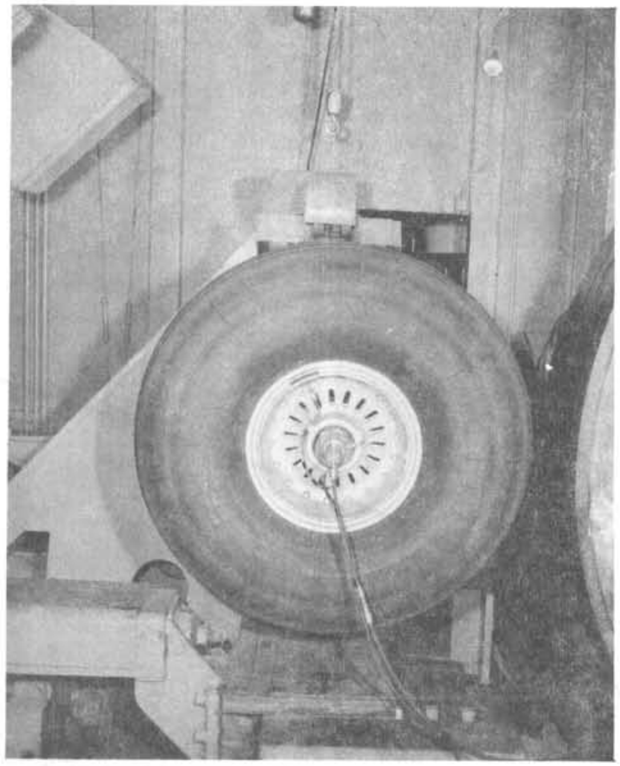


FIGURE 3. The Sidewall convoluted 23.00-20 Expandable Tire Mounted on the Carriage of the High Speed 120-Inch Dynamometer

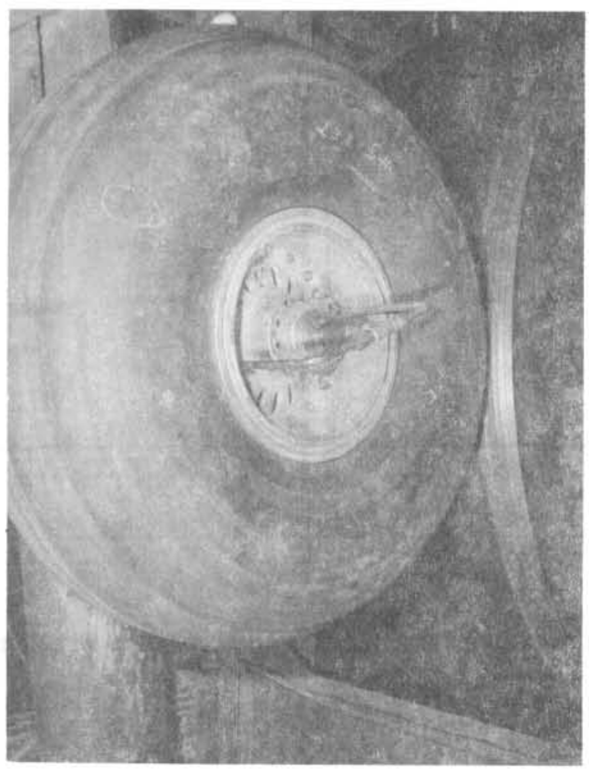


FIGURE 4. The Tread Convoluted 23.00-20 Expandable Tire Mounted on the Carriage of the Variable Inertia 120 inch Dynamometer

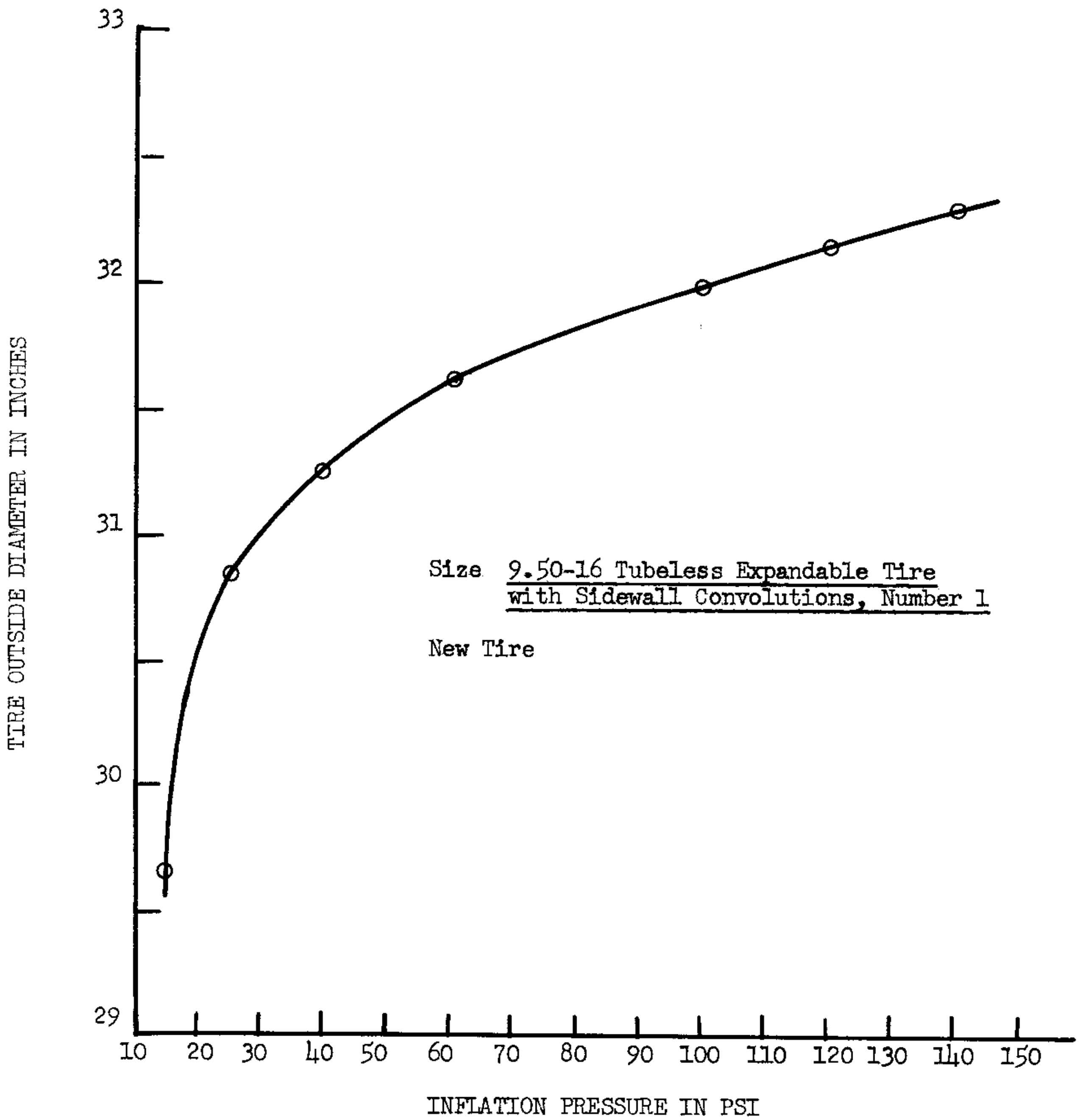



FIGURE 5. Dimensional Growth Due to Inflation Pressure Increase for a 9.50-16 Expandable Tire, Number 1

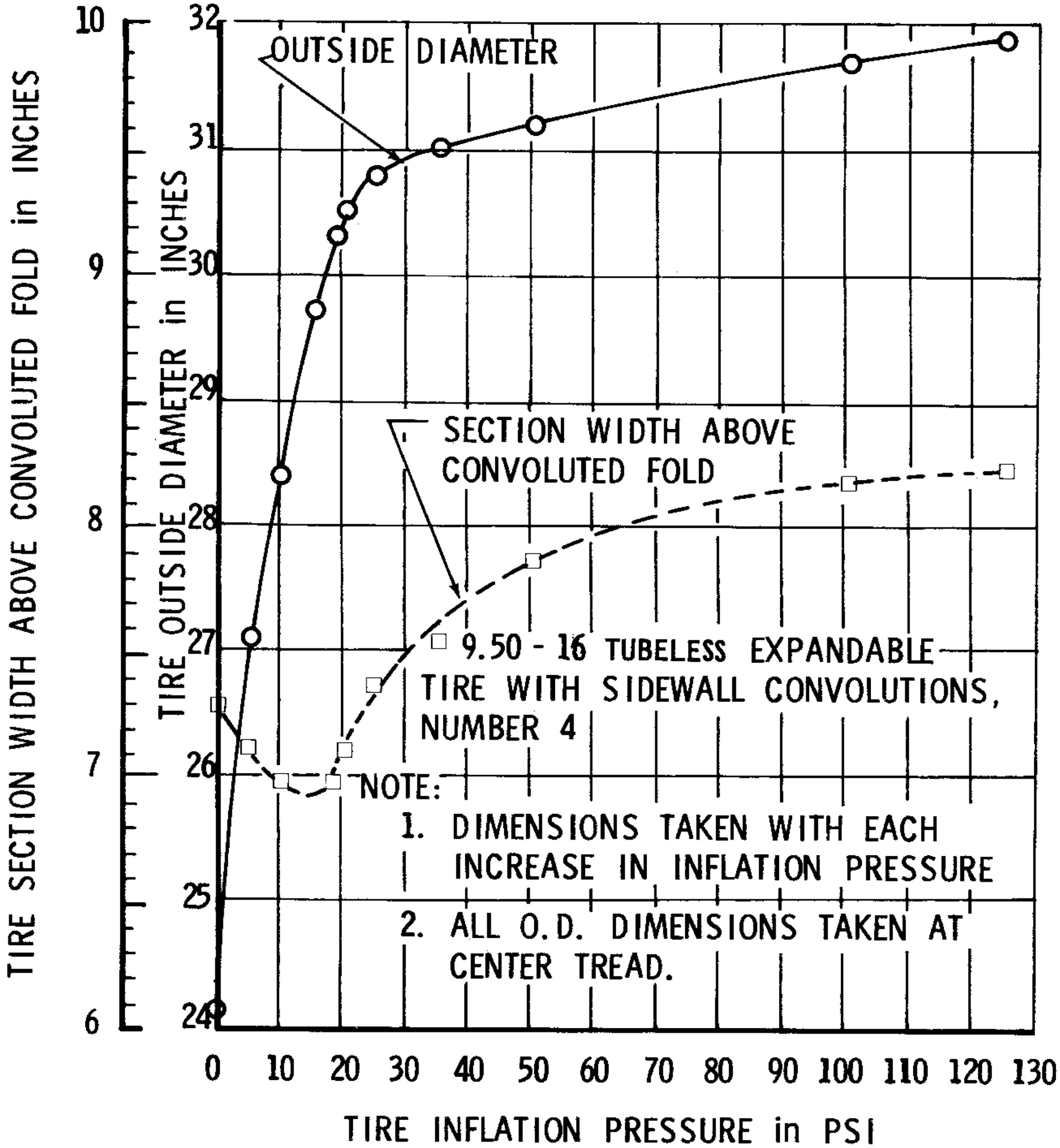



FIGURE 6. Dimensional Growth Due to Inflation Pressure Increase for 9.50-16 Expandable Tire Number 4

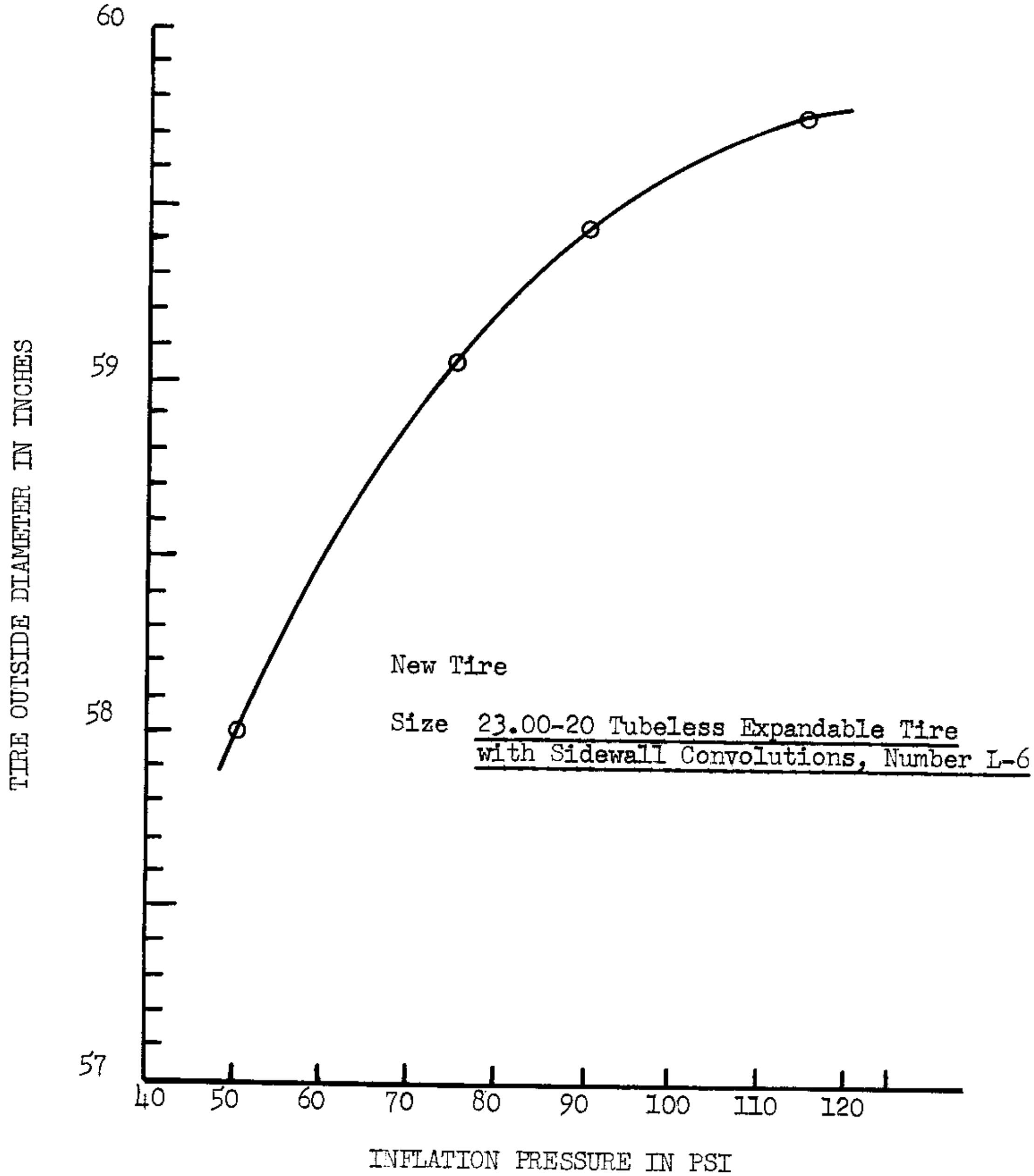



FIGURE 7. Dimensional Growth Due to Inflation Pressure Increase for 23.00-20 Expandable Tire Number L-6

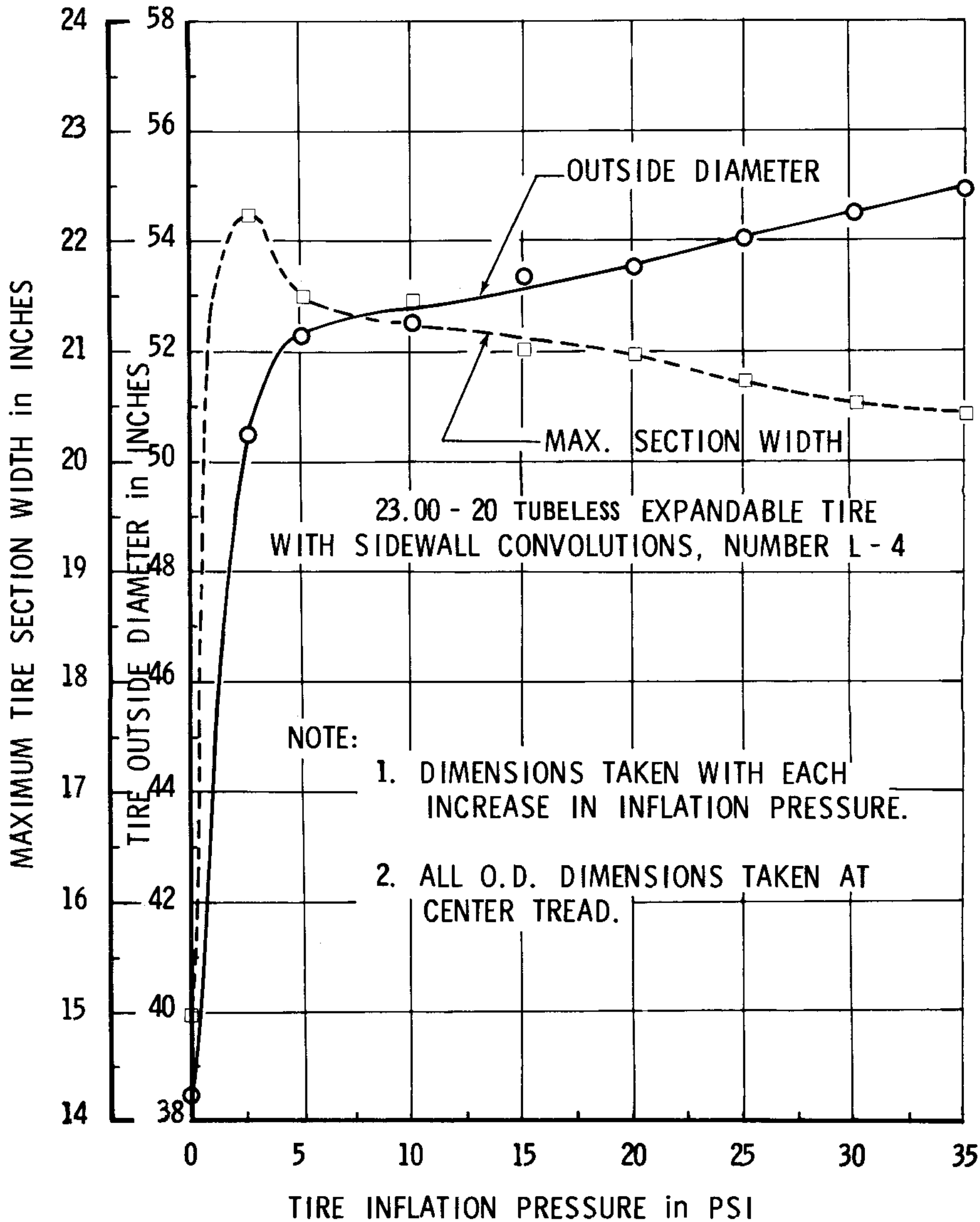



FIGURE 8. Dimensional Growth Due to Inflation Pressure Increase for 23.00-20 Expandable Tire Number L-4

