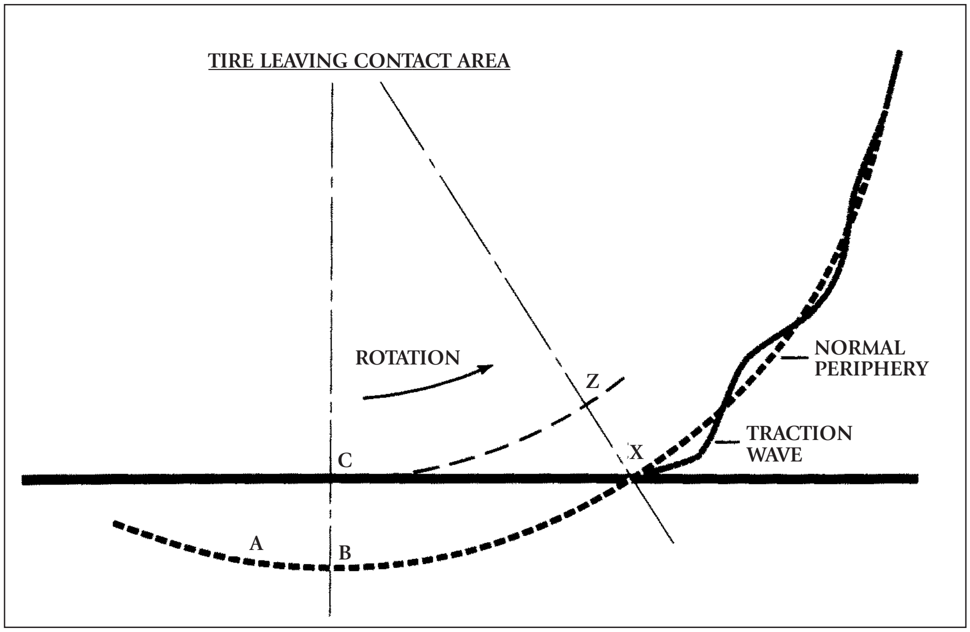
# 7 *Effects of Operating Conditions*

## CENTRIFUGAL FORCE

### CENTRIFUGAL FORCE is combination of LOAD & SPEED

Both heavy loads and high speeds contribute to the strong centrifugal forces acting on an aircraft tire. The relationship of speed versus centrifugal force is obvious. The effect of coupling speed with a heavy load is shown in the drawing below.

This drawing depicts a tire rotating counterclockwise. The heavy solid horizontal line represents the ground or runway. The distance "CX" is half the footprint length. Because the tire is pneumatic, it deflects when coming into contact with the ground. This deflection is represented by the distance "BC" or "XZ". In the same length of time that a point on the surface of the tire travels the last half of the footprint "CX", it must also move radially outward the distance "ZX".

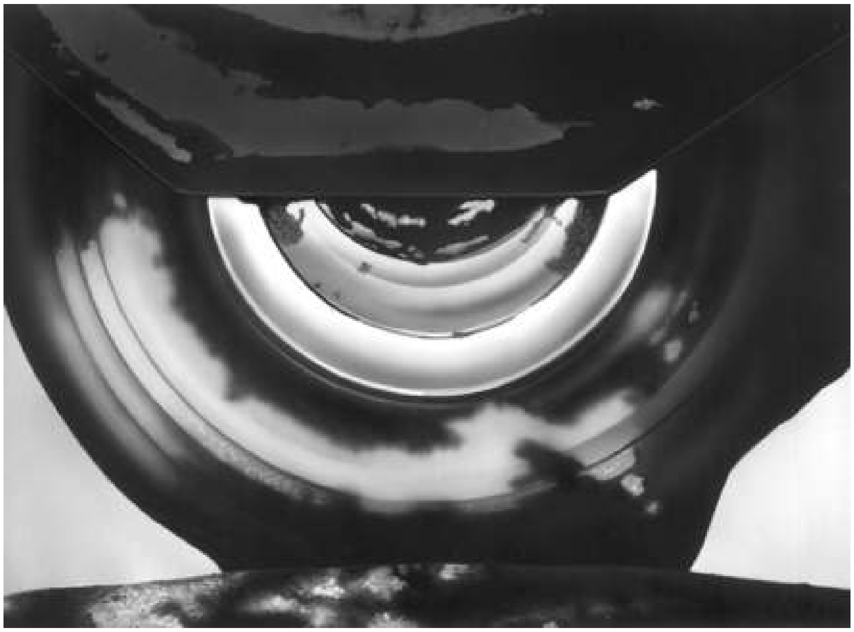


As the tire leaves the deflected area, it attempts to return to its normal shape. Due to centrifugal force and inertia, the tread surface doesn't stop at its normal periphery but overshoots, thus distorting the tire from its natural shape. This sets up a traction wave in the tread surface.

# CENTRIFUGAL FORCE (CONT'D)

## TRACTION WAVE

This photograph shows just how severe a traction wave can become under certain operating conditions.



