NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Aviation Engineering Division
Washington, DC 20594

September 11, 2009

AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL ADDENDUM FOR TIRE, WHEEL, AND BRAKE DOCUMENTATION WITH AIRCRAFT TIRE STUDY

A. **ACCIDENT:** DCA08MA098

LOCATIONS: Columbia, South Carolina

DATE/TIME: September 24, 2008

AIRCRAFT: Learjet Model 60, N999LJ, S/N 60-314

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C. SUMMARY:

On September 19, 2008, at about 11:53 p.m. EDT, a Learjet Model 60 (N999LJ) operated by Global Exec Aviation as an on-demand passenger flight under 14 CFR Part 135 overran runway 11 while departing Columbia, South Carolina, enroute to Van Nuys, California. The 2 crewmembers and 2 of the 4 passengers were fatally injured, the other 2 passengers suffered serious injuries. The aircraft was destroyed by an extensive post-crash fire. Weather was reported as clear with light winds.

The Airworthiness Group Chairman's Factual Report of July 22, 2009, contained information about the airframe and airplane components that were found. The Factual Report described where the tire debris was found, how those tire fragments were grouped into bags, and the TotalStation laser survey equipment that was used to precisely identify where on the airport each bag came from. This document describes reconstruction of the main landing gear tires, tire-related maintenance information, as well as other tire-related data that was identified during the investigation.

The material in this addendum was developed partially from an Airworthiness Group meeting of September 29-October 1, 2008, that examined the wheels, tires, and brakes at the Goodyear Engineering Technology Laboratory (ETL) in Akron, Ohio. Most of the same participants met a second time at the ETL on January 7-9, 2009, to further document the tire fragments, conduct tire reconstructions, and examine potential sources of damage. Two additional meetings were held at Learjet engineering offices in Wichita, concluding with a review of landing gear certification on February 2-5, 2009. No evidence of anomalies in Goodyear main landing gear tire design or construction was found.

Remnants of all four main landing gear tires were spread along the runway, with the airplane past the end of the foot runway and Runway Safety Area (RSA). Airplane stopping distances to remain within runway and RSA protections are based in the use wheel/tire braking and with all tires available. Performance data showed that the accident airplane should have been able to reach rotation speed and stop within the Columbia runway and RSA. Following failure of tires, transport-certified airplanes, including Learjets, have gone farther than was available at Columbia.

> Note: Many single-engine general aviation airplanes use tires that carry the proportionate load that automotive tires carry, use similar inflation pressures of less than 40 psi, and have similar sidewall thicknesses. This report primarily addresses high pressure tires that are common in transport-certified airplanes (14 CFR Part 25).

The fragments along the path of travel progressed from the outboard right tire to the outboard left tire. The spacing between the first pieces from each of the main landing gear tires was about 600 to 800 feet along the runway. The first fragments along the runway path were from the outboard right tire's sidewall. The Goodyear C&M notes that testing found sidewall damage to be predominantly consistent with taxi cycles and under-inflation, as opposed to other types of damage.[1]

Evidence consistent with operation at low pressure in each of the tires was found in the forms of liner abrasion and heat damage to the rubber and nylon fibrous cord materials.[2] Physical evidence and statements by the operator's Director of Maintenance were consistent with the tire pressures not having been checked for about three weeks prior to the accident flight. Three weeks at the rate of pressure loss (permeation) found in other airplanes resulted in potential pressure values that at which the Learjet Model 60 Airplane Maintenance Manual (AMM) called for tire replacement. Tire manufacturer publications from Goodyear, Michelin, and Bridgestone each state that under-inflation would not be visible.

The AMM did not cite daily tire pressure checks in the portion that prescribed the scheduling of maintenance. The Learjet Model 60 AMM and publications from each of the tire manufacturers contained guidance that specifically stated that tire pressures should be checked daily or before a day's first flight. Guidance calling for daily and/or "regular" checks of tire pressure were found in Advisory Circular (AC) AC 20-97B, in Learjet maintenance publications and in maintenance manuals for other jet airplanes operated by Global Exec.

Following the initial tire fragments in the debris path, black swerve marks had been found on the runway at Columbia. The swerve marks could be followed directly into the wheel rim tracks that led off the end of the runway and ground damage that led to the airplane wreckage.[3] The FAA requirements did not include side-loading as part of tire certification.[4] The FAA requirements and Learjet performance data concerning the tires were based in static loadings and with the tire held perpendicular to a dynamometer

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[1] The Goodyear Tire and Rubber Company, 1144 E. Market Street, Akron, Ohio 44316. Document: Goodyear Aircraft Tire Care And Maintenance Manual (Rev 10/04). Taxi cycle reference from page 45. Indications of inflation and other types of damage may be found on pages 14-42.

[2] The evidence was of over-deflection of the tire wall, which could technically also be from over-loading. This report contains photographic and text descriptions of the evidence, as well as results of group discussions about the differences between lack of proper inflation and overloading.

[3] The Airworthiness And Maintenance Group Chairman's Factual Report of July 22, 2009 contain photographs and runway illustrations as Figures 3-7.

[4] Lateral load requirements do exist for wheel/tire assemblies in TSO C26c.

during load, speed, and time tests (includes acceleration).[5] These requirements and performance verification tests were based upon ideal tire pressures.

Within the FAA certification requirements, the investigation found that the loss of one tire could overload the remaining Learjet Model 60 tires sequentially. This report includes research into previous and subsequent takeoff tire failure records.

The Learjet Model 60 was certified as airworthy when the airplane was added to the Learjet Type Certificate Data Sheet on January 15, 1993. The certification included similarities that existed to the original Learjet designs of the 1964 Type Certificate for the Model 24 airplane.[6] Some 14 CFR Part 25.1309 changes in regulations and Advisory Circular guidance that were put in place between 1965 and 1993 were not applicable, beyond addressing the electronic flight instrumentation and thrust reversers. (Part 25.1309 describes that equipment, systems, and installations "performed their intended functions under any foreseeable operating condition.")

The high-pressure Learjet tire design was based in intermittent service and tires on highway vehicles are generally based in continuous service. A review did find common aspects and one aspect of tire design applicable to any vehicle with multiple tires on an axle is requirement for a design margin (ratio). This is described respectively by the Federal Aviation Administration (FAA) for aircraft and the National Highway Traffic Safety Administration (NHTSA) for surface vehicles. The design margin accounts for unequal load sharing between tire on a multi tire axle to account for uneven surfaces, unequal inflation pressures, and other factors. The FAA requires a design margin of 1.07 for the ratio between rated load and service load. The NHTSA requires a ratio of 1.10 for motor vehicles (trucks, busses, etc) in commercial service.[7]

The FAA Technical Standard Order (TSO) TSO-C62 describes aircraft tires and the Model 60 used tires certified at the TSO-C62c revision. The FAA subsequently revised the TSO to TSO-C62e on September 29, 2006.[8] Also during this time, NHTSA investigated a series of vehicle roll-over accidents involving tire failures and the United States Congress enacted the Transportation Recall Enhancement, Accountability, and Documentation Act (TREAD Act), resulting in NHTSA issuance of Federal Motor

[5] The FAA requirements include other non-dynamic tests, such as allowable rates of air retention. There are no braking tests.

[6] All Learjets except the Models 23 and 45 have been certified by the FAA on Type Certificate A10CE. The earliest model on the Type Certificate was the Model 24, on March 17, 1966. The revision to add the Model 60 was dated January 15, 1993. See also: FAA Order Number 8110.48, dated 04/25/2003, titled "How to Establish the Certification Basis for Changed Aeronautical Products" and the history for this Handbook.

[7] Only the margins shown are what aircraft and surface tire requirements list in similar terms. The tires in each are de-rated in other requirements that are not in similar terms. Aircraft have a TSO-C62c (Section 5.a(8)) overload takeoff test requirement of 1.5 times the load used in the Takeoff Cycles test. This test is performed at nominal inflation and good condition of the tread is not required at completion. The NHTSA FMVSS 119 and 139 requirements de-rate surface vehicle tires in terms of Gross Axle Weight Rating, then add other requirements, such as testing at less than nominal inflation and pressing plungers into the tread to ensure passage of minimum static breaking energy tests.

[8] Current revision is TSO-C62e. The revision at the time of Learjet Model 60 certification was TSO-C62c.

Vehicle Safety Standards (FMVSS). The FMVSS 139 (49 CFR 571.139) applicable to automotive and light truck tires became effective on June 1, 2007, following the FAA revision to TSO-C62e. The change to FMVSS 139 added dynamic performance and other requirements that do not exist in the current FAA certification requirements for aircraft landing gear and tires.[7] The NHTSA investigation also resulted in issuance of FMVSS 138 for tire pressure monitoring systems (TPMS) in motor vehicles, and mandating adoption of such systems.

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D.1 BACKGROUND: TIRE DESIGN AND CONSTRUCTION

Note: Text and many of the illustrations in this background section were copied from the Goodyear Tire Care and Maintenance (C&M).[9] Publications were also obtained from Bridgestone, Michelin, and Dunlop.[10] The tire design and construction sections of the three company publications were found to be similar, so while the Goodyear material is cited most, the material from the other companies is cited when the wording or illustrations are more clear. Some interpretation and added details are from an engineering discussion about tires that took place at Wichita during meetings of February 2-5, 2009.

Tires are a multi-component item consisting of three major materials: steel, rubber and fabric. By weight, an aircraft tire is approximately 50% rubber, 45% fabric, and 5% steel. The fabric and steel are placed in tension to carry the loads between the contact surface and the wheel. The rubber binds together the load carrying components, retains pressure in the bladder, and provides a wear surface. (See Figure 1)

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[9] The Goodyear C&M is available at http://www.goodyearaviation.com/resources/pdf/aircraftmanual.pdf
The acronym C&M is used throughout this report for the Care and Maintenance publications from the tire manufacturers, although each tire manufacturer uses a slightly different name, such as the Michelin Aircraft Tire Care and Service Manual.

[10] Source #1: Michelin Aircraft Tyre, 23, place des Carmes-Dechaux, 63040 Clermont-Ferrand Cedex 9 – France. Text has been copied from the Michelin C&M and Training Guides, available at: http://www.airmichelin.com/generalcontent.aspx?id=1312
Source #2: Dunlop Limited Aircraft Tyres Limited, 40, Parkway, Erdington, Birmingham B249HL, England. Document: http://www.dunlopaircrafttyres.com

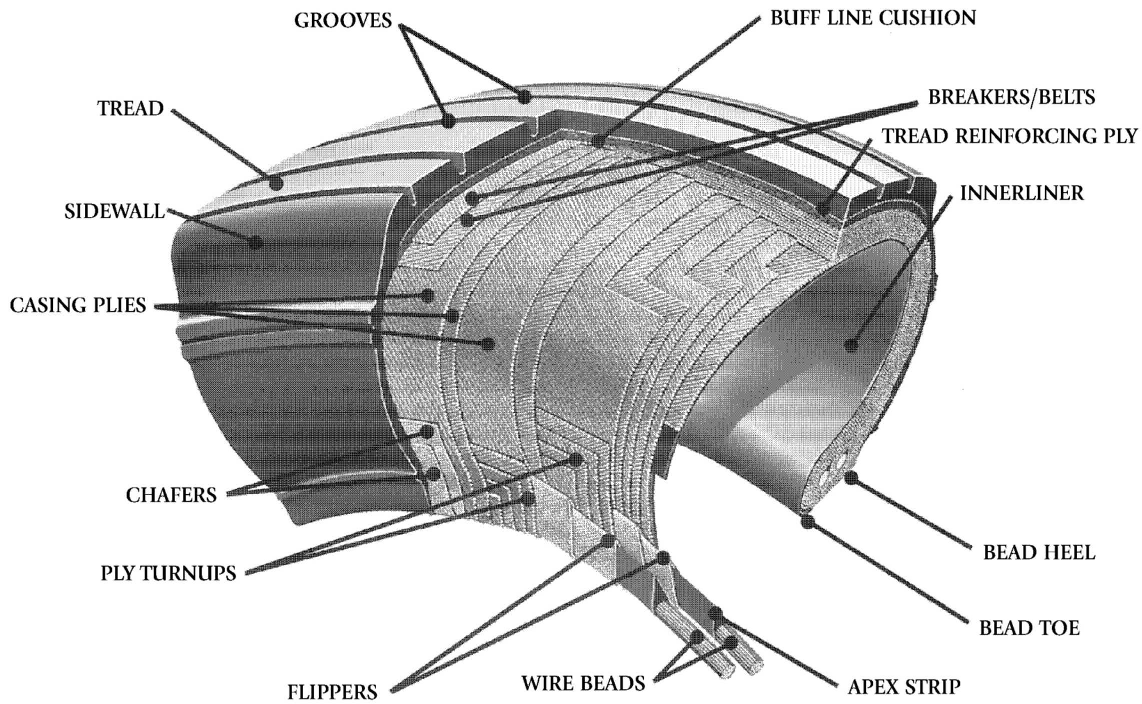


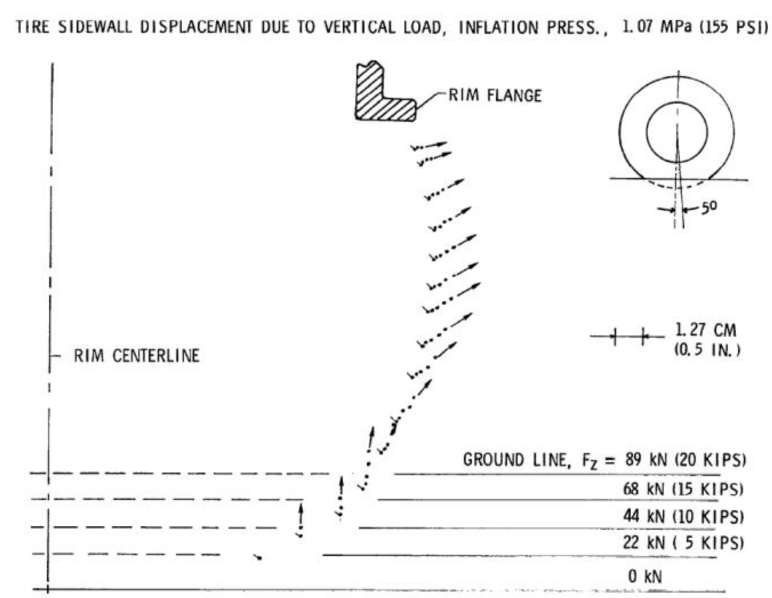
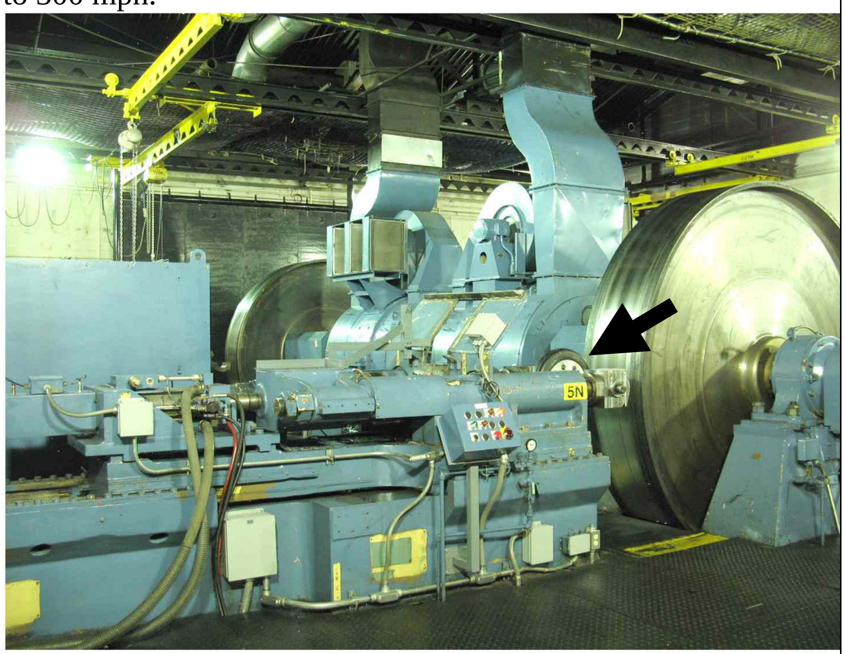
Figure 1. Bias-ply tire construction illustration from the Goodyear C&M.

D.1.1 GLOSSARY

The following terminology is used in this report:

Aspect Ratio	Measure of the tire's cross section shape. This can be calculated by the following formula: Aspect ratio = Section Height divided by Section Width
Bead	The beads or bead wires anchor the tire to the wheel. Beads are fabricated from steel wires layered together and can be embedded with rubber to form a bundle. The bundle is then wrapped with rubber-coated fabric for reinforcement. Depending on the size and design application, bias tires are constructed with 2 to 6 bead bundles (1 to 3 per side).
Bead Heel	The bead heel is the outer bead edge that fits against the wheel flange.
Bead Toe	The bead toe is the inner bead edge closest to the tire centerline.
Bias-Ply Construction	Bias aircraft tires feature a casing constructed of alternate layers of rubber coated ply cords which extend around the beads and

	are at alternate angles substantially less than 90° to the center line of the tread. Succeeding plies are laid with cord angles opposite to each other, to provide balanced carcass strength.
Breakers	Breakers are reinforcing plies of rubber coated fabric placed under the buffline cushion to protect casing plies and strengthen and stabilize tread area. They are considered an integral part of the casing construction.
Camber	The angle between the vertical axis of the wheel and the vertical axis of the vehicle when viewed from the front or rear.
Carcass Ply (Casing Ply)	Fabric cords sandwiched between two layers of rubber. The fabric used in the Learjet Model 60 main landing gear tire is nylon. The carcass body itself is made from multiple layers of carcass plies, each one adding to the strength and load bearing capability of the tire. The carcass plies are anchored by wrapping them around bead wires, thus forming the ply turn-ups.
Casing Plies	Plies are alternate layers of rubber-coated fabric (running at opposite angles to one another) which provide the strength of the tire.
Chafer	A chafer is a protective layer of rubber and/or fabric located between the casing plies and wheel to minimize chafing.
Deflection	The difference between a tire's unloaded or free radius and the loaded radius. The Goodyear C&M states that "The term % Deflection is a calculation made using the following formula: % Deflection = (Free Height – Loaded Free Height)/(Free Height.)" The following illustration is from "Overview Of Nasa Tire Experimental Programs" by John A. Tanner, and shows the change in sidewall position at various deflections due to changes in vertical load.

	
Dynamometer	A tire test system, in which the tire is pressed against a large steel wheel that is driven by an electric motor. The conditions and results are recorded in a separate room. The following are a set of two aircraft testing dynamometer wheels at the Goodyear laboratory, with an arrow showing a test tire. The large steel wheels are 120 inches (10 feet) in diameter and two test tires can be run against each of the large steel wheels at speeds of up to 300 mph. 
Eutectic	The proportion of constituents in an alloy or other mixture that yields the lowest possible complete melting point. At the eutectic, the solidus and liquidus temperatures are the same.

Flippers	These layers of rubberized fabric help anchor the bead wires to the casing and improve the durability of the tire.
Grooves	Circumferential recesses between the tread ribs.
Inflation Pressure	Inflation pressure pre-tensions the fabric plies in the construction of a tire. Every rotation is a fatigue cycle for the fibers in the plies. Incorrectly inflated or overloaded tires may result in the fibers cycling between tension and compression, rather than remaining in tension.
Liner	In tubeless tires, this inner layer of low permeability rubber acts as a built-in tube and restricts gas from diffusing into the casing plies.
Ply	Casing plies are anchored by wrapping them around the wire beads, thus forming the ply.
Ply rating	The term “ply rating” is used to indicate an index to the load rating of the tire. Years ago when tires were made from cotton cords, “ply rating” did indicate the actual number of plies in the carcass. With the development of higher-strength fibers such as nylon, fewer plies are needed to give an equivalent strength. Therefore the definition of the term “ply rating” (actual number of cotton plies) has been replaced to mean an index of carcass strength or a load carrying capacity.
Radial Construction	As opposed to bias-ply construction, each carcass ply is laid at an angle approximately 90° to the centerline or direction of rotation of the tire. Each successive layer is laid at a similar angle. Radial constructed tires of the same size have a fewer number of plies than do tires of a bias construction, because the radial cord direction is aligned with the burst pressure radial force. From the February 2-5, 2009 meetings: Aircraft tires have historically been bias-ply, but the industry is adopting radial-ply tires. Radial tires are lighter than the equivalent size bias-ply tire. The weight benefit lessens as the tire size decreases. Changing the specific tire for an airplane application also requires complete certification testing. The adoption of radial tires has been most rapid in the fleet of large airplanes that consume more tires and have greater weight potential weight benefits associated with requiring larger tires.
Rated Load	The maximum allowable load that the tire can carry at a rated inflation pressure.

Rated Pressure	Rated pressure is the maximum inflation pressure to match the load rating. Aircraft tire pressures are given for an unloaded tire; i.e, a tire not on an airplane. When the rated load is applied to the tire, the pressure increases by 4% as a result of a reduction in air volume.
Rated Speed	Maximum speed to which the tire is qualified.
Sidewall	The sidewall is a protective layer of flexible, weather-resistant rubber covering the outer casing ply, extending from tread edge to bead area.
Section Height	This measurement can be calculated by using the following formula: Section Height = (Outside Diameter - Rim Diameter)/2
Section Width	This measurement is taken at the maximum cross sectional width of an inflated tire.
Serial Number	Goodyear serial number codes consist of eight (8) characters. For the example: YJJJNNNN, position 1 (Y) represents the year of production, positions 2, 3 and 4 (JJJ) signify day of year (Julian Date), positions 5, 6, 7 and 8 (NNNN) signify the Individual Tire ID Number. Tires manufactured in the Goodyear Danville plant range from 0001 to 4999
Service Load (Operational Load)	Load on the tire at maximum aircraft takeoff weight.
Service Pressure (Operational Pressure)	Corresponding pressure to provide proper deflection at service load.
Tread	The tread refers to the crown area of the tire that operates in contact with the ground. Most aircraft tires are designed with circumferential grooves molded into the tread area. The grooves provide a means to cool the tire and channel water from between the tire and runway surface, which helps to improve ground adhesion. The tread compound is formulated to resist wear, abrasion, cutting, cracking and heat build-up. It helps prolong the life of the casing by protecting the underlying carcass plies.
Tread	One or more layers of fabric that strengthen and stabilize the

reinforcement	tread.
Vented Construction	The outer layers of sidewall construction in an aircraft tire may have small vent perforations, typically near the bead and wheel rim. These perforations prevent pressure from developing between the plies, which could lead to delamination of the construction layers.

The serial numbered side of a Goodyear tire is normally mounted outboard from the brake, because that side has a red colored balance dot which is aligned with the inflation valve during assembly. This became a reference point during reconstruction of the accident tires. (See Figure 2) Additional nomenclature was found on the tire sidewalls.

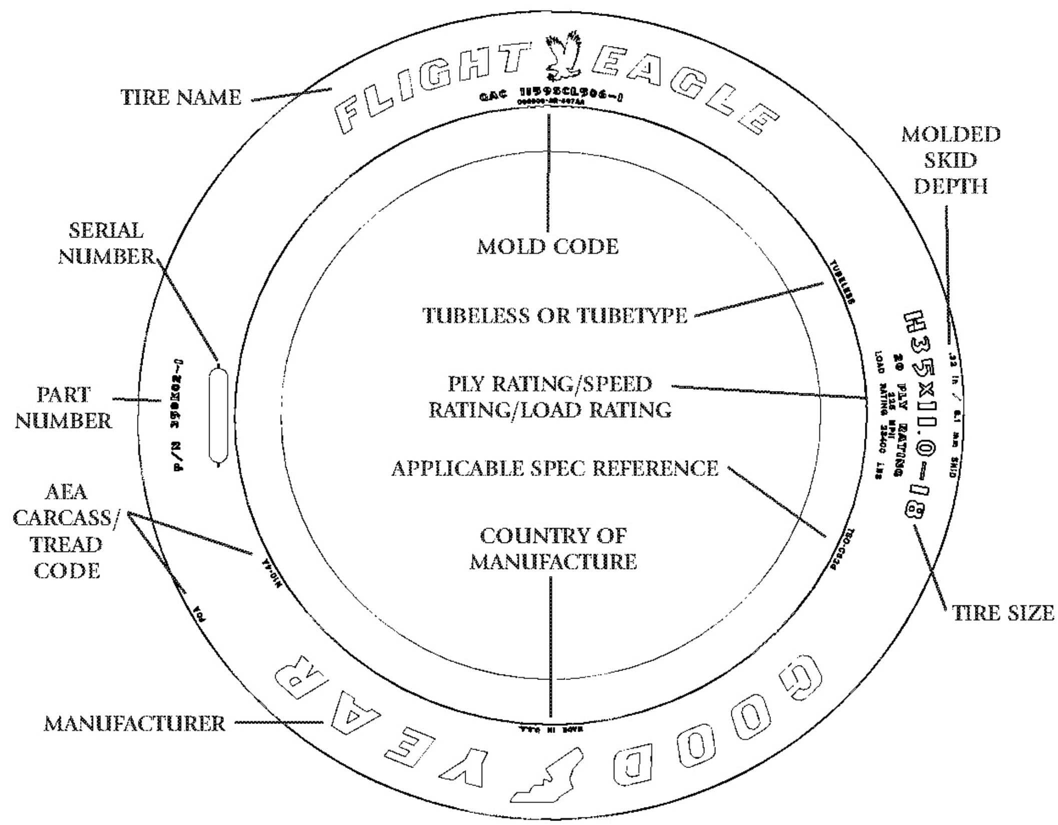


Figure 2. Tire sidewall nomenclature cited in the individual fragment descriptions, copied from the Goodyear C&M. These features were used for pattern-matching in reconstruction of the accident airplane tires.