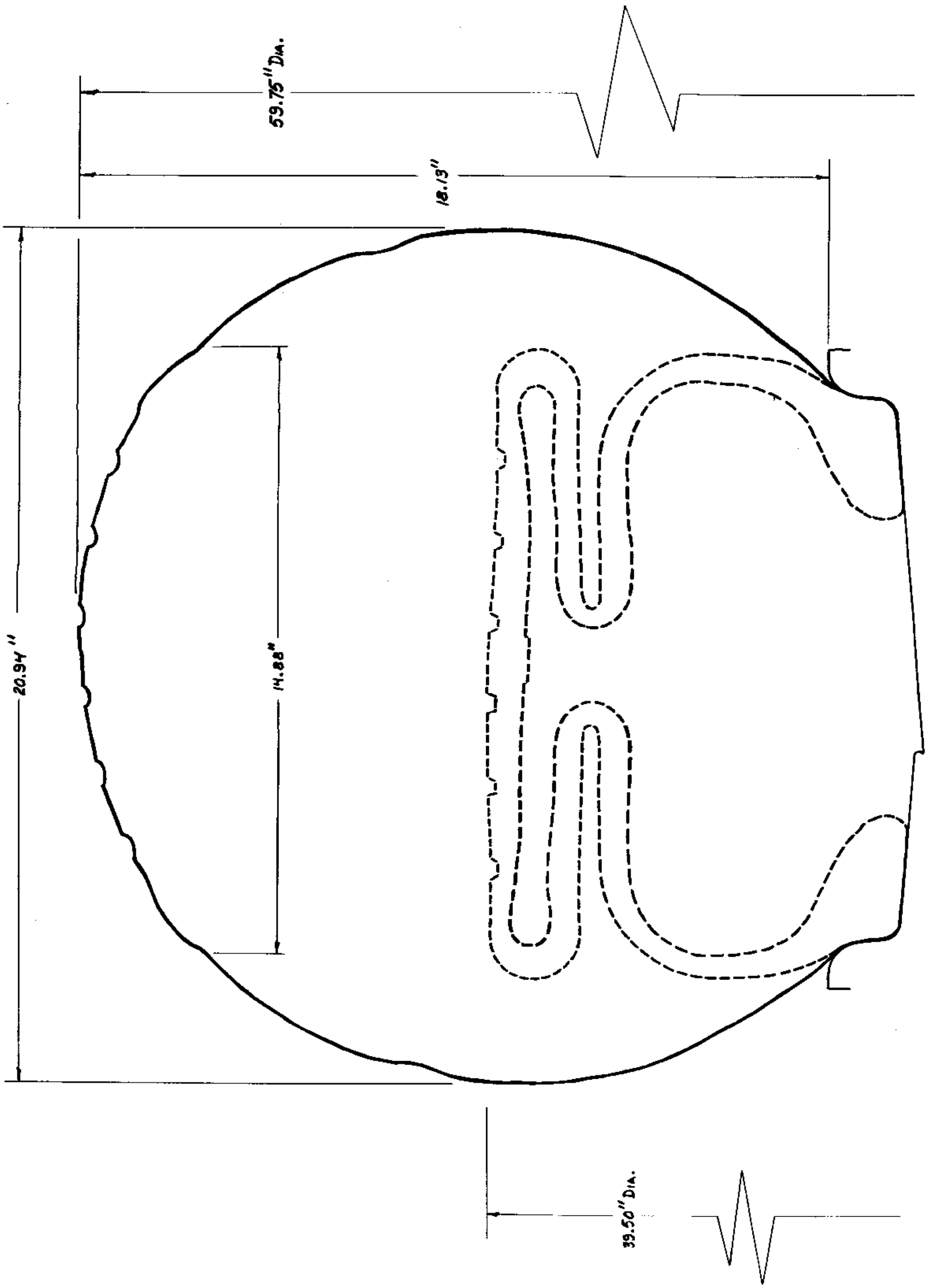



FIGURE 9. Section Profile of 23.00-20/16 PR Tubeless Expandable Tire at 115 PSI Inflation Pressure. New Tire. Number L-6

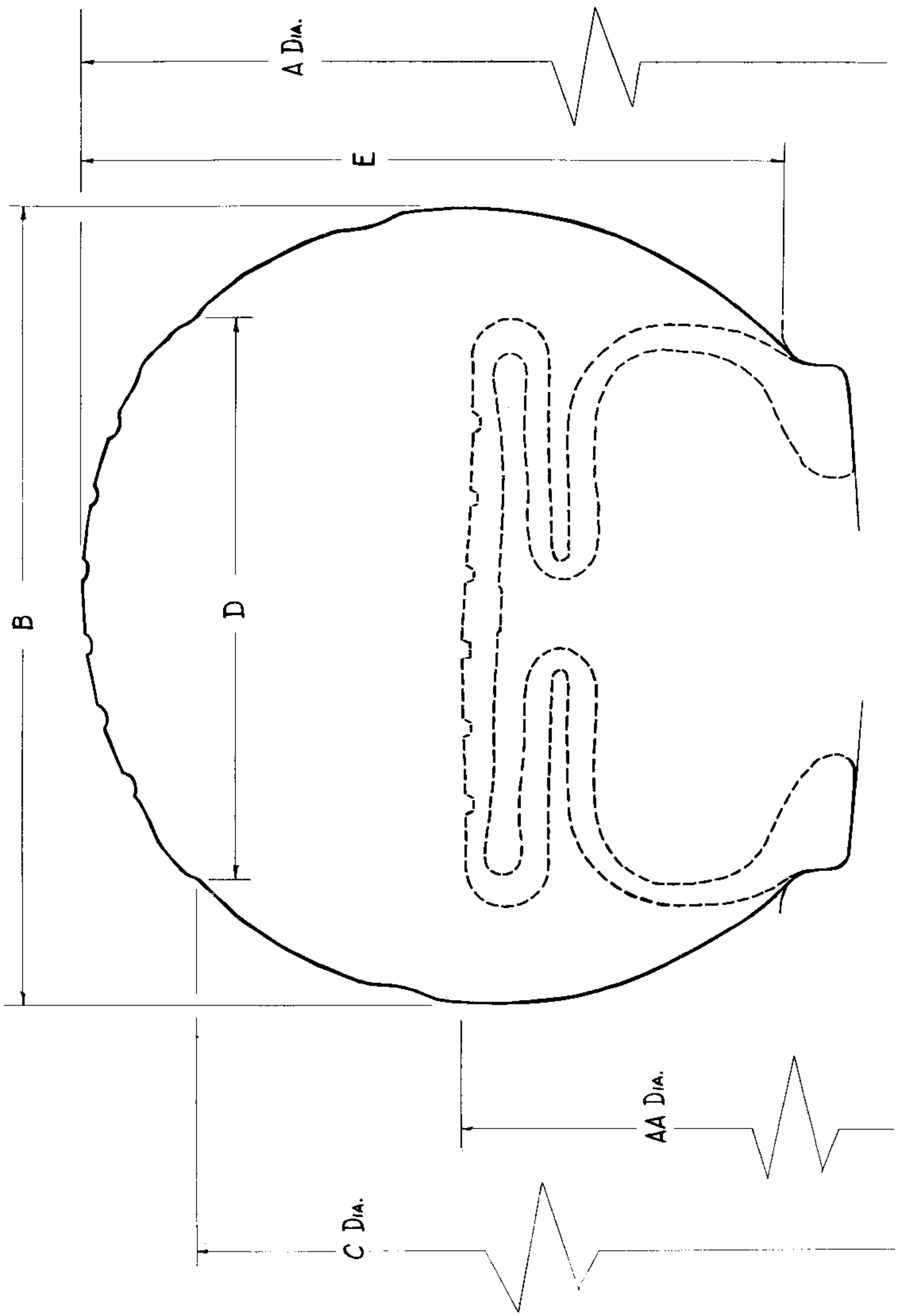
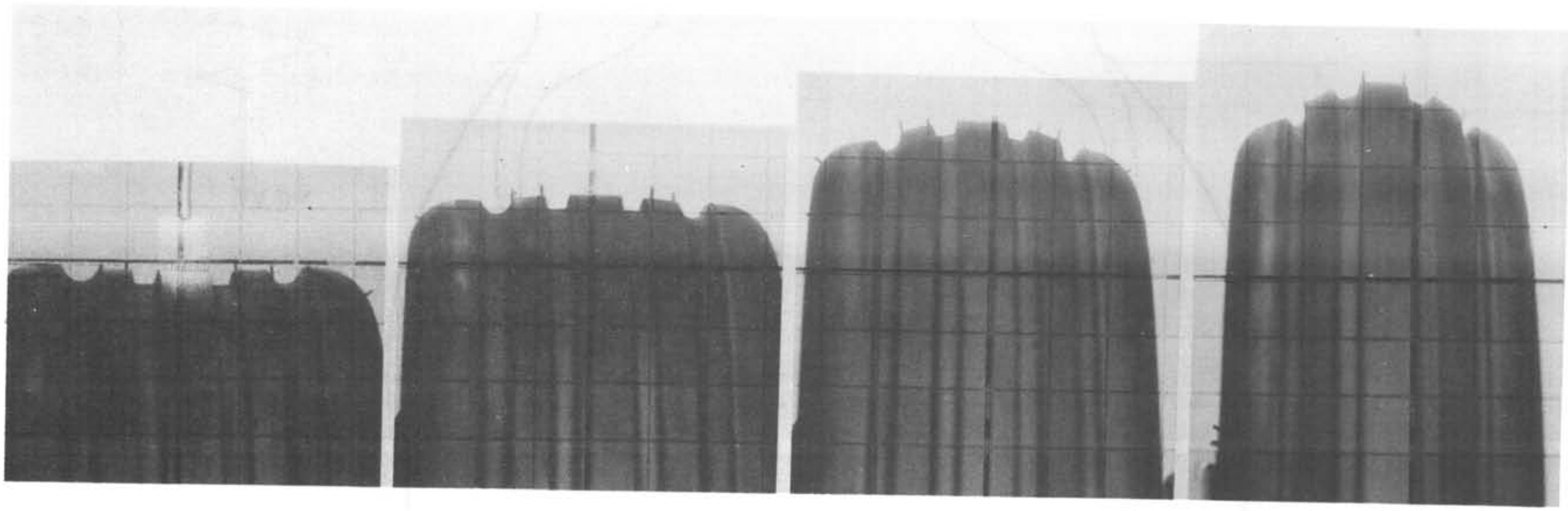



FIGURE 10. 23.00-20/16 PR Tubeless Expandable Tire Section Profile



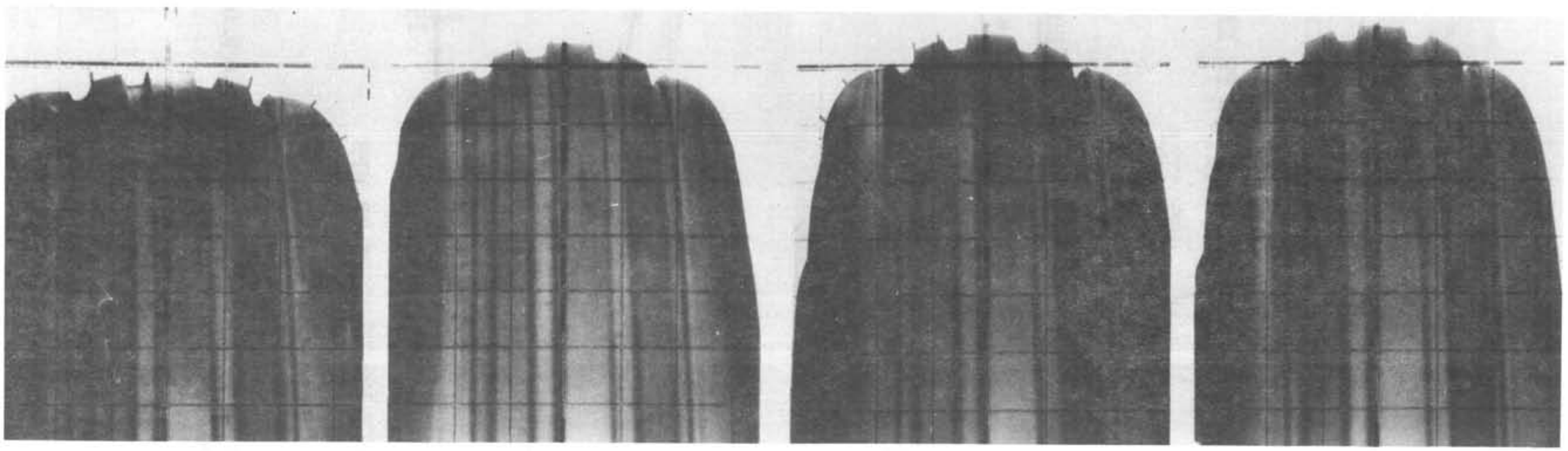
(a) Static Condition.

(b) 75 MPH Peripheral Speed Condition.

(c) 100 MPH Peripheral Speed Condition.

(d) 125 MPH Peripheral Speed Condition.

FIGURE 11. Centrifugal Growth Profile of the 9.50-16/12 PR Tubeless Expandable Tire, Number 2. Non-Inflated



(a) Static Condition. (b) 100 MPH Peripheral Speed Condition. (c) 150 MPH Peripheral Speed Condition. (d) 135 MPH Peripheral Speed Condition.

FIGURE 12. Centrifugal Growth Profile of the 9.50-16/12 PR Tubeless Expandable Tire at 50 PSI Inflation Pressure. Tire Number 2

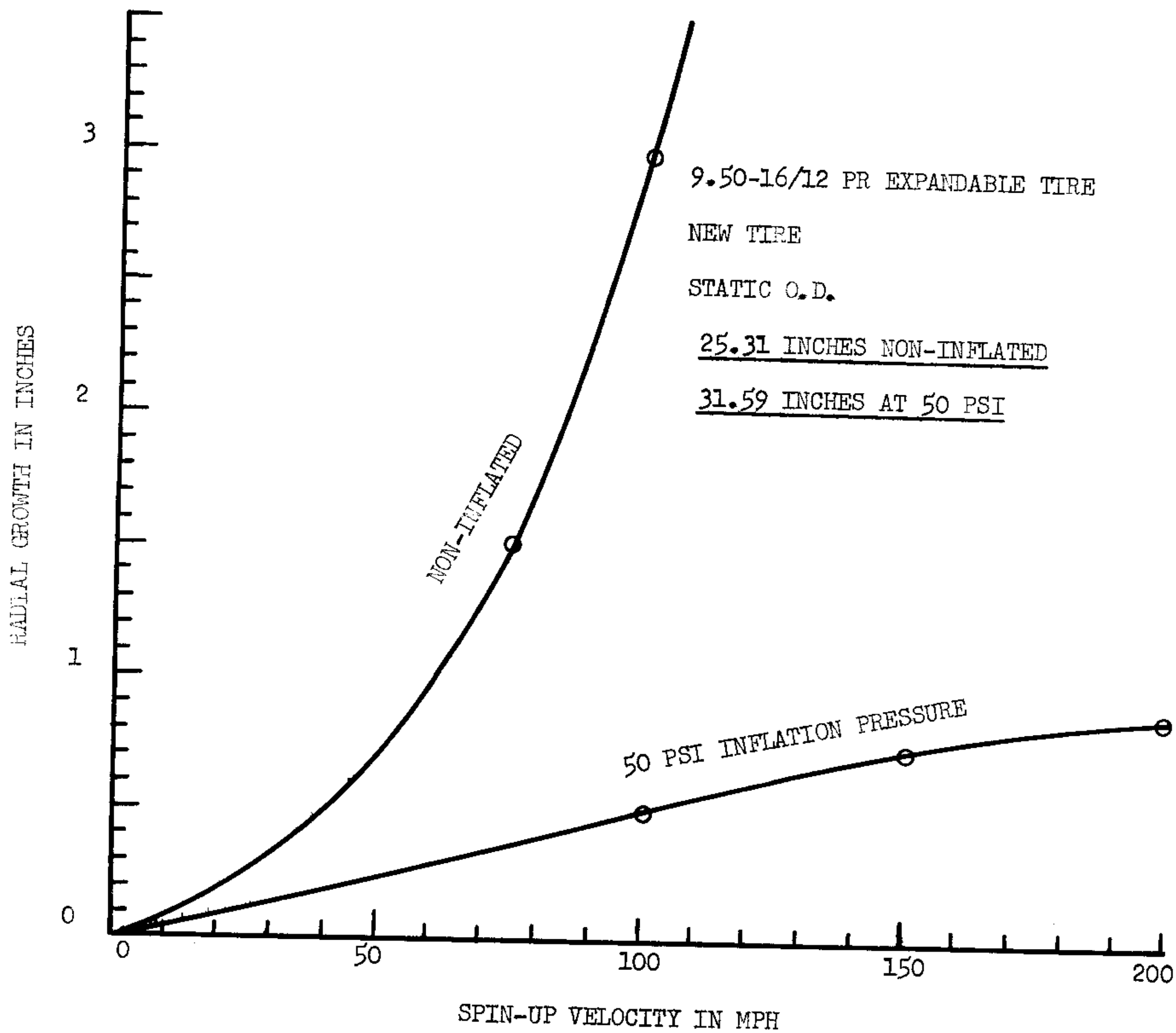
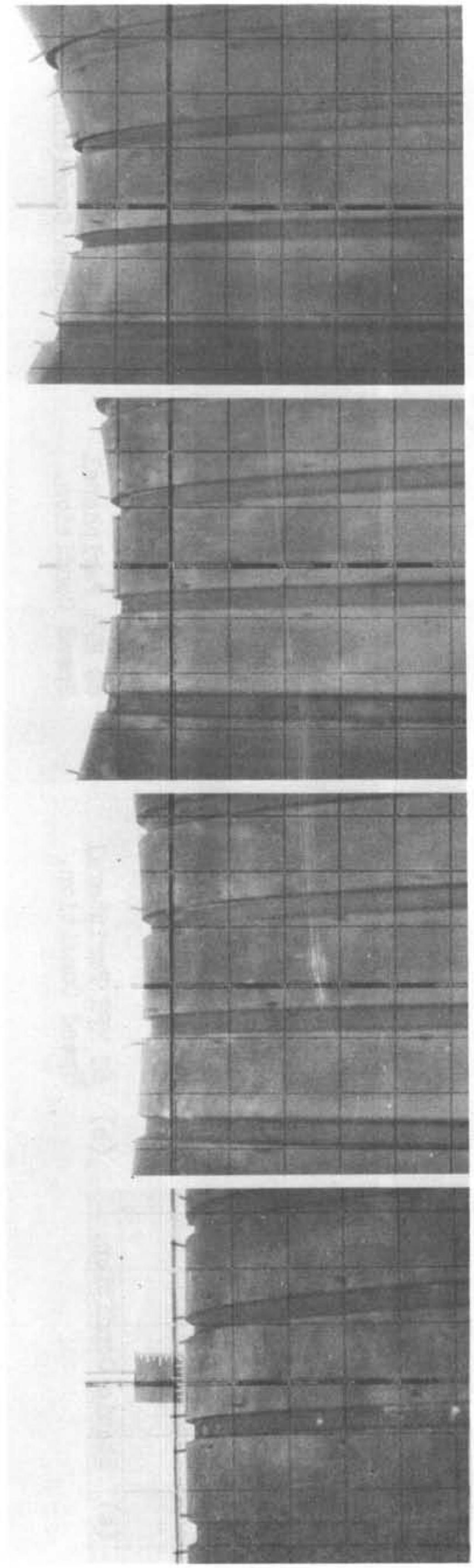



FIGURE 13. Centrifugal Tire Growth Characteristics for a 9.50-16/12 PR Tubeless Expandable Tire, Number 2



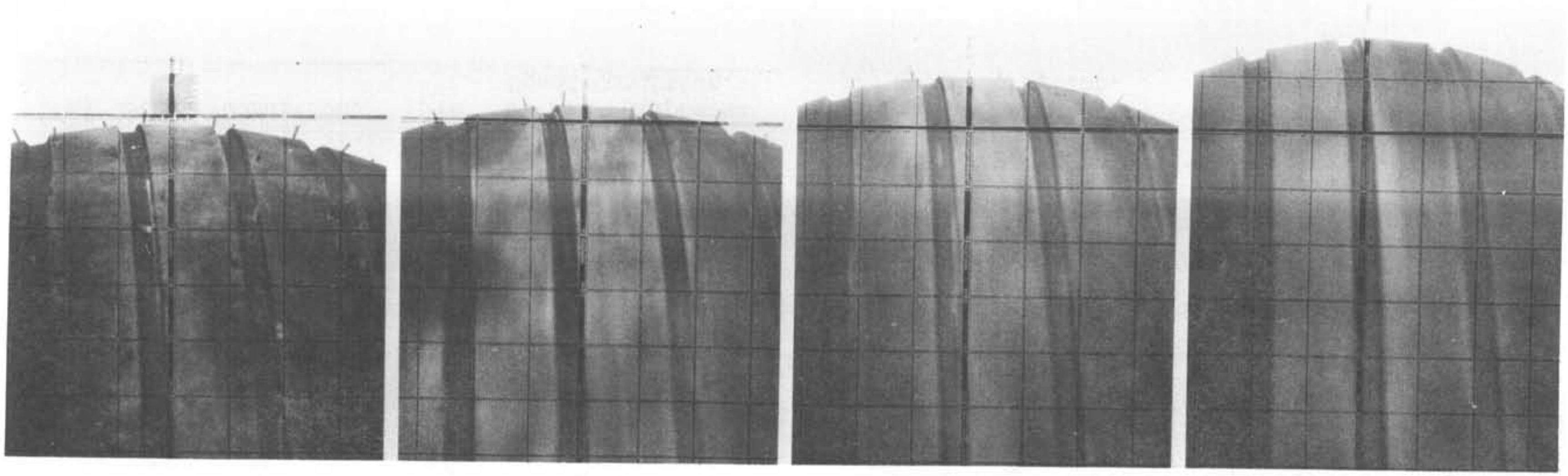
(a) Static Condition.

(b) 40 MPH Peripheral Speed Condition.

(c) 50 MPH Peripheral Speed Condition.