The following parameters help explain the magnitude of forces acting on the tire carcass and tread as it runs on a test dynamometer.

| | |
|---|---|
| **Speed** | **250 MPH** |
| **Revolutions per Minute** | **4,200** |
| **Deflection** | **1.9 inches** |

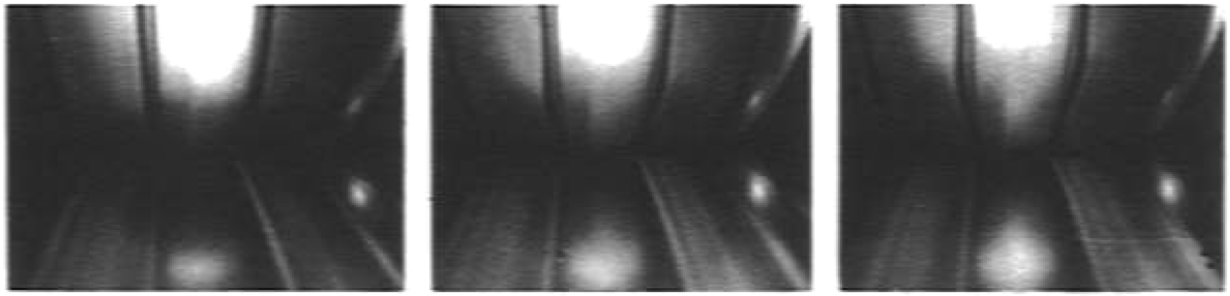
At this speed, it takes only 1/800 of a second to travel 1/2 the length of the footprint (CX). In that same time, the tread surface must move radially outward 1.9 inches. This means an average radial acceleration of 200,000 ft./sec./sec. That's over 6,000 G's!

This means the tread is going through 12,000 to 16,000 oscillations per minute.

Obviously, a tire cannot withstand this type of punishment. How can a traction wave be reduced or eliminated? In other words, what factors affect the traction wave? The following page shows effects of **SPEED** and **UNDERINFLATION**.

# CENTRIFUGAL FORCE (CONT'D)

## Traction Wave -vs- Speed

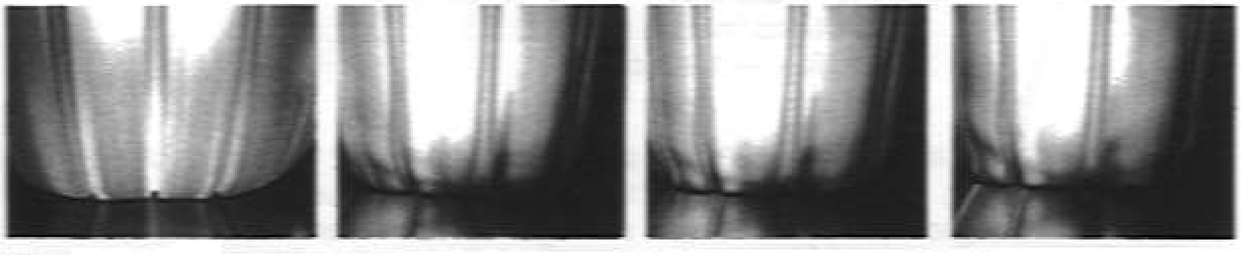


**40X14 24 PR @ Rated Pressure**

The above photographs show the tread of a tire as it leaves the footprint moving toward the reader. The only test variable is speed, showing from left to right 190, 210, 225 mph. The higher the speed, the more pronounced the traction wave.

One of the major tasks of the tire design engineer is to minimize this traction wave at the required speeds and loads.

## Traction Wave -vs- Underinflation



**40X14 24 PR 225 MPH**

All tires in the above photographs are traveling at 225 mph. In the picture to the far left there is no appreciable traction wave because the tire is properly inflated. The only test variable is pressure, showing from left to right rated pressure, -10 psi, -15 psi, -20 psi. Obviously, the greater the underinflation, the more pronounced the traction wave.

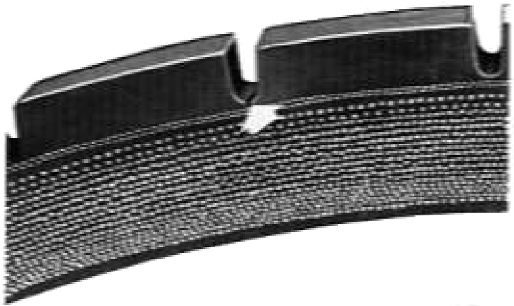
Note how the grooves open and close as the tread passes through the traction wave.

## CENTRIFUGAL FORCE (CONT'D)

The centrifugal forces that generate a traction wave, combined with the thousands of revolution cycles, can cause tread problems such as Groove Cracking and Rib Undercutting, which could result in tread loss.

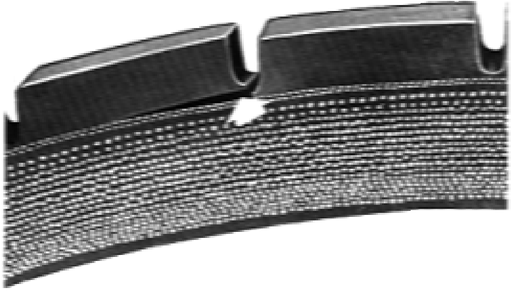
### GROOVE CRACKING

is a circumferential crack that can develop in the base of the groove caused by the repeated flexing of the groove when a traction wave is present. Tires should be inspected frequently and removed if any fabric is visible.



### RIB UNDERCUTTING

is normally a continuation of the groove cracking that continues under the tread rib between the rubber and the tread reinforcing fabric.



Rib undercutting can progress to a point where pieces of the rib or the whole rib can become separated from the carcass. In severe cases the complete tread can come off the carcass. Progression from deep groove cracks to undercutting and ultimate tread loss can occur rather quickly. Therefore, careful examination of the tires before each take-off is extremely important. The tire should be removed if the fabric is exposed.