D.1.2 BACKGROUND, AIRCRAFT TIRE LOADS:

Goodyear personnel noted repeatedly that a normal person's tire knowledge is based in familiarity with what is installed on an automobile, but that there are substantial differences between auto and aircraft tires. The Goodyear C&M conveyed the same message, stating that:

> "the major design philosophy of an aircraft tire, as compared to other tire types such as passenger and truck tires, is that the aircraft tires are designed for intermittent operation. Because of this design feature and to allow the lowest possible ground bearing pressure, the aircraft tire operates at much higher deflections than other tire types" and "aircraft tires are designed to operate at 32% deflection, with some at 35%. As a comparison, cars and trucks operate in the 17% range. The tires may be similar in size, but that is where similarities end."

The Goodyear C&M provides a comparison of two 27-inch diameter tires and the characteristics of the aircraft tire cited have similarities to the tire installed on the Learjet Model 60. The cited aircraft tire carries 9650 lbs., which is approximately six times the passenger tire load of 1598 lbs. It is also traveling over twice as fast. The operating pressure of the aircraft tire is almost 6 times that of the passenger tire, and the aircraft tire is operating at a deflection of 32%, as compared to what is shown to be 11% for the passenger tire. The Load per Tire Weight ratios of the two are 244 for the aircraft tire and 78 for the passenger car tire.

Further showing the differences between aircraft and other tires, the following paragraphs and Figure 3 are also quoted from the Goodyear C&M:

> The heavy load coupled with the high speed of aircraft tires makes for extremely severe operating conditions.
>
> Only Aircraft tires have the worst of both loads and speeds. This means that maintenance practices and operating techniques that work fine for passenger tires are not acceptable for aircraft tires. Because of the severe conditions under which aircraft tires operate, any deviation from proper techniques and practices will have severe consequences.
>
> 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. Because the tire is pneumatic, it deflects when coming into contact with the ground. 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. An average tread for [an example

30 inch diameter] tire would weigh approximately 8 lbs. At 100 mph, this example tire would have a force at the tread of 500-G's, causing a single ounce to exert a force of 33 pounds, and the tread to be able to exert a force of 4,000 pounds. The effective weight of the total tread at 200 mph would be 16,600 lbs.

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.

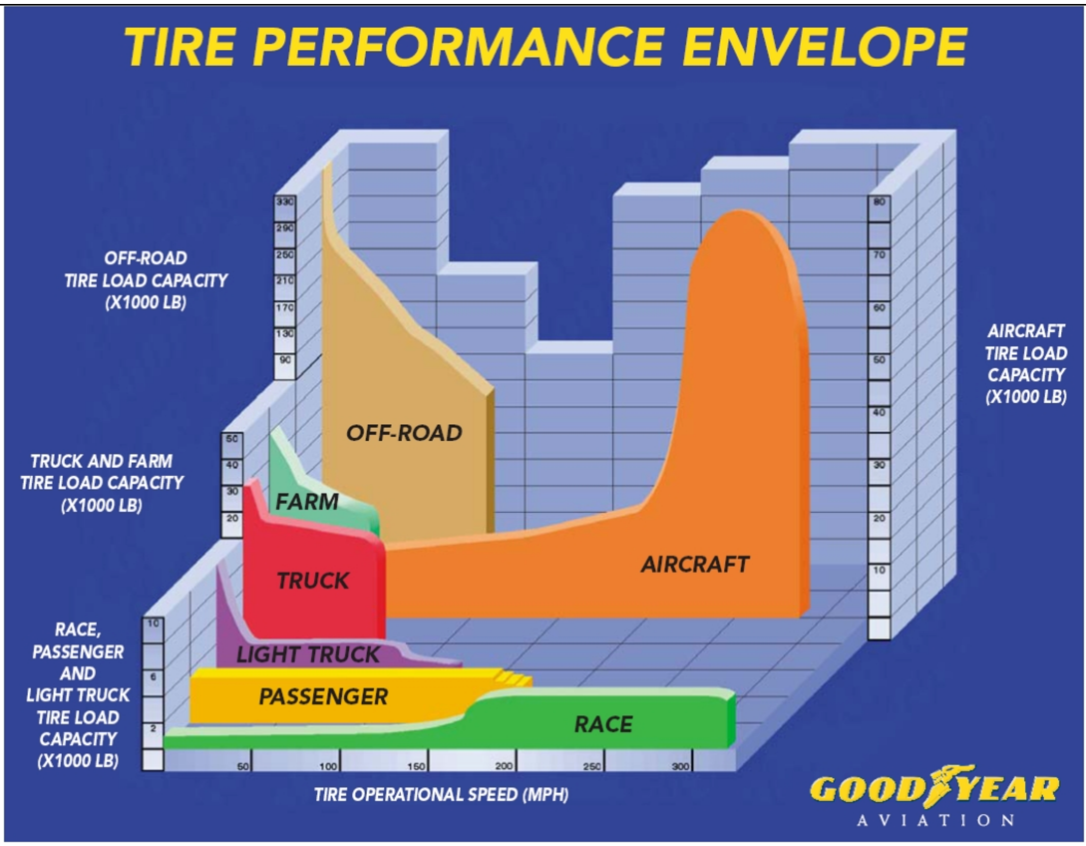


Figure 3. Goodyear Tire Performance comparison chart, from Goodyear C&M and Goodyear web-site.

Because of the high centrifugal forces that can be released when tires are occasionally destroyed during tests, the wall of the dynamometer room at the Goodyear laboratory is covered with diamond-plate steel surfaces. Tire fragments have dented the plates in numerous places. (See Figure 4)

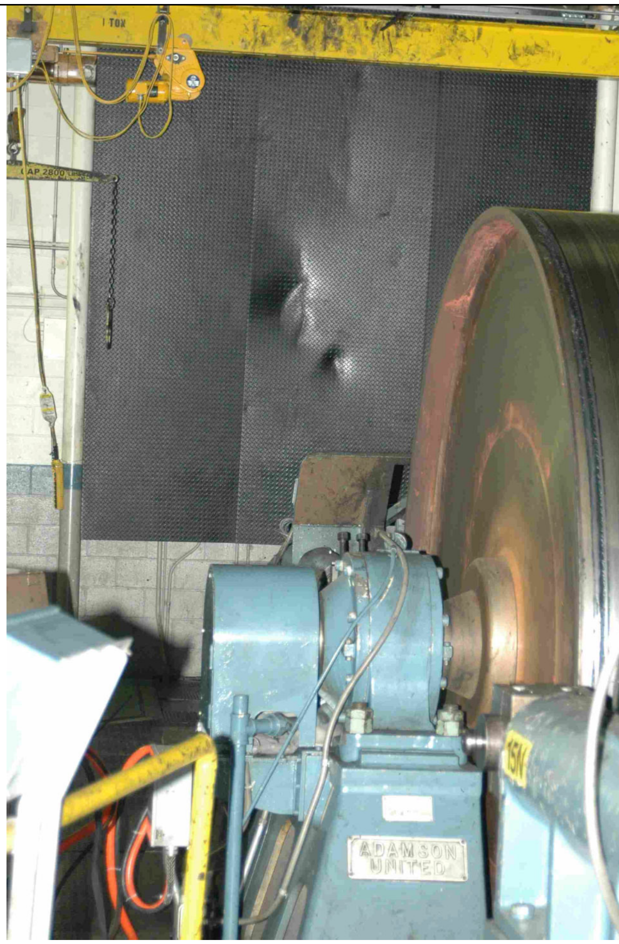


Figure 4. Dents in the diamond-plate steel on the walls of the Goodyear dynamometer test room. For scale reference, the large steel wheel is 120 inches in diameter and the smaller dent is fully the size of a man’s fist.

D.1.3 BACKGROUND, AIRCRAFT TIRE HEAT GENERATION

To accomplish the increased loading of an aircraft tire, the construction is very different than that of an automotive tire. Tires on surface vehicles are designed to permit continuous use through less heat creation and more opportunity for cooling, than are the type of high-pressure tires installed on the Learjet and other 14 CFR Part 25 airplanes. The high-pressure, high speed, tires are designed for intermittent use that is followed by lengthy periods of cooling. For the same speed, a smaller diameter aircraft tire may heat faster, due to faster rotation. The aircraft tire utilizes more plies, additional beads, and thicker construction for the increased loading, causing the tire carcass to be substantially thicker. The following are section views of the construction of a tire from a Learjet Model 60, taken during the N999LJ investigation, and of a typical automotive tire. (See Figures 5 and 6) Note that the high-pressure aircraft tire walls may be thick and have proportionately little surface area for heat rejection when compared with the thin-wall structure and large surface area of the automotive tires that carry significantly less load.

Note: Many single-engine general aviation airplanes use tires that carry the proportionate load that automotive tires carry, use similar inflation pressures, and have similar wall thicknesses. This report primarily addresses high pressure tires that are common in transport-certified airplanes (14 CFR Part 25).

Figure 5. Section of tire from Learjet Model 60, showing thick construction and less relative surface area than in an automotive tire. Note six-inch ruler across top of the tire for scale.

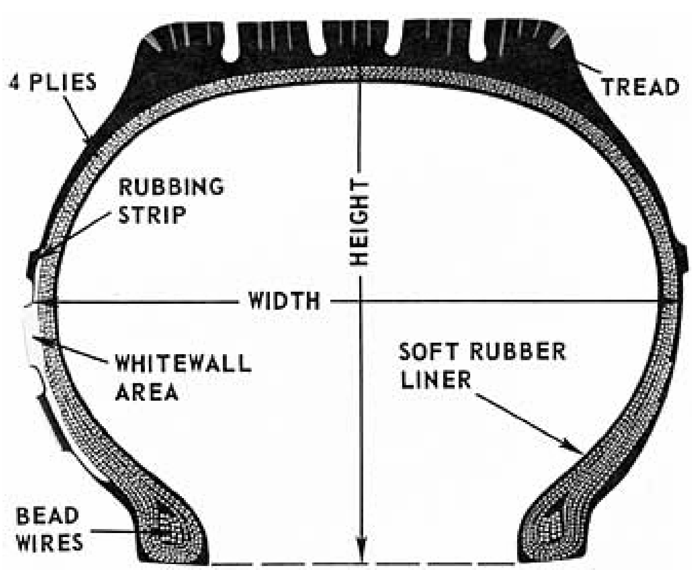


Figure 6. Typical section of automotive tire.

The flexing of tires creates heat in the construction itself, as the rubber molecules move in relation to each other. The Goodyear C&M does not cite how the heat is created, but the Michelin C&M captures the concept of heat generation in the following passage:

> An aircraft tire in use is capable of generating high internal temperatures. This is a result of the natural hysteretic nature of tire materials and the relatively high tire deflections necessary for the loads carried. The fact that rubber is a poor conductor of heat accentuates this problem. The magnitude of this temperature rise is dependent on the duration of service and the speeds obtained. Excessive heat buildup from running overloaded or under-inflated as well as from high taxi speeds is detrimental to the functional life of the tire. High heat will also adversely affect the wear characteristics of the tread rubber.

As discussed at the Wichita group activity of February 2-5, 2009, the Learjet installations are designed for 32% deflection. These values are relatively standardized and come from the Tire and Rim Association (TRA). Goodyear engineering personnel related that the reason for the values was that prior testing found these values as approximately at the knee of a curve in a plot of heat generation versus deflection.

Goodyear personnel and the C&M's show that takeoff is worse for tires than landing. The reasons listed in the C&M for this include:

1. Rubber is an insulator and heat may be retained from a previous flight.
2. Heat is generated during taxi to the runway, versus being allowed to cool at altitude during cruise flight.
3. Takeoff rolls are generally longer than landing distances.
4. Taxiing and takeoffs are performed with more fuel weight.

The Goodyear C&M states that "As severe as the effects of 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." The C&Ms from Goodyear, Michelin, and Dunlop are consistent in descriptions about the damage and shortened carcass life resulting from heat.

The Goodyear C&M publication contained charted data pertaining to tire temperatures and tire inflation. Similar data were contained in the C&M from Michelin and Bridgestone. Although the data had not been developed from testing of the specific types of tires used on the Learjet Model 60, the Goodyear personnel used the Goodyear C&M as a reference to convey the results of tire performance generically. As shown below, nearly identical information was found from other tire manufacturers. The data were used as trend references while in Wichita when reviewing the Learjet tire maintenance and inflation requirements.

A chart on page 40 of the Goodyear C&M showed that the temperatures in different parts of the tires would continue to rise with distance. (See Figure 7) A second chart on the page (Figure 8) showed that the temperatures could rise to the point of failure in the lower sidewall before reaching thermal equilibrium.

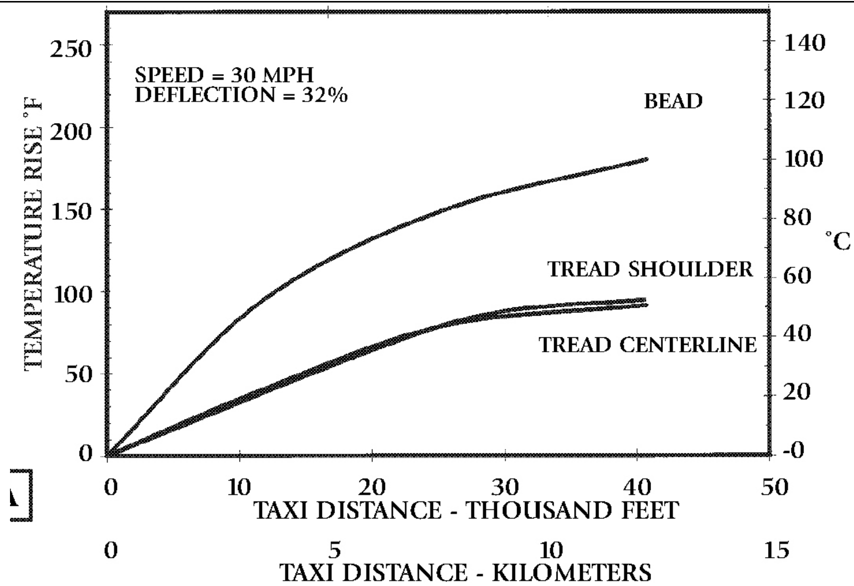


Figure 7. Illustration from page 40 of the Goodyear C&M, titled Heat Rise Vs Taxi Distance. The caption stated: “Even when an aircraft tire is properly inflated and operated at moderate taxi speeds, the heat generation will always exceed the heat dissipated. (This is indicated by the ever increasing slope of the lines.) The farther the taxi distance, the hotter the tires will be at the start of the take-off.”

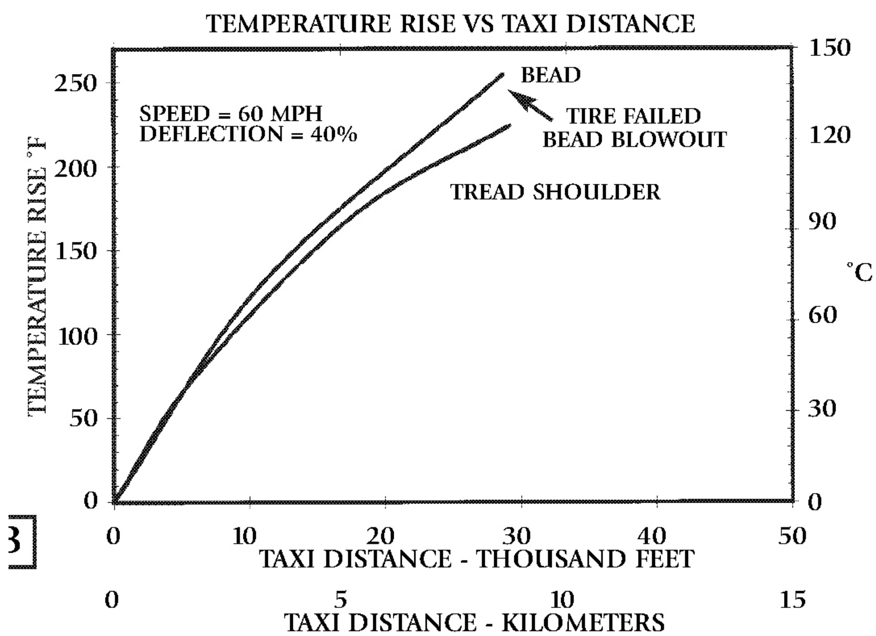


Figure 8. Illustration from page 40 of the Goodyear C&M, titled Temperature Rise Vs Taxi Distance. The caption stated: “This chart shows the effect of under-inflation coupled with the high speed taxiing. A comparison is made between a tire run at 32% deflection and one run at 40% deflection. Not only 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.”

The Bridgestone C&M provides similar illustrations to each of these Figures, adding an illustration(See Figure 9) that is captioned"

> …the trend in the influence that a combination of under-inflation and increased deflection will have on internal heat build-up. Operating under such conditions may cause the tire to exceed tire temperature limits. As shown by the graph, nylon cord strength decreases as temperature rises.

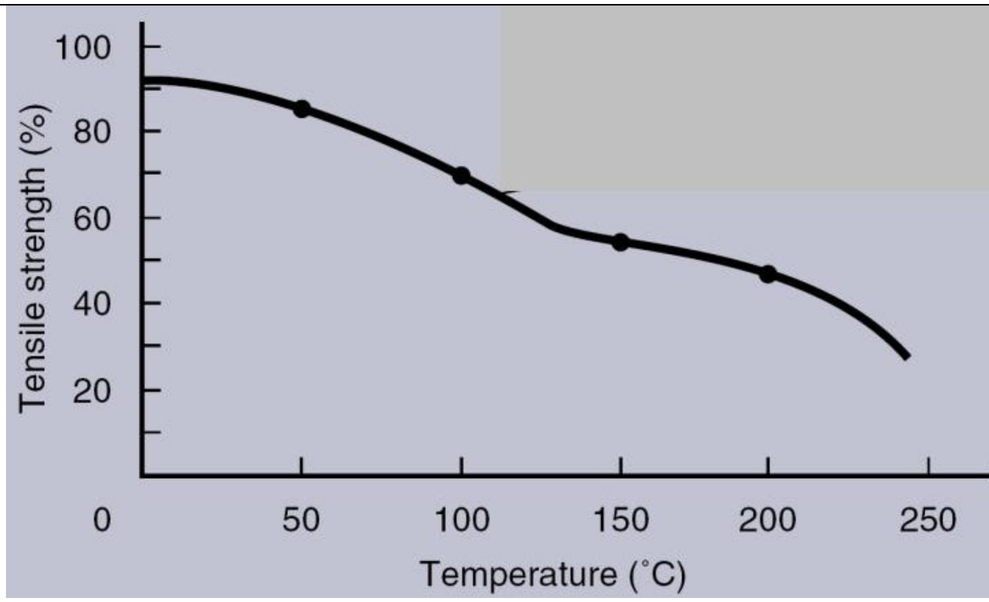


Figure 9. Bridgestone C&M illustration that was captioned "nylon cord strength decreases as temperature rises"

The Goodyear C&M pages 44 and 45 showed the effects of this increase in heat in terms of how under-inflation reducing the tire fatigue life and in reduced takeoff cycles.[11] As little as 5% under-inflation could reduce the tire fatigue life by more than 50% with.[12] (See Figure 10) Under-inflation of 10% in dynamometer tests resulted in main landing gear tire failure in as few as 7 take-off cycles. (See Figure 11)

11 Ref. Publication 700-862-931-538, as revised 10/04, which is also available on the Goodyear web-site.

12 Elsewhere, the publication points out that the tests were conducted on a dynamometer and not on an aircraft. The takeoff loads were to severe certification criteria which surpassed what could be expected of normal aircraft installations, and included continuous loads at maximum weight, high speed takeoff rolls for potentially more than a minute, etc. Goodyear personnel contacted by telephone pointed out that the chart was presented not as specific data and was based in dynamometer tests of only a limited number of tires. They emphasized that this and other charts in the publication were intended only to convey the relative aspects of what each chart plotted; in this case the effects of under-inflation.

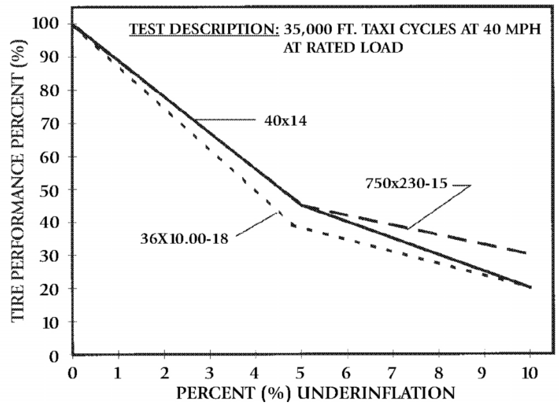


Figure 10. Illustration from Goodyear C&M page 44, showing the effects of under-inflation on tire fatigue capability. The Title was “Carcass Fatigue Due To Under-inflation”

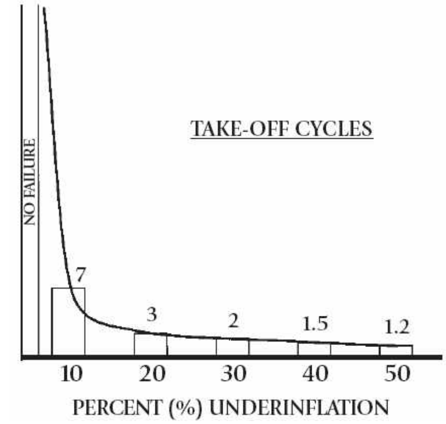


Figure 11. Illustration from Goodyear C&M page 45, conveying the conceptual relative reduction in the number of takeoff cycles that could result from under-inflation. The Title was “Cycles to Failure Versus “Under-inflation”

D.1.4 REFERENCES REGARDING EVIDENCE OF TIRE DAMAGE

As an indication regarding heat external to the construction of the tires, the N999LJ wheels had eutectic thermal fuse plugs, designed to release tire pressure at about 390 degrees F and all of the fuse plugs were intact as received.

The Goodyear C&M stated that “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 manual goes on to show heat evidence in the form of rubber surfaces acquiring a blue tint, hardening of nylon as the individual fibers melt and resolidify in one mass, and tackiness as the rubber reverts to the uncured state. The following were more detailed potential indications regarding the results of temperature that the Goodyear C&M included:

Appearance of blue color	210-230 degrees F
Rubber reversion to uncured state:	280-320 degrees F
Rubber becomes hard and dry:	355-390 degrees F
Melting point of nylon:	>400 degrees F

The nylon threads at the edges of unheated rubber fragments are soft and generally feel like the edge of fabric. As an indication about heat generated internal to the construction of tires, microscopic examination of tire fragments from the N999LJ tires showed that the hardened nylon tips described in many individual fragment descriptions were nylon which had melted and re-solidified into one strand. With a finger, these could feel stiff and like the tips of a bristle broom.