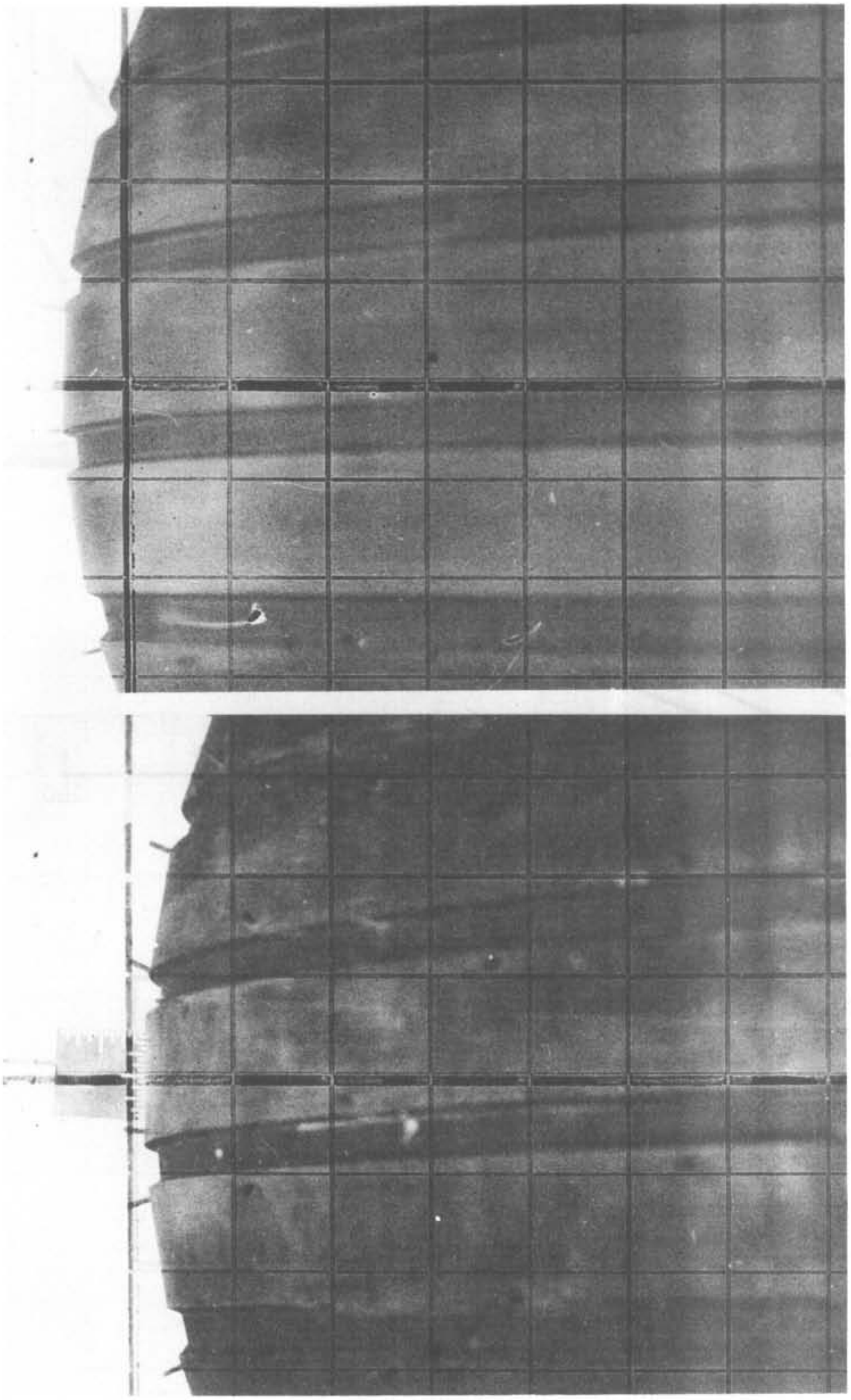
(d) 60 MPH Peripheral Speed Condition.

FIGURE 14. Centrifugal Growth Profile of the 23.00-20/16 PR Tubeless Expandable Tire, Non-Inflated. Tire Number L-6



(a) Static Condition. (b) 60 MPH Peripheral Speed Condition. (c) 80 MPH Peripheral Speed Condition. (d) 135 MPH Peripheral Speed Condition.

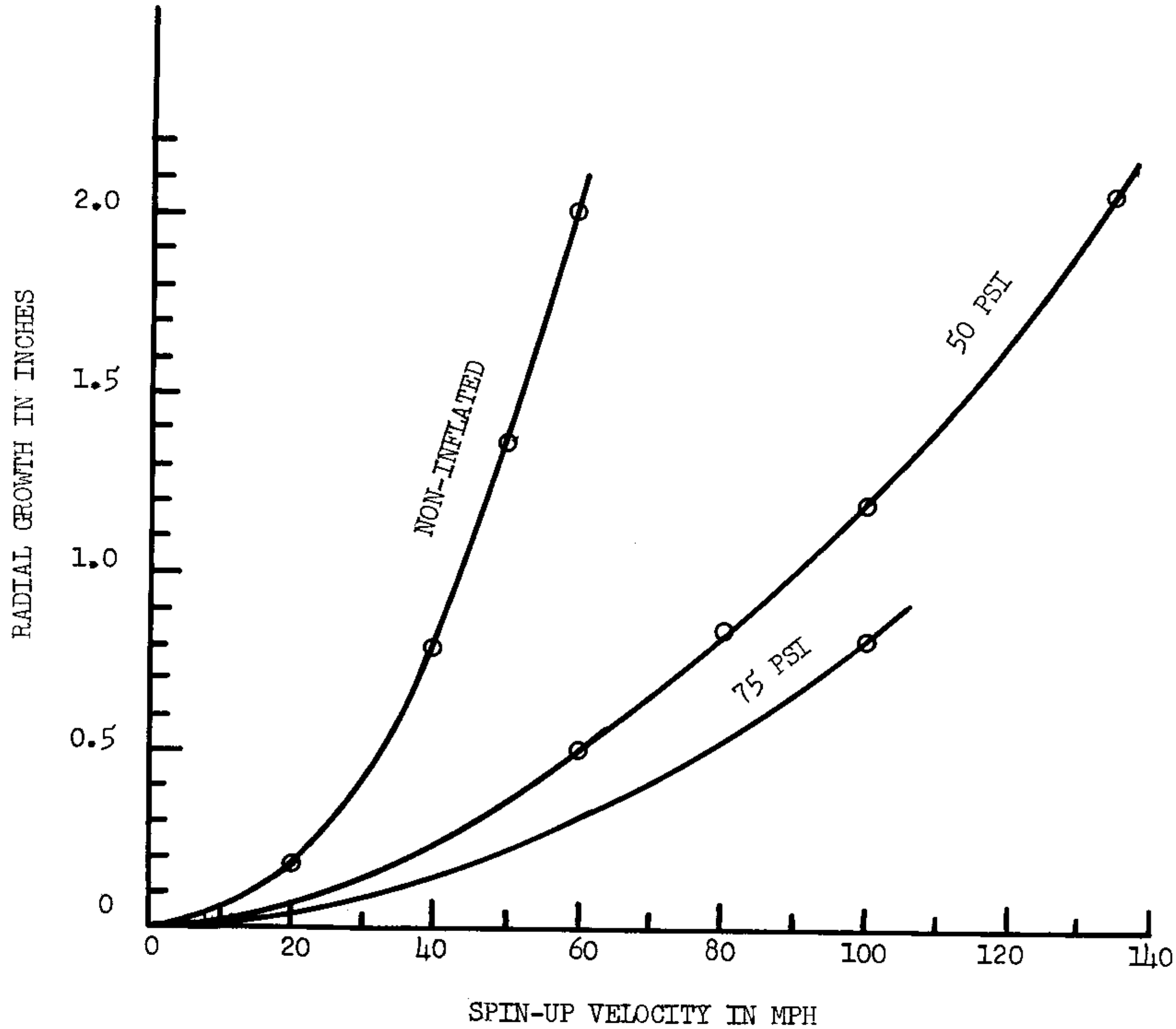
FIGURE 15. Centrifugal Growth Profile of the 23.00-20/16 PR Tubeless Expandable Tire at 50 PSI Inflation Pressure. Tire Number L-6



(a) Static Condition.

(b) 100 MPH Peripheral Speed Condition

FIGURE 16. Centrifugal Growth Profile of the 23.00-20/16 PR Tubeless Expandable Tire at 75 PSI Inflation Pressure. Tire Number L-6




(a) Radial Growth vs. Spin-up Velocity

| Tire Inflation Pressure (PSI) | Static O.D. (Inches) | Remarks |
|---|---|---|
| Non-Inflated | 39.50 | O. D. dimensions taken at center of tread. |
| 50 | 58.00 | |
| 75 | 59.06 | |

(b) Initial Outside Diameter Dimensions

FIGURE 17. Centrifugal Tire Growth Characteristics for a 23.00-20 Tubeless Expandable Tire, Number L-6

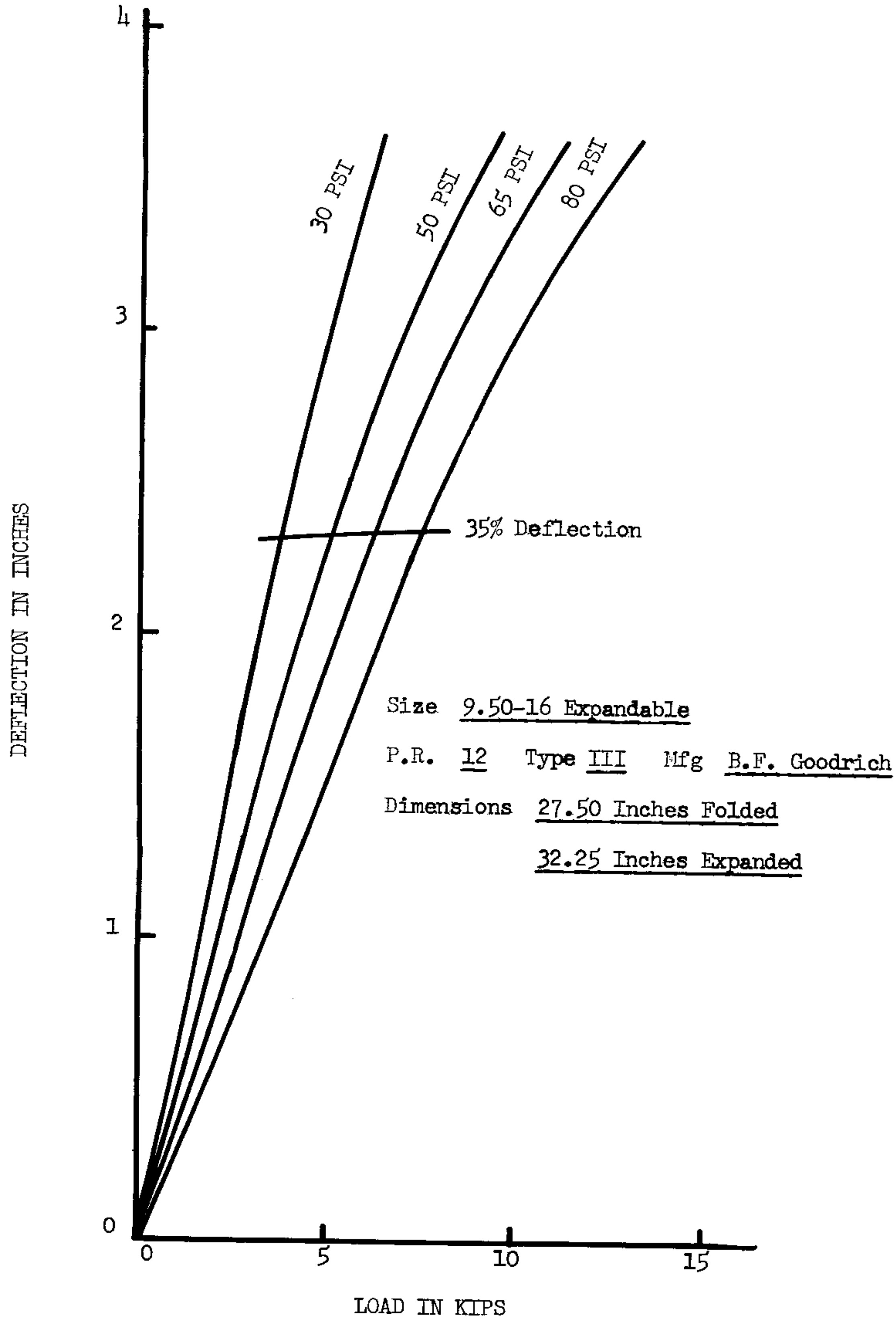



FIGURE 18. Load-Deflection Curve for 9.50-16 Expandable Tire, Number 1

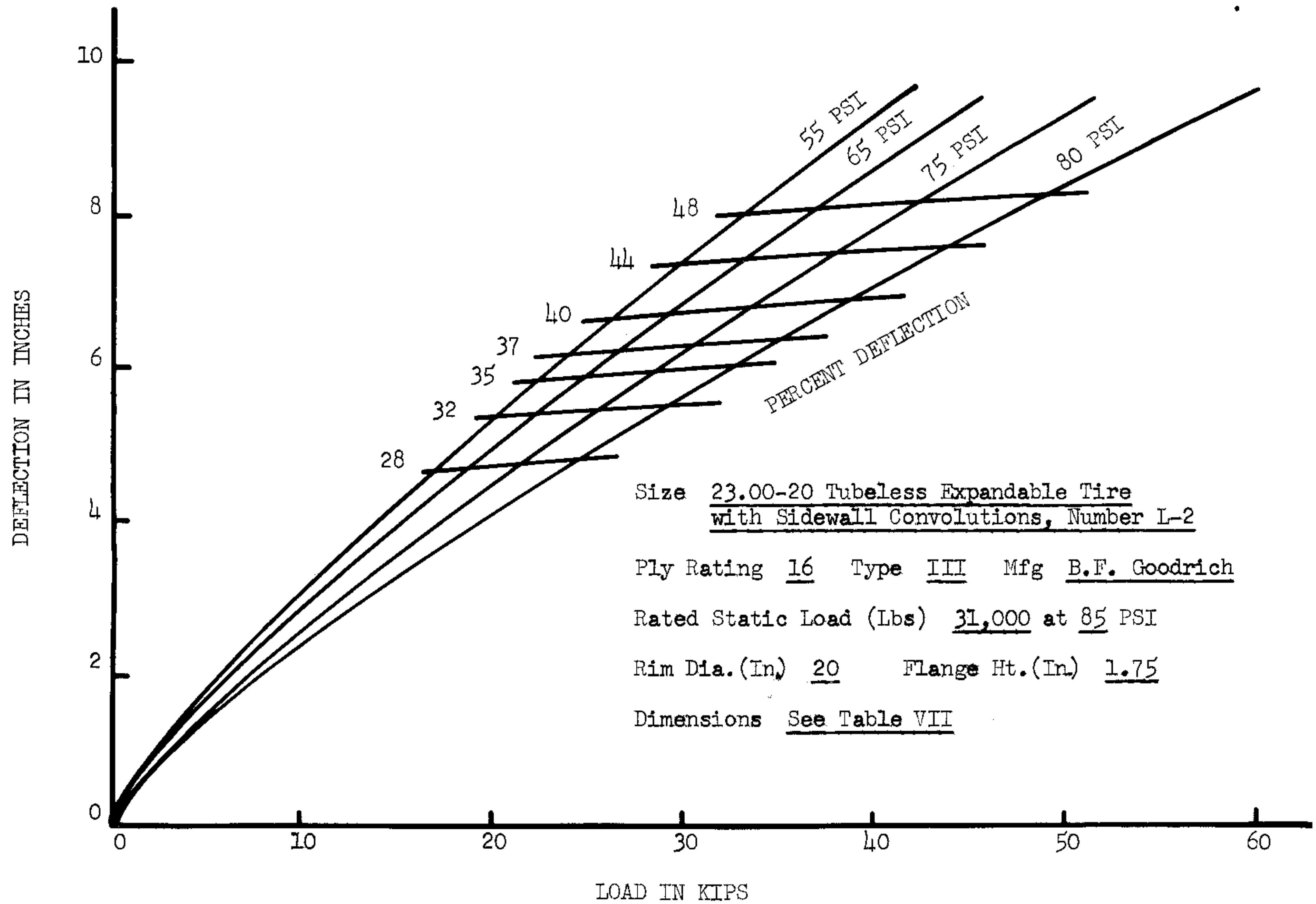



FIGURE 19. Load-Deflection Curves for 23.00-20 Expandable Tire, Number L-2

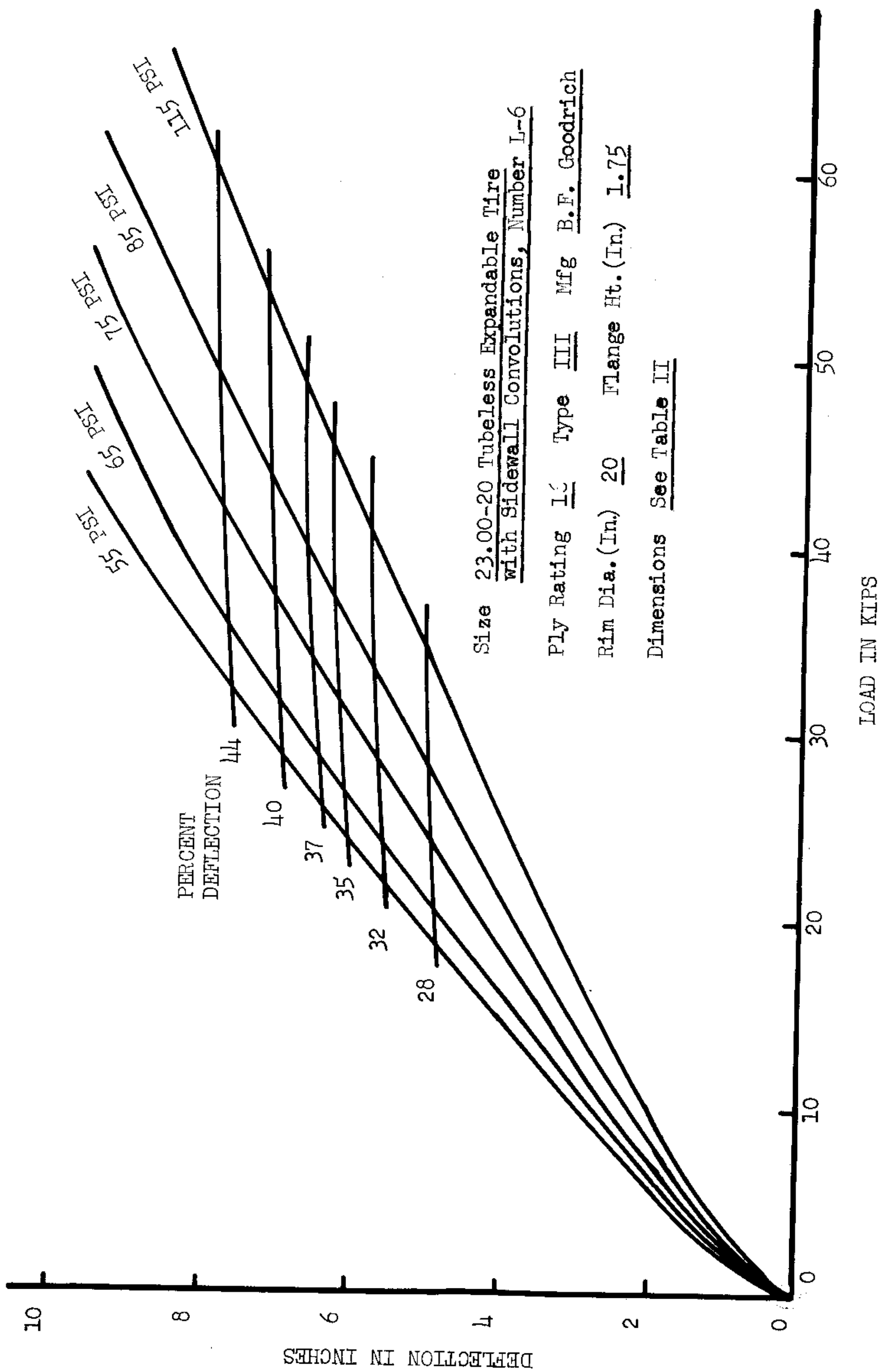



FIGURE 20. Load-Deflection Curves for 23.00-20 Expandable Tire, Number L-6

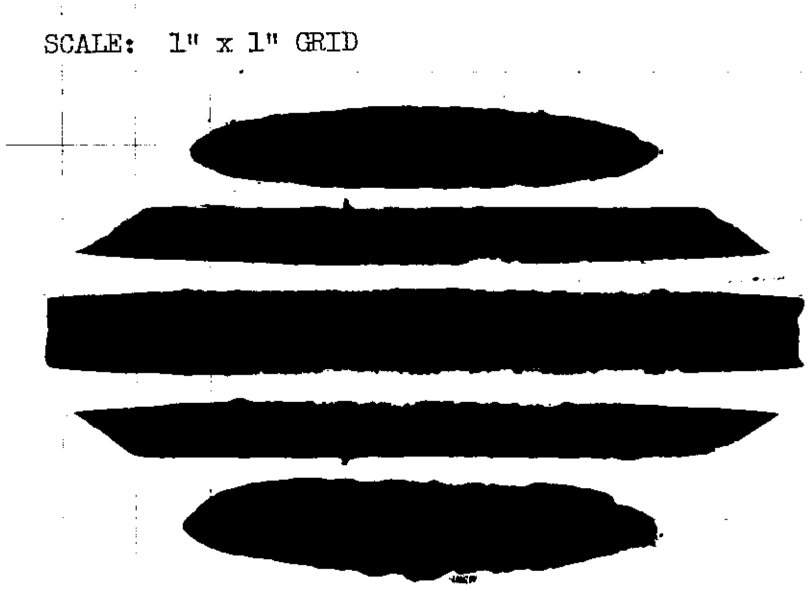



FIGURE 21. 9.50-16 Expandable Tire Contact Area Print at 140 PSI Inflation Pressure and 5,000 Pound Load. New Tire. 50.7 Square Inches Gross Contact Area