Before leaving the subject of centrifugal force, it is interesting to look at the magnitude of these forces due to speed only, disregarding other radial accelerations caused by loads and deflections. This chart shows the centrifugal forces acting on one ounce of tread rubber on a 30-inch diameter tire.

**Centrifugal Forces**
**30-Inch Diameter Tire**

| MPH | Gs | FORCE ON 1 OZ OF TREAD | FORCE ON TOTAL TREAD (8 LBS) |
|---|---|---|---|
| 100 | 500 | 33 LBS | 4,000 LBS |
| 200 | 2000 | 130 LBS | 16,600 LBS |
| 300 | 4500 | 300 LBS | 38,500 LBS |
| 400 | 8000 | 528 LBS | 67,500 LBS |

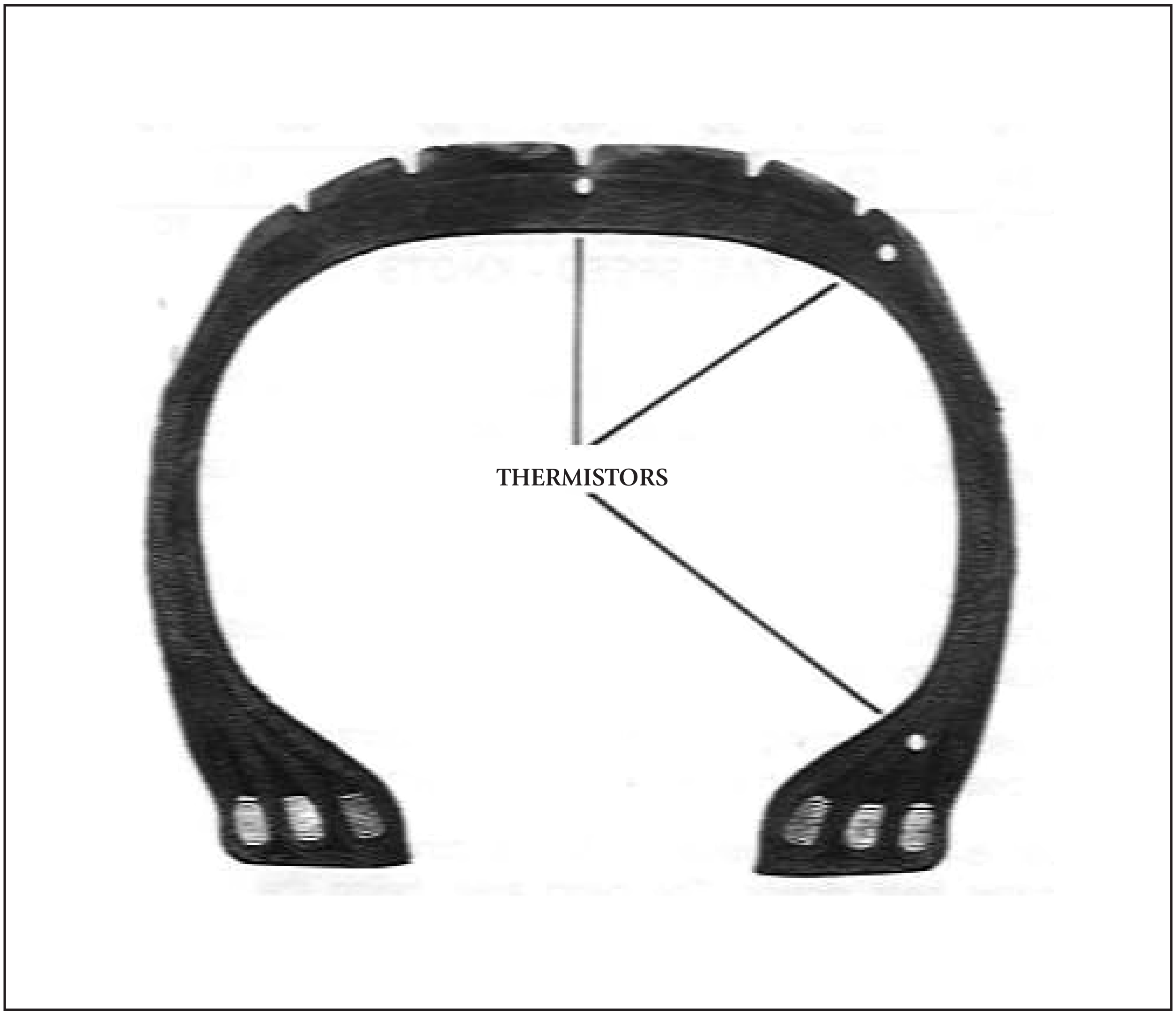
The force increases as the square of the speed from 500 Gs, or 33 lbs. per ounce, at 100 mph, to an extreme of 8000 Gs, or 528 lbs. per ounce, at 400 mph.

An average tread for this size tire would weigh approximately 8 lbs. This means that the effective weight of the total tread at 200 mph would be 16,600 lbs. and at 400 mph would be 67,500 lbs.

With forces like these, it is amazing that a tread can stay on a tire at all.