DAMAGE COMPARISON CASES:

A collection of Goodyear photos from previous aircraft, car, and truck tire failures was examined for comparison with the reconstructed tires from N999LJ. The Michelin Aircraft Tire Care & Service Manual and similar documentation from Bridgestone contained similar photo documentation, in less quantity. Goodyear had grouped the types of prior failures into the following damage or failure characteristics:

- Impact failures

- Overdeflection. This characteristic had historically been found in cases of under-inflation and/or over-load.
  - Run-soft / run-flat sidewall rupture
  - Tread / Belt Detachment

- Mounting damage

- Tire injury evidence, including
  - Punctures
  - Wheel issues, such as leaking valves and damaged flanges
  - Contamination leading to rubber degradation
  - Belt edge separation
  - Ozone degradation / Weathering
  - Stress cracking
  - Impact or over-deflection liner cracks
  - Belt edge blows due to over deflection
  - Stone drilling/Chipping from gravel surface operations
  - Tread wear patterns and conditions
  - Tread / Belt retention damage

Nearly identical information regarding loads, heat, and damage was available from each of the tire manufacturers.

D.2 LEARJET MODEL 60 LANDING GEAR DESIGN:

The Learjet Model 60 was equipped with five wheel/tire assemblies, one in the nose position, and sets of two on each main landing gear. Each of the four main landing gear wheel/tire assemblies also contained a multi-disc style brake assembly.

D.2.1 TIRE SELECTION AND QUALIFICATION

The Goodyear Flight Eagle tires (Part Number 178K43-1, size 17.5X5.75-8) used on the Learjet Model 60 main landing gear were of bias-ply construction. (Ref. Figures 1 and 5) The tires were of 4-groove, center-rib in external features, and constructed from 8 rubber-coated nylon plies that wrapped from bead to bead, and with 3 “breaker” plies beneath the tread. Two small “chafer” plies wrapped around the steel bead wires. The replacement criteria is that the tire should be replaced when the tread is worn to the base of any groove at any point. The grooves were .21” deep when new.

Learjet selected the Goodyear 17.5X5.75-8 tire for the M55 and subsequently continued with the same tire on the M60. The tire fulfilled the targeted load and speed requirements within the FAA certification limits of 14 CFR Part 25.733 and TSO-C62c for a multiple axle installation. Learjet engineering personnel related that the tire is the largest capable of fitting in the main landing gear well and selection of a larger tire with more load capability would have required an extensive redesign of the wing, due to the multiple wing spar configuration.

The FAA Chicago Aircraft Certification Office found the tire as a component (without respect to any intended airplane installation) to conform to 14 CFR Part 21 and approved the tires for Goodyear in accordance with Technical Standard Order (TSO) C62c in a letter dated April 3, 1982.[13] The FAA letter of authorization referred to Goodyear Qualification Test Report (QTR) 461B-3044-TL, dated January 27, 1982. The separate QTR showed that the tires were for the Learjet Model 50 Series of airplanes, with a load rating of 6050 pounds, and to be manufactured in a Goodyear facility in Danville, Virginia. At an inflation pressure of 220 psi during a dynamometer test, a tire survived a takeoff test of 34 seconds that reduced the load from 9075 pounds to 8700 pounds as speed increased to 210 mph. At 220 psi, the tire deflection was measured to be 1.95 inches at 12,200 pounds.

Almost all testing is performed at the rated pressure, except when airframe customers or other specific requirements call for the addition of overload or other parameters. The customer provides a tire manufacturer with load curves (also known as “LST curves,” for

13 TSO-C62c was released by the FAA on September 12, 1984, more than two years later. Goodyear personnel believe that tires approved in the period had to be re-qualified as meeting the more stringent TSO-C62c criteria, rather than TSO-C62b, and that this tire had been designed from the outset to meet TSO-C62c.

Load/Speed/Time) to design to, and the load curves may include weights that decrease with takeoff speed. As an example of additional potential customer requirements, Boeing requires that Goodyear design and test results to fit within upper and lower characteristics, such as lateral deflection (stiffness) for cornering on some tires. Lot testing is conducted for burst pressure and other requirements.

Tire loads are carried by the tension in the cords in the footprint and if the tire has a camber or lateral (side) load, the load on one sidewall will increase. Reference material from non-aircraft sources and Learjet ground test data showed that the footprint and lateral loading would change with respect to camber (vehicle or airplane roll) angle. (See Figures 12 and 13)

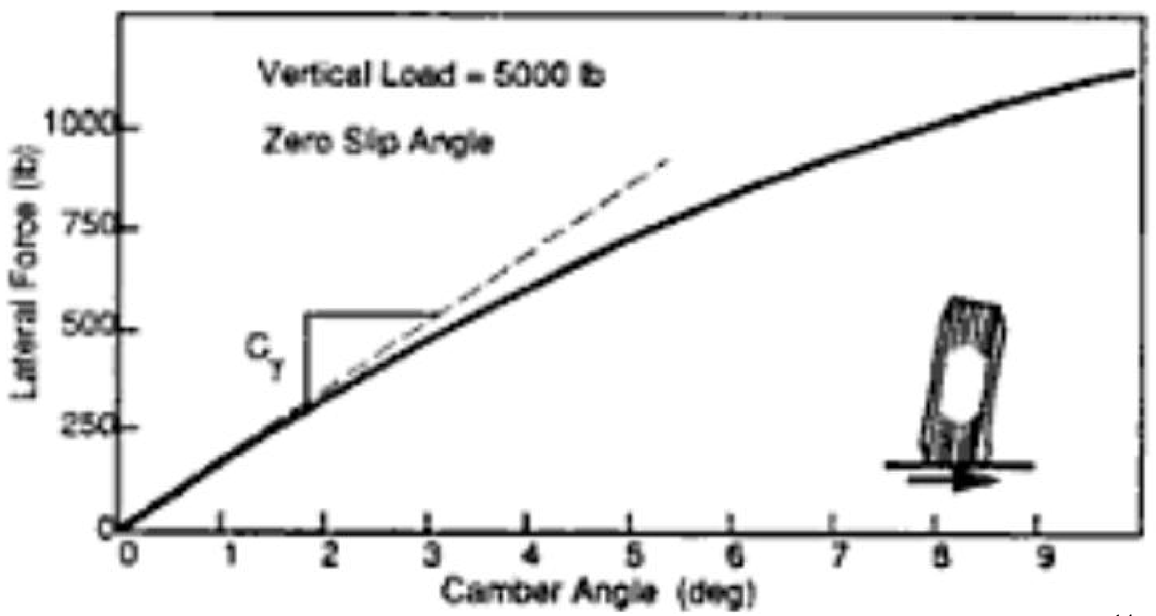


Figure 12. A chart of "Lateral Force (camber thrust) caused by camber of a truck tire."[14]

The aircraft roll angles in Learjet data (Figure 13) represent testing with the following conditions:

AIRCRAFT ROLL ANGLE:	TEST CONDITION:
0 degrees	Baseline, all tires and struts properly inflated.
1 degree	Flat main landing gear tires on one side of the airplane.
2.61 degrees	One side of the airplane resting on inflated tires and strut. The other side resting on the outboard wheel and inflated strut.
3.79 degrees	One side of the airplane resting on inflated tires and strut. Flat strut and flat tires on opposite side of airplane.

14 Published by the Transportation Research Board of the National Research Council, National Cooperative Highway Research Program, as 1993 Report 353, titled Effects Of Heavy-Vehicle Characteristics On Pavement Response And Performance, © by Thomas D. Gillespie.

5.31 degrees — One side of the airplane resting on inflated tires and strut. Opposite side resting on flat strut and outboard wheel.

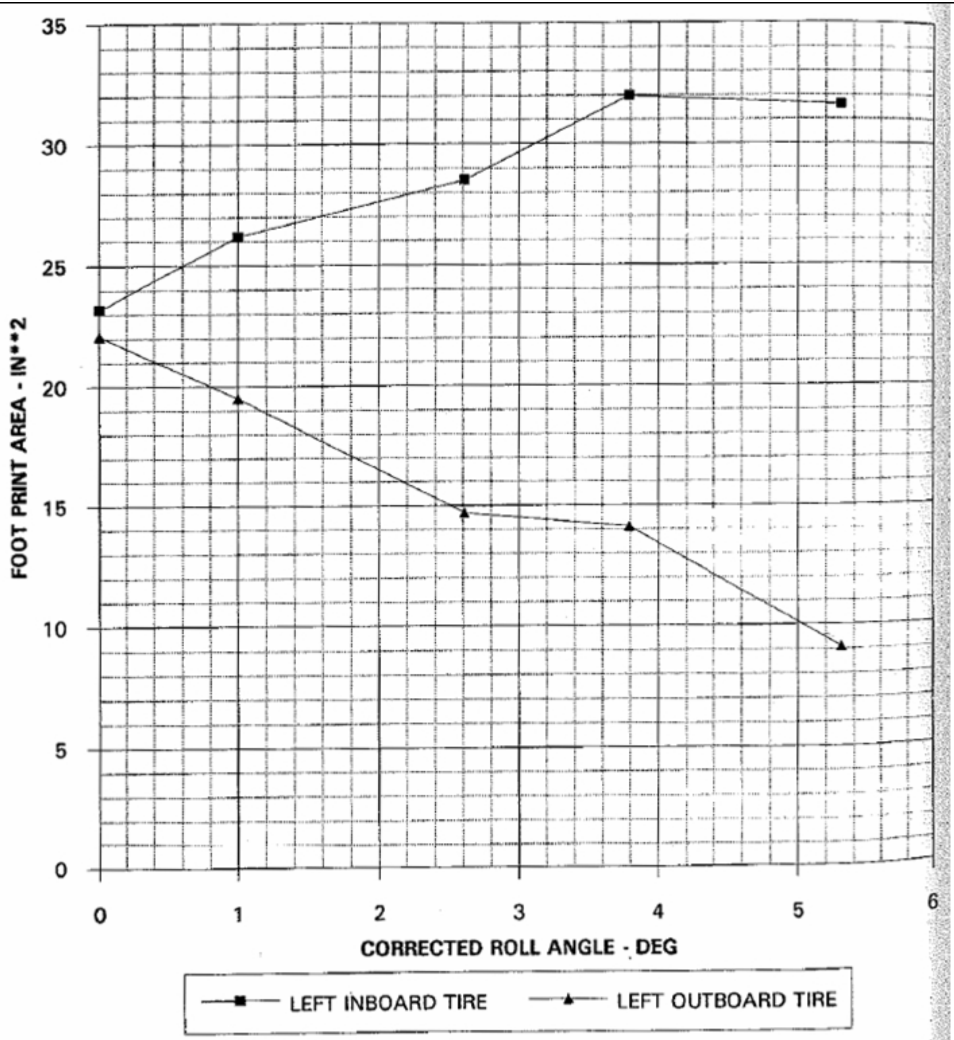


Figure 13. Footprint versus airplane roll angle for the two left tires on a flight test airplane on a surface slanted (rolled) to the right.

Data corresponding with this Learjet test result was found following a takeoff incident at El Paso International Airport on August 19, 2009, in the left tires of a Learjet Model 25D (Registration XB-MYG) were destroyed during takeoff. The Learjet Model 25D has similar landing gear dimensions and following the incident, the left side of the airplane was resting on the wheels and right side was resting on flat tires. (See Figures 14A, 14B, and 14C) The El Paso airplane landing gear would have been between the 1 degree and 2.61 degree Learjet configurations shown in the list and Figure above. The roll angle of the airplane at El Paso was measured to be 1.8 to 1.9 degrees.

Figure 14A. XB-MYG displays 1.8 to 1.9 degree airplane roll angle that existed with flat right tires and resting on left wheel rims.

Figure 14B. View from the rear of the airplane, XB-MYG, showing the left wheels and tire remnants.

Figure 14B. View from the rear of the airplane, XB-MYG, showing the right wheels and deflated tires.

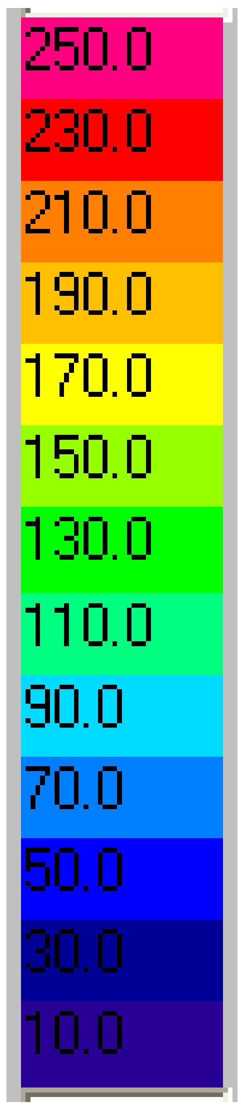
At Columbia, the investigation documented that the N999LJ left outboard wheel had a nearly full height on the outboard flange and the tire beads. The right outboard wheel had no flanges remaining, indicating that an aircraft roll angle may have existed as the airplane traveled along the runway.

Before the above aircraft roll angles were learned from Learjet, Goodyear was asked what potential changes in load that camber could create. As a result, Goodyear provided documentation to show footprints for the main landing gear tire at two tire pressures and cambers. The camber values used were 0.55 degrees to represent an estimated airplane roll value with one flat tire, and 2.0 degrees as an estimated value for one side of the airplane to have two tires missing.

The results show that the load in the center of the tread decreased (became lighter in the center of the Figures) and that the load on the sidewalls increased as the tire pressure was reduced. The load increased on one sidewall at increased camber. (See Figures 15A-15P)

TEST NOTES:

1. The tire was a 17.5x5.75-8 14PR, with the footprints at 0.55 and 2.0 deg camber.
2. Vertical Load of 5,654 lb was used for all footprint tests.
3. Construction: 7QP422-23, Test: 8QP01A-L59A, B, Start Date: 4/7/09
4. SLR denotes Static Loaded Radius, i.e., the distance from the ground to the center of the axle under load.
5. The Gross Footprint area is shown, which is the total area, including whatever area would be in the tread grooves.
6. Colors on the following Figures (15A-15P) denote pressure exerted against the surface in psi with the following scale.



Footprints at 209 psi inflation:

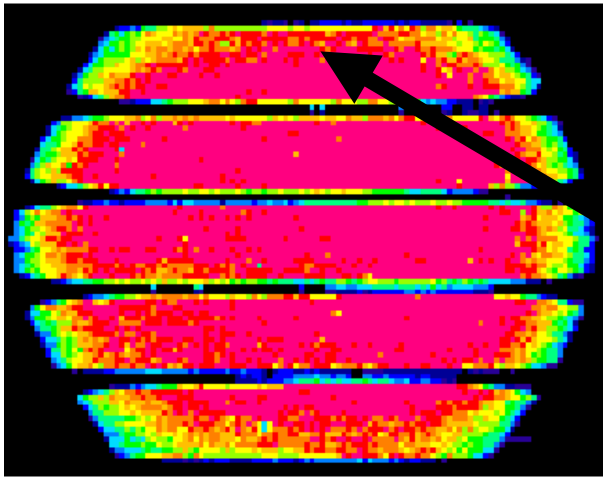
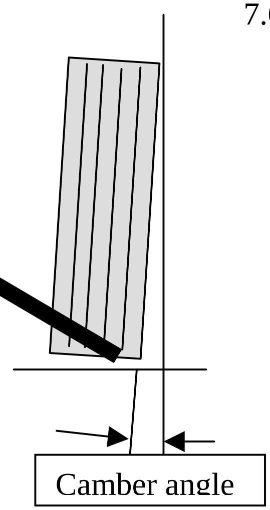


Figure 15A. Footprint at 0.55 degrees camber
7.75 inch SLR, 23.1% deflection, 28.95 sq in gross area



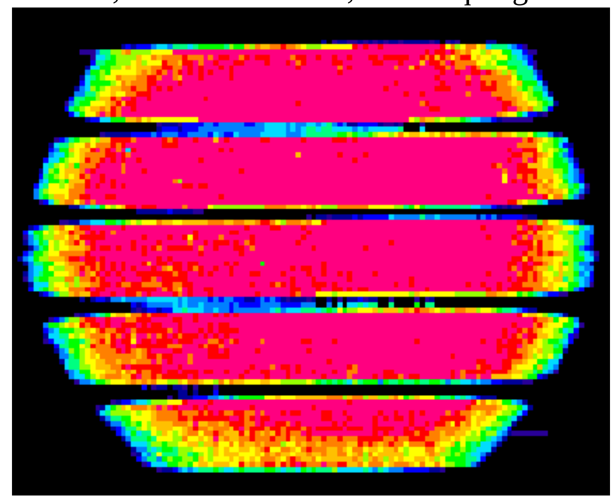


Figure 15B. Footprint at 2.0 degrees camber
7.68 inch SLR, 25.0% deflection, 29.20 sq in gross area

Footprints at 199 psi inflation:

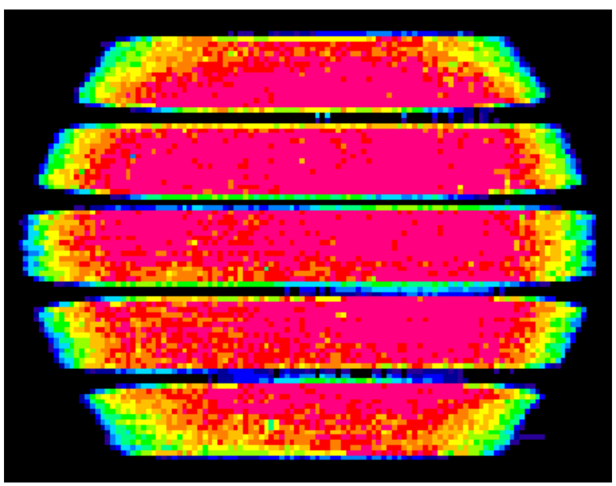


Figure 15C. Footprint at 0.55 degrees camber
7.71 inch SLR, 24.2% deflection, 29.76 sq in gross area

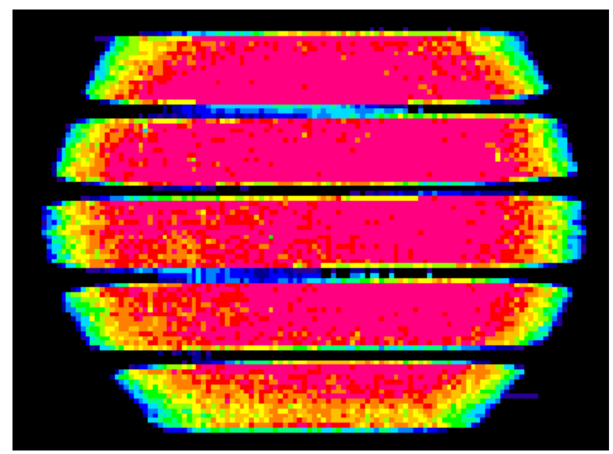


Figure 15D. Footprint at 2.0 degrees camber
7.65 inch SLR, 25.8% deflection, 29.61 sq in gross area

Footprints at 188 psi inflation:

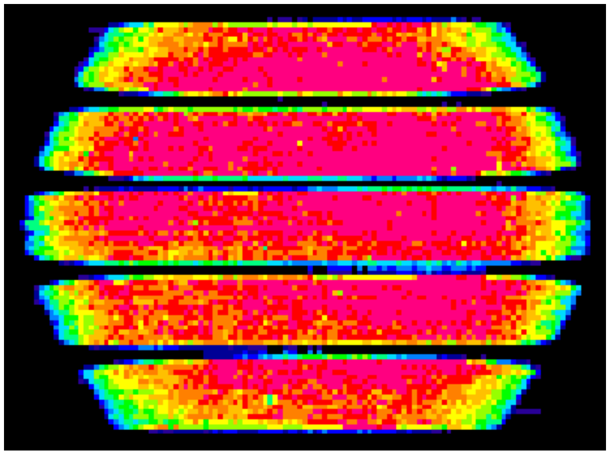


Figure 15E. Footprint at 0.55 degrees camber
7.67 inch SLR, 25.3% deflection, 30.48 sq in gross area

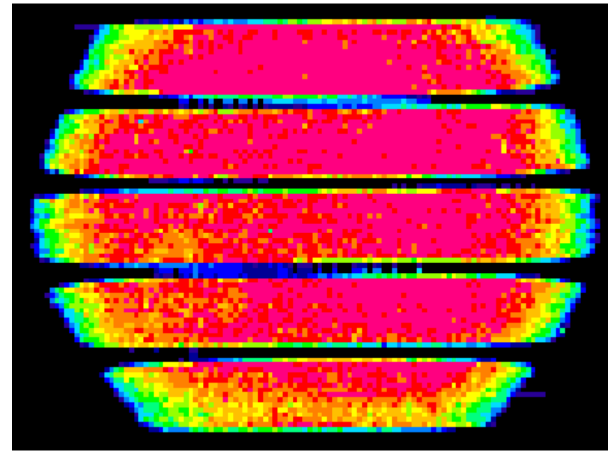


Figure 15F. Footprint at 2.0 degrees camber
7.60 inch SLR, 27.1% deflection, 30.38 sq in gross area

Footprints at 178 psi inflation:

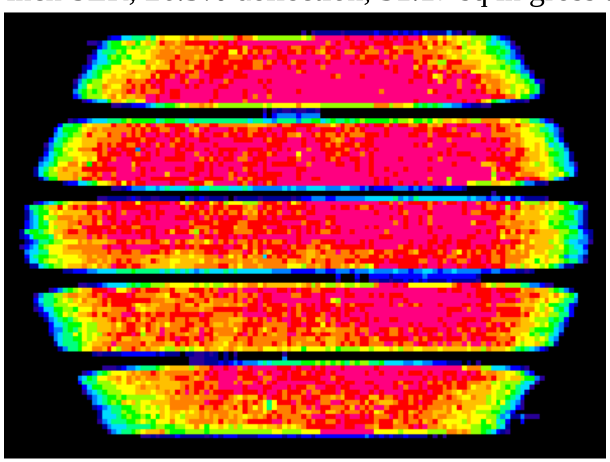


Figure 15G. Footprint at 0.55 degrees camber
7.63 inch SLR, 26.3% deflection, 31.17 sq in gross area

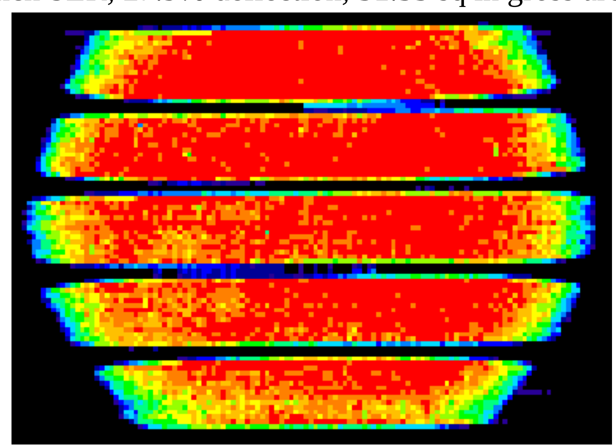


Figure 15H. Footprint at 2.0 degrees camber
7.57 inch SLR, 27.9% deflection, 31.33 sq in gross area

Footprints at 167 psi inflation:

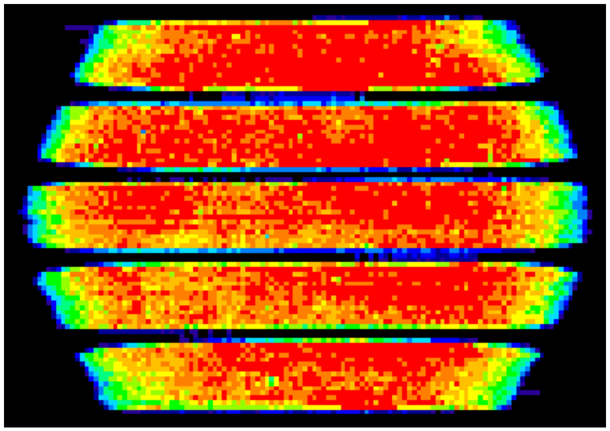


Figure 15I. Footprint at 0.55 degrees camber
7.59 inch SLR, 27.4% deflection, 32.13 sq in gross area