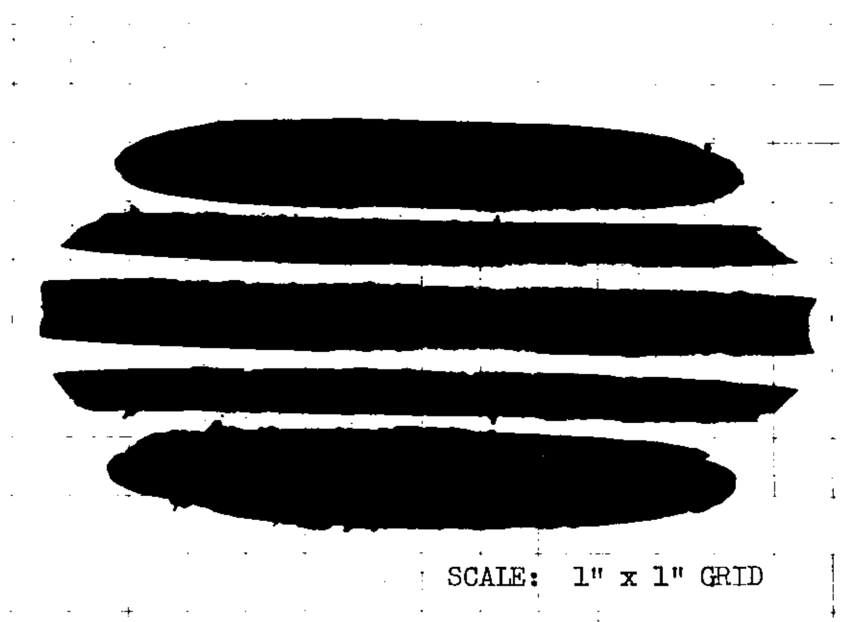



FIGURE 22. 9.50-16 Expandable Tire Contact Area Print at 140 PSI Inflation Pressure and 10,000 Pound Load. New Tire. 90.5 Square Inches Gross Contact Area

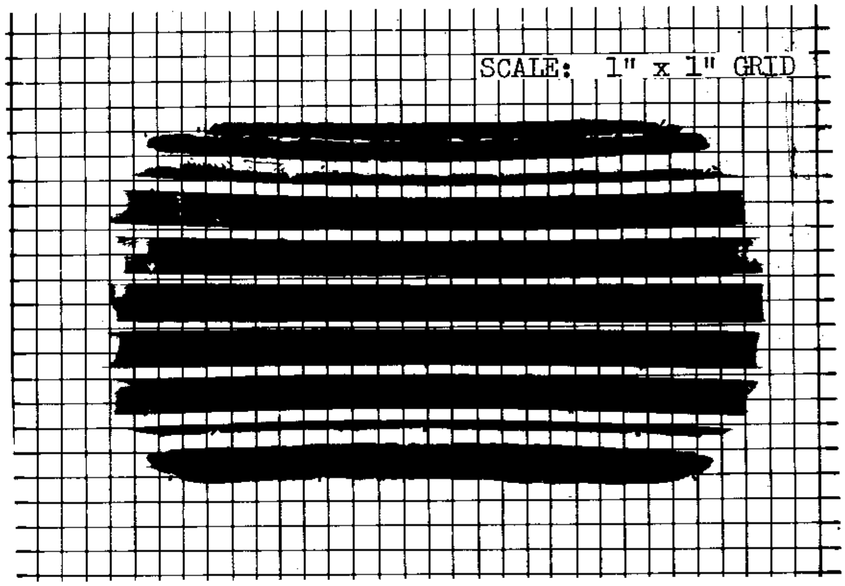



FIGURE 23. 23.00-20/16 PR Expandable Tire Contact Area Print at 34.7% Deflection on Flat Surface. 20,500 Pound Load at 50 PSI. New Tire. 370.5 Square Inches Gross Contact Area

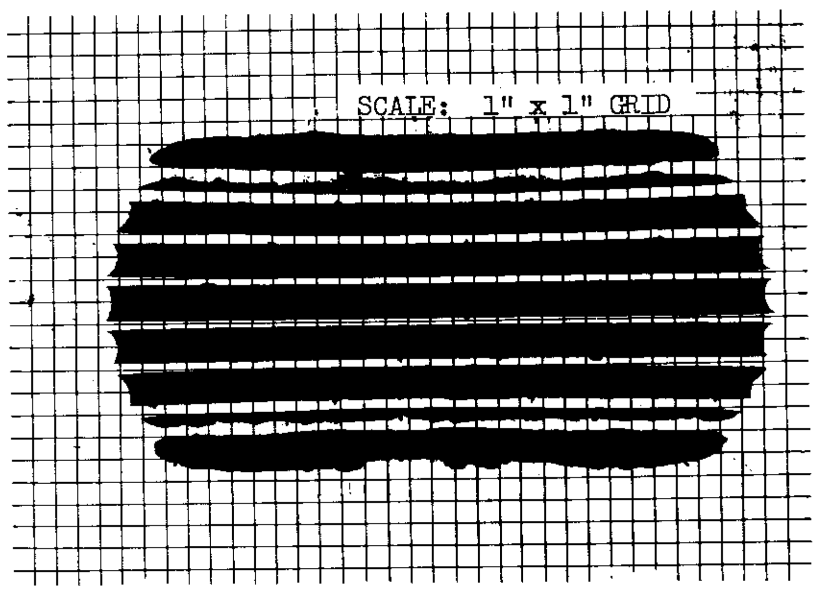



Figure 24. 23.00-20/16 PR Expandable Tire Contact Area Print at 39.6% Deflection on Flat Surface. 24,000 Pound Load at 50 PSI. New Tire. 416.0 Square Inches Gross Contact Area

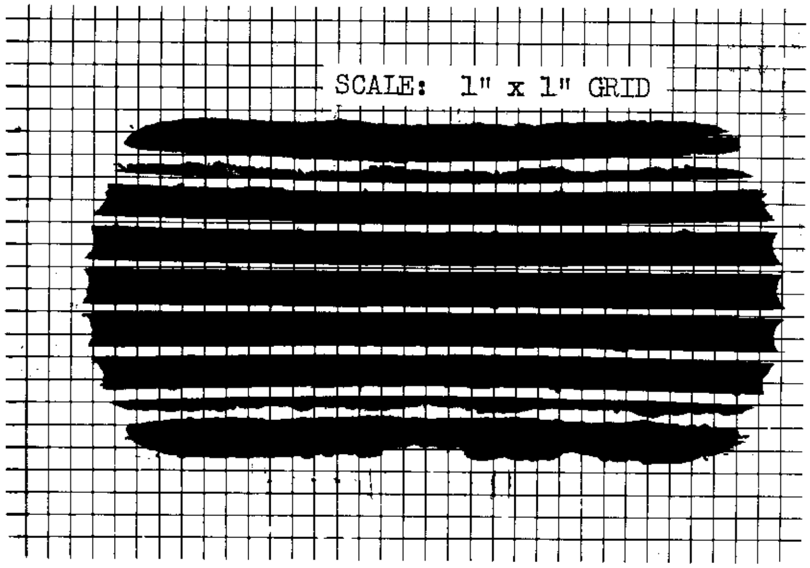



FIGURE 25. 23.00-20/16 PR Expandable Tire Contact Area Print at 43.5% Deflection on Flat Surface. 27,000 Pound Load at 50 PSI. New Tire. 445.1 Square Inches Gross Contact Area

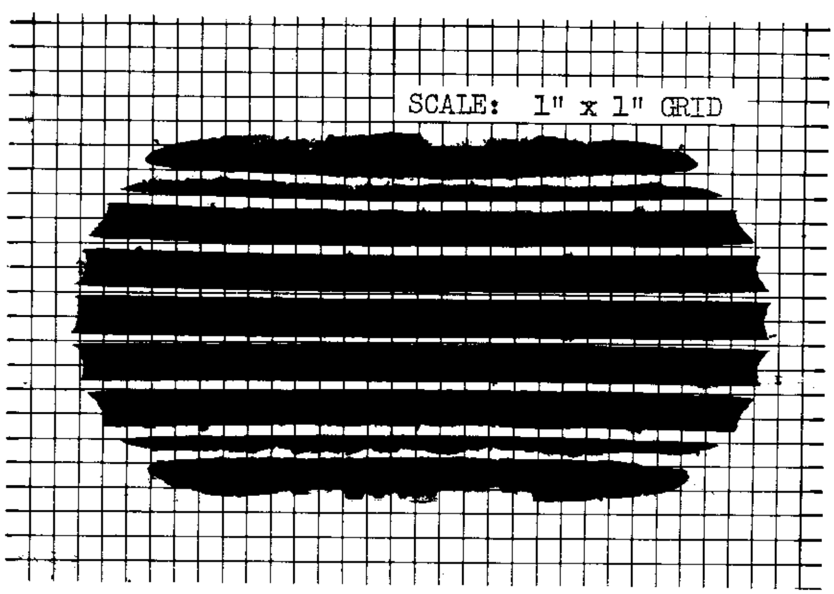



FIGURE 26. 23.00-20/16 PR Expandable Tire Contact Area Print at 34.8% Deflection on Flat Surface. 31,000 Pound Load at 75 PSI. New Tire. 380.3 Square Inches Gross Contact Area

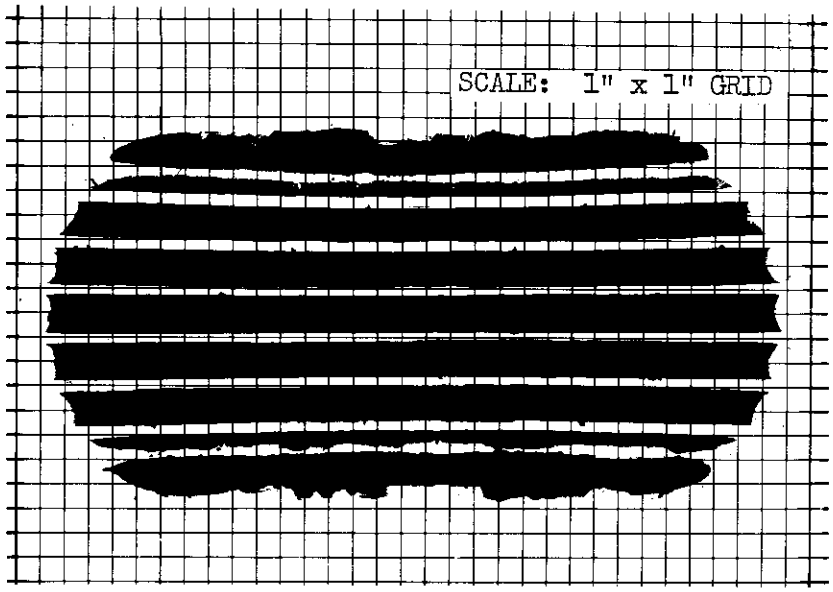



FIGURE 27. 23.00-20/16 PR Expandable Tire Contact Area Print at 38.8% Deflection on Flat Surface. 35,600 Pound Load at 75 PSI. New Tire. 418.3 Square Inches Gross Contact Area

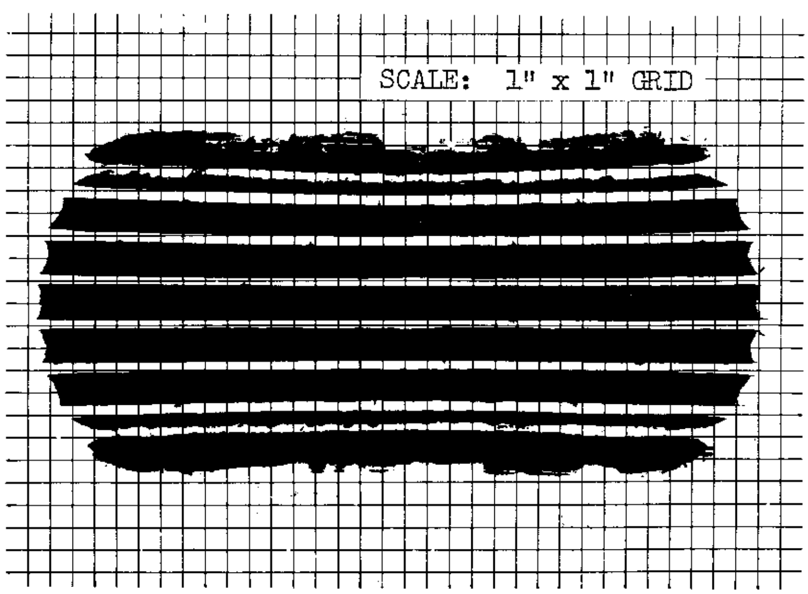



FIGURE 28. 23.00-20/16 PR Expandable Tire Contact Area Print at 43.8% Deflection on Flat Surface. 41,400 Pound Load at 75 PSI. New Tire. 456.9 Square Inches Gross Contact Area

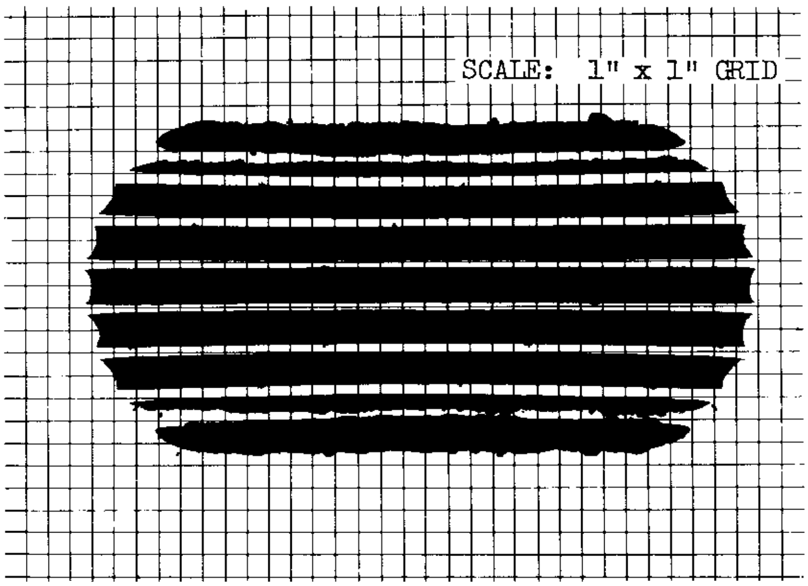



FIGURE 29. 23.00-20/16 PR Expandable Tire Contact Area Print at 35.6% Deflection on Flat Surface. 39.600 Pound Load at 90 PSI. New Tire. 406.4 Square Inches Gross Contact Area

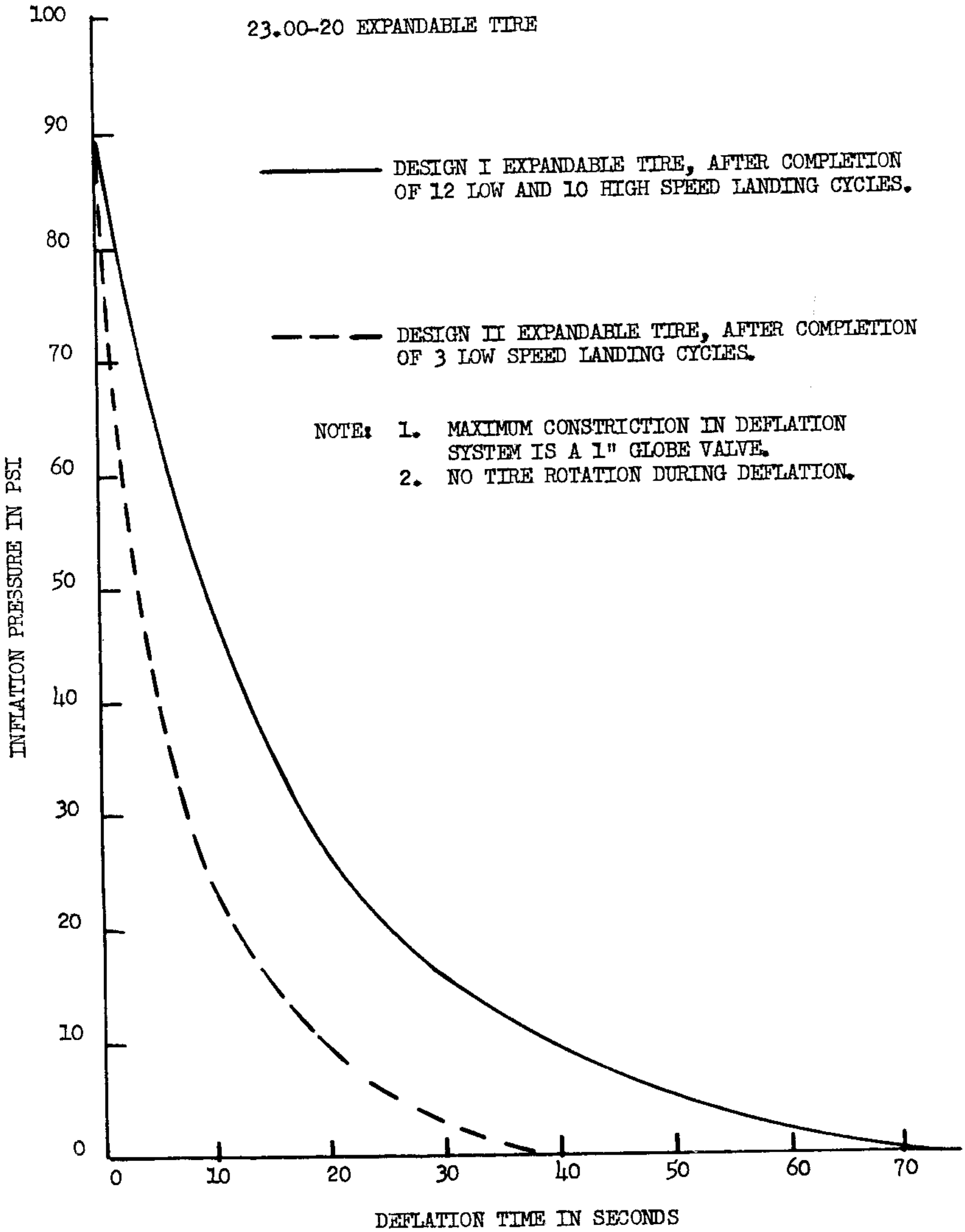



FIGURE 30. Contained-Air Pressure Changes During Deflation of a Design I and Design II, 23.00-20 Expandable Tire