## HEAT GENERATION

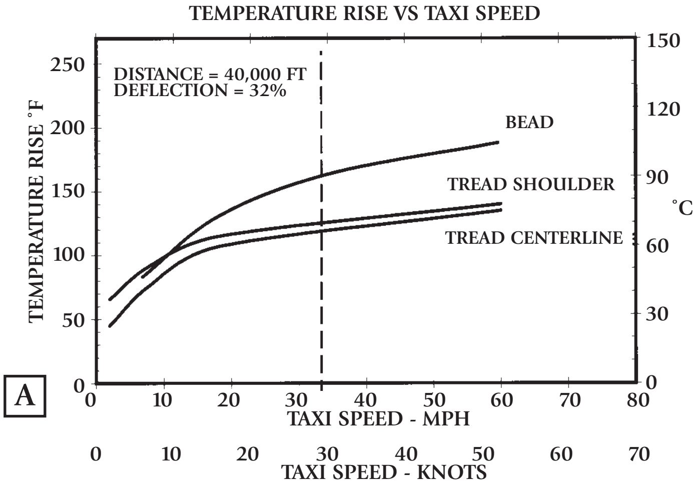
As severe as the effects of these high centrifugal forces are, **HEAT** has a more detrimental effect. **HEAVY LOADS** and **HIGH SPEEDS** cause **HEAT GENERATION** in aircraft tires to exceed that of all other tires.



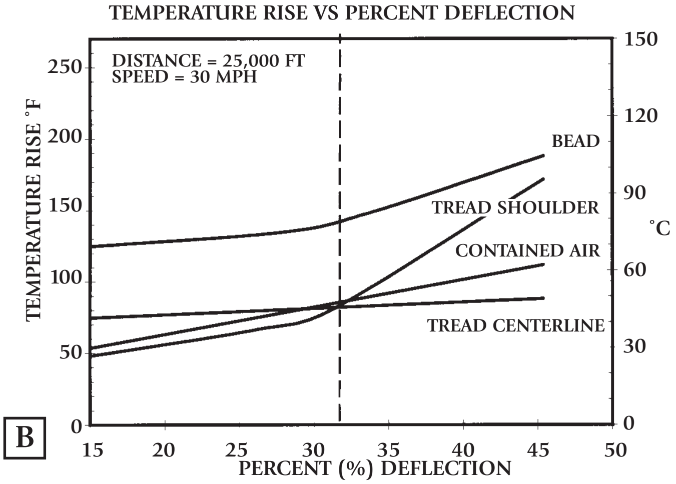
To understand the magnitude of heat generated in typical aircraft tires, several test tires were fitted with temperature sensors, or thermistors, mounted at the locations indicated. The actual temperature rise during a variety of free-rolling taxi tests was monitored and recorded. The following charts show the effect of taxi speed, inflation pressure, and taxi distance on internal heat generation for typical main landing gear tires.

## HEAT GENERATION (CONT'D)

A



B



**A** The vertical dotted line at 35 mph (30 knots) indicates the recommended maximum taxi speed. On the above chart, the curves constantly slope upward with higher taxi speeds. In other words, the faster an aircraft travels over a given distance, the hotter the tires will become.

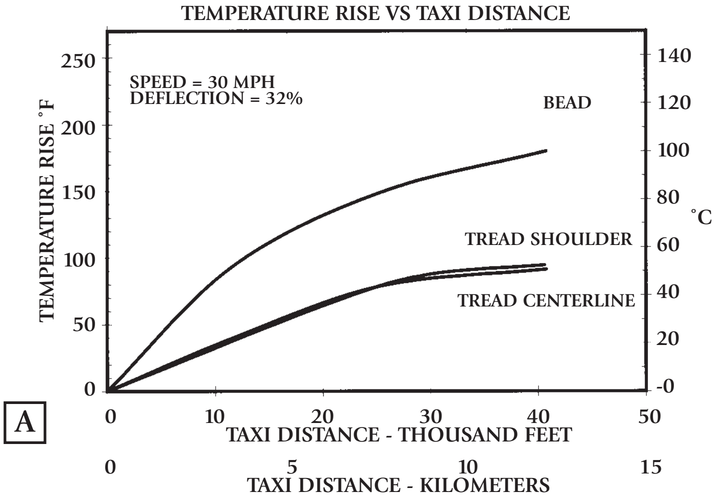
Many people would expect the shoulder area to generate the most heat. In reality, the bead and lower sidewall area are the hottest. There are two major reasons for this:

1. All forces, in or acting on a tire, ultimately terminate at the bead. This is an area of high heat generation.
2. Rubber is a good insulator; or said another way, it dissipates heat slowly. The bead area, being the thickest part of the tire, retains the heat longer than any other part of the tire.

**B** This tire was designed to be operated at 32% deflection, as the vertical dotted line indicates. Left of this line designates overinflation, and to the right underinflation. When the speed and the distance traveled are constant, the more a tire is underinflated the hotter it becomes.

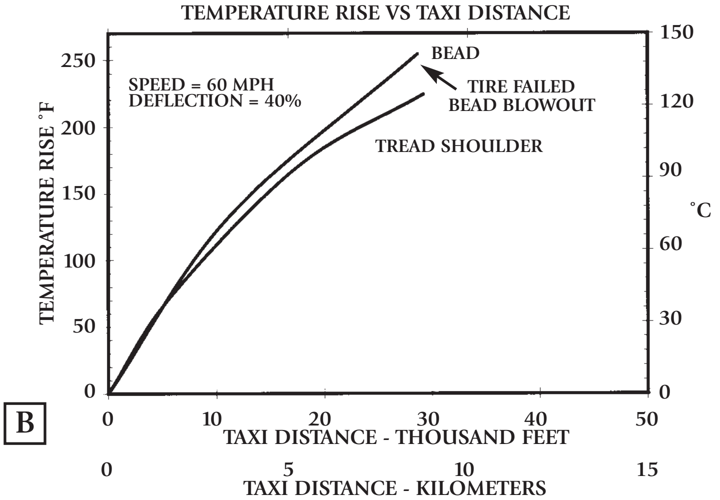
The rate of temperature rise versus underinflation is the highest in the shoulder area due to increased flexing. The bead area, however, still remains hottest.