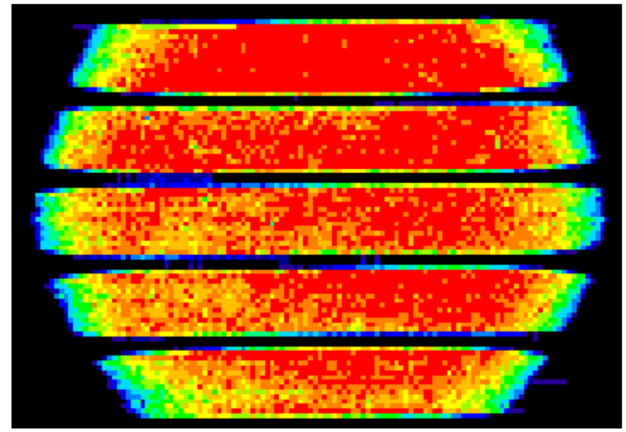


Figure 15J. Footprint at 2.0 degrees camber
7.52 inch SLR, 29.3% deflection, 32.20 sq in gross area

Footprints at 157 psi inflation:

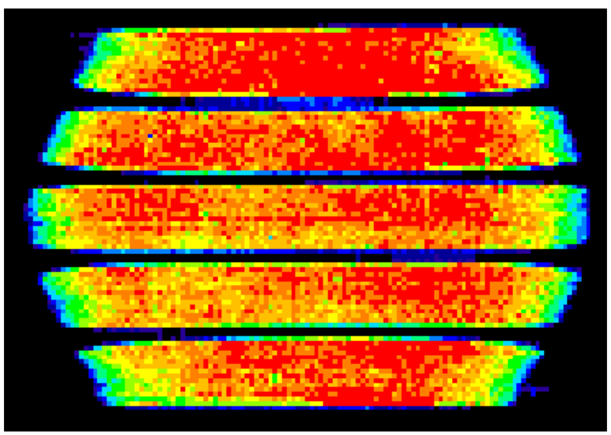


Figure 15K. Footprint at 0.55 degrees camber
7.55 inch SLR, 28.5% deflection, 33.17 sq in gross area

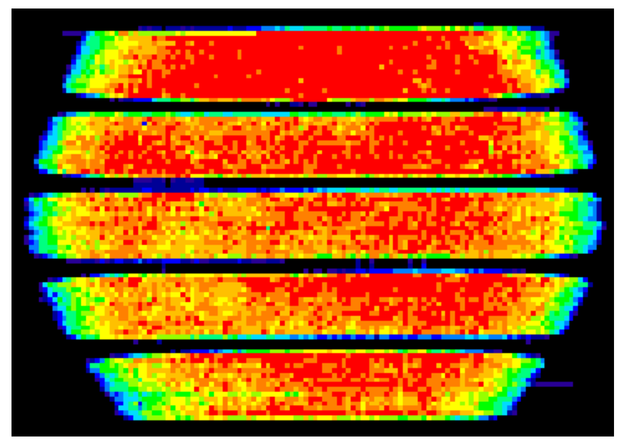


Figure 15L. Footprint at 2.0 degrees camber
7.47 inch SLR, 30.6% deflection, 33.10 sq in gross area

Footprints at 146 psi inflation:

Figure 15M. Footprint at 0.55 degrees camber
7.47 inch SLR, 30.6% deflection, 34.24 sq in gross area

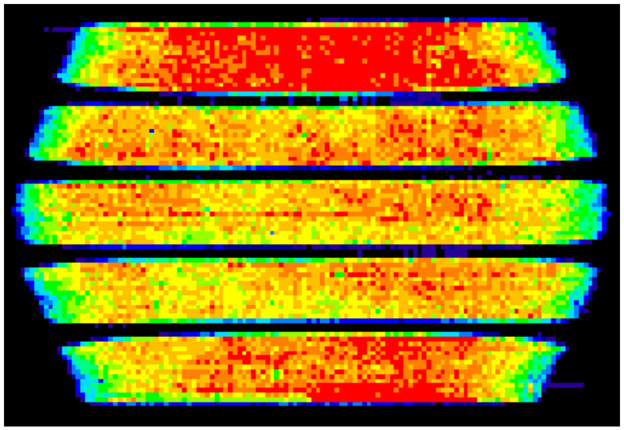
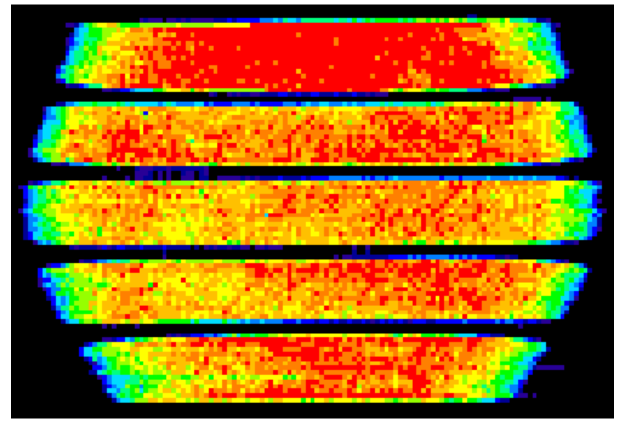


Figure 15N. Footprint at 2.0 degrees camber
7.42 inch SLR, 32.0% deflection, 34.25 sq in gross area



Footprints at 136 psi inflation:

Figure 15O. Footprint at 0.55 degrees camber
7.41 inch SLR, 32.2% deflection, 35.53 sq in gross area

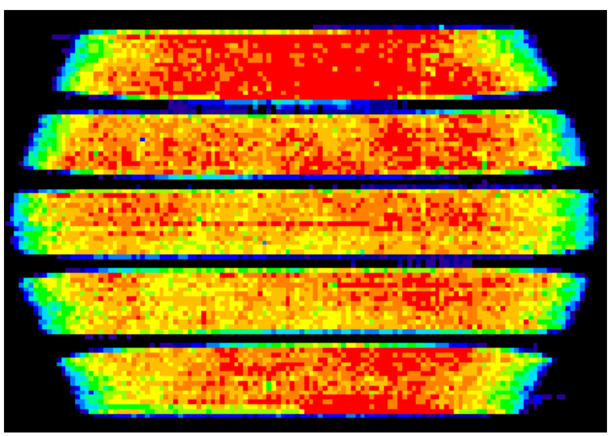
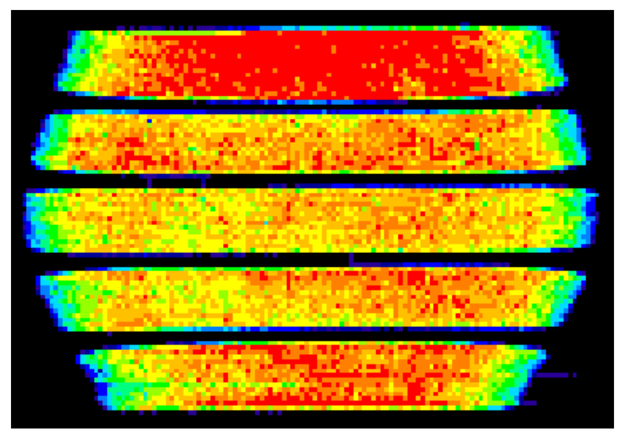


Figure 15P. Footprint at 2.0 degrees camber
7.37 inch SLR, 33.3% deflection, 35.27 sq in gross area



The FAA does not require tire certification to include camber testing or side-loading. For 14 CFR Part 25 certified airplanes, TSO C26c for wheels would require a wheel/tire combination to be tested in both the inboard and outboard directions at 0.15 times the maximum static load for 100 miles each. A Learjet main landing gear tire should have undergone a side-load test to meet this requirement at a wheel manufacturer. (The wheel manufacturer that was not visited during the investigation.) The tire would have been inflated to the pressure recommended for maximum static load.

While no data was required to be developed, or was found, for lateral load capability of the tire used on the Learjet, such data does exist for other types of tires. The maximum lateral load at the point of the tire slipping on a surface exceeded 15% in references, especially with increasing camber. An example was a paper from the 2000 Proceedings of the Winter Simulation Conference, titled *Tire Model For Simulations Of Vehicle Motion On High And Low Friction Road Surfaces*, by James Lacombe, of the U.S. Army Engineering Research and Development Center. (See Figure 16)

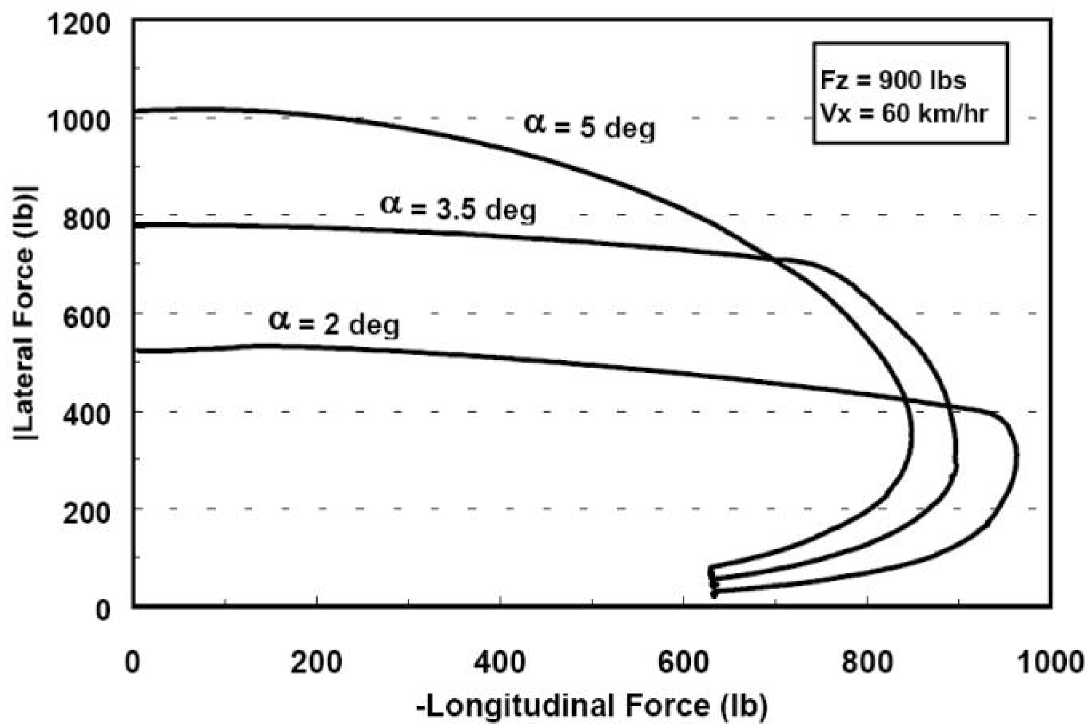


Figure 16. Tire Force Predictions – Dry Pavement

Goodyear personnel noted that some airframe manufacturers add additional requirements for commercial aircraft tires, citing Airbus and Boeing as examples. Some military airplanes were noted to have camber in the landing gear and have additional design requirements. No documents from Learjet or Goodyear were found to indicate that Goodyear had been required to meet requirements beyond 14 CFR Part 25.733 or TSO-C62c for the tires used on the Learjet Models 55 or 60.

The dynamometer tests performance to the LST curve of the TSO or additional design requirements and is a tool for imparting loads and speeds for specific time periods to tires. The dynamometer does not replicate other variables that are experienced in actual service use by customers. Tires in actual use are replaced because they wear out or are otherwise damaged, not typically from the conditions tested on a dynamometer. Relating dynamometer results to real world tire performance is based on monitoring the field performance of tires over time in actual use. Goodyear personnel who track such data were part of the investigation and stated that the company assures the adequacy of the TSO requirements by monitoring of real-world performance through warranty, FAA Service Difficulty Reports, and other types of service reports. Examples of service reports for a variety of tire products were reviewed while in Akron.

The tire testing for the QTR is performed to the specific required values for each of the types of required tests, rather than to the point of failure. For example, if 50 test runs are required to a certain speed at a load or other value and are passed, Goodyear does not find how many more runs can be achieved, or run to higher speeds and loads. The QTR for the Learjet Model 60 tire shows the tire passed the TSO requirements through testing to a variety of parameters.

Manufacturing and warranty data were reviewed. The production and warranty numbers are proprietary and not listed here. The summary is that out of thousands of tires made, two items were found within the 2007 manufacturing serial number range; neither as warranty claims. One was a tire with a sidewall blister. The second was a set of four tires that had been destroyed during a takeoff following a (N55UJ, 55-090) rejected takeoff at Punta Cana, Dominican Republic, believed to have been in September 2008.

D.2.2 TIRE AND LANDING GEAR-RELATED DISCUSSION RECORD

The information that follows in this section was recorded during the group meetings at Wichita.

The tire selection for some new airplanes is negotiated between the tire provider and the airplane designer. The development of the Learjet Model 60 was based on the existing Model 55 and did not require development of a new tire. The physical constraints were related to the wheel well dimensions, which were relatively unchanged since the original Learjet Model 20-series airplanes. Tires for Learjet airplanes designed before the Learjet Model 60 were inflated to lower pressures and had lower ply ratings.

Many of the Learjet models certified before the Learjet Model 60 had tires with a higher ratio of rated load to service load. The minimum ratio of 1.07 was introduced for the Learjet Model 55, and both the Learjet Model 55 and Learjet Model 60 comply with this requirement. The Learjet Model 60 was the end of the development since the Learjet Model 24 in 1964 and brief review found that the designs and certification requirements for the newer Learjet Models 45 and 80 were totally different.

With respect to the effects that maximum braking could have on tires, the Learjet Model 60 did meet the six required maximum performance stops at Roswell, New Mexico. Personnel who had attended the test related that the treads of the tires were totally worn after the sixth stop. Goodyear personnel noted the test was intended to be this severe and that similar tire destruction took place in airplanes from other airplane manufacturers.

In dual-tire installations, the tire that is less under-inflated (i.e., overloaded) usually fails first from carrying relatively more load, causing it to heat faster. When a landing gear axle is fitted with more than one wheel and tire assembly, the load carried by each tire, when multiplied by 1.07, may not be greater than the rated load of the tire. (Ref. 14 CFR Part 25.733) This is to account for potential inequities of load-sharing in service (See Figure 17). This is not intended to account for improper/uneven inflation or a deflated tire.

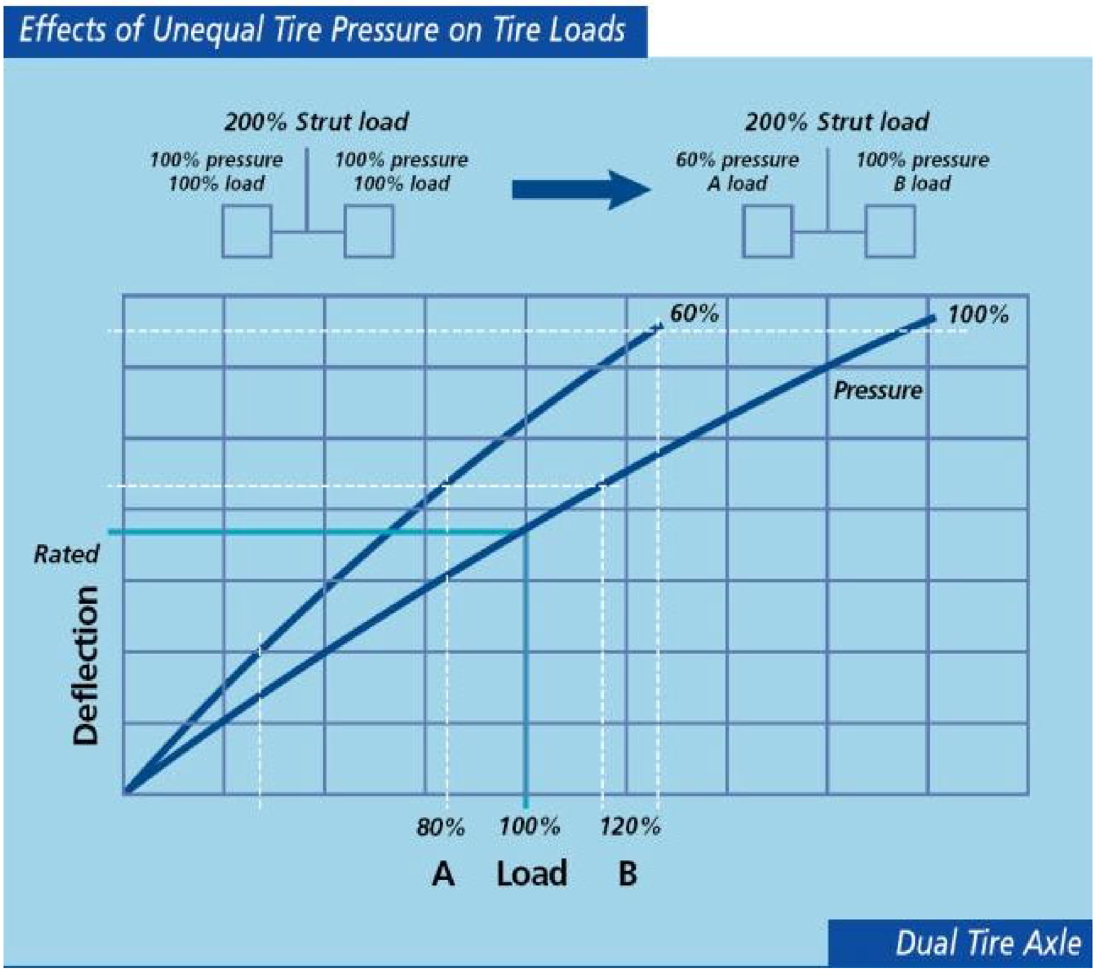


Figure 17. This illustration from the Michelin C&M shows how under-inflation of one tire can overload the adjacent tire on a common axle.

The tires for the Learjet Model 60 have a rated load of 6050 pounds, but can not be used in a dual installation service load of more than 5654 pounds.

The FAA certification of the Learjet Model 60 included a large fuel tank in the aft fuselage and operation near both the gross weight and the aft limit of center of gravity. These conditions place the tires for the Model 60 at the certified limit of a 1.07 (+7%) margin of safety at the maximum allowable load requirement. The Lead Engineers for the Stress and Aerodynamics engineering groups were asked whether other regulatory limits had been reached at this combination of load and center of gravity. They responded that no structural, performance (examples: stall speed or aft center of gravity), field length, or other similar regulatory requirements had been reached in the development of the airplane now identified as the Learjet Model 60, although changes in gross weight or center of gravity would require additional certification testing.

Tires are designed to carry a certain load at a specified pressure to operate at a target percentage of deflection. The deflection needs to be kept reasonably constant to prevent tire damage or a reduction in aircraft performance. To keep the required deflection, if the inflation pressure is reduced, the load must also be reduced by a roughly equivalent percentage. The changes in inflation pressure and load would be implemented through use of data (curves) that are in the tire certification report. What tests to conduct with an airplane would then be evaluated, such as for demonstration of the required braking performance.

The tire certification report shows a pressure loss of about 2.2% per day, as compared with the FAA TSO allowable limit of 5%.[15] The Learjet factory has a pre-flight requirement for a check of tire pressures on all airplanes that depart for flight from the factory. As an informal test of air retention, the tire pressures were checked in an airplane that had last flown three days prior to the check. The technician related that the cold inflation pressure target was 209-219 psig; the 2.2% would equate to 4.6 psig. He found that the four pressures were 203 psig, 202 psig, 203 psig, and 203 psig. From the average of 214 psig, the 11 psig pressure loss would be 1.71% per day.

> NOTE: Learjet personnel performed additional tire pressure surveys following the meetings in Wichita and found the air loss rate to consistently be slightly more than 1%. The loss of pressure for tires at varying inflation pressures was also found in data from other airplanes. (See Figure 33)

The Lead Stress engineer for Learjet performed static calculations with no dynamic consideration to approximate the load on each tire, at gross weight, and on level ground. (See Figure 18) This was for total load, not the loads on the sidewalls, as shown in Figures 15A-15P. Dynamics not considered in the following calculations include the load of falling from the height of two inflated tires to the height of one tire if a tire were to suddenly deflate, side-loads from swerving on the runway, etc. The nose gear load is assumed to be negligible:

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15 This was the test tire after the qualification test, and mounted on a test wheel.

Figure 18. List of static tire load calculations. (Ref. Figures 12-14C)

Condition:		Load on left outboard tire	Load on left inboard tire	Load on right inboard tire	Load on right outboard tire
Properly inflated tires:	Under-inflation (psig)	0%	0%	0%	0%
	% Load (from ¼ of gross weight)	100%	100%	100%	100%
Low pressure in #4 tire: (The change in deflection results in an estimated 0.1 degree change in airplane roll attitude)	Under-inflation (psig)	0%	0%	0%	40%
	% Load (from ¼ of gross weight)	97%	100%	122% (About 7000 pounds)	80%
No pressure in #4 tire: (The change in deflection resulted in an estimated 0.55 degree change in airplane roll attitude)	Under-inflation (psig)	0%	0%	0%	100%
	% Load (from ¼ of gross weight)	86%	102%	213% (About 12,000 pounds)	0%

Note: The calculations for aircraft roll attitude change used 2 degrees to represent a fully inflated left outboard tire, flat right outboard tire with no remaining wheel flanges, and proportionate heights for the inboard tires.

The group reviewed data that compared the tires used in the Learjet Model 60 with the previous models. (See Figure 19)

Figure 19. List of Learjet-provided data pertaining to main landing gear tire loading (estimates) in various models.

MODEL	FAR 25.733 C(1) AMDT	Take Off Weight	Tire Load	Tire Rating	Tire Part number	Tire Ply Rating	Actual Factor	Required Factor	Notes	No. of A/C built	No. of Tire failure events (See Note 3)
35/35A/36	No Amdt	17,000	4000	4000	185F03-1	10	1.00	N/A		739	15
35/35A/36/36A	No Amdt	18,000	4000	4000	185F03-1	10	1.00	N/A			
35/35A	No Amdt	17,000	4078	5000	178K23-5	12	1.23	N/A	14 Ply tire may also be installed		
35/35A	No Amdt	18,000	4318	5000	178K23-5	12	1.16	N/A	14 Ply tire may also be installed		
35/35A	No Amdt	18,300	4390	5000	178K23-5	12	1.14	N/A	14 Ply tire may also be installed		
36	No Amdt	17,000	4078	5000	178K23-5	12	1.23	N/A	14 Ply tire may also be installed		
36/36A	No Amdt	18,000	4318	5000	178K23-5	12	1.16	N/A	14 Ply tire may also be installed		
36A046 & subq	No Amdt	18,300	4390	5000	178K23-5	12	1.14	N/A	14 Ply tire may also be installed		

31	23	15,500	3749	5000	178K23-5	12	1.33	N/A	14 Ply tire may also be installed	242	3
31 (Option)	23	16,500	3991	5000	178K23-5	12	1.25	N/A	14 Ply tire may also be installed		
31A	23	15,500	3749	5000	178K23-5	12	1.33	N/A	14 Ply tire may also be installed		
31A (Option 1)	23	16,500	3991	5000	178K23-5	12	1.25	N/A	14 Ply tire may also be installed		
31A (Option 2)	23	17,000	4112	5000	178K23-5	12	1.22	N/A	14 Ply tire may also be installed		
55	23	21,000	4991	5000	178K23-5	12	1	N/A	14 Ply tire may also be installed	147	6
55	23	21,500	5341	6050	178K43-1	14	1.13	N/A			
60	72	22,750	5654	6050	178K43-1	14	1.07	1.07		355	19
60	72	23,100	5654	6050	178K43-1	14	1.07	1.07			
60	72	23,500	5654	6050	178K43-1	14	1.07	1.07			

NOTES:

1. Some configurations have CG limitations in the flight manual due to tire load limits.
2. The design of the Learjet Model 60 wheel and tires was based in nominal tire inflation.
3. Additional failure records are contained in a later section.

D.3 ACCIDENT AIRPLANE (N999LJ)

D.3.1 GENERAL PATH OF TRAVEL AND SEQUENTIAL TIRE LOSS:

The tire debris was collected as individual pieces or in small groups. The South Carolina Highway Patrol Multi-Disciplinary Accident Investigation Team (MAIT) used laser-based TotalStation survey equipment to accurately established the locations. The sequence of tire destruction was related to an airport map when the tires were reconstructed, by relating the sources of fragments to each of the reconstructions of the serialized tires.[16]

The outboard right tire fragmented closest to the initiation of the takeoff roll, followed shortly by the inboard right tire, the inboard left tire, and then the outboard left tire.[17] Corresponding with finding this from the mapped locations of tire debris, the general wear across the remnants of the four wheels was worst on the right-outboard and progressively better toward the left-outboard wheel. Measuring from the initial piece of each tire to the initial fragment of the next tire were distances of 600-800 feet along the runway. The initial fragments of the outboard right tire on the runway were from the outboard sidewall. The distance between the initial fragment of the right outboard tire to the initial fragment of the right inboard tire was slightly less than 800 feet and at 140 knots (236 feet/second),[18] the time between the initial fragment locations for the right two tires was calculated to have been about 3.4 seconds.