FIGURE 31. 23.00-20 Expandable Tire, Number L-1, After Hydrostatic Burst

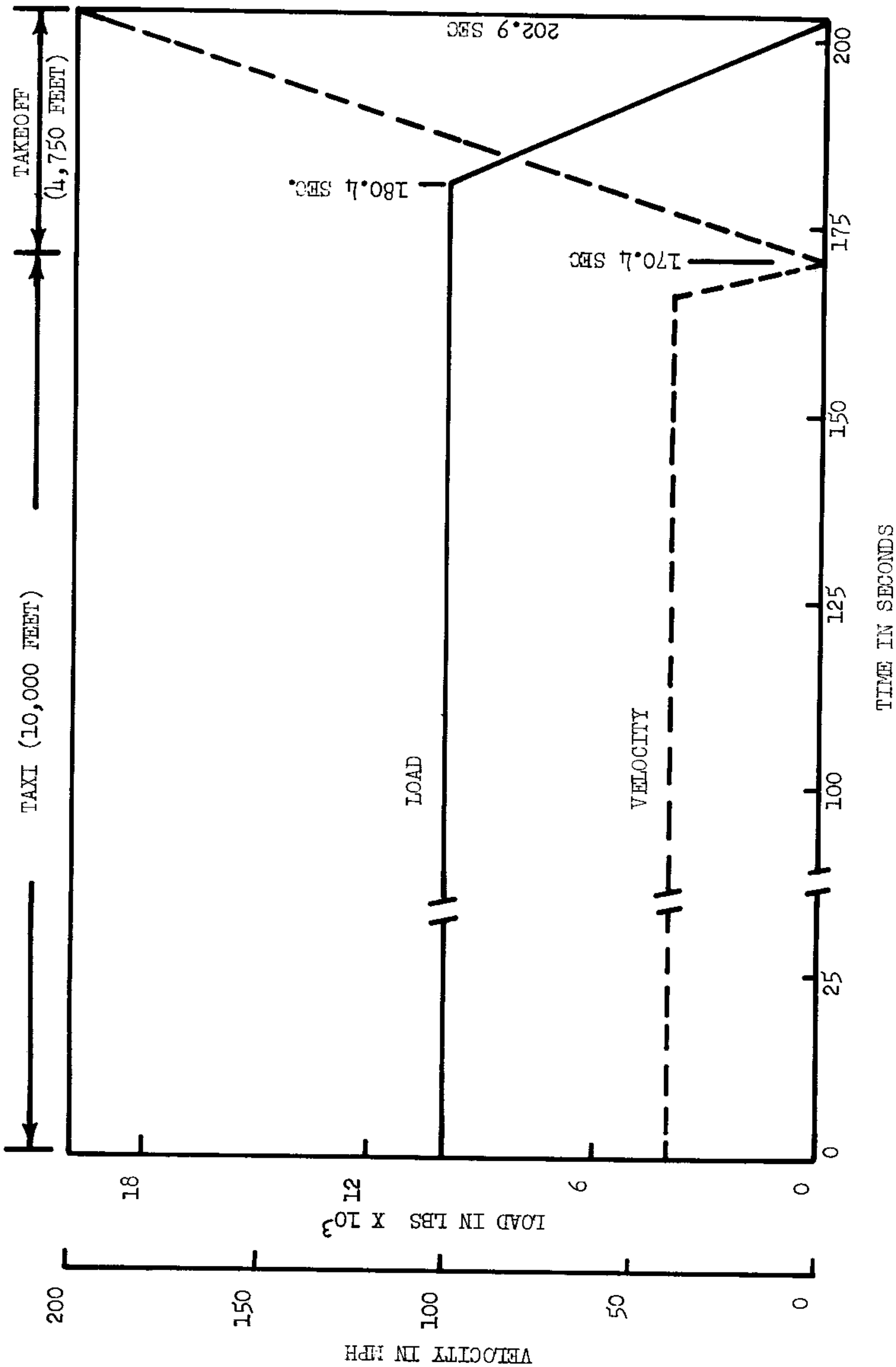



FIGURE 32. Taxi Takeoff Profile for 9.50-16 Expandable Tire Number 2

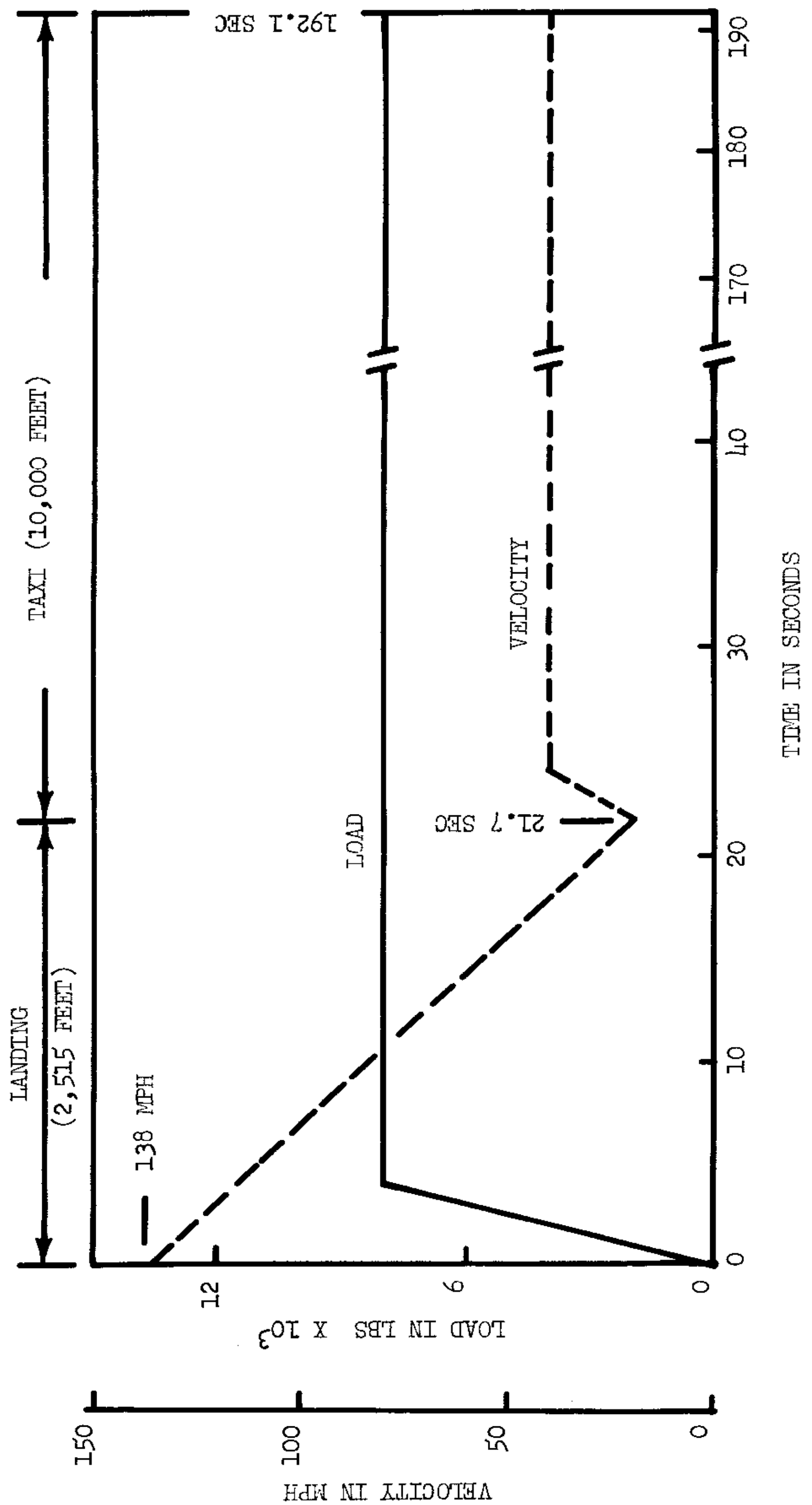



FIGURE 33. Landing Taxi Profile for All 9.50-16 Expandable Tires

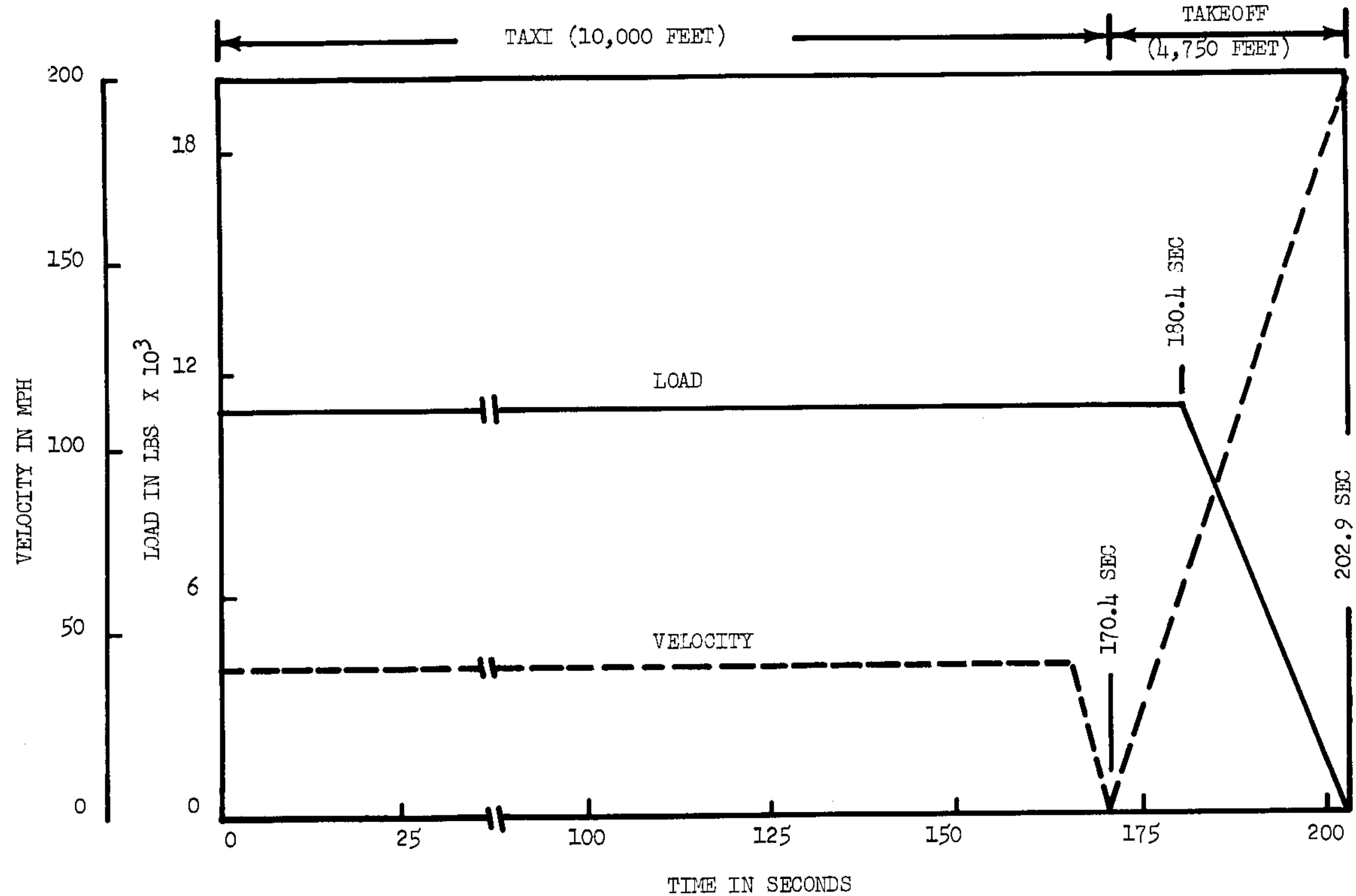
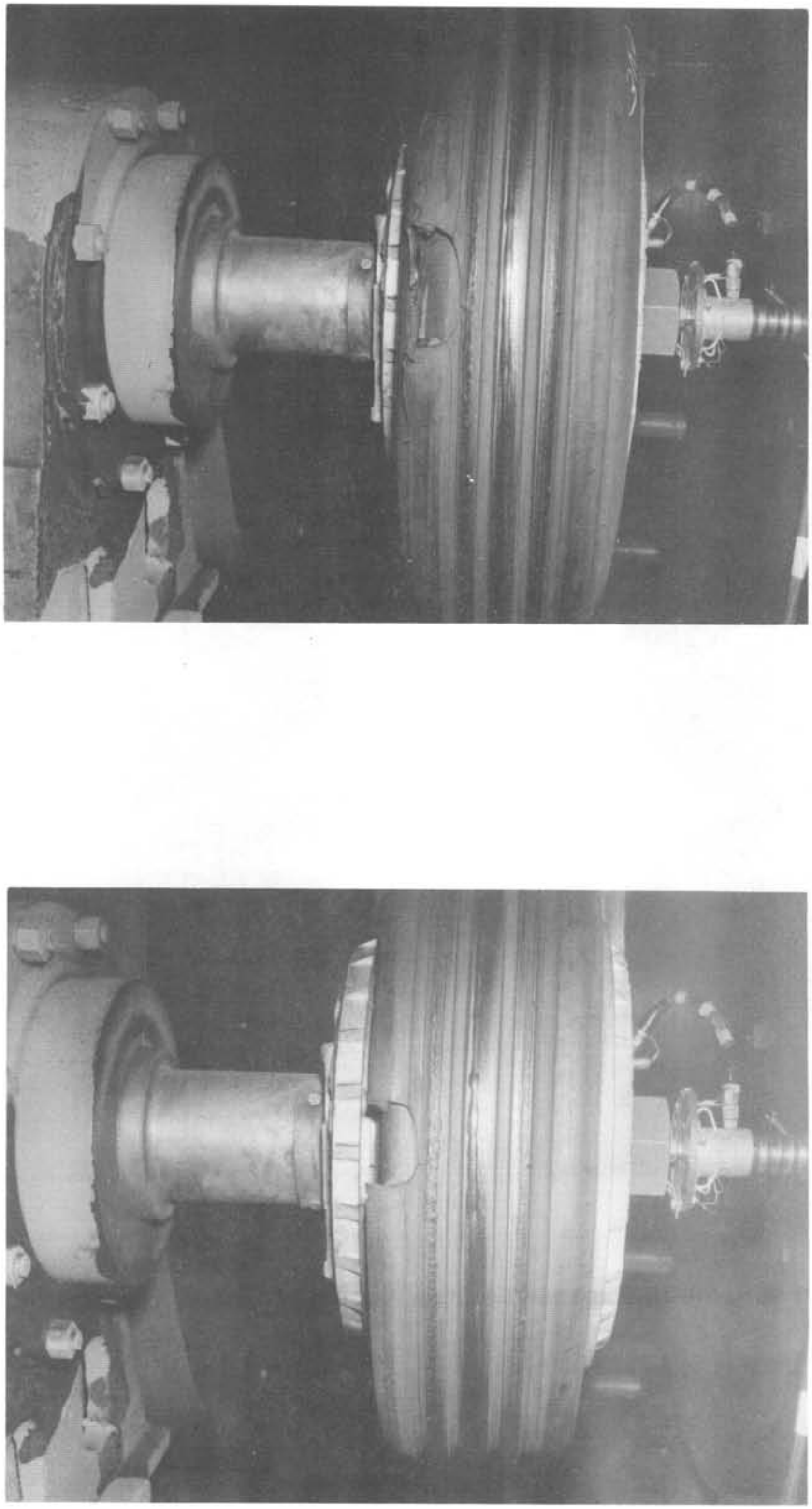



FIGURE 34. Taxi Takeoff Profile for 9.50-16 Expandable Tires Number 3, 5, 6, and 8



a) Folded Position

b) Inflated Position

FIGURE 36. Progression of Tread Chunking on 9.50-16 Expandable Tire Number 3 After Completion of 60 Missions

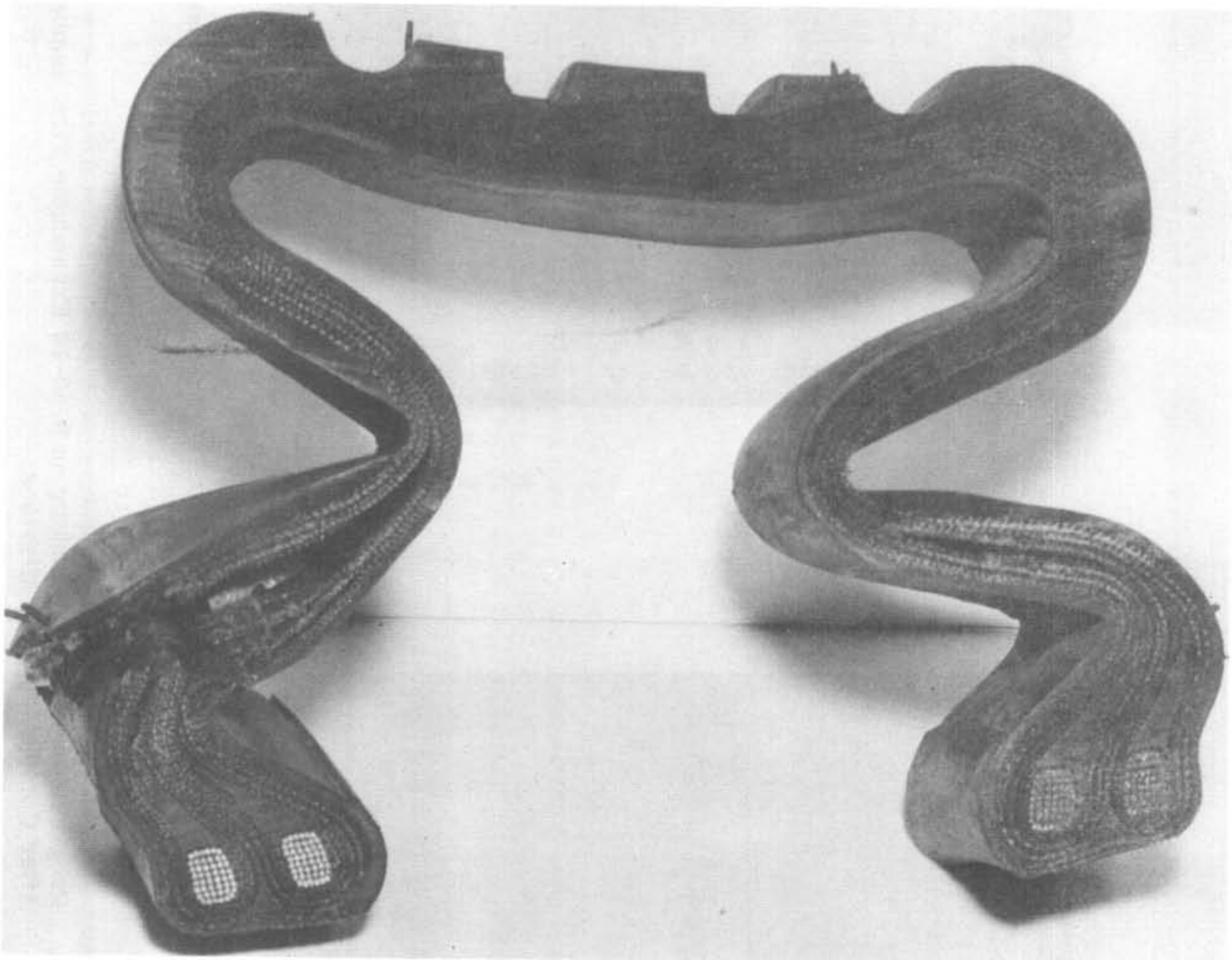


FIGURE 37. Section of 9.50-16 Expandable Tire Number 5 Taken Through Failed Sidewall