## HEAT GENERATION (CONT'D)



A

**A** Even when an aircraft tire is properly inflated and operated at moderate taxi speeds, the heat generation will always exceed the heat dissipated. (This is indicated by the ever increasing slope of the lines.) The farther the taxi distance, the hotter the tires will be at the start of the take-off.

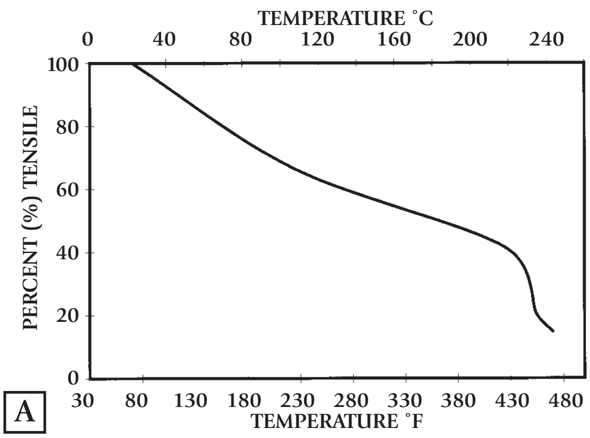


B

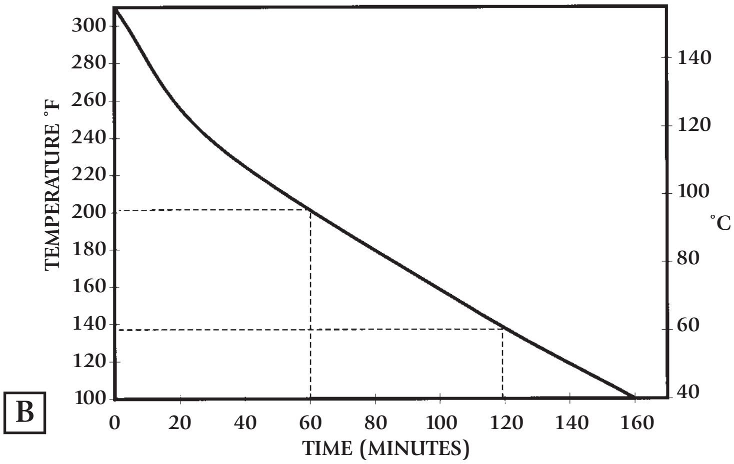
**B** This chart shows the effect of underinflation coupled with the high speed taxiing. A comparison is made between a tire run at 32% deflection and one run at 40% deflection. Not only is the slope of the 40% deflection curves much steeper (due to higher rate of heat generation) than the 32% curve, but the 40% deflection tire blew out in the lower sidewall after traveling about 30,000 feet.

# HEAT GENERATION (CONT'D)

TENSILE VS TEMPERATURE



TIME FOR TIRE TEMPERATURE TO DISSIPATE



**A** The carcass or body of the tire is usually made up of rubber-coated layers of nylon fabric which extend from bead to bead. This fabric, which is anchored to the bead bundles, is a structural member of the tire to give it shape and strength.

As good as nylon is, it has limitations. There is a reduction in strength when exposed to high temperatures. Nylon melts at temperatures slightly above 400°F (200°C).

**Effect of Temperature on Rubber Compounds**

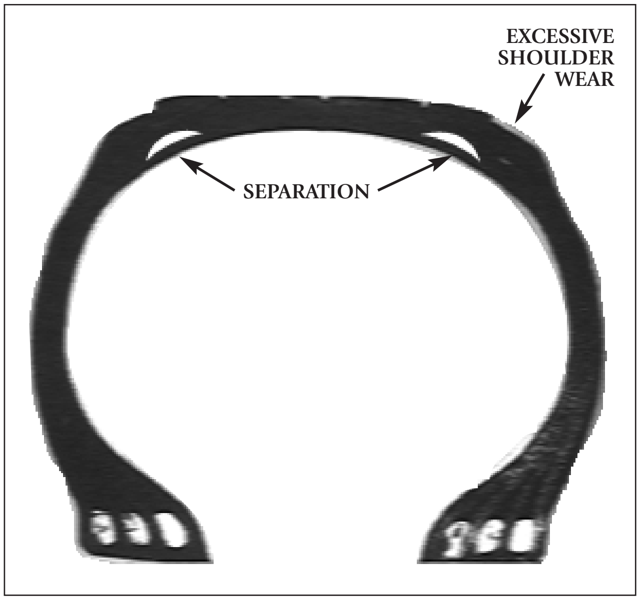
| EFFECTS | °F | °C |
|---|---|---|
| APPEARANCE OF BLUE COLOR | 210 - 230 | 100 - 110 |
| RUBBER REVERTS | 280 - 320 | 140 - 160 |
| RUBBER BECOMES HARD & DRY | 355 - 390 | 180 - 200 |

The physical properties of rubber compounds are also susceptible to degradation by high temperatures. Both strength and adhesion are lost when the rubber reverts to the uncured state. The temperatures shown in the above chart are related to time. Brief exposure to these temperatures are not as damaging to the tire as are prolonged exposures.