D.3.2 N999LJ LANDING GEAR INSTALLATION BASIC DATA:

The logs showed that all four tires were Goodyear part number 178K43-1, that all tires were new and not re-treaded, that all had been installed in December 2007, and that all had 20 landings. Meggitt Corporation (formerly ABSC) of Akron, Ohio, had manufactured the wheels and brakes. For the reconstruction, the following lists the component serial numbers by source of data (See Figure 20):

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16 See Appendix B of the Airworthiness Factual Report. As an electronic PDF document, the map may be viewed at 2000+ magnification to see and measure details that are cited in this addendum.

17 Various Learjet documents identify the main landing gear tires by the positions listed above, by the abbreviated position (such as L-Inbd and R-Outbd), and as numbers one through four from left to right.

18 This speed reference was based in the Cockpit Voice Recorder Group Chairman's Sound Spectrum Study of July 23, 2009, which cited airspeeds of about 138 and 143 knots. This reference defers to any future additions or changes in performance data from the Performance or Cockpit Voice Recorder Group Chairmen reports.

Figure 20. List of tire, wheel, and brake serial numbers from N999LJ.

	Left outboard position	Left inboard position	Right inboard position	Right outboard position
Logbook for tire	70160910	70160918	70160887	71580882
Logbook for wheel	JUN06-2264	JUN06-2260	JUN06-2262	JUN06-2256
Logbook for brake	JUL08-0951	JUL08-0975	JUL08-0967	MAR06-0726
As-found for wheel	JUN06-2260	JUN06-2264	JUN06-2256	JUN06-2262
As-found for brake	JUL08-0951	JUL08-0975	JUL08-0967	MAR06-0726
As-found for wheel speed transducers (p/n 40-911)	7595	7599	7598	7597

Tire, wheel, and brake debris, along with other airplane components, were found along the 8,601 foot runway. In general, the wheel flanges were totally missing from the right outboard wheel and were most complete on the outboard left wheel, along with wheel bead material. The degrees of damage increased progressively from one side to the other.

The nose landing gear wheel assembly was p/n 9544207-4, serial number JUN06-10162 and the wheel spun freely on the axle. The yoke had fractured and separated from the strut. The pressurized tire had cuts and was deflated on-scene for safety reasons before the pressure could be checked.

D.3.3 MAIN LANDING GEAR TIRE-RELATED SUMMARY:

The investigation used reference publications and damage description photographs from the three manufacturers of most aircraft tires (Goodyear, Michelin, and Bridgestone).[19] Photographs from Goodyear records of previous tire failure investigations were also used as a reference. Investigation handbooks developed for ground vehicle tires and used as nomenclature references included:

> *The Pneumatic Tire,*
> Published August 2005 by the National Highway Traffic Safety Administration under Department of Transportation Contract DTNH22-02-P-07210 and edited by A. N. Gent and J. D. Walter of the University of Akron.
>
> *The Investigator's Guide to Tire Failures*

19 (1) Goodyear Aircraft Tire Care and Maintenance (C & M), (2) Michelin Aircraft Tire Care & Service Manual (C & S, MAT-CSM-01 Rev. A), (3) a Bridgestone publication called Care & Maintenance, and one titled as Recommended Action.

By R. J. Grogan

Tire Forensic Investigation: Analyzing Tire Failure
By Thomas Giapponi.

In summary, no evidence was found of design, manufacturing, or operational defects in any of the four tires as a component. The recovered bead areas did not show evidence of brake overheat or generally have more heat damage than that found in the sidewall areas (Ref. Goodyear C&M page 42). Melting of the nylon and blue coloring of torn rubber were typical evidence of heat that was found in each of the four tires.[20] Each of the tires also had wrinkles and wear of the inner liner (some more than others), which the Goodyear C&M cites as a potential indication of over-deflection, which may be from under-inflation, overloading, or a combination of both.

Surface contaminates were found on some tire fragments and the material typically crossed surface edges and torn areas. Fluid marks were found on tire fragments and under strong light the marks had the appearance of oil or petroleum contaminates. Laboratory examination revealed hydraulic fluid on fragments from the right outboard tire.
Silver colored smears were found and excised samples of the silver were submitted to the Goodyear materials laboratory. The available exemplar sources of silver had some elements in common with the smears, but in different proportions or missing other elements than the smears contained. The exemplars included paint from a wheel, wheel brake, landing light, and a runway reflector. While photographs of the outboard main landing gear doors of the airplane showed a silver color and beaten appearance, none of the door material was available.

Fragments were pattern-matched and found to fit together, and then observations were recorded.

The upper sidewalls and tread/crown areas had generally separated as larger torn fragments in a different manner than the numerous small fragments found from the lower and mid-portions of the sidewalls. With the exceptions noted, the similar types of inner and outer sidewall damage had a ragged or torn appearance at a fairly constant radius from the hub.
(See Figure 21)

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20 For details regarding specific evidence, see the individual notes in this report.

Figure 21. Overall photograph of the reconstruction of the right outboard tire, on the outboard sidewall.[21] Visible is the generally ragged or torn appearance of the edge that is at a relatively constant radius from the hub. The added arrows show the relatively constant distance from a decorative rib.

The location of the radius from the hub and where the plies were "turned up" around the beads wires matched the lower sidewall compression break shown on Goodyear C & M page 46. (See Figures 22A-22D) The illustration was captioned: "This is the start of the type of failure caused by under-inflation or overloading. The above photo shows carcass cords that are starting to fail due to flex fatigue." The Bridgestone C&M publication contained a photograph of damage from a different view and captioned the photo "An example of Casing Break Up (CBU) in a bias tire at the lower sidewall caused by running the tire at pressures below those recommended."

21 The use of "inboard" and "outboard" throughout this document refer to the orientation from the perspective of the airplane installation.

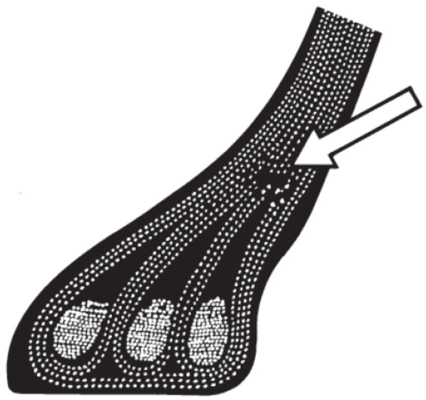

Figure 22A. Goodyear C & M page 46 illustration

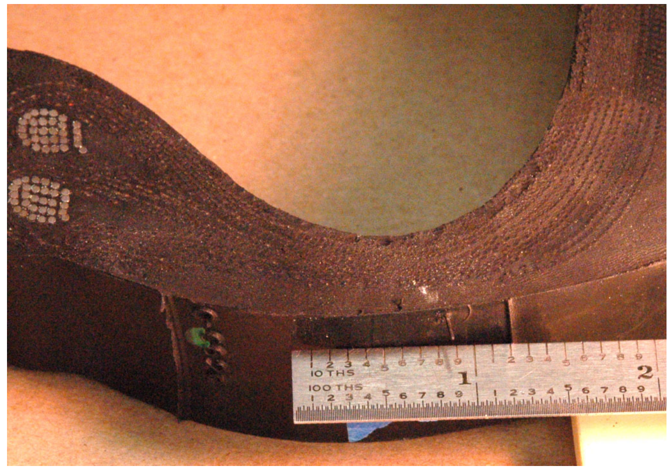

Figure 22B. Photo of a sectioned exemplar Learjet Model 60 tire, with the scale showing that the 1.2 inch measurement from the decorative rib arriving at the same location shown in the two Figures below.

Figure 22C. N999LJ fragments #2 and #3 laid on an exemplar tire, with the scale measurement of 1.2 inches.

Figure 22D. Two N999LJ fragments placed on the exemplar tire. The fragments had been found near each other at the #7 location along the runway.

The location of these sidewall breaks was about 1.2 inches toward the hub from the decorative ribs, especially in both sidewalls of the outboard right tire, the outboard sidewall of the inboard right tire, and the right (inboard) sidewall of the left inboard tire. Extensively more shredding and tearing was found to the inboard sidewall of the right inboard tire (wheel position #3) and to the left outboard tire (wheel position #1).

The numbering of fragments followed the sequence in which they were recovered and the fragments on the first half of the runway typically followed the progression of finding the fragments along the path of the airplane. Therefore, fragment #1 was the first piece, fragment #2 was the second piece along the path, etcetera.[22]

The lowest-numbered fragments of sidewall liner from the outboard right tire had liner wrinkling, liner abrasion, and heat-related damage. (Described in subsequent descriptions of individual tire examination results.) The liner and types of heat damage found along the edges of the tear matched photo and text documentation of over-deflected damage. Three of the tire manufacturers specifically stated that over-deflection was attributed to operating at low pressure or with gross overloading. (See Figure 23 for relation between deflection, inflation pressure, and weight)

The examination researched whether the potential for wrinkle damage or liner abrasion could have been from overloading. For corporate memory or experience, Goodyear design engineers and engineering personnel experienced in tire failure examinations were consulted. While noting that heat and rolling distance could affect the start of wrinkling, no engineering personnel knew of wrinkling and liner damage in tires that had been properly inflated. This included tires that had been tested at Goodyear and those coming out of service, where it was known that the tires had been kept properly inflated. (Example, the Goodyear company airplanes and other test airplanes that Goodyear had worked with.)

The Goodyear Qualification Test Report (461B-3044-TL, dated January 27, 1982) showed overload testing that the tires had been required to pass. No wrinkling had been found after two 40 mph taxi tests of 7 mile duration (35,000 feet) at a 20% overload.[23] The QTR showed that at an inflation of 220 psi, a single tire had been proven capable of withstanding a takeoff overload of up to 9075 pounds, also without wrinkling. The Learjet Model 60 gross weight is 23,750 pounds, distributed among the four main landing gear tires, or 5650 pounds. (A small amount of the weight is also on the nose tire, which was omitted for this calculation.) The 9075 pound test value would have been for an equivalent airplane weight of 36,300 pounds.[24]

Evidence of sidewall collapse was found in the N999LJ outboard right tire remnants. Goodyear conducted static testing during qualification of tires for the Learjet Model 60 main landing gear. A qualification static test of a test tire did not deflect to the amount of collapse indicated by the N999LJ sidewall remnants until the test tire was loaded to 12,200 pounds. This weight was more than half of the gross weight of the airplane.

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22 Seven small pieces of hard pavement-type material and debris were also found and had been numbered B1 through B7, counting backwards from tire fragment #1, because they had been found up-path from the first tire fragment.

23 No adjustment in inflation for the overload was used; the test condition was at rated pressure and load, rather than operating pressure and load.

24 The documentation from the three manufacturers and the FAA all showed that takeoff loads were the worst-case condition. Technical Standard Order (TSO) C62c calls for testing under takeoff loads and speeds. The load shown slightly decreased as the dynamometer simulated an airplane gaining speed and lift through the takeoff roll.

With respect to under-inflation, the Michelin and Goodyear publications showed that tires are designed to operate with a specific amount of deflection. In the case of the 17.5X5.75-8 tires, the loaded deflection for the Learjet Model 60 was 32%. Decreasing pressure increases the amount of deflection for the same load. An estimated static load deflection chart (LDF) for the Learjet Model 60 tires was generated by Goodyear engineering personnel. (Ref. Figure 23) The chart included curves to show various inflation pressures, beyond the 220 psi curve that the QTR documented. The curves were used to establish an initial minimum level of under-inflation that would be required to achieve the as-found sidewall damage.

The QTR overload loads of 9075 pounds were plotted on the LDF curves at 220 psi[25] and then related back to the rated load of 6050 pounds. Moving from the curve that showed nominal pressure, to keep the deflection constant at rated load, would equate to about 140 psi. This was about a 36% under-inflation.[26] Under-inflation in N999LJ should have been worse than this estimate, as this was a method to use known data to show an extreme level of deflation at which no sidewall liner damage would be created, at least for the one take-off cycle that the data was based on.[27]

25 For the TSO qualification test, the pressure was set with the tire unloaded, the test restricted to one cycle, with the 5000 foot takeoff roll test cited in the QTR.

26 Calculation: 220 psi -140 psi = 80 psi. 80/220 = 36%

27 The TSO-C62c required take-off cycles that were more extreme than actual take-off cycles.

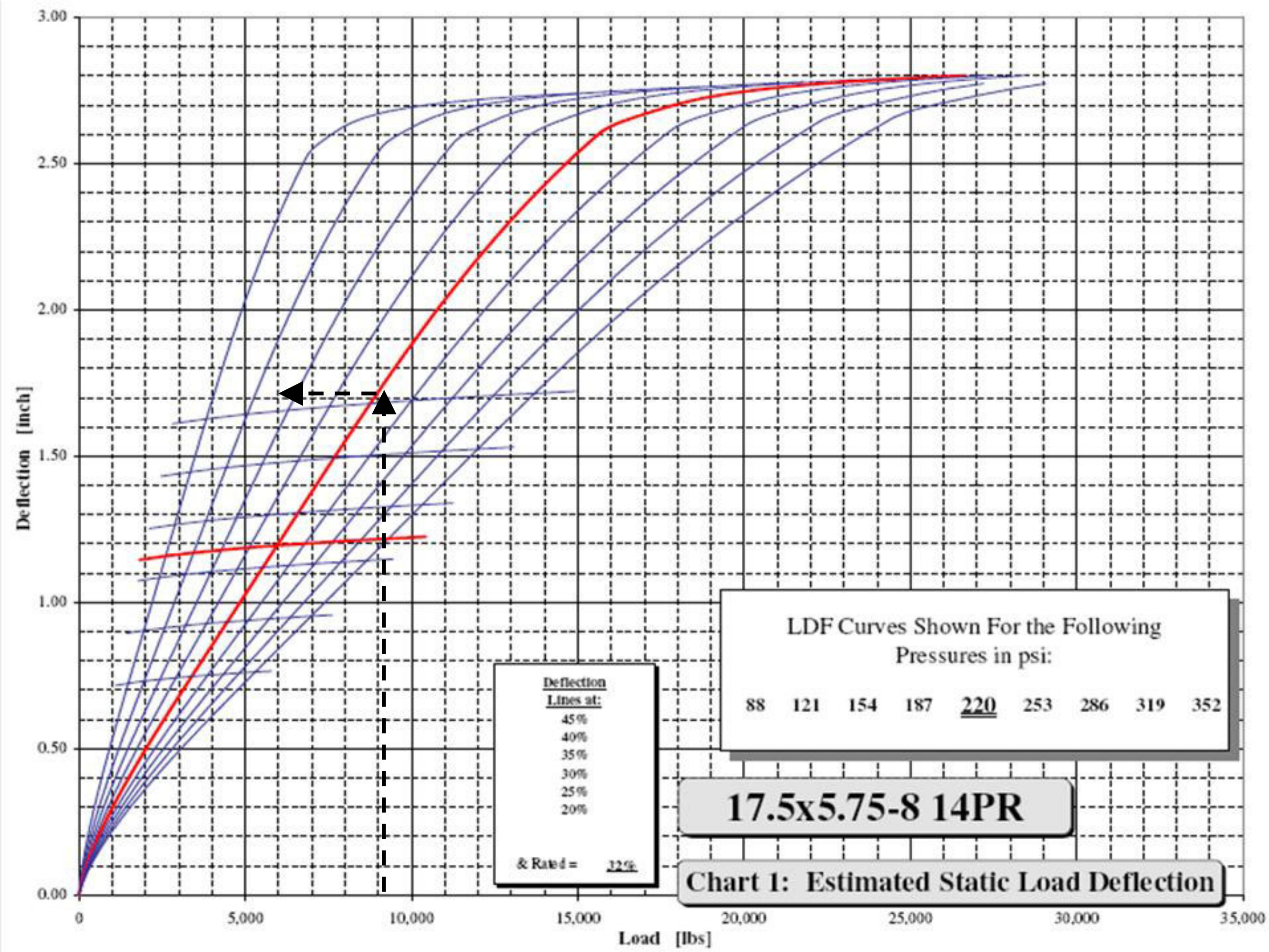

Figure 23. Load deflection chart at the rated pressure is shown in red, with additional inflation pressure curves shown in blue. The dashed arrows show the 9075 pound load interpolation to the approximately 140 psi pressure at the rated 6050 pound load, as described in the text. Note that the deflection is greater than the 45% line.

The investigation examined the loss of inflation pressure over time. The publications from each of the tire manufacturer C&M publications discussed the loss of pressure over time. The Goodyear C & M stated that "A wheel/tire assembly can lose as much as five percent (5%) of the inflation pressure in a 24-hour period." The tire manufacturers were all found to cite the 5% value that was in the FAA TSO-C62c document that the tires had been approved to. The Goodyear QTR showed that the test tire had a diffusion rate of 2.20% after the completion of required testing. (See Figure 24)

Figure 24. A chart that shows calculated inflation pressures at various rates of pressure loss. The colors approximately depict the following amounts of pressure loss:

196.2 psi = 10% loss Reference value in AC20-97B.
185.3 psi = 15% loss. The pressure at which the Learjet Maintenance Manual calls for tire replacement.
140 psi = 36% loss The pressure shown in the Figure 13 calculation.

Loss rate => Day number	**1%**	**2%**	**3%**	**4%**	**5%**
0	218.00	218.00	218.00	218.00	218.00
1	215.82	213.64	211.46	209.28	207.10
2	213.66	209.37	205.12	200.91	196.75
3	211.53	205.18	198.96	192.87	186.91
4	209.41	201.08	192.99	185.16	177.56
5	207.32	197.05	187.20	177.75	168.68
6	205.24	193.11	181.59	170.64	160.25
7	203.19	189.25	176.14	163.82	152.24
8	201.16	185.47	170.86	157.26	144.63
9	199.15	181.76	165.73	150.97	137.39
10	197.16	178.12	160.76	144.93	130.52
11	195.18	174.56	155.94	139.14	124.00
12	193.23	171.07	151.26	133.57	117.80
13	191.30	167.65	146.72	128.23	111.91
14	189.39	164.29	142.32	123.10	106.31
15	187.49	161.01	138.05	118.17	101.00
16	185.62	157.79	133.91	113.45	95.95
17	183.76	154.63	129.89	108.91	91.15
18	181.92	151.54	125.99	104.55	86.59
19	180.10	148.51	122.21	100.37	82.26
20	178.30	145.54	118.55	96.36	78.15
21	176.52	142.63	114.99	92.50	74.24
22	174.76	139.78	111.54	88.80	70.53
23	173.01	136.98	108.19	85.25	67.00
24	171.28	134.24	104.95	81.84	63.65
25	169.57	131.56	101.80	78.57	60.47
26	167.87	128.92	98.75	75.42	57.45
27	166.19	126.35	95.78	72.41	54.58
28	164.53	123.82	92.91	69.51	51.85
29	162.88	121.34	90.12	66.73	49.25
30					

The person checking the tire pressures is required to get under the wing of the airplane. The outboard tires have a valve which may be concealed by the landing gear door, requiring the person to lay on the pavement. (See Figures 25 and 26)

Figure 25. Checking inboard tire pressure at the Learjet factory.

Figure 26. Checking outboard tire pressure at the Learjet factory.

With respect to the individual tires, wheels, and brakes:

RIGHT OUTBOARD (POSITION #4) TIRE RECONSTRUCTION:

Roughly 80% of the outboard right tire was ultimately reconstructed with approximately (18) pieces from bag numbers 5, 7, 9, 10 & 15. There was not a clear impact-type X or diamond-shaped (Bridgestone C&M terminology) failure in the immediate tread area. Using the underlying carcass, a Y-shaped pattern could be found under the edge of fragment 5, which could have been indicative of partial ply damage. The tire had more than ¾ of the tread remaining and where not damaged by the accident sequence, the surface appeared to be in very good condition.

Evidence of extended significant over-deflection (under-inflation, over-load, or a combination, per the Goodyear Aircraft Tire Care And Maintenance Manual) causing excessive heat build-up was found throughout the tire construction. The symptoms of this were blue colored torn rubber and stiff/hardened reinforcement nylon cord material found in many of the fragments. Melted nylon indicated that the tire construction internally reached more than 400 degrees F in some areas.

Fragment 5 was a large section with tread that is in very good condition, differing from most of the other fragments in this tire, making it appear to be the first, or one of the first fragments to separate from the rest of the casing. Fragment 5 had a combination of blue rubber and some nylon tips in the non-serial (inboard or brake) side of the upper sidewall that are not hardened or brittle. The underlying casing appears to have run on the rough surface of the runway after fragment 5 detached early in the sequence, and the underlying casing was in at least a partially inflated condition after the separation.

The tread-depth in the center grooves of this tire varied from 0.15 to 0.16 inches (about 5/32 inch), with the outer-most grooves measuring about 0.19 inches (6/32 inches). An apparent cut/puncture through the casing was examined and reassembly found that a continuous flap of rubber from the surface had covered that area. The flap indicated that the apparent cut/puncture was not part of the original tire failure. A diagonal cut/snag across the tread/crown ripped through the casing and left a silver smear of residue on the tread & top breaker. The fragment 5 tread has smears and a gouge at the end from a foreign object.

The assembly includes the following fragments:

#5, a major fragment, with smaller fragments 5c, 5G, 5B, 5I, 5F,
#9 mating with 5E, 5H, 6D, 6
#7 mating with smaller 5A,
#10 mating with 5A, 5E, 5D, 5F,
15A

The first fragment found along the runway that could be positively related to features of a specific tire was a sidewall fragment (Fragment #3). (Fragment #2 is discussed below.) The first of these fragments had been found less than 200 feet from the first tire fragment (#1), which had also been a generic sidewall fragment that was not identifiable as to source. Partially by elimination of finding similar fragments from the other tires, fragment #3 was matched to the outboard (serial) sidewall of the outboard right main landing gear tire.[28]

Evidence such as the split between sidewall fragments #2 and #3 indicated that an initial failure happened along the mid-sidewall area. This was also found on the inboard tire sidewall. The ragged appearance found 1.2 inches from the decorative rib shown in Figure 1 existed almost completely around the sidewall. The exception was of a short section of the outboard sidewall on fragment #10.

Examination for an initial break, rather than for a continuing type of tear, focused on the hub-side edge of fragment #10. The tearing on this one edge of this one fragment from the serial (outboard) side of the tire evenly crossed the diagonal directions of the underlying nylon fabric plies. Fragment #3 had unique portions of lettering that could be both matched on an exemplar tire and matched to the end of the tear on Fragment #10.