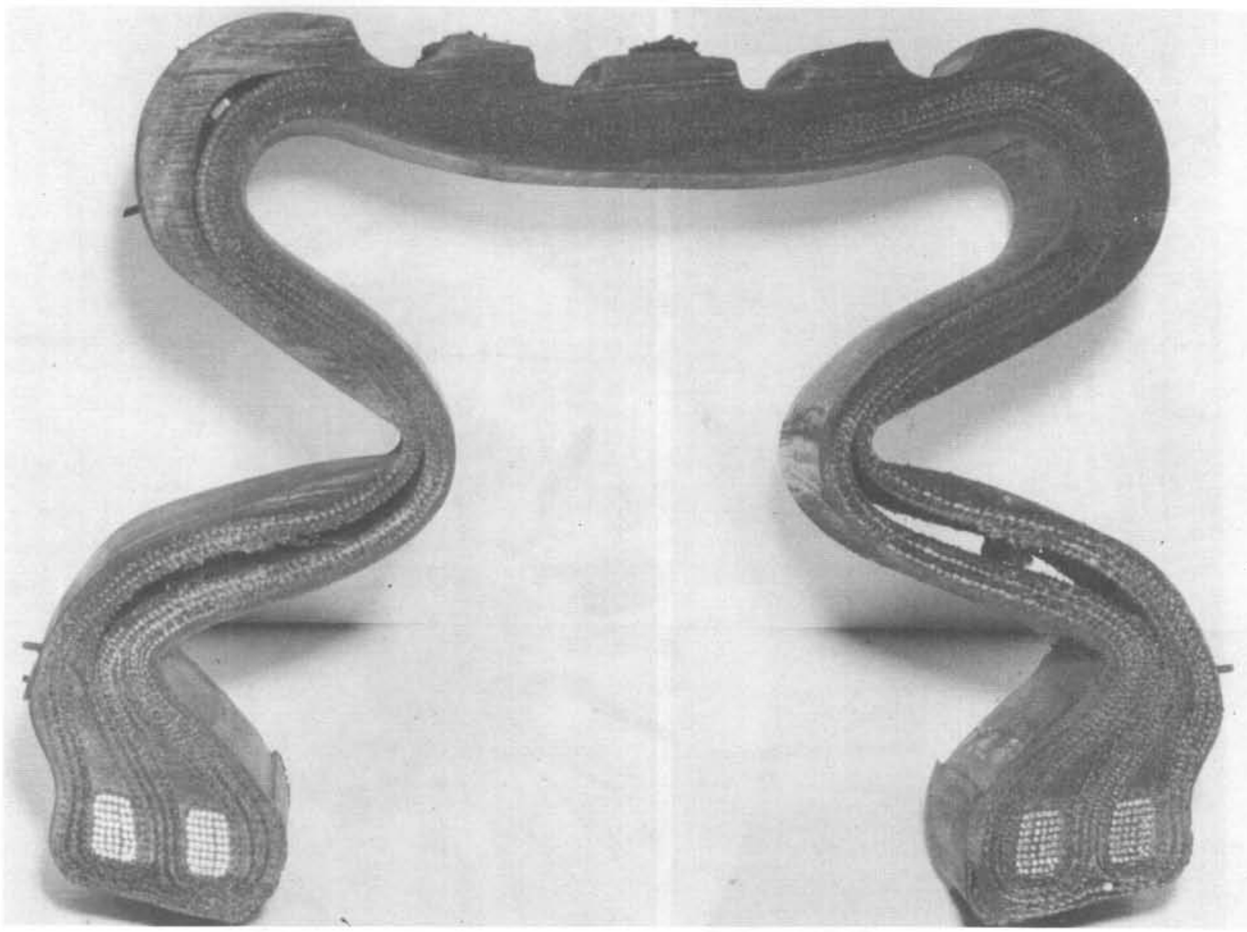


FIGURE 38. Section of 9.50-16 Expandable Tire Number 6 After 60 Missions and 110 Camber Taxi Cycles

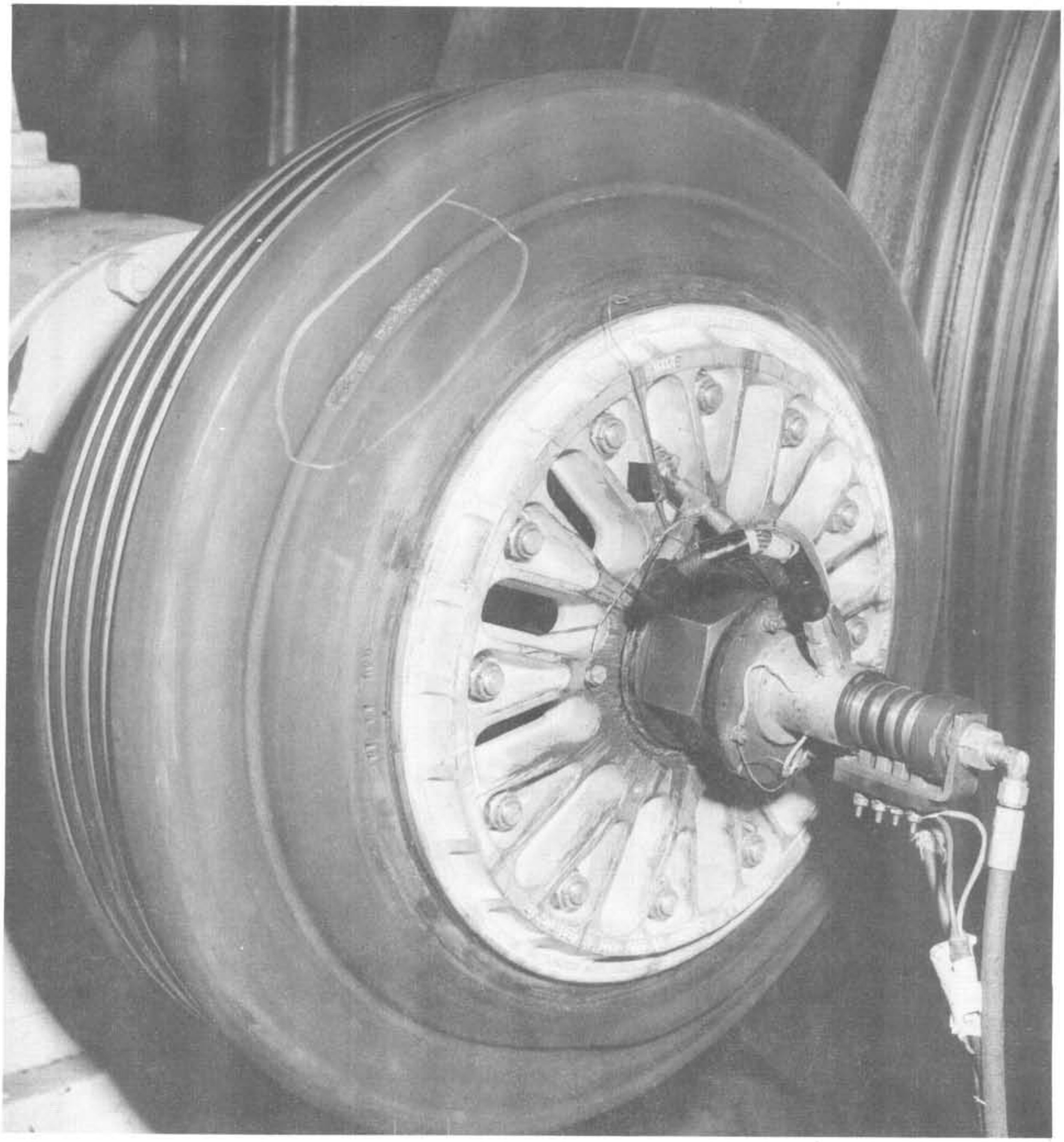


FIGURE 39. Cord-Fraying on 9.50-16 Expandable Tire Number 8 After Third Mission

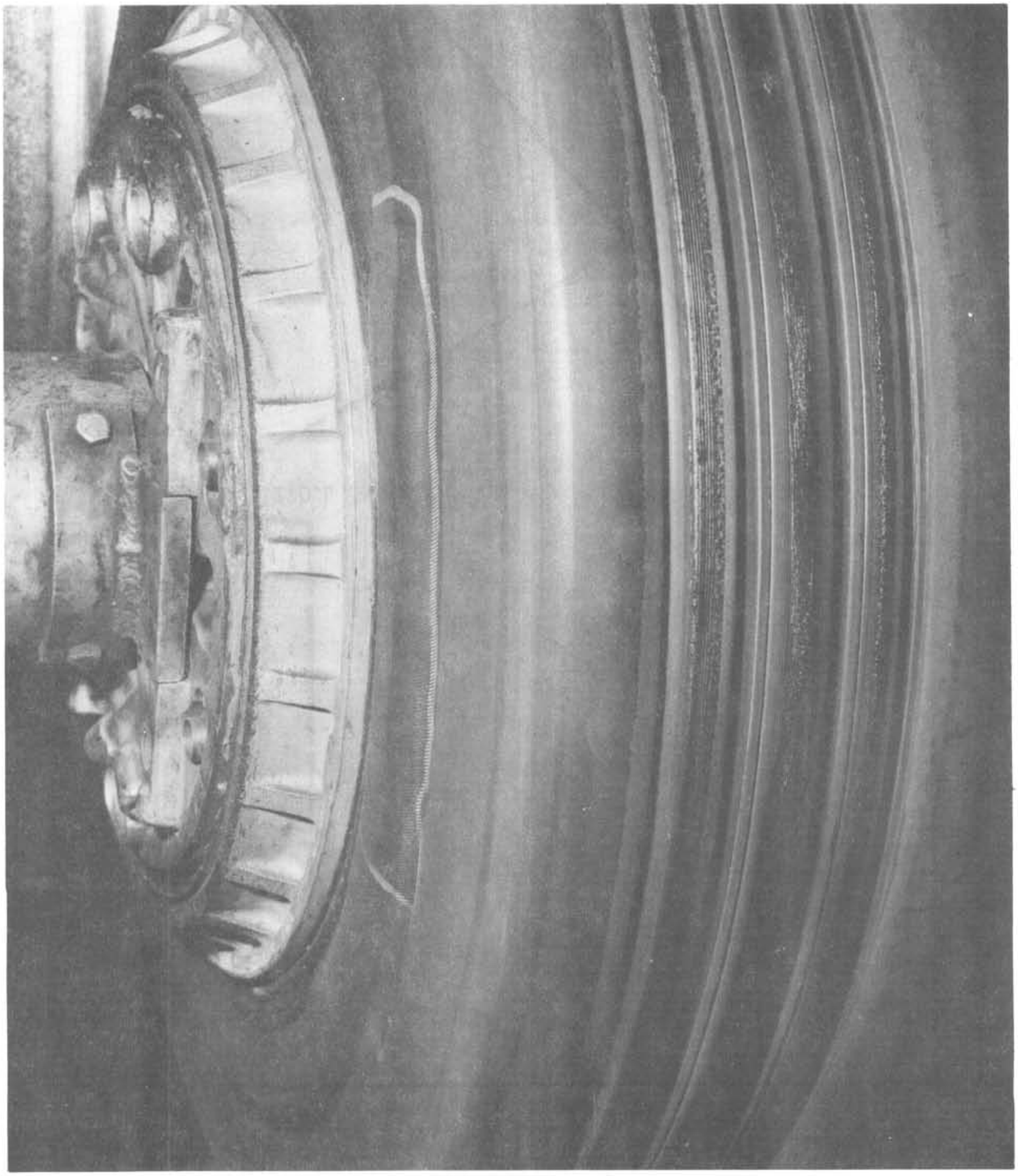


FIGURE 40. Blister on Inboard Sidewall of 9.50-16 Expandable Tire Number 8 after Sixth Taxi Takeoff Cycle

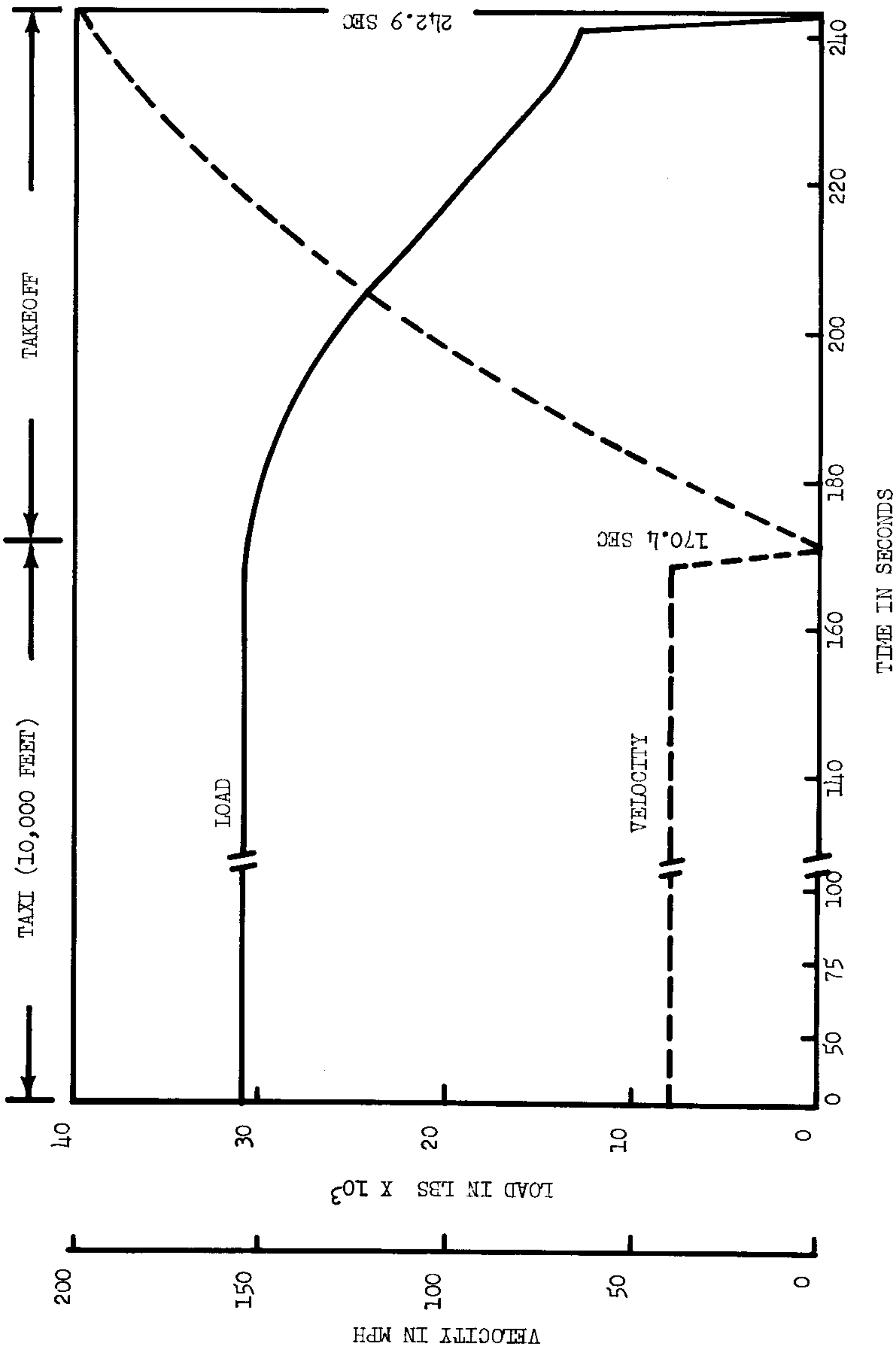



FIGURE 41. Taxi Takeoff Profile for 23.00-20 Expandable Tire Number L-2.