**B** On the previous charts it must be remembered that only temperature rise was indicated. Heat is cumulative. This chart shows the time required to cool the bead area of a test tire with two fans blowing on it. This would equal approximately a 30 mph breeze. The curve indicates that the temperature in a hot tire drops 100°F in the first hour and somewhat less in subsequent hours. The cooling time of a tire mounted on an aircraft would be slightly longer due to the effect of brake temperature.

## HEAT GENERATION (CONT'D)

High internal temperatures deteriorate both compound and fabric, resulting in the following problems:

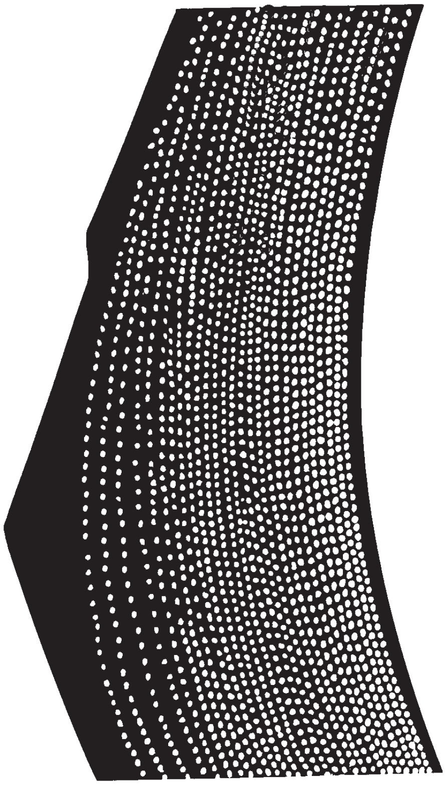


**Tread & Casing Separations** - Here we see separation in both shoulders. The wear pattern indicates this tire was run underinflated.

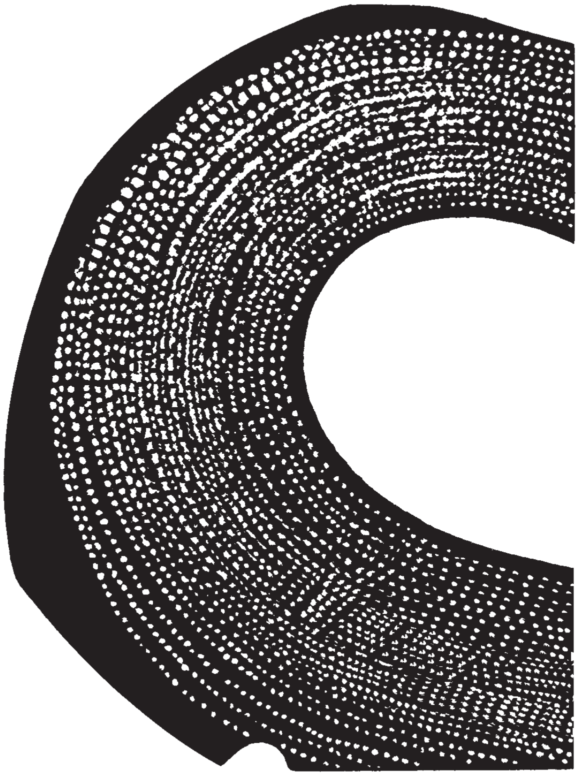
**Bead Face Damage** - Up to now, only heat generated internally has been discussed. This is an example of damage due to external heat from the brakes.

# TENSILE, COMPRESSION AND SHEAR FORCES

A discussion of aircraft tires would not be complete without showing the effect of **LOAD** and **SPEED** on the **TENSILE, COMPRESSION** and **SHEAR FORCE**S within a tire.



**UNLOADED CROSS SECTION**



**LOADED CROSS SECTION**

Tensile, compression and shear stresses can best be visualized by comparing an unloaded tire section to a loaded one as shown in the above photos. The following points can be made:

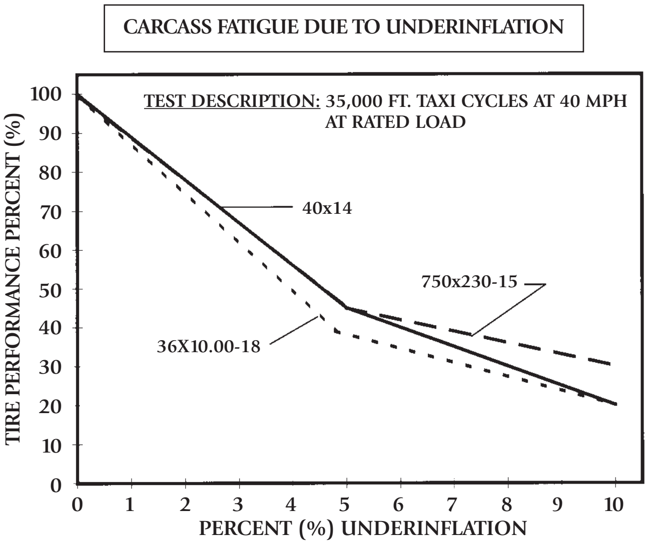
1. An aircraft tire is designed so that in the unloaded condition the internal tensile forces acting on each layer of fabric are uniform.