Fragment #2 was from the hub portion of a broken sidewall and had mold flashing to locate it in radius from the hub (between the sidewall and bead). The fragment seemed to be from the outboard sidewall of the same tire, but had no features to locate the precise original placement around the hub. Fragment #2 had been found between fragments #1 and #3 and the edges of both fragments #2 and #3 came to the 1.2 inch reference measurement from the decorative rib. (See Figure 4) This edge of the #2 fragment from along the 1.2 inch measurement was examined under 20 and 50 power magnification and at least two layers of tearing were observed. The torn interface between the layers was rough and not a single adhesive type of failure. The inner layer was different from the outer layer in that the inner layer had the cord material still embedded and had relatively more heat discoloration, referred to as moderate to severe (blue tint). The outer layer did

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28 Fragment #3 was located by matching the tear pattern on fragment #10, as well as from the unique “GL” on the sidewall words “FLIGHT EAGLE.” Under 20X magnification, red on the inner edge of fragment #3 was apparent as red spray paint that had been used to mark the runway where the fragment was found. The red was not on the adjacent edges of fragment #10.

have heat discoloration, but significantly less where closer to the surface of the tire and away from the nylon cords. (See Figure 27)

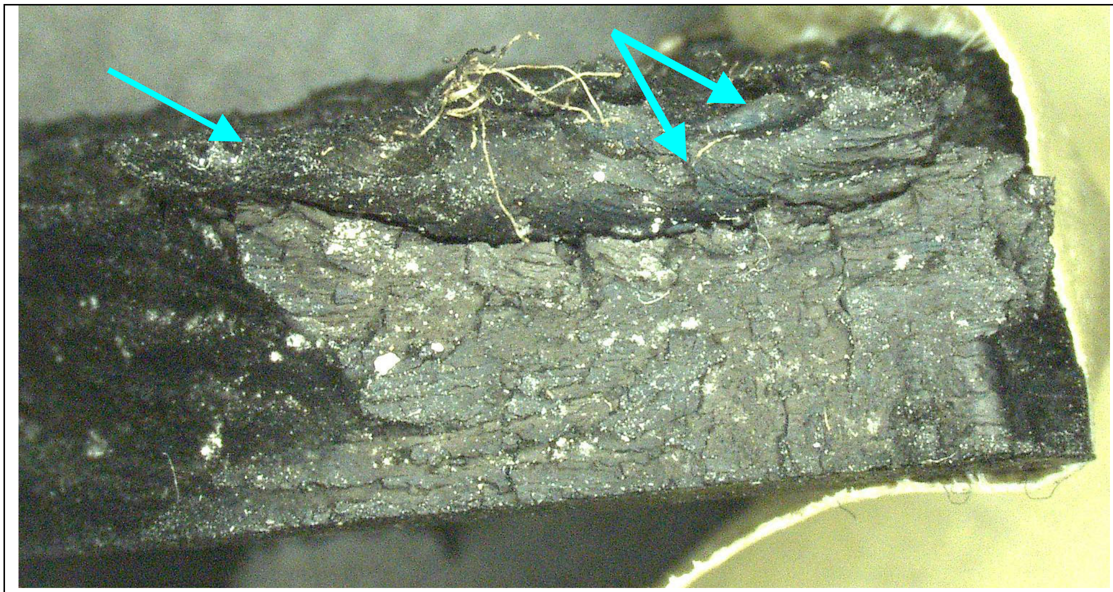


Figure 27. Fragment #2 edge that had been 1.2 inches from the decorative rib, with arrows pointing to blue tinting from heat damage.

The sidewall fragments overall (not limited to fragments #1-#4) had extensively more evidence of heat than the shoulder and tread areas of the tire.[29] The first fragments that had been found along the runway path were from the outboard right tire sidewall and had the following indications of heat and over-deflection:

Fragments #2, #3 (under cord impressions of the outer-most ply), #4A, and #4C had significant heat discoloration. In some locations near the cord material the blue tint associated with heated rubber was verging on turning to purple.

Fragment #4C had surface cracking on the rubber.

Fragment #10 had extreme abrasion in the liner adjacent to the straight separation edge.

Fragment #10 has heat discoloration (blue tinting) where the liner tore loose from the inner-most ply in the upper sidewall area and in other locations.

Many broken nylon cords on the straight edge of fragment #10 are stiff and have lost the normal soft pliable feel.

Examining for evidence of potential manufacturing defects, no evidence was found that any portions of the tread had an adhesive separation from the rest of the tire construction. No "polishing" of the rubber from rubbing adjacent separated surfaces was found, no adhesive failures were observed, and the fragments had torn roughly apart.

The reconstructed tread and sidewalls were examined extensively for evidence of an initial foreign object type of damage and none was found. Silver coloring was found

29 Descriptions of the heat damage found on the individual fragments are listed in a later section.

transferred to the tread of the tire. The construction and cord beneath this area did not have "X or diamond-shaped fracture lines that the three tire manufacturer publications showed as damage typically related to a puncture or foreign intrusion. The sidewalls could not be totally reconstructed, but of the fragments identified, none were found to exhibit foreign object types of damage.

A hole in the liner was examined on at least two occasions. The hole did not also penetrate the tread fragment that had covered the liner with the hole. The interior surface of the liner had been cut to either side of the hole and the cuts were those of a sharp edge, rather than what would be associated with a single puncturing type of device, such as a nail. Additional cuts were found on the interior surface. The cuts were found to not be evenly distributed around the periphery from when the tire was complete. The cuts were found in some fragments and not others.

Fragments from bags 40, 42, 44, and 45 contained bead material that had been recovered from the earlier portion of the runway. Although not able to absolutely establish the original location of each, the runway location and remaining tire beads on the other three wheels indicated that these fragments were from the right outboard tire. The beads of all four tires had no evidence of extreme heat from the wheel brakes. (See Figures 28 and 29)

Both tire beads were missing from the right outboard wheel (# 4) and one bead from the left inboard wheel (#2).

Figure 28. As copied from the Bridgestone Tire Care and Maintenance publication and as a comparison for the photo to the right. This photo shows how a tire bead with evidence of brake overheating could appear.

Figure 29. These fragments from N999LJ show the tire beads (Fragments #45 and 66), and the lack of heat-type damage that is visible in the photo to the left. Specifically, note the lack of damage under the lettering “45” and “66.” The ragged edges visible in this photo are where the bead material had rolled on the grooved pavement.

RIGHT INBOARD (POSITION #3) TIRE RECONSTRUCTION:

For reference, fragment #14A was the first part of this tire found along the runway path. Less of the assembly was completed and the assembly was in smaller fragments, with less of the tread intact as individual significant items. Fragments from position #3 (example: fragment 14A) had melted nylon cord and many fragments had blue rubber.

The tread depths were 5/32 in the center groove and 6/32 in the shoulder grooves. The assembly consisted of 14A, 19, 18, 20, 23A, 24, 21B, 21, 20B, 22.

The sidewalls of this tire did not have the matching inboard/outboard sidewall damage that the outboard right tire had exhibited. The inboard right tire (position #3) had the same type of lower mid-sidewall fracture on the outboard side of the tire, as had been found on both sidewalls of the outboard right tire. The inboard (serial) side of the position #3 tire was erratically torn without following the 1.2 inch measurement along the sidewall.

In further detail, about 60-70% of the non-serial side (outboard, facing the outboard right tire) circumference had separated along the sidewall 1.2 inches toward the hub from the decorative rib (which is about 1 inch from the tread shoulder). Additional evidence of over-deflection on the outboard sidewall included:

Heat damage (discoloration) on the upper sidewall, above the word FLIGHT of FLIGHT EAGLE.
Extensive liner abrasion near the edges. This sidewall had as much abrasion as seen in the fragments of the outboard tire.
Cords along the edges that heated to the point of becoming as stiff as broom bristles.
The edges have heat discoloration (blue tinting).

The erratic tearing on the serial sidewall (inboard, or fuselage) included complete detachment between the sidewall and shoulder, with missing material past the corner of the shoulder in one portion. A short portion of the plies from the bead area at the serial number was identified for the reconstruction. The sidewall remnants did have heat discoloration (blue tinting) and blue tinting was found at the balance pad of the liner. This erratically torn sidewall of the tire had liner abrasion, but not the complete and concentric ring of liner abrasion seen on the outboard side of this tire.

The tread had skid marks but no apparent flat spots on the 50% of the reconstructed tread. No polishing indicative of a pre-existing rubbing of parts was seen. Tears and fractures were found to be ragged and not as a loss of adhesion in nature. Some gouges and small cuts were found on the interior of the inner liner. The small cuts were mainly found on specific fragments and not evenly distributed along the reconstructed surface of the inner surface.

LEFT INBOARD (POSITION #2) TIRE RECONSTRUCTION:

The reconstruction did not find enough detail to distinguish which side of this reconstructed tire came from the serial side, versus the non-serial side. The mid-sidewalls had been found as numerous small fragments, as opposed to the larger tread and upper sidewall fragments. This characteristic was similar to that seen on the right outboard tire (position #4). A difference was that this reconstruction had an “egg” shape. The small end had the appearance of being restrained and in different/smaller fragments than the rest of this reconstruction. Fragment #34 at the larger end of the egg shape had a ground, abraded, and blue tinted surface with the appearance of being dragged. Fragment #34 was further down along the runway than most of the fragments used in the reconstruction.

Fragments 31, 32A, and 33 establish about 50% of the circumference and the sidewall location of tearing measurement of about 1.2 inches is similar to the measurement found in the position #4 tire and the outboard side of the position #3 tire. On one side of the tire, the mid-sidewall tear on fragment #31 is the straightest portion of the tear across the construction plies. On the opposite side of the tire, the straightest portion of the tear is along 34, 31A, and 32.

Some sidewall area liner abrasion was found. The sidewall area liner abrasion in this tire was significantly less than seen in the right set of tires and was not completely around the periphery of the reconstruction. Blue tinting was found around the shoulder and sidewall areas.

Fragments fitted to this reconstructed tire included #33, 32, 31, 32A, 26, and 32B.

LEFT OUTBOARD (POSITION #1) TIRE RECONSTRUCTION:

The reconstruction did not find enough detail in the fragments to distinguish which side of this tire came from the serial side, versus the non-serial side.

Most of the crown area was reconstructed of eight fragments. This tire had a more torn and shredded appearance overall and a more abraded appearance to the outer surfaces than the other three tires. None of the larger fragments had the complete thickness of the tire construction, which was a difference from the other three tire reconstructions. The fragments had extensive tearing through the various layers of construction and not failures of adhesion. Fragment 40B extends from the mid-sidewall to about the centerline of the crown and is approximately 19 inches in overall circumferential length. The shoulder area has extensive abrasion, almost obliterating the “EAGLE” lettering. The entire edge of the fragment is extensively blue tinted and the nylon cord fragments are very stiff. The mating #42B has significantly less blue tinting and heat-type indications.

Some liner abrasion and scuffing exists on four fragments that have remaining liner. The liner abrasion is similar to that seen in the other tires.

The un-numbered and dirty fragment that had been found on highway SC 302 matched the ply count and type of construction used in the Goodyear tires. The size of the fragment and the oval mold mark with a fragment of the number “1” matched the part number marking on an exemplar tire. The rough size of the fragment best fit with the fragments from wheel position #1.

The assembly was stopped when consisting of fragments 40D, 40, 40A, 42, 38, 38A, 44A, 36, 38B, 42B, 43. Believed to be part of this assembly due to condition, but not positively fitted to the rest of assembly were fragments 42A, 41, 42D, 38C, 40B, 40C, 44, 35, 36A, 35B, 38.

GOODYEAR FORENSICS LABORATORY RESULTS:

The Goodyear Global Forensics Laboratory was used to attempt identification of specific materials. Potential sources of silver contaminates provided to the laboratory were:

Exemplar runway reflector
Landing light fragments
Wheel surface sample
Brake surface sample

Silver was found crossing some of the fragment edges and ending at others. The tire fragments with silver which were examined included 4A, 4C, 5, 5E, 5F, 6C, 7, 8A, 8B. None of the silver was found on fragment #10 from the outboard sidewall of the outboard right tire, where tearing consistent with initial tire failure was found.

Samples from fragments 4A, 4C, 5, 5E, 5F, 6C, 7, 8A, 8B were examined by energy dispersive spectroscopy (EDS) for the constituate elements. The elements were plotted for comparison of peak heights. The same elements were seen in most of the samples with the exception of the landing light and the wheel. The landing light had sodium which the other samples did not have. The wheel had cadmium and chromium which were also unique. With those exclusions, the other samples had varying amounts of carbon, oxygen, aluminum, and silicon as the main constituents. Other elements were found in varying trace quantities. The summary was that none of the available donor materials conclusively matched the silver on the tire fragments.

With respect to the shiny areas on the tire fragments, the samples were analyzed by Fourier Transform Infrared (FTIR). The analysis showed that sample 7A (from the right outboard tire) and hydraulic fluid which was obtained from a wheel brake assembly were a match. Sample 5 from the same tire had fluid marks and the mark was characterized as a nitrogen-containing material, such as a urea, amine, or something similar.

D.3.4 WHEEL AND BRAKE EXAMINATION RESULTS

A working group was formed for the wheel and brake inspection in the same room as the tire examination at Goodyear, and at the same time that the tire examinations took place.

No indications were found to indicate that the wheels or brakes had been overheated. This included inspections for general coloring of components and the intact nature of the fuse plugs. No indications were found of brake lock-up, as indicated by the conditions of the brake rotor drive tangs. The left outboard (#1) wheel had witness marks on the outboard flange that suggested some wheel locking occurred after the tire was gone; three individual flat spots were found on the flange that varied from one to two inches length. Nothing was found to indicate when this occurred or whether this may have been due to pressure applied by the brake.

Each of the four wheels had two eutectic thermal fuses, designed to melt at about 390 degrees F. The fuse plugs were tested for leakage in a test wheel/tire that was pressurized with shop air at 100 PSIG, then using a soap-water solution to look for visible bubbles over a minimum period of five minutes. All eight fuse plugs passed the test by not leaking.

Examinations revealed that two wheels had threaded valve bodies could be removed by finger torque (left inboard and right outboard). (See Figure 30) The specification for installation required 190 in-lbs.

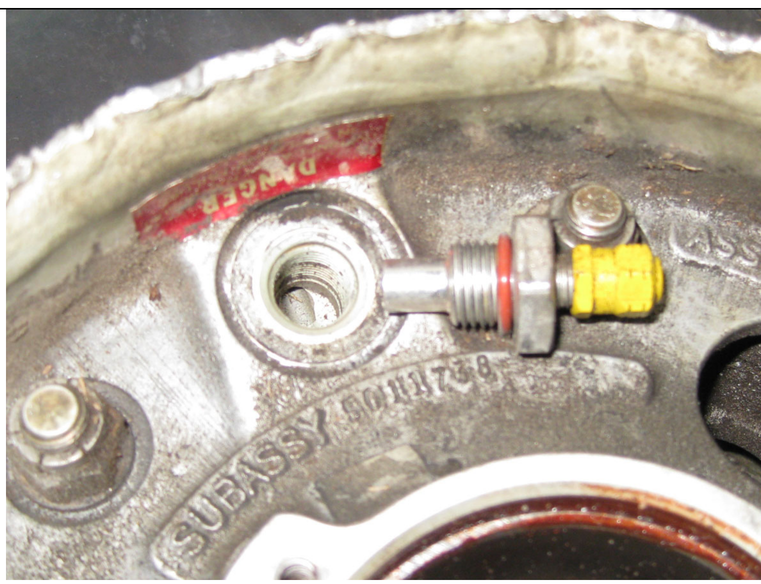


Figure 30. One of two tire inflation valve found finger-tight.

The four tire inflation valves were tested with 18 psig shop air to check for leakage of the internal valve mechanism. (This did not test for leakage between the valve body and the wheel.) Each valve was pressurized from the inside out and none of the valves leaked.

The evidence of heat and over-deflection in these two tires was not significantly different than in the reconstructions of the two tires that had tight inflation valves.

WHEEL, RIGHT-OUTBOARD INSTALLATION (#4)

Identification data: P/N: 5011740; S/N: JUN06-2262

Disassembly of the right-outboard wheel bolts found all to be tight and the wheel seal was found in good condition. The inflation valve was found to be finger tight.

Visual inspection observations:

> The bearing cups appeared undamaged.
>
> Both the inboard and outboard hubs were undamaged and the hub cap retaining threaded holes were undamaged.
>
> The inside tube-well appears generally undamaged, other than dirt buildup.
>
> All flanges had been completely worn off.
>
> Tapered wear existed across the wheel, with the outboard worn more than the inboard.
>
> No damage visible to the tie bolts.
>
> No damage visible to the fuse plugs, however a visual pinhole/black mark was visible in the center of one fuse plug.
>
> No apparent overheat condition generally.
>
> No damage to inflation valve.
>
> The inboard side of the tube-well wall had been worn to a sharp edge and the outboard side of tube-well wall is rough.

The wheel had even wear around the 360 degrees of wheel and bearing surfaces, consistent with rotation. The inboard side of tube-well wall had worn to a sharp edge from contacting the right-outboard brake back-plate rib, located at the 6:00 o’clock position.

BRAKE, RIGHT-OUTBOARD INSTALLATION (#4)

Identification data: P/N: 90002424-2; S/N: MAR06-0726; Functional test date: Nov. 20, 2007; Assembly date: 4Q07

Disassembly of the right outboard brake found the back-plate bolts to be more than finger tight, but at less than the specified torque.

Visual inspection observations:

All disks were found intact within the brake stack. Normal heat coloring was visible on the disk surfaces.

The only visible evidence of sticking/binding of the disks was found at the worn/ground location on the bottom where the brake had rubbed against the pavement.

The six back-plate bolts appeared and felt intact and tight.

No lock-wire was present and discussion with personnel who had been in Columbia confirmed that the wire had been removed during brake removal from the landing gear.

Three of four return mechanisms appeared to be undamaged. The fourth return mechanism had been damaged consistent with wearing through the spring holder. The visible spring is damaged due to wear, but remains unbroken.

Both hydraulic inlet fittings had been damaged, with the back (inlet) fitting (as installed on the right outboard) bent down against tire rotation direction) and sheared off. The front fitting (bleed port) had been bent downward.

All rotor drive tangs had been damaged, with rotor 1, 2 and 3 tangs staggered (misaligned).

The back-plate had been damaged on the inboard with 360 degrees mechanical grinding – consistent with grinding on the right outboard wheel inboard sidewall.

Major wear existed on the bottom of the brake disks and housing, measuring about 4 ½ inches across and ½ inch deep at the backplate. There was a tapered wear, with the backplate side worn deeper than the housing side.

The top of the #1 rotor was visibly bent toward housing and damage to the other disks was not as conspicuous. The rotor #1 tangs had been bent toward the housing, different than the rotor tangs from rotors 2 and 3, which were worn lower and displayed a mushroom head.

Minor surface rust corrosion exists on the inside of the hub, toward the back-plate side, at the 6:00 o'clock position. Housing bolts (2 large & 3 small) were found tight & lock-wired. The disks did not rotate and did not move back and forth across torque tube.

Additional observations:

The return mechanism damage was consistent with sliding on pavement.

The staggering of the rotor drive tangs was consistent with the brake disks being able to rotate after the wheel flanges were ground off.

Major wear on bottom of brake disks and housing was consistent with sliding on pavement.

The return mechanism condition and material on the brake pads were consistent with a brake assembly that had relatively few landings in service.

All damage was consistent with runway contact and appeared to be of a secondary nature.

WHEEL, RIGHT-INBOARD INSTALLATION (#3)

Identification data: P/N: 5011740; S/N: JUN06-2256

Disassembly of the right inboard wheel found the bolts to be more than finger tight, but not at full torque. The wheel seal was found in good condition.

Visual inspection observations:

The wheel/tire bead flanges were present.

No visual damage was found to the inboard and outboard hub and cups, the tie bolts, fuse plugs, inflation valve, or hub cap retaining threaded holes

The inside tube-well appeared undamaged overall, other than having a dirt buildup.

The inboard & outboard wheel flanges had been severely worn. The flange wear was tapered inboard more than it was on the outboard side. The inboard flange had damage on the inside diameter of flange. The inboard flange inner diameter wear was consistent with pavement contact on the brake back-plate.

A groove on the inside of inboard hub was consistent with a loose rivet on the brake back-plate.

The inboard drive lugs were missing.

No visible signs were found of heat damage.

BRAKE, RIGHT-INBOARD INSTALLATION (#3)

Identification data: P/N: 90002424-2; S/N: JUL08-0967

Visual inspection observations:

The back-plate bolts were found tight and lock-wired.

Oil/grease residue was on the inside of the back-plate.

Two of six rivets holding the back-plate to the endplate were found out of position.

The outer diameter of the back-plate had been worn, consistent with contacting the wheel.

The rotor #1 and #2 tangs aligned and all showed damage from physical contact. The #1 rotor tangs had been bent toward the housing. The rotor #2 tangs had been worn and mushroomed.

Rotor #3 had been broken and partially missing, with one remaining section partially protruding from the stack. Rotor #3 had a remaining piece that had visual evidence of heat (blueish color) and witness marks that were consistent with physical contact.

Major wear existed on the bottoms of the brake disks and housing, measuring about 3 ¼ inches across, by a quarter-inch deep.

The housing mounting bolts were found to be tight and lock-wired.

Three of four return mechanisms were received undamaged. The fourth return mechanism had damage from wear, which did not penetrate the spring housing.

The bleed port hydraulic fitting was found undamaged.

The inlet fitting had been damaged but was tightly intsalled. It had been bent downward against tire rotation direction, rotated out of position, and separated from the housing.

Disassembly of the right inboard brake revealed no abnormal conditions. The condition was generally similar to the right outboard brake. Rotor number 3 was found broken, but no signs of aligning problems were found on the mating disks.

Dirt inside the torque tube hub inner diameter and wheel contact surface was consistent with having been deposited after the brake was removed from the landing gear.

WHEEL, LEFT-INBOARD INSTALLATION (#2)

Identification data: P/N: 5011740; S/N: JUN06-2264

Visual inspection observations:

One tire bead (inboard) remained on the wheel.

Undamaged components appeared to include the inboard and outboard hub and cup, tie bolts, fuse plugs, inflation valves, the hub cap retaining threaded holes, and the inside tube-well (other than dirt buildup).

The inboard and outboard wheel flanges were found severely worn. The flange wear was even between the inboard and outboard sides. The outboard flange also had deformation along the outer circumference that interfered with the circular shape.

Light scoring marks were found on the inside diameter of inboard tube-well intermittent around the circumference consistent with loose rivets on brake back-plate.

The inboard drive lugs were missing.

No visible signs of heat damage were found.

The inflation valve was found finger tight.

One fuse plug was found to be finger tight (specification = 80 in-lbs.).

Dis-assembly of the wheel found all of the bolts to be tight and the wheel seal in good condition.

BRAKE, LEFT-INBOARD INSTALLATION (#2)

Identification data: P/N: 90002424-2; S/N: JUL08-0975

Visual inspection observations:

The back-plate bolts were found tight and lock-wired.

Dirt and oil/grease residue were on the inside of the back-plate.

Four of six rivets (holding back-plate to end-plate) were found out of position. The outer diameter of the back-plate showed light physical contact in the form of light polishing with no true wear.

Rotor #1 and #2 tangs were found misaligned. All tangs showed damage consistent with physical contact. None of the rotor 1 tangs had been bent toward the housing; all had been worn and mushroomed.

Rotor #3 is broken and partially missing - one small section remained in the stack.

The housing mounting bolts were found lock-wired tightly.

Three of the four return mechanisms were found undamaged. The fourth return mechanism had been slightly damaged by impact (not wear).

The bottom of the housing had multiple types of damage. Some indications were consistent with runway contact and subsequent wear on the bottom or on the brake disks. Some additional damage was of unknown origin.

The bleed port hydraulic fitting was undamaged.

The inlet fitting was undamaged. It had been rotated out of position approximately 115 degrees clockwise.

Disassembly of the inboard left brake revealed no abnormal conditions.

WHEEL, LEFT-OUTBOARD INSTALLATION (#1)

Identification data: P/N: 5011740; S/N: JUN06-2260

Visual inspection observations:

Both tire bead flanges remained with the wheel.

Significantly more impact damage to the inboard wheel half was found than was found to the outboard wheel half. Damage to both wheel half flanges in the axial direction were consistent with impact loads.

Tire bead wire on the wheel sustained damage consistent with high-load impacts.

The outboard flange had areas of wear that were consistent with contacting the runway surface at three separate locations (not distributed around for 360 degrees around the periphery).

Slight traces of wear/grinding were found on the inboard flange. Two of the seven drive bosses remained on the inboard flange. The inboard bead seat had been cracked.

Visually undamaged were the inboard and outboard hubs and cups, tie bolts, fuse plugs, inflation valves, and the hub cap retaining threaded holes.

No visible signs of heat damage were observed.

Disassembly of wheel #1 found the bolts to be tight and the wheel seal was found in good condition.

BRAKE, LEFT-OUTBOARD INSTALLATION (#1)

Identification data: P/N: 90002424-2; S/N: JUL08-0951

Visual inspection observations:

The back-plate bolts were found tight and lock-wired, with dirt and oil/grease residue on the inside of the back-plate. None of the six rivets had damage. The back-plate outer diameter damage was consistent with high impact load.

The rotor tangs had been misaligned and displayed mushroom-type head damage.

The disk outer diameters had been localized damage in about the 6:00 o'clock location, contrasting with the normal distribution of operational wear.

The housing had broken in half at about the 6:00 o'clock position, with about half remaining. One large bolt remained, the other large bolt and three smaller bolts had been sheared off. The housing damage was consistent with high impact loads.

Signs of impact damage also existed in the steel pressure plate and disks.

The return mechanisms were missing, other than one spring housing that remained in the housing bore.

Impact loads to both the wheel and brake were consistent with most of the damage of unknown origin. The alignment of the impact marks and bolts shearing off were consistent with one impact.