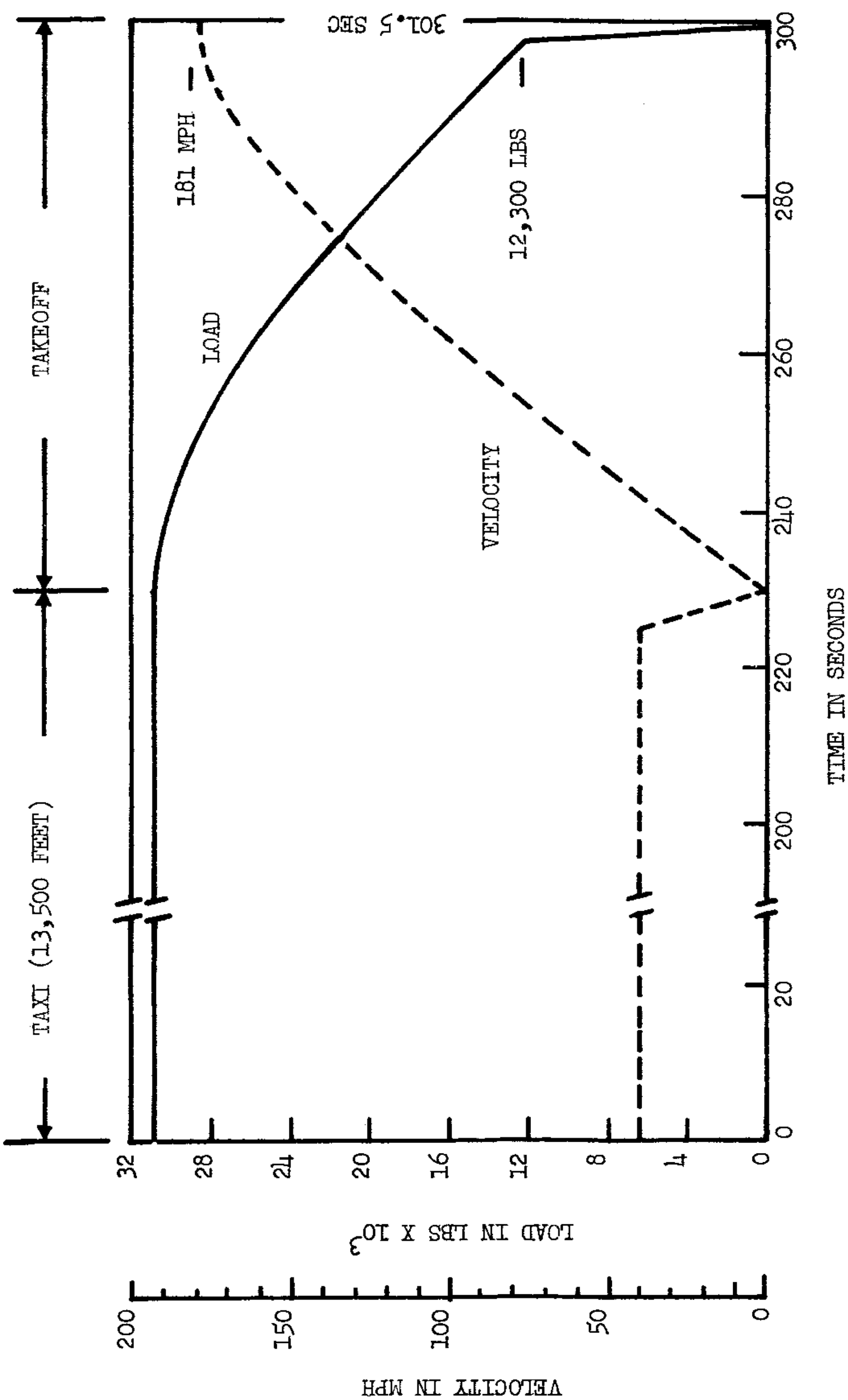



FIGURE 42. Taxi Takeoff Profile for 23.00-20 Expandable Tire Number L-6

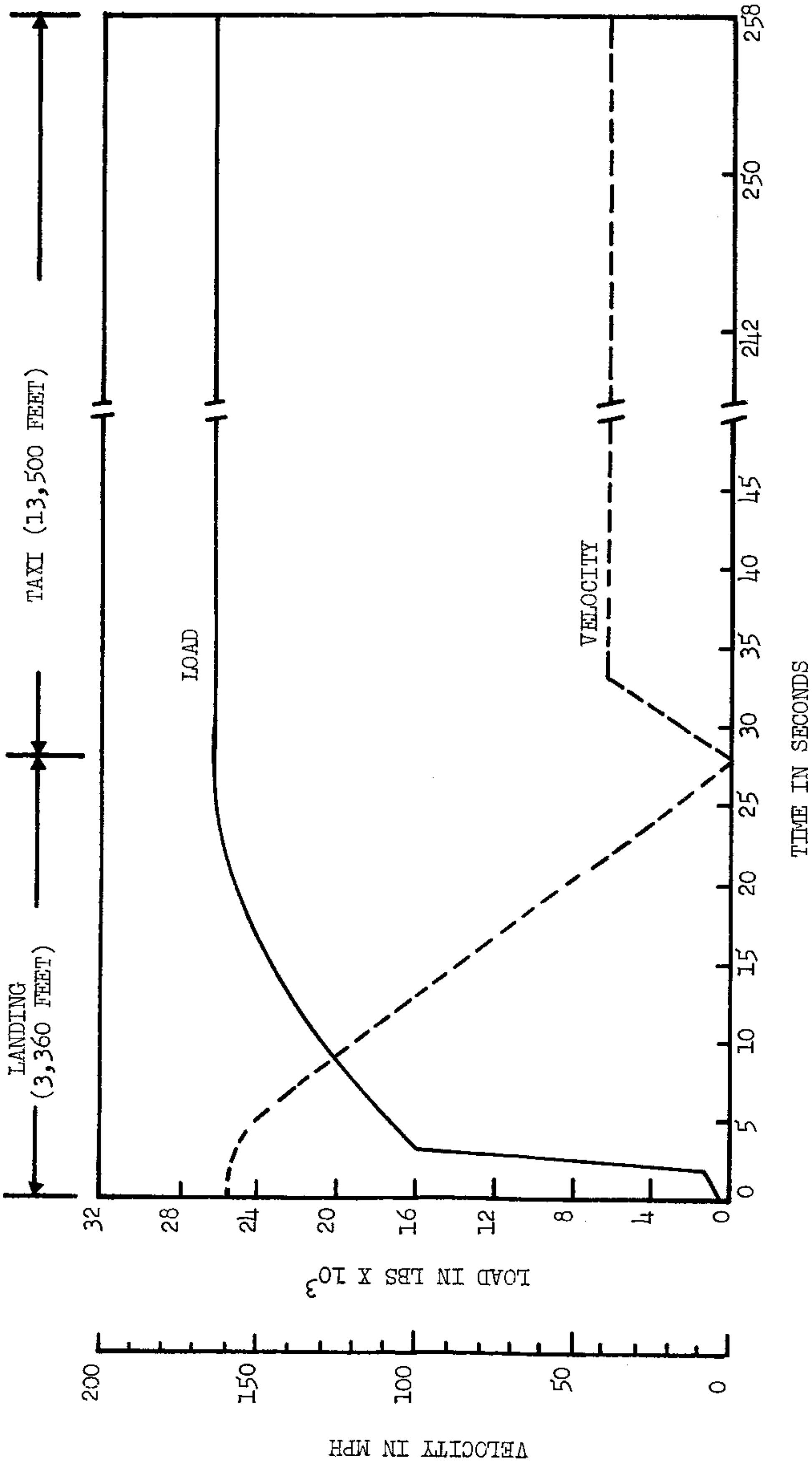



FIGURE 43. Landing Taxi Profile for 23.00-20 Expandable Tire Number L-6

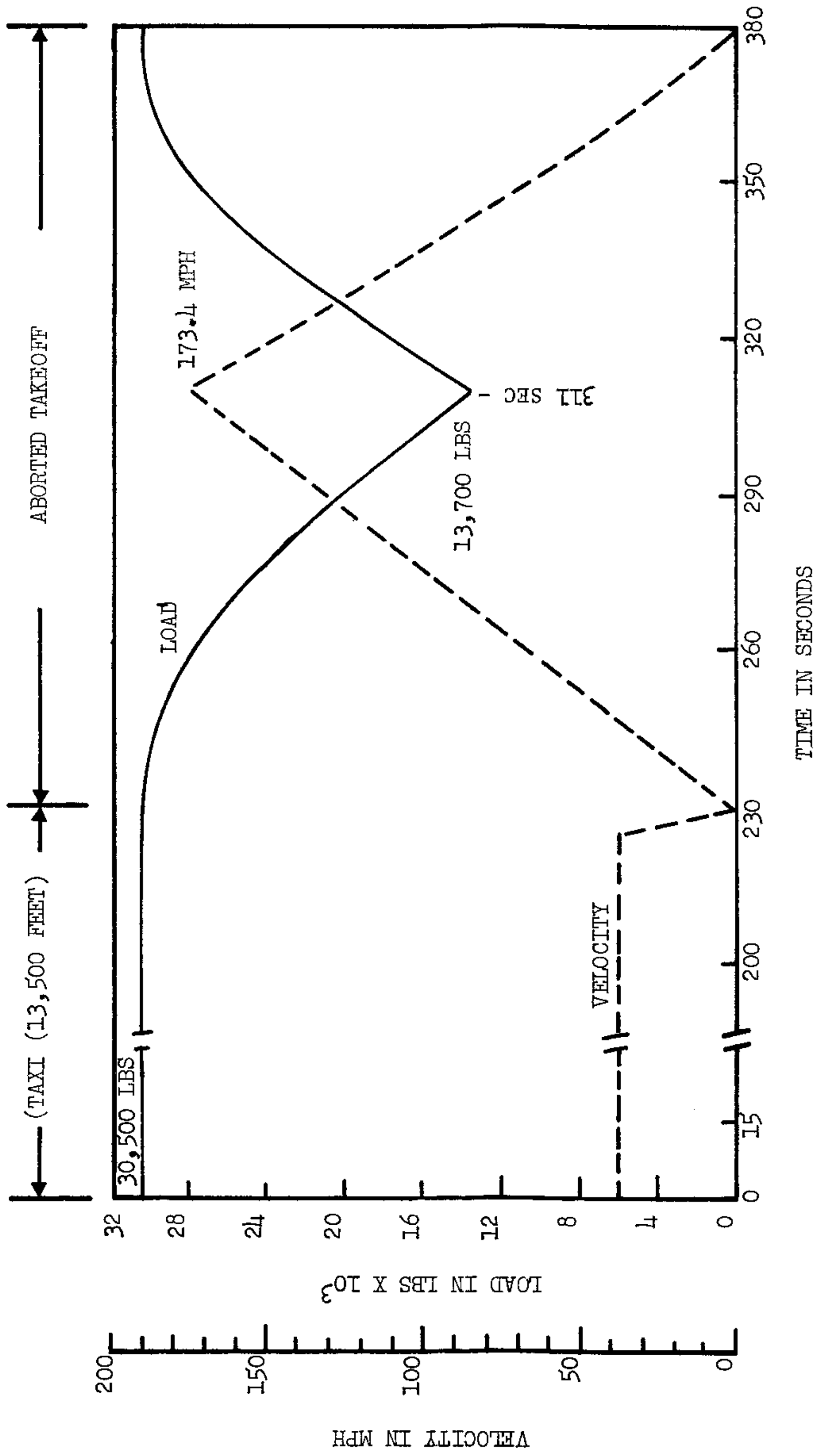



FIGURE 44. Aborted Takeoff Profile for 23.00-20 Expandable Tire Number L-6

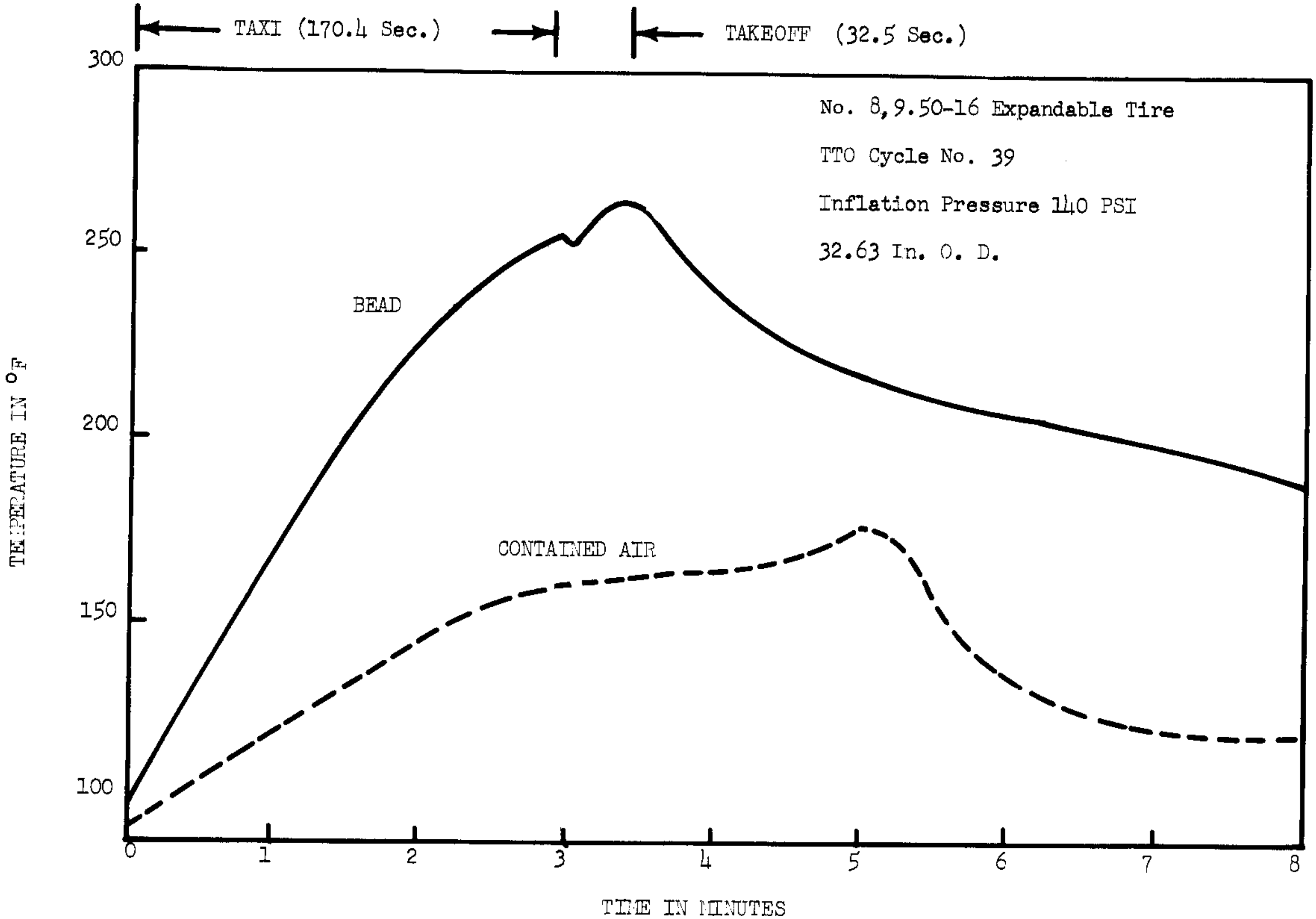



FIGURE 45. Typical Taxi Takeoff Temperature Profile of 9.50-16 Expandable Tire Number 8

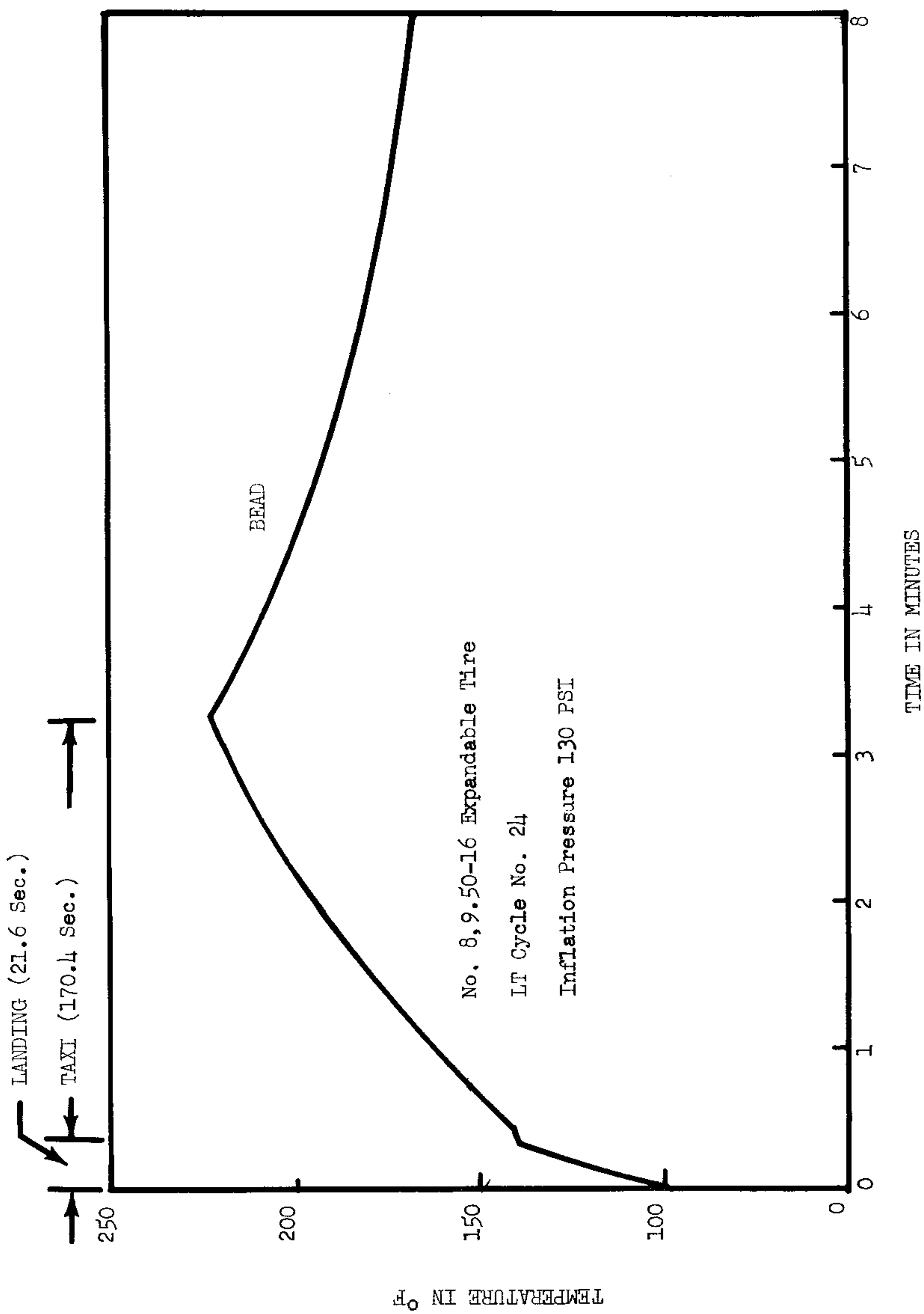
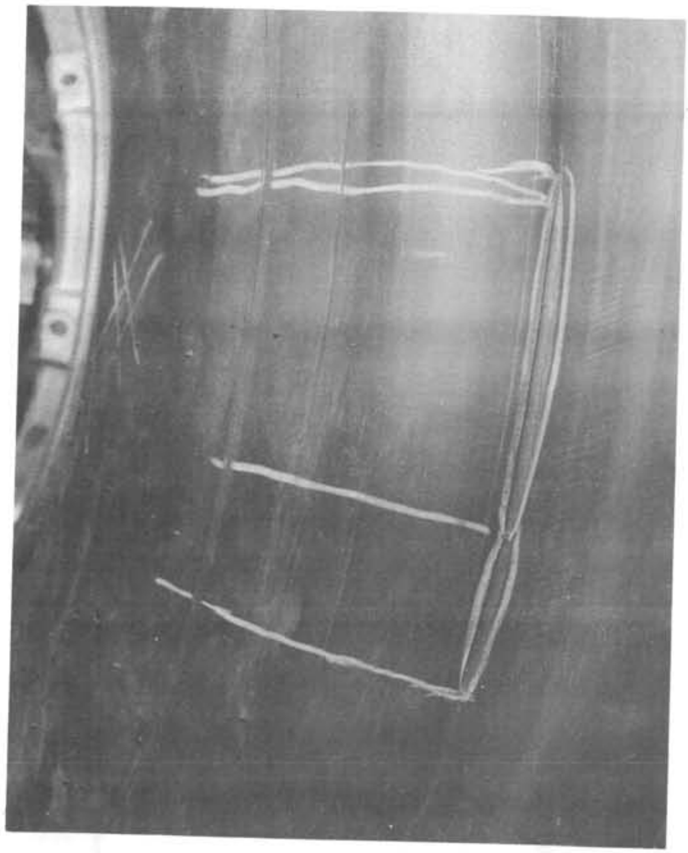
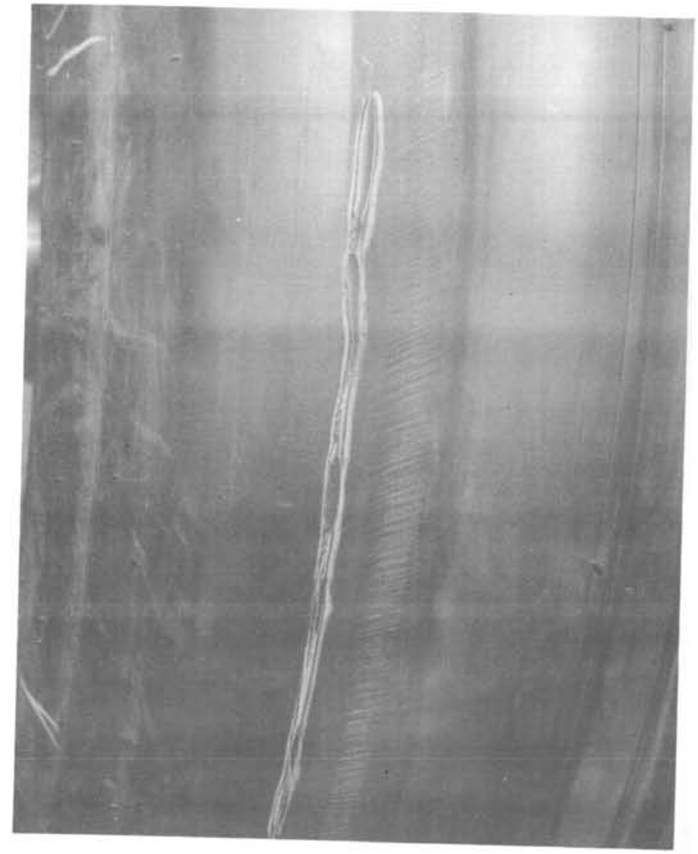



FIGURE 46. Typical Landing Taxi Temperature Profile of 9.50-16 Expandable Tire Number 8