2. Due to the high deflection of the tire section under the load, the tensile forces on the outer plies will be higher than those on the inner plies.

3. Due to the force gradient from outer to inner plies, shear forces are developed between the various layers of fabric.

4. Underinflating or overloading a tire will increase these shear forces, thus rapidly decreasing the life of an aircraft tire.

## TENSILE, COMPRESSION AND SHEAR FORCES (CONT'D)



To demonstrate how rapid carcass fatigue can occur due to underinflation, the chart above shows the average of three different tire sizes run at the following conditions:

1. One tire of each size was run on successive taxi cycles consisting of 35,000 ft. each at 40 mph. This was repeated until tire failure occurred. Since this tire was properly inflated, the test result was recorded as 100% durability performance.

2. A second tire of each group was run to the same test, but was 5% underinflated.

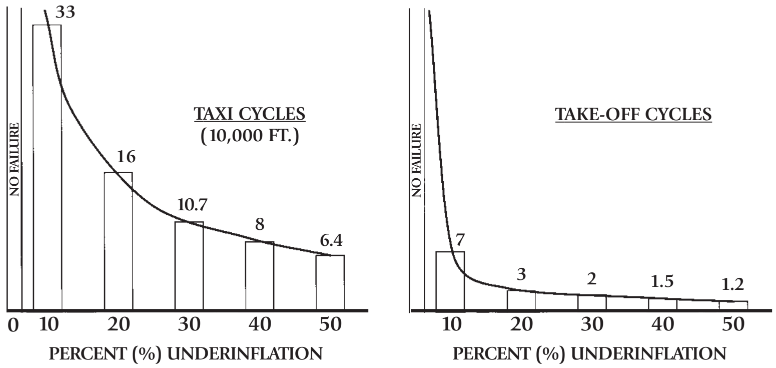
3. A third tire of each group was also run to the same test, but at 10% underinflation.

Obviously, one would expect the tire durability to decrease with underinflation. What's impressive, however, is the magnitude of reduction.

To further study the effect of underinflation on tire failure, additional tests were run on the dynamometer. Several tires, at various degrees of underinflation, were run to failure. Some tires were run to take-off cycles and others to 10,000 ft. taxi cycles. As would be expected, the cycles to failure decrease as the percent of underinflation increases.

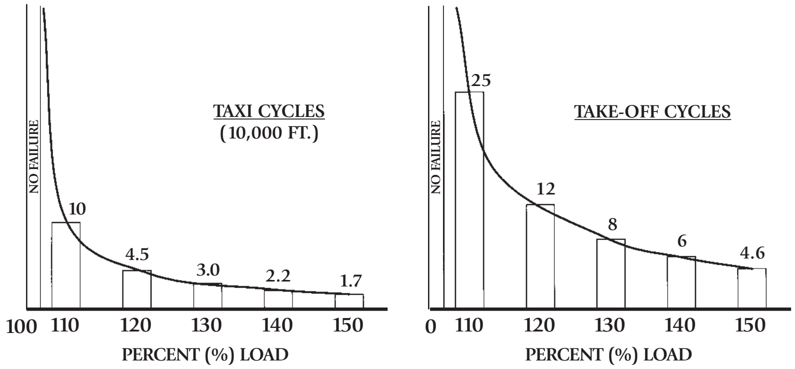
## TENSILE, COMPRESSION AND SHEAR FORCES (CONT'D)

CYCLES TO FAILURE VERSUS UNDERINFLATION



A couple of interesting findings in this study were that all the taxi cycle failures were blowouts in the lower sidewall, while the take-off cycle failures were thrown treads. From the shape of the curves we see that take-off cycles were more sensitive to underinflation than were taxi cycles.

CYCLES TO FAILURE VERSUS OVERLOAD



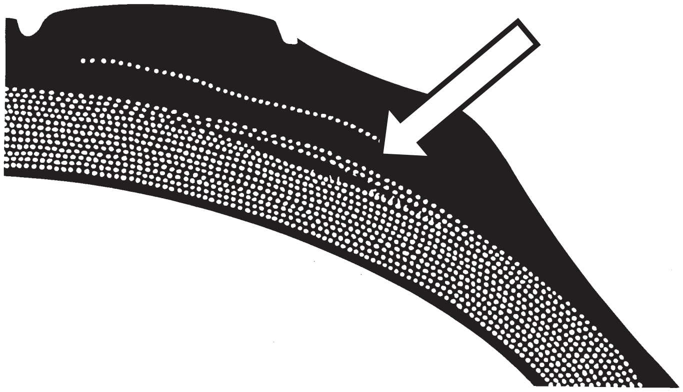
To determine if overloading has the same detrimental affect on tire life as underinflation, the same tests were run on several tires with increasing overloads. As expected, the more a tire is overloaded the quicker it fails.

A couple of interesting findings in this study were that all the taxi cycle failures were still lower sidewall blowouts, and only thrown treads occurred during the take-off cycles. This test shows that taxi cycles are more sensitive to tire overloading.