Disassembly of the left outboard brake found the assembly to be normal. The lock-wired back-plate bolts were found to be more than finger tight, but not at full torque. The disk coloring differed from the others in that this one had more blue color.

Envelope #82 contained one half of a brake housing, which matched the missing part of the brake from the #1 installation. One large bolt had been sheared off, the inlet port was missing the hydraulic fitting, and there was internal thread damage. No return mechanisms remained with the partial housing. Two pistons were missing from the partial housing. The general appearance of the fragment included knicks, dings, and scratches.

D.4 N999LJ TIRE-RELATED MAINTENANCE

The Global Exec Aviation Operation Specifications (OpSpecs) showed that the operator was required to comply with the Learjet maintenance manual. Reviewing the flight history with the Director of Maintenance (DOM) found that the airplane had flown on five days over a 12-day period and the DOM did not know when the tire had last been checked or what the pressure had been. Maintenance records did not show when the tire pressures had been checked last.

D.4.1 TIRE-RELATED DISCUSSION OF SEPTEMBER 23, 2008

A group in Columbia gathered to discuss the service which was performed at Teterboro by Meridian Jet Center. The names have been replaced by titles for each of the individuals. The group in Columbia was comprised of [Learjet person #1], [Learjet person #2], and [Global Exec DOM]. Toward the end of the telephone call, the Global Exec Director of Operations [Global Exec DoO] joined the group in Columbia. The group in Teterboro included the Vice President of Meridian; Meridian Director of Maintenance; Meridian Chief Inspector; a Meridian mechanic and inspector; and a Meridian mechanic.[30]

The group in Columbia had no speaker-phone, so the Airworthiness Group Chairman would listen and repeat what was said by the group in Teterboro, then speak for the Columbia group. The following notes were paraphrased by the Airworthiness Group Chairman and checked by the group in Columbia.

Initial question: What maintenance was performed at Meridian?

Answer by [Meridian mechanic and inspector]: The plane had left on Friday [September 12, 2008] and flown for about 45 minutes when the pilots had to return for left/right bleed air lights. The crew said that the lights came on in the air, they backed off power, shut off the wing/stab heat, and the lights had gone off for them.

Meridian checked for pneumatic leaks visually and found nothing. The engines were run and leaks were found in the Wiggins couplings in both pylons, so the seals were replaced. A leak check turned out OK, but the left mixing valve was still sticking. The Meridian personnel spoke with a Learjet Field Service

30 Names have been replaced with titles to de-identify the individuals.

Representative, the airplane was on warranty, and a replacement valve was ordered. The new valve was received and replaced on Tuesday morning. An operational check was performed and the results were OK. The crew did a test flight on Thursday for about 45 minutes and got to 25,000 feet.

[Meridian Director of Maintenance]: The airplane then departed on Friday. They took on 500 gallons of fuel to depart.

[Meridian mechanic and inspector]: No other maintenance was done. We finished working on the plane Wednesday and no other maintenance was performed other than a walk-around. No tire or fluid checks were done by Meridian. The customer did not request Meridian to do any checks prior to flight, so none were performed.

[Meridian Director of Maintenance]: Nobody saw the crew preflight the airplane. [Meridian Director of Maintenance] explained what was done to the crew and gave them the paperwork for the maintenance. They did their own preflight and the test flight at night.

[Vice President of Meridian]: Line service is a separate group at Meridian.

[Meridian mechanic and inspector]: The tires "looked to be in pretty good condition" with some normal tire wear.

This was the end of the telephone conversation. The group in Columbia continued to talk and [Global Exec DoO] joined the group. The following shows the notes written at the time to paraphrase what was said and agreed to (initialed) by the participants at the end of the activity:

[Global Exec DOM]: The Lear left Long Beach on September 7 and first went to Carlsbad, then to Teterboro on Monday, September 8. The crew took off from Teterboro on Friday, September 12, and had the problem with the bleed lights, so they went back to Teterboro.

The maintenance was performed and a test flight was flown on September 18. The airplane was going to deadhead back to Long Beach, but the flight from Columbia was found and on September 19, the airplane flew from Teterboro to Columbia. It was on the ground for about 45 minutes and then the accident happened at the beginning of the next flight.

There were no tire pressure checks by the maintenance personnel in Long Beach before the airplane left. The pre-flight would have been performed by the flight crew. [Global Exec DOM] does not remember when the tire pressures were last checked on N999LJ. If tire pressure checks are made, the pressures are not recorded and there is no requirement to record them.

[Global Exec DoO]: The pilots are instructed to conduct a general condition visual inspection. Looking from the right leading edge, inspect for sidewall bulges and tread defects, look for a leaning airplane, or strut that is not vertical. Move to the end of the wing and look for the tires to match in diameter and for flat spots. He would move to the back of the wing during the pre-flight and look again from the back. Sometimes he would kick the tires.

Pilots never check tire pressures. Absolutely not. They are not trained to do this and it would require a number of procedural changes for them to be able to.

If suspecting a tire, just like any other issue related to the airplane and its maintenance, the pilots are instructed to call the Director of Maintenance, who is [Global Exec DOM]. The pilots are also directed by the company GOM to do this.

[Global Exec DOM]: I get calls frequently. The pilots definitely will call from the road while they are on a trip.

[Global Exec DoO]: On a multiple day trip, only abnormalities would lead to checking tire pressures. With respect to flying the airplane with the 3-rotor brakes, the stopping action is perceptibly better. It takes less pedal pressure and seems to stop faster.

[Global Exec DoO] and [Global Exec DOM] together: We don’t know how often the tires are supposed to be checked.

[Global Exec DOM]: I would have to check for how often the tire pressures need to be checked, but don’t know what it is. There is no requirement to record tire pressures when they are checked and so it is not something that we do.

[Global Exec DoO]: Learjets occasionally blow tires, just like any other jet. I’ve been flying Lears for 11 years and nobody said the tires needed to be checked at the beginning of the day. The Challengers have this requirement in the aircraft flight manual, but not the Lears.

[Global Exec DOM]: I’m not very familiar with Learjet tires or why they would be different.

In a follow-up discussion the following day (September 24) between [Global Exec DOM] and Robert Swaim:

[Global Exec DOM]: We have more than one type of airplane and I use the times in the manufacturers’ maintenance manuals to know what needs to be done for the scheduled items on each.

D.4.2 MAINTENANCE PUBLICATIONS REGARDING INFLATION:

NOTE: Temporary Flight Manual (TFM) change 2009-03 revised the Learjet Maintenance Manual passages cited below. (Ref: Operations Group Chairman's Factual Report Addendum of June 9, 2009). Following adoption of the TFM, the tire pressures must be checked within 96 hours before flight.

Prior to TFM 2009-03, the Learjet Model 60 Aircraft Maintenance Manual (AMM) did not cite daily tire pressure checks in the portion prescribing scheduling of maintenance. Another section of the Learjet Model 60 AMM did contain guidance that specifically stated that tire pressures should be checked daily. Publications from tire manufacturer called for daily tire pressure inspections; none of which were part of the scheduled maintenance program for any particular model of airplane.

Guidance calling for "regular" checks of tire pressure were found in Advisory Circular (AC) AC 20-97B and in a Gulfstream maintenance manual for other jet airplanes operated by Global Exec.

D.4.2.1 LEARJET AMM

The DOM statement that the AMM did not specifically require daily tire inspections was researched.

Chapter 5 of the Maintenance Manual contained the minimum maintenance requirements for operation of the airplane and stated:

> This chapter contains the minimum maintenance requirements for continued airworthiness recommended by the aircraft manufacturer. All inspections and maintenance requirements defined herein are in accordance with FAR 91.409 (f)(3). (ref. 5-10-00, page 1, June 25, 2007)

The page continues by describing the need for scheduled inspections, special inspection requirements, and unscheduled maintenance checks. The page had no descriptions of maintenance at intervals of less than 300 flight hours or 12 months, whichever came first, with the following underlined exception:

> The Learjet Inspection Program is based on 24 Phase Inspections, accomplished one at a time, in groups or collectively, as scheduled by the aircraft operator, and in accordance with Allowable Inspection Tolerances. (Refer to Allowable Inspection Tolerances, this section.) Each Phase Inspection is contained within one of four hourly or calendar driven inspection intervals, the 300 Hour or 12 Month A-Phases, 600 Hour or 24 Month B-Phases, 1,200 Hour or 48 Month C-Phases, and 2,400 Hour or 96 Month D-Phases. Each of the primary inspection intervals (A, B, C, and D) contain six standalone Phase Inspections. <u>The Learjet Inspection Program also contains other inspections and individual standalone</u>

> inspection checks, which must be accomplished at the specified intervals. All periodic inspections, inspection checks, and maintenance requirements are designed to preserve aircraft reliability and ensure the continued airworthiness and safe operation of the aircraft.

The minimum requirement for inspection of tire pressures was found in Inspection Phase A5, due at each 300 hour interval, as Inspection Reference Number (P1210055), which stated:

> "Nose and Main Tires - Check for proper inflation. (Refer to 12-10-05.)"

The minimum interval requirements for airworthiness were described in Chapter 5. How to accomplish tire-related tasks was described in Chapter 12. Section 12-10-05, pages 301 and 302 of the AMM were titled TIRE-SERVICING, and (1. Service Tires, A. General) the Chapter described general aspects about how to accomplish tire-related tasks. The following passages were found in Section 12-10-05 on pages 301 and 302:

> (7) The dual main gear tire pressures must be kept as closely as possible to each other. If the tire pressure[s] are not kept as equal as possible, an overload of one tire beyond its rated capacity is possible.
>
> (15) Important inflation practices and tips are as follows:
>
> (a) Measure the cold tire pressure before the first flight of every day or every 10 day[s] on in service tires which are not in use.
>
> (g) Service the main tires as closely as possible to each other,

The AMM section also provided the following statement, showing that only inspection with a tire pressure gauge was capable of detecting an under-inflated tire:

> (16) Do not under-inflate the tire. An under-inflated tire generally can not be detected visually.

The Learjet Model 60 Aircraft Maintenance Manual did not include a list of daily maintenance inspection items.

A Learjet engineering representative to the group stated that "Tire care and maintenance has been a presentation topic at all the M&O's [Maintenance and Operations Conferences] since I have been in tech services." [2002] He separately stated that: "We do not require a tire pressure check in [any] recommended publication (flight manual, pilots manual, operating handbook). Preflight tire pressure checks are usually a part of program that the operator gets local approval to operate under."

ADDITIONAL LEARJET PUBLICATIONS:

Learjet posted at least nine tire-related maintenance publications and articles since 1999 for operators. Portions of Learjet One Forum (weekly news) articles have been included below, as well as Three Information Service (monthly news) articles:

Operator Letter of March 1999:

> Goodyear's Aviation Product Division has released an updated version of "The Comprehensive Guide to Aircraft Tire Care and Maintenance". This publication is an excellent resource for any aircraft technician covering everything from bias and radial tire construction, inspection, maintenance and effects of operating conditions, and its free. Additionally, Goodyear has produced four full color videos available on CD-ROM. These provide an audio/video presentation of the information contained in the guide and more. The CD's are in limited supply but are available for $10.00.

September 2001: Maintenance Publication, titled “Aircraft Tire Care and Maintenance ”

> Learjet Field Service would like to remind all operators of the requirements for the proper care and maintenance of tires. In 1997, Goodyear published an Information Report #97001 on Learjet tire maintenance which outlines proper care and maintenance.
>
> Also available is a Comprehensive Guide to Aircraft Tire Care and Maintenance, publication #700-862-931-538. Operators may contact any Goodyear Distributor for these publications. If you require additional information contact [names and telephone numbers]

September 2004: Product Support Publication, titled “Everyday Maintenance of Tires and Brakes” (Figure 31)

Product & Support News... Cont'd **BOMBARDIER**

LEARJET, CHALLENGER AND GLOBAL SERIES
Everyday Maintenance of Tires and Brakes - ATA 12 / 32

In the hustle of today's aviation world, it is possible to overlook some of the details that are considered everyday aircraft maintenance. One such item is the care that is given to the tires and brakes of our aircraft. At times, it is easy to assume that our tires and brakes are in good working condition and need little attention, yet we hear of aircraft departing the runway every year due to tire or brake failures.

Tire inflation levels and runway surfaces are a couple of things to consider when determining proper maintenance practices for tires. Over-inflation of tires leads to reduced traction, makes the tire more susceptible to cutting and accelerates center tread wear. Under-inflation reduces the life of the tire due to excessive flex heating, deterioration of the sidewalls, and increased wear at the tire shoulders. Ground operating conditions such as cross-grooved runways and taxiways or runways that have gravel or rocks on their surfaces, provide prime conditions for cutting and chunking of your tires and should be noted by operators working in these conditions.

Tire servicing should be accomplished in accordance with Chapter 12 of the Maintenance Manual. Tire pressures are affected by temperature and should be checked and serviced at ambient temperature. Avoid servicing or checking tires outside in extremely cold climates or within two hours of aircraft landing or high-speed taxi. Always replace the adjacent tire when a tire is damaged and a loss of pressure takes place during taxi, takeoff, or landing.

Other hints for tire servicing are as follows:

1. Check cold tire pressure before the first flight of every day or every ten days on tires installed on aircraft that are not operated daily.
2. Inflate tires to worst operating conditions.
3. Use extreme caution when handling dry nitrogen gas.
4. Increase tire pressure by 4% for tires under a not jacked condition.
5. Allow twelve-hour stretch period after mounting a new tire.
6. Do not reduce pressure of a hot tire.
7. Service pressure in the main tires within 5 psig of each other.
8. Keep tire pressure gauge calibrated (preferably dial type).
9. Complete a leak check of the valve core after each service.

Braking is another issue that greatly affects the service life of aircraft tires. From a maintenance standpoint, it is important to monitor the taxiing of an aircraft for maintenance purposes. It is important to ensure that brakes are not used excessively during normal taxiing or during high speed runs used for maintenance troubleshooting and testing. The main wheels are equipped with fuse plugs that will relieve tire pressure when the wheels are heated excessively. If this happens, both tires on the side affected will require replacement.

Tires, wheels, and brakes are susceptible to any number of damaging forces. Diligence is important in the maintenance practices for these components and will increase the life and reliability each item.

Also available at: http://www.goodyearaviation.com/img/pdf/aircraftmanual.pdf is a Comprehensive Guide to Aircraft Tire Care and Maintenance.

Figure 31. Learjet Product Support Publication

D.4.2.2 GOODYEAR PUBLICATIONS

Goodyear provides the C&M to both customers and the general public. The publication is available on the Goodyear web-site.

Goodyear also publishes dealer publications for customers and occasional information specific to operators or airplane models. Information Report 97001, dated January 9, 1997, was titled “Learjet Tire Maintenance.” The top three-quarters of the page describes “Mounting Tubeless Tires” The following is the last line of the second last paragraph on the page:

> Tire pressures should be checked with an accurate gauge on a daily basis. IT IS STRONGLY RECOMMENDED THAT TIRE PRESSURES BE CHECKED PRIOR TO THE FIRST FLIGHT OF THE DAY.

D.4.2.3 PRESSURE SURVEY DATA

The state of current tire pressures throughout the jet fleet was sought and the FAA has a ramp-check capability that the NTSB does not have. Tire pressure information was collected from two fixed base operators (FBO, see Figures 32 and 33), historical data (2005-2009), eight random commercial and regional operators (582 tires represented in Figure 34), and conversations with maintenance managers of an airline that operates Boeing and McDonnell-Douglas airplanes. Two additional potential general aviation sources collected data and did not provide the information. To obtain cooperation in obtaining data and permission to use the results, the information in this section has been de-identified and separated from the sources. Resources were not available for an extensive and statistically significant sampling that accurately represented the entire national fleet of airplanes. Enough information was collected (and is shown) for the data to be repetitive.

While acquiring the data, the maintainers of business jets were asked about their maintenance programs. The near-unanimous response was that the FAA Operations Specifications (OpSpec) for that operator called for the use of the airplane manufacturer maintenance manuals. The FBO operator represented by the Figure 61 data noted that some maintenance manuals do not call for mandatory tire pressure checks as part of the scheduled maintenance. This was similar to what the Global Exec DOM related about the Learjet AMM. When the FBO maintenance manager was asked why his shop checked tire pressure at all, since the checks were only guidance, he related that his experience found that weekly checks were a good practice, necessary, and similar to most other shops. He did note that he was aware of some owners who would not have the tire pressures of their airplanes checked on a regular basis, or until about to use their airplane, but that those airplanes were generally not in commercial service. The cargo airline operator noted that their OpSpec was also based in the airplane manufacturer’s requirements (with the airline’s modifications), but that the manufacturers of the larger airplanes had already placed tire pressure checks in required inspections that take place daily (or otherwise frequently).

The data gathered found that while most airplane tire pressures were within 10% of nominal, airplanes were flown with tire pressures below that value, at which the tires should be replaced.

TIRE PRESSURE SURVEY FOR LIGHT JETS										
CONTACT: R. Swaim, 202-314-[redacted]										
DATE:	AIRPORT	APPROX TEMP.	AIRPLANE MODEL	S/N or N# (Need this to obtain tire cert data. Will later be deleted.)	TIRE MODEL (On sidewall)	MAIN ↓ NOSE PRESSURE SHOULD BE	PRESSURE FOUND	DAYS SINCE LAST FLOWN	DAYS SINCE LAST CHECKED	NOTES
3-2-09	[redacted]	60°F	HS125	[redacted]	031-525-0 NOSE 033-504-0 MAIN	150/110	145/110	3	7	
3-2-09		60°F	B200		301-393-005	65/60	65/60	8	7	
3-4-09		50°F	HS125		DR6-3877 NOSE [illegible] MAIN	150/110	130/105	1	UNK	NEW AIRCRAFT
3-4-09		50°F	CITATION 560		031-613-0 NOSE [illegible] MAIN	140/125	135/120	1	7	
3-9-09		40°F	HS125			150/110	147/108	3	5	
3-9-09		40°F	C560			140/125	137/122	4	5	
3-9-09		50°F	HS125			150/110	148/109	1	5	
3-9-09		50°F	B200			65/60	64/53	16	8	
3-16-09		60 F	C560			140/125	144/128	3	7	
3-16-09		50°F	HS125			150/110	148/109	1	7	
3-16-09		50°F	B200			65/60	65/60	4	7	
3-30-09		50°F	HS125			150/110	147/108	6	7	
4-9-09		60°F	HS125			150/110	148/108	2	10	
4-9-09		60 F	HS125			150/110	148/108	1	10	
4-9-09		60°F	B200			65/60	64/59	20	24	
4-10-09		65°F	C560			140/125	136/122	1	25	
4-14-09		65°F	B200			65/60	65/60	1	5	
4-14-09		65°F	C560			140/125	138/123	4	7	
4-14-09		60°F	HS125			150/110	146/108	3	5	
4-14-09		65°F	HS125			150/110	148/109	3	5	
4-27-09		95°F	HS125			150/110	156/114	3	13	
4-28-09		92°F	C560			140/125	144/128	6	14	
4-28-09		92°F	B200			65/60	65/65	7	14	
4-28-09		92F	HS125			150/110	153/115	4	14	
5-4-09		65°F	HS125			150/110	150/110	4	7	
5-4-09		65F	C560			140/125	140/125	6	7	
5-4-09		65F	B200			65/60	65/60	14	7	
5-5-09		60F	HS125			150/110	150/110	3	9	

Figure 32. Tire data recorded by a fixed base operator. The following is an example of a redacted survey data sheet that was returned by an FBO. Most of the airplanes were based at the FBO and the tires were checked on a weekly basis.

Calculations made with the Figure 32 FBO data revealed the following items. These calculations ommitted the new arrival airplane that had main landing gear tires with 13% less than specified tire pressures, and did not use the April 28 samples that followed a 27 degree (F) rise in temperatures from the previous week:

Since last check on pressure, average pressure losses of 1.2% per day for nose tires and 1.4% loss from the main tires.

A correlation between nominal pressure and pressure loss, with higher pressure tires losing more pressure per day. (See Figure 33)

Extending a simple straight line slope through the Figure 33 data, the loss per day for a 210 psi tire would be about 0.5% per day. This 1.05 psi is slightly less than Learjet found when sampled tires and about 1/10 of the pressure loss allowable by TSO-C62 (all revisions).

The changes in temperature correspond with C&M statements regarding the ability of tire pressures to change when the ambient temperatures changed. A 27 degree increase in temperature between two weekly checks resulted in the pressures of tires on two airplanes to not only not decrease for the week, but to increase by 3.6-4 %.

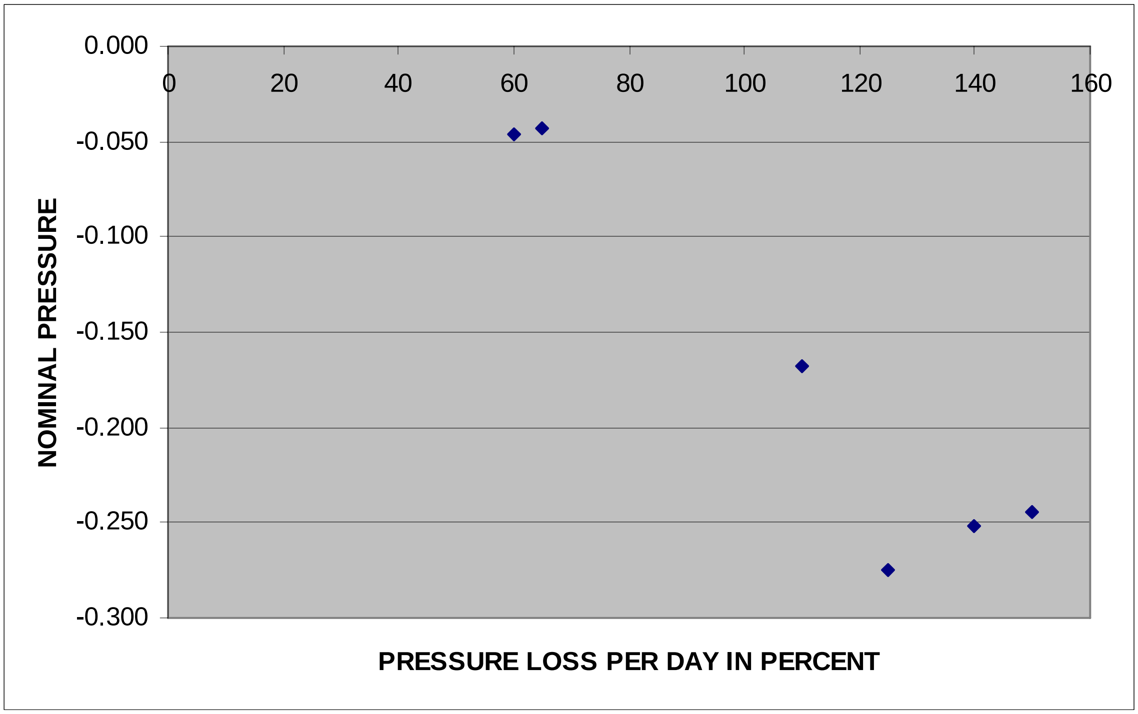


Figure 33. Pressure loss per day in percentage values.

Commercial and/or Regional Operator	Quantity of Tires Checked	Number below 90% Inflation	Percentage With Less Than 90% Inflation
A	104	0	0%
B	60	0	0%
C	60	9	15%
D	60	0	0%
E	48	1	2%
F	66	1	1.5%
G	124	0	0%
H	60	31	52%

Figure 34. A broader sample of pressure data from 582 tires. This commercial and/or regional operator data summary has been de-identified and provides a simple sampling of this portion of the airplane fleet.