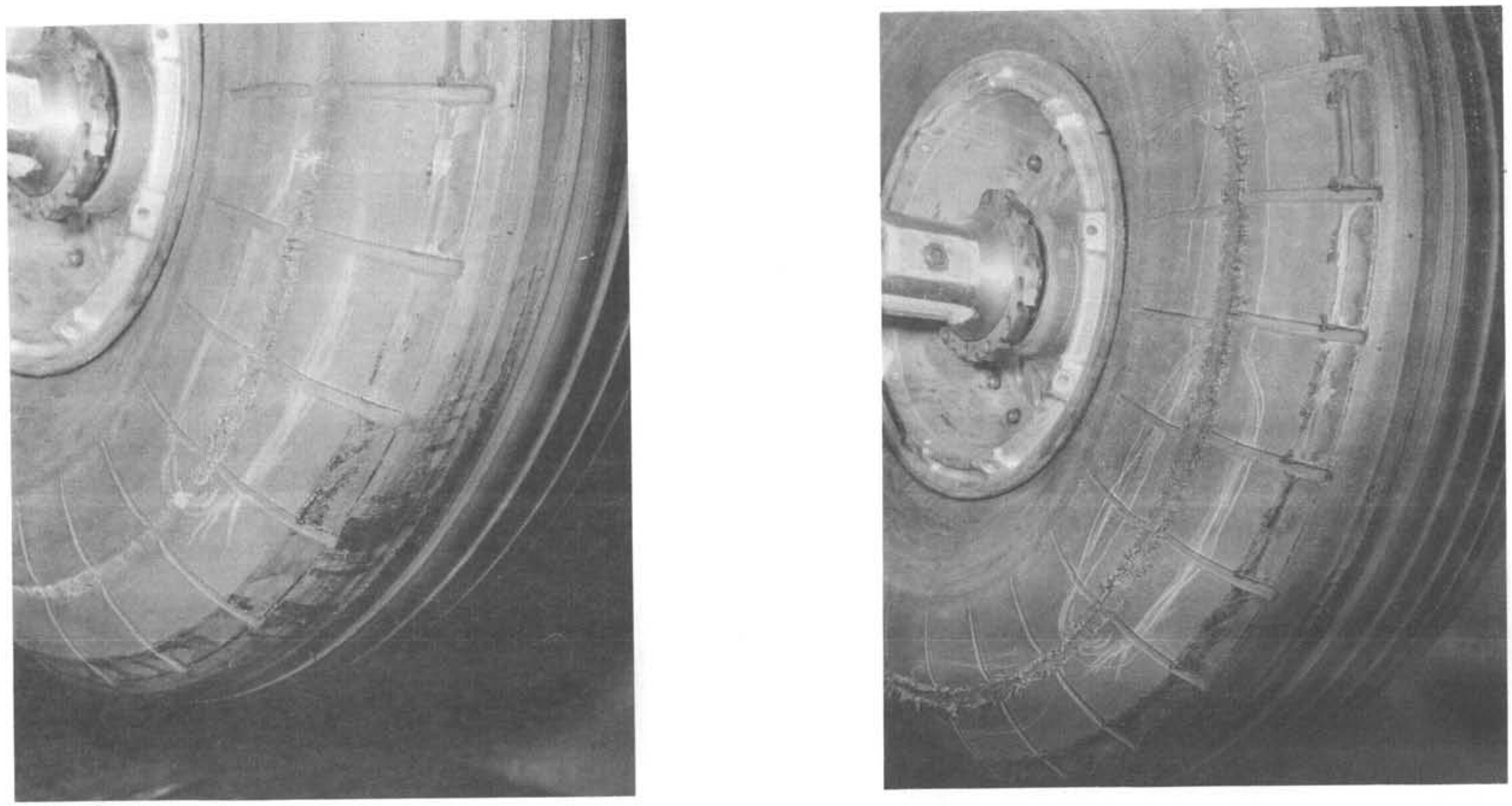


a) After 29 Low and 25 High Speed Landing Cycles



b) After Completion of 200 MIL-T-5041D Landing Cycles

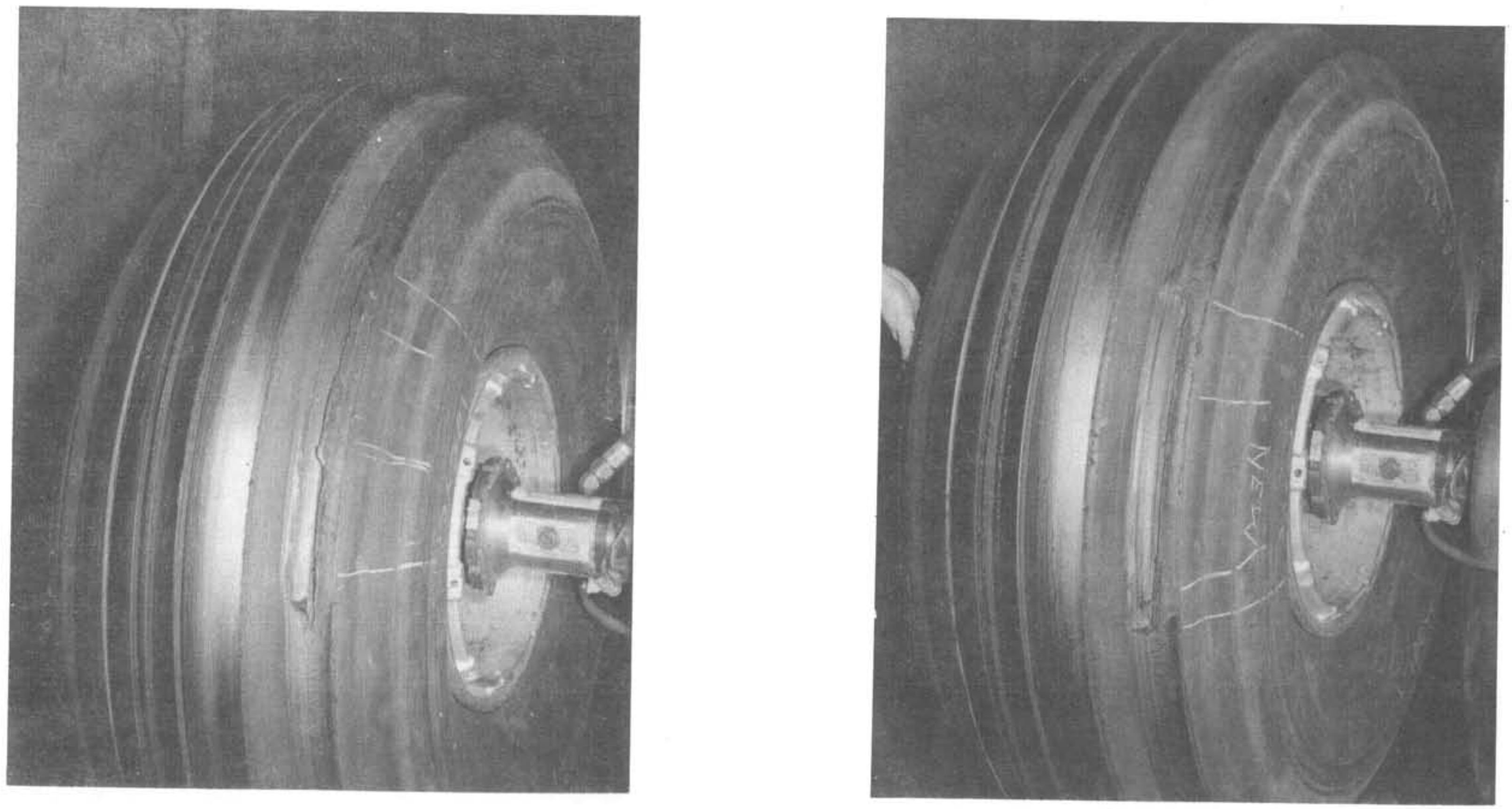
FIGURE 47. Progression of Cord Fraying on 23.00-20 Expandable Tire Number L-3



a) Continuous Flow Cracks

b) Intermittent Flow Cracks

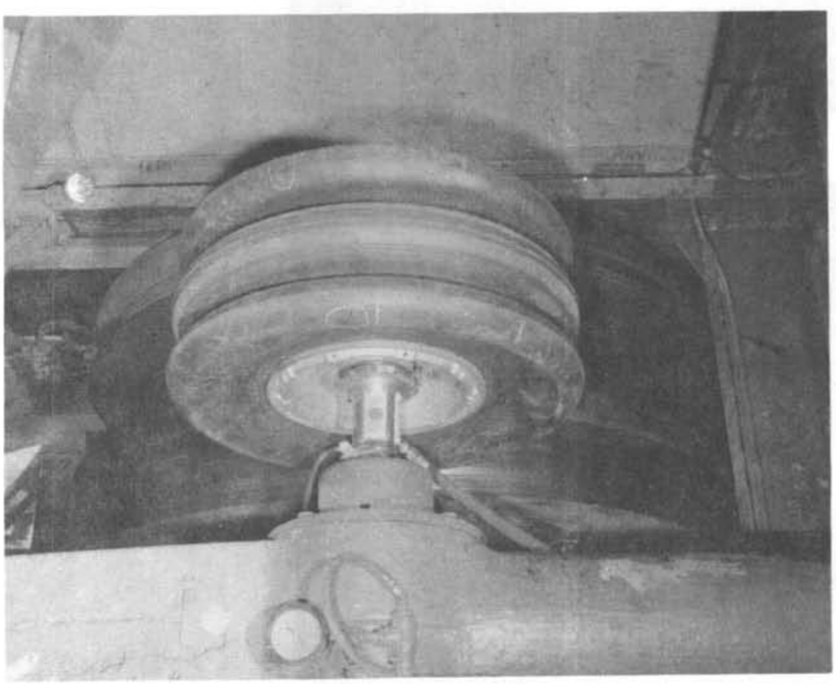
FIGURE 48. Flow Cracks, 120 Degrees Apart, on 23,00-20 Expandable Tire Number L-5 at New Condition



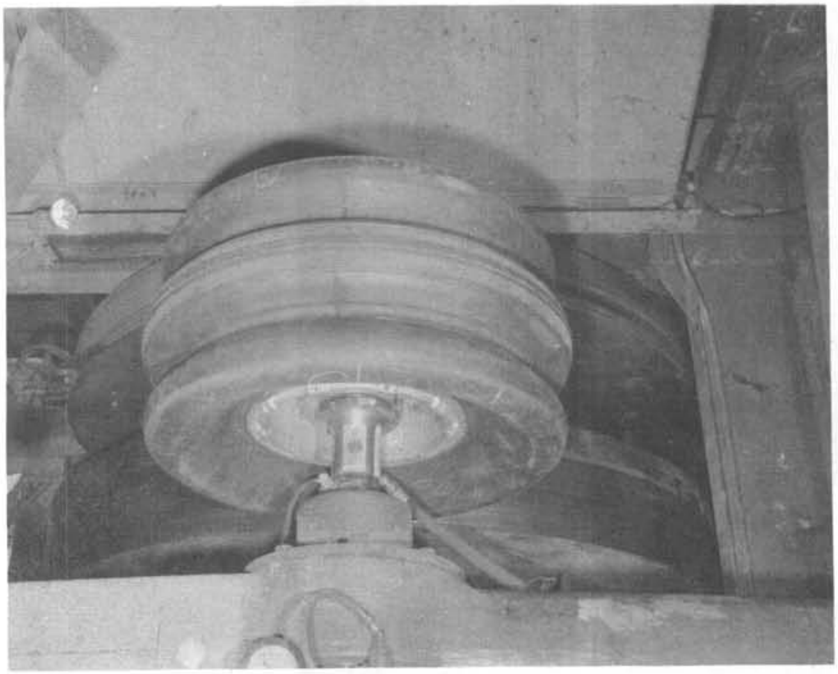

a) First Location on Inboard Side

b) Second Location on Inboard Side

FIGURE 49. Progression of Flow Cracks, 120 Degrees Apart, on 23.00-20 Expandable Tire Number L-5 After 10 Low Speed Landing Cycles

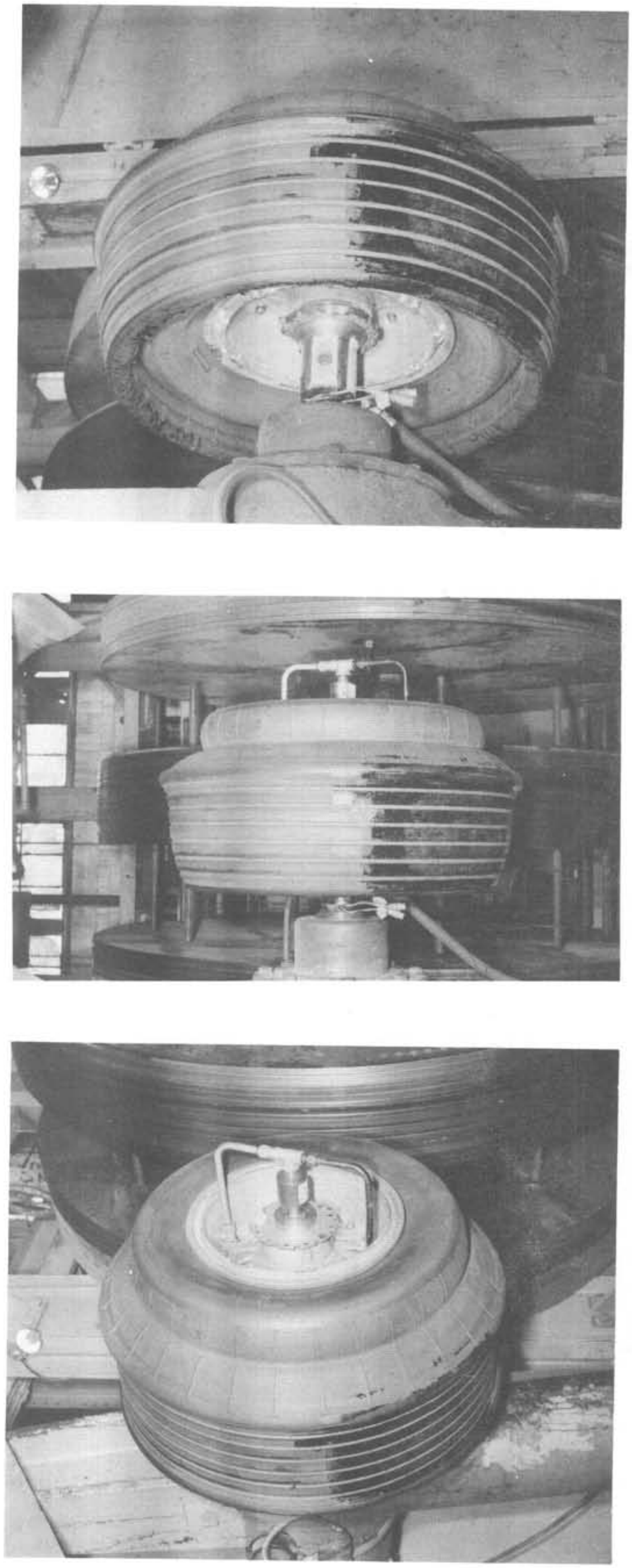


a) Folded Shape



b) Tire at 10 PSI Inflation Pressure

FIGURE 50. Design I, 23.00-20 Expandable Tire at Folded and Partially Inflated Shapes

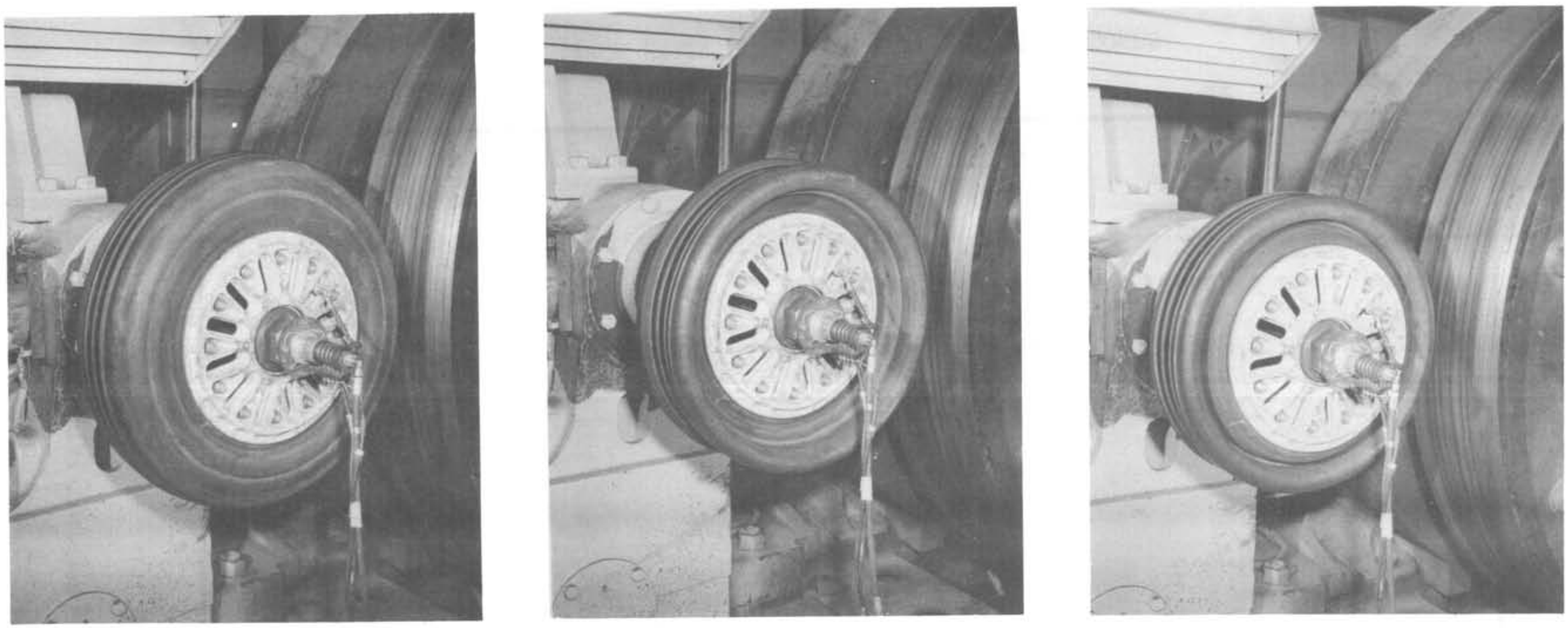


a) Outboard View

b) Front View

c) Inboard View

FIGURE 51. Axial Shifting of 23.00-20 Expandable Tire During Inflation



a) Fully Inflated b) Tire Crown Shifting Outboard c) Tire Returns to Folded Shape

FIGURE 52. Lateral Instability During Folding of a 9.50-16 Expandable Tire

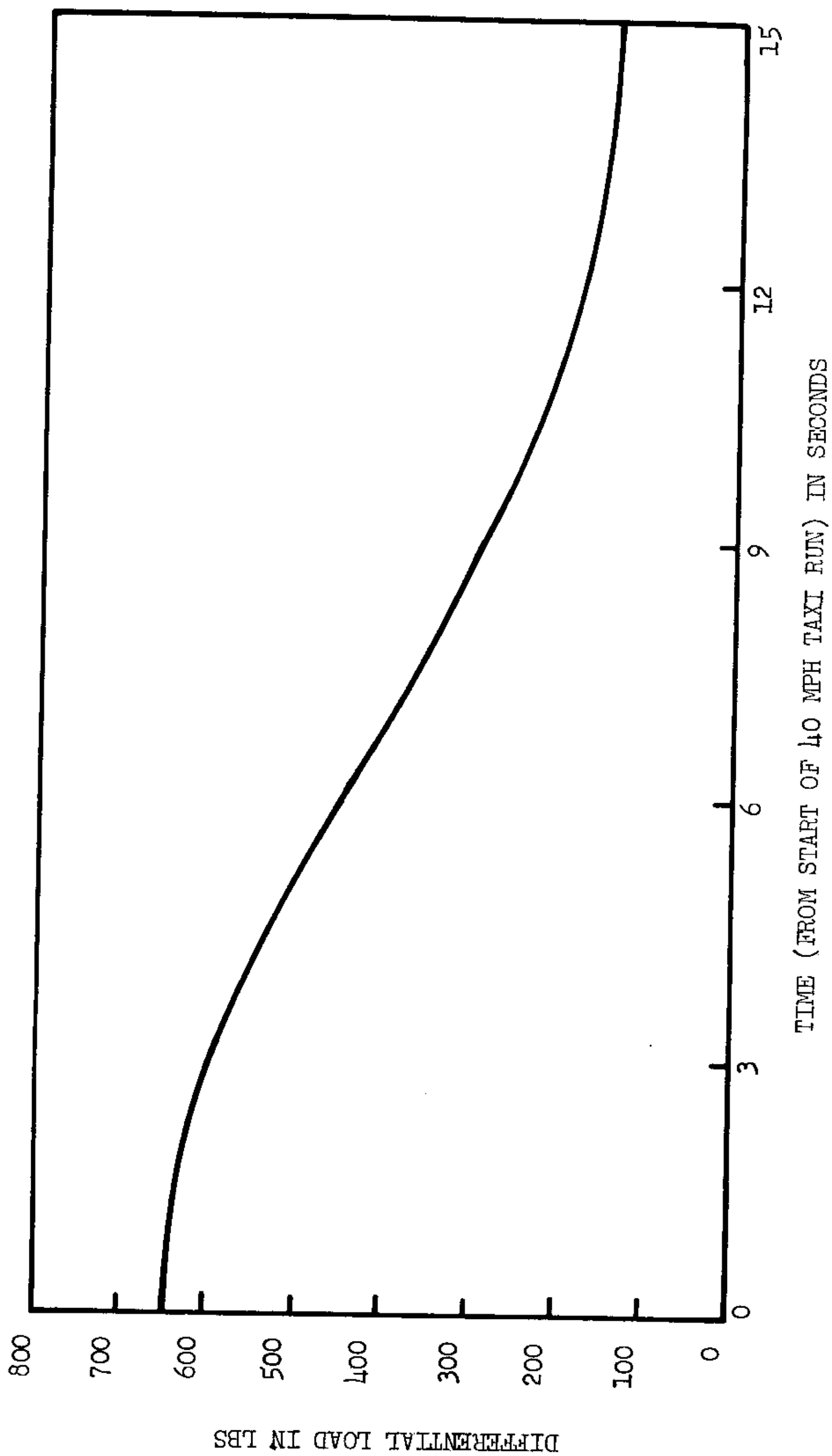



FIGURE 53. Differential Load Versus Time During Flatspot Taxi Runout on 9.50-16 Expandable Tire Number 5

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13. ABSTRACT

Type III (low pressure) expandable aircraft tires of the 9.50-16 and 23.00-20 sizes were investigated. These tires with their 30 to 50 percent outside diameter expansion capabilities were subjected to simulated landing taxi and taxi takeoff conditions. Results indicate that the load capacity and life of the expandable tires are equivalent to standard tires of the same size. Takeoff speeds on the order of 200 MPH were obtained on tires of both sizes.

One 9.50-16 expandable tire with sidewall convolutions successfully completed 60 simulated C-141 main tire missions and 110 taxi camber cycles in accordance with C-141 nose landing gear tire requirements. Two 23.00-20 expandable tires, one with sidewall convolutions and the other with tread convolutions, successfully completed 200 landing cycles in accordance with procedures outlined in MIL-T-5041D. One 23.00-20 expandable tire (with sidewall convolutions) successfully completed 80 taxi takeoff and 100 landing taxi cycles and one aborted takeoff cycle. The simulated conditions for this tire were derived from estimated operating characteristics of a heavy cargo type of aircraft. Another 23.00-20 sidewall convoluted expandable tire successfully completed 18 taxi takeoff cycles at takeoff speeds of 200 MPH.

Abstract Con't

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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Expandable Tire - Low Pressure Tire | | | | | | |
| Aircraft Tires | | | | | | |

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The tread convoluted (Design I) expandable tire displayed excellent foldability during tire inflation and deflation. After a number of folding operations, the sidewall convoluted (Design II) expandable tire in a nonrotational state would experience lateral shifting. However, a symmetrical folding procedure was obtained on a Design II expandable tire at peripheral tire speeds as low as 30 MPH.

The Design II expandable tire has the most promising fold from an expansion capability standpoint. In the 23.00-20 expandable tire size, the Design I offered an expansion of 33 percent compared to the Design II expansion of 50 percent in outside diameter.

A landing at 120 MPH was accomplished on a folded (deflated) Design II expandable tire indicating that the expandable tire has operational potential even after battle damage.