## TENSILE, COMPRESSION AND SHEAR FORCES (CONT'D)

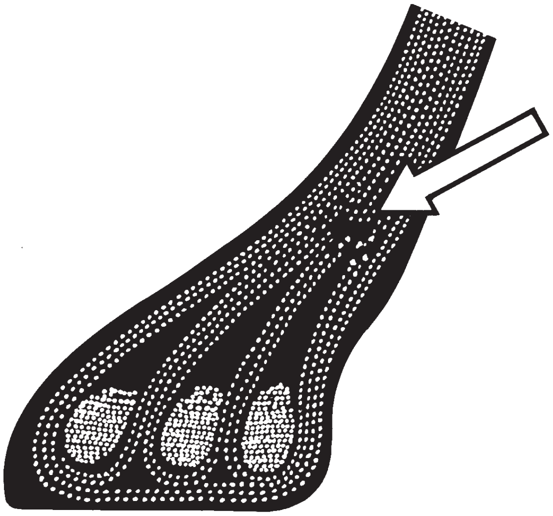
Tensile, compression, and shear forces in aircraft tires are extremely high. When the tires are not properly maintained, these forces go even higher until the compound and/or fabric start rapid deterioration. When this happens the following problems can occur:

**SHOULDER SEPARATION**



Shoulder separation is most likely to occur between outer plies where the shear forces are highest.

**LOWER SIDEWALL COMPRESSION BREAK**



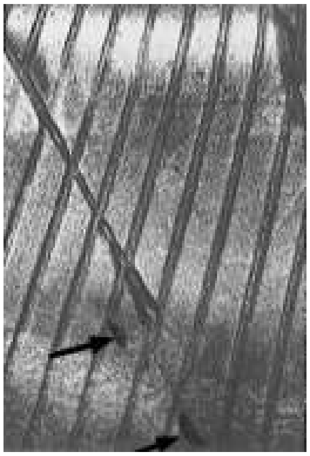
This is the start of the type of failure caused by underinflation or overloading. The above photo shows carcass cords above the bead area that are starting to fail due to flex fatigue.

## TENSILE, COMPRESSION AND SHEAR FORCES (CONT'D)

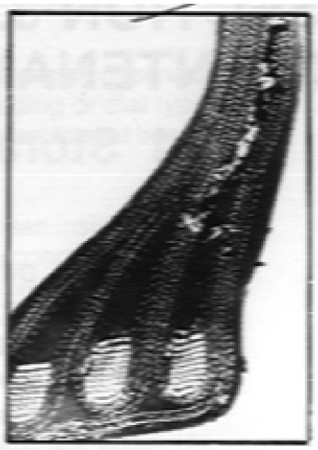
These photos show how underinflation or overloading can cause lower sidewall compression flex breaks.

**Sidewall Crack** - The first signs of compression flex break in the lower sidewall can appear on the outside sidewall or the inside liner. This photo shows a crack developing in lower sidewall.

**Liner Crack** - The first signs of a compression flex break can also appear on the inside liner. This condition will also be apparent by tire pressure loss. This pressure loss then magnifies the problem, resulting in sidewall blowout.



**Massive Separation** - During the creation of a sidewall or liner crack, the carcass plies on the inside become severely deteriorated, along with massive separations. This results in possible sidewall blowout.



These three photographs show the stages of progression. Never mistake these conditions for simply a sidewall or liner crack, as a blowout is imminent.

# 7 Effects of Operating Conditions

## TIRE INFLATION

Heavy loads and high speeds are here to stay. In fact, they will probably get worse in the future. If they do, centrifugal force, heat generation, tensile, compression and shear forces will also increase.

This section has shown that aircraft tires will function properly only when they have the correct inflation pressure. It has also shown that there is a relatively small amount of tolerance in the amount of deflection in which the tire can operate effectively.

Many times we think we can look at the tire deflection and determine if it is under-inflated as we often do with our passenger car tires. This judgment is even more difficult with the aircraft sitting unloaded and low fuel, a condition typical when tire pressures are taken.

**QUESTION:** Can you tell which tire in this nose gear is underinflated?

**ANSWER:** No. You cannot tell by looking. The "mate" tire will share the load and the two tires will look equal. Therefore, you should always use a calibrated inflation gauge to check tire pressure.

On a four-wheel or six-wheel gear, visual inspection of a low pressure tire is even worse, as there are more tires picking up the load from the underinflated tire.

**IMPORTANT - INFLATION PRACTICES**

**(See Section 2, Proper Inflation Procedures)**

1. **CHECK DAILY WHEN TIRES ARE COOL**
2. **INFLATE TO WORST CONDITIONS**
3. **USE DRY NITROGEN GAS (SAFELY)**
4. **INCREASE PRESSURE 4% FOR TIRES UNDER LOAD**
5. **ALLOW 12-HOUR STRETCH AFTER MOUNTING**
6. **NEVER REDUCE THE PRESSURE OF A HOT TIRE**
   **REMEMBER – 1% PRESSURE CHANGE FOR 5°F (3° C)**
7. **EQUAL PRESSURE FOR DUALS**
8. **CALIBRATE INFLATION GAUGE REGULARLY**

**NOTE:** Following the suggested maintenance procedures and operating techniques in this manual can greatly extend tire life.

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Goodyear warrants that, when operated and maintained in accordance with approved instructions, every new tire or tube bearing Goodyear's name and complete serial number, or retread bearing Goodyear's or Air Treads' name and serial number, is warranted to be free from defects in workmanship and material. The sole and exclusive remedy for the customer for a tire, tube, or retread returned to us freight prepaid and determined by us to be defective, or which there is a pro-rata charge for service, is the repair or replacement of such tire, tube, or retread, or other suitable allowance.

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