D.5 FAA REGULATORY AND ADVISORY INFORMATION:

AC20-97B, dated 4/18/05 is titled AIRCRAFT TIRE MAINTENANCE AND OPERATIONAL PRACTICES. It states that the FAA has initiated a project to update standards and advisory material, including revisions to TSO-C62d and AC20-97A. The AC includes the following sentences:

> [4.b]
> However, a tire’s safe performance is jeopardized when it experiences either overheating or damage by foreign objects. Both conditions can be directly influenced by the operational practices of the operator and the local airport authority.
>
> [5.b]
> In-Service Maintenance of Tire-Wheel Assembly.
> (1) Inflation Pressure Control. Tire pressure should be checked DAILY using a calibrated gauge whose scale is suited to the pressure range that is being monitored. The pressure gauge measurement accuracy should be within +-2 percent for the entire operating pressure range.
> **NOTE: Accurately maintaining the correct pressure is the single most effective task in preventive maintenance regimen for safe tire operations!** [bold emphasis in original AC20-97B text]

D. 6 LANDING GEAR CERTIFICATION REVIEW

Select certification criteria were reviewed for the wheels, tires, and brakes, as well as how those criteria were met at the time of certification. The applicable Federal Aviation Regulations are shown in italics, followed by what the review found about how those requirements were met. Numerous proprietary reports, drawings, and other documents were reviewed, but specific citations have been omitted here. Two regulations that cite the landing gear in general and that were not part of the review were:

14 CFR 25.721 General.

(b) Each airplane that has a passenger seating configuration excluding pilots seats, of 10 seats or more must be designed so that with the airplane under control it can be landed on a paved runway with any one or more landing gear legs not extended without sustaining a structural component failure that is likely to cause the spillage of enough fuel to constitute a fire hazard.

14 CFR 25.723 Shock absorption tests.

a(2) The test attitude of the landing gear unit and the application of appropriate drag loads during the test must simulate the airplane landing conditions in a manner consistent with the development of rational or conservative limit loads.

D.6.1 CERTIFICATION BASIS

Type Certificate Data Sheet A10CE showed that the Certification Basis for the Learjet Model 60 aircraft was:

> FAR 25, as effective February 1, 1965, as amended by 25-1 through 25-73, except as stated. Sections 25.305(d), 25.562, 25.361, 25.672, 25.773(d), 25.812 and 25.832 are not applicable. The following sections are effective at the amendment level noted: Sections 25.109, 25.365, 25.671, 25.695, 25.775, 25.783, 25.801, 25.805, 25.979, 25.1309, 25.1401 and 25.1435 effective February 1, 1965; Sections 25.807 and 25.855 of Amendment 25-15; Section 25.1529 of Amendment 25-21; Sections 25.561, 25.571, 25.625, and 25.721 of Amendment 25-23; Sections 25.785, 25.853 and 25.1413 of Amendment 25-51; Section 25.1307 of Amendment 25-54; FAR Part 34 effective September 19, 1990; FAR Part 36 effective December 1, 1969, as amended by Amendments 36-1 through 36-18; Special Conditions 25-99-CE-14 dated March 10, 1981 and Special conditions 25-ANM-46 dated July 17, 1991 (Lightning Protection and High Intensity Radiated Fields). For the Electronic Flight Instrument System (EFIS) with associated components, and the fully modulated spoiler system, FAR 25.1309 as amended through Amendment 25-

> 41 [effective September 1, 1977] is applicable in addition to the above certification basis.

Part 14 CFR 25.1309 was applicable as of the revision existing on February 1, 1965, with the exception of EFIS and the spoiler system, which were limited to Amendment 25-41, dated September 1, 1977. The regulatory and guidance improvements and changes to ensure that equipment, systems, and installations “performed their intended functions under any foreseeable operating condition” put in place between 1965 and 1993 were not applicable.

The following regulations were covered by the review:

14 CFR 25.729 Retracting Mechanism

> *(f) Protection of equipment in wheel wells. Equipment that is essential to safe operation of the airplane and that is located in wheel wells must be protected from the damaging effects of—*
>
> *(1) A bursting tire, unless it is shown that a tire cannot burst from overheat; and*
> *(2) A loose tire tread, unless it is shown that a loose tire tread cannot cause damage.*

The Learjet Model 60 compliance checklist referenced a report that had originated with development of the Model 54 for compliance with this regulation and the report related that two 390°F fuse plugs are installed in each main wheel to prevent overheating explosions. Tire burst tests had been conducted to demonstrate results for adjacent structure.

For part (2) of this regulation, the Model 54-based report related that return of hydraulic fluid on gear retraction passes through a restrictor, raising the brake return pressure through the brake valve to the brakes to stop wheel rotation prior to entering the wheel wells.

Compliance with the regulation for the nose wheel well was also based in the Model 54 and reviewed.

14 CFR 25.731 Wheels

> *(a) Each main and nose wheel must be approved.*

Proprietary material used to show compliance with this requirement were reviewed. Letters from the supplier were found which stated that the wheels were TSO approved. The nose wheel assembly, part number 9544207-4, was approved to TSO C26b. The main wheel assembly, part number 5011740, was approved to TSO C26c.

(b) The maximum static load rating of each wheel may not be less than the corresponding static ground reaction with –

(1) Design maximum weight; and
(2) Critical center of gravity.

Model 60-based material was reviewed for how compliance had been shown for this requirement.

The investigation found that the TSO report for the main wheel assembly (Meggitt Aircraft Braking Systems) was not included in the Learjet report. An engineering change from Aircraft Braking Systems did show that the wheel's rated static capacity was increased from 5500 lb to 6000 lb on 12-23-91. The TSO report showed the maximum static load rating was 6000 lb. The maximum static ground reaction shown for the main wheel is 5850 lb, which is half of the 11,699 lb found in a Learjet document. This is greater than the main tire load requirement (5654 lb). The entire structural CG envelope was considered, which was larger than the AFM CG envelope. The AFM CG envelope showed a maximum ground reaction of 5654 lb.

The maximum static nose wheel load rating is 3250 lb, per a letter from the FAA to ABSC dated November 21, 1997. The maximum static ground reaction for the nose wheel is 1894 lb.

(c) The maximum limit load rating of each wheel must equal or exceed the maximum radial limit load determined under the applicable ground load requirements of this part.

Model 60-based material was reviewed for how compliance had been shown for this requirement.

The supplier had provided a letter from the FAA to ABSC, dated November 21, 1997, stating that the maximum radial load of the nose wheel assembly was 12,100 lbs. The supplier also sent a TSO report for the main wheel assembly, which listed a radial limit load of 21,000 lbs. A Learjet report showed the maximum radial limit load was 15,807 lbs resulting from the turning condition with the assumption that one tire was flat (ref 14 CFR 25.495 and 14 CFR 25.511(e)). This was below the wheel's rated radial limit load of 21,000 lbs.

A Learjet Model 60 document showed the maximum radial limit load was 7777 lbs, which occurred in the nose gear 3 point level landing condition (ref 14 CFR 25.479(c)(2)(e)(2)(ii)). This was within the wheel's rated radial limit load of 12,100 lbs.

14 CFR 25.733 Tires

(a) When a landing gear axle is fitted with a single wheel and tire assembly, the wheel must be fitted with a suitable tire of proper fit with a

speed rating approved by the Administrator that is not exceeded under critical conditions and with a load rating approved by the Administrator that is not exceeded under—
The loads on the main wheel tire, corresponding to the most critical combination of airplane weight (up to maximum weight) and center of gravity position, and

A proprietary report for the Model 60 stated that the system complied with this requirement. The reason that this part of the regulation had been considered to be applicable to the Learjet Model 60 main tires was not found, since there are two wheels and tires on each axle.

(a) When a landing gear axle is fitted with a single wheel and tire assembly, the wheel must be fitted with a suitable tire of proper fit with a speed rating approved by the Administrator that is not exceeded under critical conditions and with a load rating approved by the Administrator that is not exceeded under—

(2) The loads corresponding to the ground reactions in paragraph (b) of this section, on the nose wheel tire, except as provided in paragraphs (b)(2) and (b)(3) of this section.

Model 60-based material was reviewed for how compliance had been shown for this requirement.

The investigation found that nose tire part number 184F10-2 (part number of Goodyear; 18 x 4.4, 10 ply rated, Type VII rib reinforced tubeless tire with dual chines) was approved to TSO C62c, and that tire had a rated speed of 210 mph, per Goodyear's TSO report and a Learjet report. The maximum speed of the tire to be considered for the Learjet Model 60 aircraft is 210 mph (182 knots) per page 1-25 of the Learjet Model 60 AFM.

Per Goodyear's TSO report, the nose tire has a rated load of 3550 lb. The aircraft's required load was not found in the compliance report. A Learjet stress engineer showed that the maximum nose tire load was 2947 lbs. Reference 14 CFR 25.733(b)(2), shown below, pertains to this tire.

(b) The applicable ground reactions for nose wheel tires are as follows:

(1) The static ground reaction for the tire corresponding to the most critical combination of airplane weight (up to maximum ramp weight) and center of gravity position with a force of 1.0g acting downward at the center of gravity. This load may not exceed the load rating of the tire.

Model 60-based material was reviewed for how compliance had been shown for this requirement.

The investigation found that Goodyear's TSO report showed that the nose tire had a rated load of 3550 lbs. Per Learjet, the aircraft's required load is 1894 lbs.

> *(2) The ground reaction of the tire corresponding to the most critical combination of airplane weight (up to maximum landing weight) and center of gravity position combined with forces of 1.0g downward and 0.31g forward acting at the center of gravity. The reactions in this case must be distributed to the nose and main wheels by the principles of statics with a drag reaction equal to 0.31 times the vertical load at each wheel with brakes capable of producing this ground reaction. This nose tire load may not exceed 1.5 times the load rating of the tire.*

Model 60-based material was reviewed for how compliance had been shown for this requirement.

The investigation found that Goodyear's TSO report showed that the nose tire has a rated load of 3550 lbs. The aircraft's required load was not found in the compliance report. A Learjet stress engineer showed that the maximum nose tire load had been calculated to be 2947 lbs.

> *(3) The ground reaction of the tire corresponding to the most critical combination of airplane weight (up to maximum ramp weight) and center of gravity position combined with forces of 1.0g downward and 0.20g forward acting at the center of gravity. The reactions in this case must be distributed to the nose and main wheels by the principles of statics with a drag reaction equal to 0.20 times the vertical load at each wheel with brakes capable of producing this ground reaction. This nose tire load may not exceed 1.5 times the load rating of the tire.*

Model 60-based material was reviewed for how compliance had been shown for this requirement.

The investigation found that Goodyear's TSO report showed that the nose tire has a rated load of 3550 lbs. The aircraft's required load was not found in the compliance report. A Learjet stress engineer showed that the maximum nose tire load had been calculated to be 2570 lbs.

> *(c) When a landing gear axle is fitted with more than one wheel and tire assembly, such as dual or dual-tandem, each wheel must be fitted with a suitable tire of proper fit with a speed rating approved by the Administrator that is not exceeded under critical conditions, and with a load rating approved by the Administrator that is not exceeded by—*
>
> *(1) The loads on each main wheel tire, corresponding to the most critical combination of airplane weight (up to maximum weight) and center of gravity position, when multiplied by a factor of 1.07; and*

Model 60-based material was reviewed for how compliance had been shown for this requirement.

The investigation found that main tire part number 178K43-1 (part number of Goodyear; 17.5 x 5.75 – 8, 14 ply rated, rib reinforced tubeless tire) had been approved to TSO C62c and had a rated speed of 210 mph, per Goodyear's TSO report and a Gates Learjet report for the Model 54. The maximum speed of the tire that will be seen by the Learjet Model 60 aircraft is 210 mph (182 knots) per page 1-25 of the Learjet Model 60 AFM.

Goodyear's TSO report showed that the main tire had a rated load of 6050 lb. The aircraft's required load is 5654 lbs. Multiplying 5654 lbs. by the 1.07 factor listed in the regulation results in a load of 6050 lbs.

> *(d) Each tire installed on a retractable landing gear system must, at the maximum size of the tire type expected in service, have a clearance to surrounding structure and systems that is adequate to prevent unintended contact between the tire and any part of the structure or systems.*

Model 60-based material was reviewed for how compliance had been shown for this requirement.

14 CFR 25.735 Brakes

> *(a) Each brake must be approved.*

A Model 60-based document stated that the system with the original two rotor brake complied with this requirement. The compliance statement for the original three rotor brake and the compliance statement for the improved three rotor brake which had been installed on N999LJ were reviewed. A letter from the supplier, Meggitt Aircraft Braking Systems, stated that the original two rotor brake had been TSO approved, and a letter from the supplier stated that the improved three rotor brake was TSO approved. The two rotor brake assembly, part number 5003096-7, had been approved to TSO C26c. The original three rotor brake assembly, part number 9002424, had been approved to TSO C26c. The improved three rotor brake assembly, part number 90002424-2, had been approved to TSO C26c.

> *(b) The brake system and associated systems must be designed and constructed so that if any electrical, pneumatic, hydraulic, or mechanical connecting or transmitting element (excluding the operating pedal or handle) fails, or if any single source of hydraulic or other brake operating energy supply is lost, it is possible to bring the airplane to rest under conditions specified in 25.125, with a mean deceleration during the landing roll of at least 50 percent of that obtained in determining the landing distance as prescribed in that section. Subcomponents within the brake assembly, such as brake drum, shoes, and actuators (or their*

equivalents), shall be considered as connecting or transmitting elements, unless it is shown that leakage of hydraulic fluid resulting from failure of the sealing elements in these subcomponents within the brake assembly would not reduce the braking effectiveness below that specified in this paragraph.

A Model 60 document stated that the system with the original two rotor brake complied with this requirement.

A Model 60 document stated that the original three rotor brake complied with the requirement and the page was part of a document written in 2003. The means of compliance for this part of this regulation included a design review and aircraft flight testing.

A Model 60 document stated that the improved three rotor brake was in compliance and the page was part of a document written in 2007. The means of compliance for this part of this regulation included a design review.

(c) Brake controls may not require excessive control force in their operation.

A Model 60 document stated that the system with the original two rotor brake complied with this requirement, and referenced a Model 54-based document. A review of this document revealed force calculations and aircraft testing that was performed on the Model 54 to show compliance with this regulation. A Learjet engineer showed that the only difference between the brake control systems on the Model 54 and the Learjet Model 60 was the brake assembly installed (either the original two rotor brake, the original three rotor brake, or the improved three rotor brake).

This part of the regulation was not addressed in Model 60 addendums for the original three rotor brake or for the improved three rotor brake. A Learjet engineer showed that the only difference between the brake control systems on the Learjet Model 60 with the original two rotor brake assembly and the Learjet Model 60 with either three rotor brake assembly was the brake assembly itself.

(d) The airplane must have a parking control that, when set by the pilot, will without further attention, prevent the airplane from rolling forward on a paved, level runway with takeoff power on the critical engine.

A Model 60 document stated that the system with the original two rotor brake complied with this requirement, in that the parking brake was shown to have adequate authority to hold the aircraft stationary with either or both engines at takeoff power.

For the original three rotor brake assembly, the aircraft parking control system was unchanged from the existing Learjet Model 60 design. Aircraft testing was carried out to demonstrate that the new brakes would prevent the airplane from rolling at an aircraft weight of 23,380 lb. [Note: Maximum ramp weight is 23,750 lbs.]

For the improved three rotor brake assembly, the parking control system was unchanged from previously FAA certified existing Learjet Model 60 design. The only change is to the brake unit itself, the torque tubes were made more robust and related parts changed to accommodate the torque tube change.

> *(e) If antiskid devices are installed, the devices and associated systems must be designed so that no single probable malfunction will result in a hazardous loss of braking ability or directional control of the airplane.*

A Model 60 document stated that the system with the original two rotor brake complied with this requirement. A fault analysis showed compliance with 14 CFR 25.735(b). (Note: "(b)" is not a typo).

14 CFR 25.735(e) was not addressed in a Model 60 basis for the original three rotor brake assembly. A Learjet engineer showed that the antiskid system is unchanged from the previously FAA certified existing Learjet Model 60 design, with the exception of the brake assembly.

For the improved three rotor brake assembly, the parking control system was unchanged from previously FAA certified existing Learjet Model 60 design. The only change is to the brake unit itself, the torque tubes were made more robust and related parts changed to accommodate the torque tube change.

> *(f) The brake kinetic energy capacity rating of each main wheel-brake assembly may not be less than the kinetic energy absorption requirements determined under either of the following methods:*
>
> *(1) The brake kinetic energy absorption requirements must be based on a rational analysis of the sequence of events expected during operational landings at maximum landing weight. This analysis must include conservative values of airplane speed at which the brakes are applied, braking coefficient of friction between tires and runway, aerodynamic drag, propeller drag or powerplant forward thrust, and (if more critical) the most adverse single engine or propeller malfunction.*
>
> *(2) Instead of rational analysis, the kinetic energy absorption requirements for each main wheel brake assembly may be derived from the following formula, which assumes an equal distribution of braking between main wheels:*
>
> $$KE=0.0443\ WV^2/N$$
>
> *where--*
> *KE = Kinetic energy per wheel (ft.-lb.);*
> *W = Design landing weight (lb.);*
> *V = Airplane speed in knots. V must be not less than* V_{S_0} *, the poweroff*

stalling speed of the airplane at sea level, at the design landing weight, and in the landing configuration; and
N = Number of main wheels with brakes.

The formula must be modified in cases of unequal braking distribution.

A Model 60 document stated that the system with the original two rotor brake complied with this requirement. The main wheel and brake were also addressed.

A Model 60 document stated that the original three rotor brake complied with this requirement, and the kinetic energy absorption requirements were determined by the rational analysis method. This was written in 2003. The means of compliance for this part of this regulation included design review, calculation/analysis, laboratory tests, and equipment qualification.

For the improved three rotor brake assembly, Learjet documentation stated that "The brake kinetic energy absorption requirements are unchanged, therefore the previously FAA certified kinetic energy absorption data remains unchanged."

(g) The minimum stalling speed rating of each main wheel-brake assembly (that is, the initial speed used in the dynamometer tests) may not be more than the V used in the determination of kinetic energy in accordance with paragraph (f) of this section, assuming that the test procedures for wheel-brake assemblies involve a specified rate of deceleration, and, therefore, for the same amount of kinetic energy, the rate of energy absorption (the power absorbing ability of the brake) varies inversely with the initial speed.

A Model 60 document stated that the system with the original two rotor brake complied with this requirement. The main wheel and brake were also addressed.

A Model 60 document stated that the original three rotor brake complied with this requirement, and the velocity used to determine the maximum kinetic energy requirement per brake as described in paragraph (f) of this section was 146.1 knots. The actual aircraft demonstrated maximum kinetic energy condition was run at 152 knots. This was written in 2003. The means of compliance for this part of this regulation included design review, laboratory tests, and equipment qualification.

For the improved three rotor brake assembly, the installation was found to have no impact to the previously FAA certified minimum stall speed data, which remained unchanged.

14 CFR 25.1301 Function and Installation

Each item of installed equipment must—

(a) Be of a kind and design appropriate to its intended function;

A Model 60 document stated that the system complied with this requirement. The compliance statement referenced a section of the same report, which described the main wheel and brake. This Equipment Data Sheet did not specifically address this regulation, and it also did not cover the other equipment included in this report (main tire, nose wheel, nose tire). The Model 60-based document contained TSO approval letters for the nose wheel, nose tire, main wheel, main tire, original two rotor brake assembly, and the improved three rotor brake assembly.

Model 60 documents stated that the original and improved three rotor brakes complied with this requirement, and the means of compliance included design review, laboratory testing, and equipment qualification.

(b) Be labeled as to its identification, function, or operating limitations, or any applicable combination of these factors;

A Model 60 document stated that the system complied with this requirement. The compliance statement referenced section 3.1.2 of this report, but that section did not specifically state how the equipment is labeled. TSO requirements contain specific labeling instructions, but it is unknown if they cover the requirements in this specification (the group did not compare TSO labeling requirements to the requirements in this regulation).

Model 60 documents stated that the original and improved three rotor brake complied with this requirement, and a design review showed compliance to this regulation.

(c) Be installed according to limitations specified for that equipment; and

A Model 60 document stated that the system complied with this requirement. The compliance statement referenced a paragraph. The paragraph did not list specific limitations/requirements (set by Learjet) or TSO test results for the equipment.

Model 60 documents stated that the original and improved three rotor brake complied with this requirement, and a design review showed compliance to this regulation.

(d) Function properly when installed.

A Model 60 document stated that the system complied with this requirement. The compliance statement referenced another section of this report, but that section did not specifically state how it was shown that the equipment functions properly when installed. The compliance statement also referenced other Model 60 documents.

Model 60 documents stated that the original and improved three rotor brake complied with this requirement, and the means of compliance included design review, laboratory testing, aircraft flight testing, and equipment qualification.

D.7 LANDING GEAR AND WHEEL WELL PROTECTION

The N999LJ hydraulic lines in the main landing gear wells had extensive damage. This was especially true on the right side of the airplane, where much of the landing gear well had been consumed by fire.

D.7.1 LEARJET MODEL 60 COMPONENTS NEAR PLANE OF TIRE ROTATION

The N999LJ wreckage contained a dented filter cap on the right anti-skid sensor and black rubber transfers were found on hydraulic tubing for the landing gear. Hydraulic fluid was found on fragments that had been among the first found along the runway. Examination of the right main landing gear on other Learjet Model 60 airplanes found that the hydraulic supply tube to the antiskid module was about six inches inboard of a line drawn upward from the inboard tire. The hydraulic fluid filter was closer to the tire. The wiring for the squat switch and wheel speed sensors, as well as the hydraulic lines, were seen mounted on the main landing gear strut near the outboard tires. (See Figure 35)

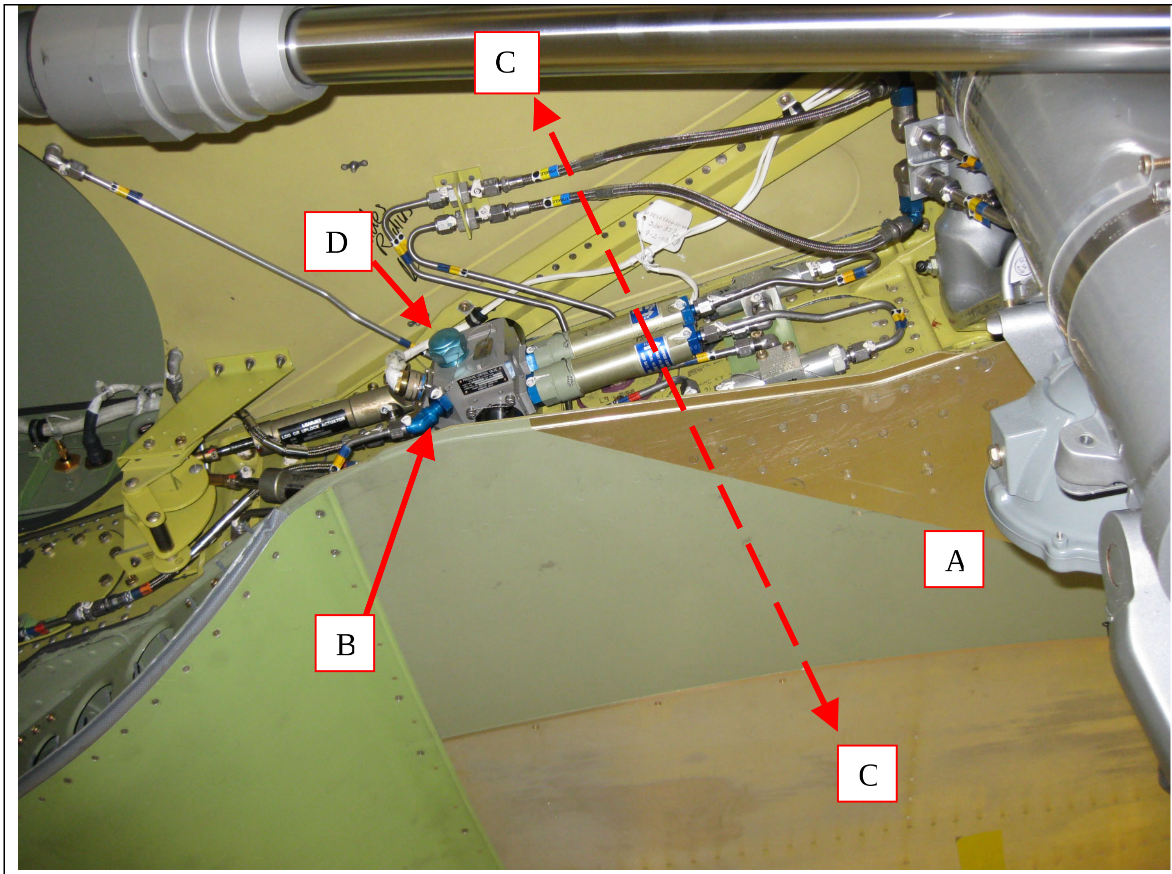


Figure 35. This view from a similar airplane is upward from the side of the inboard right main landing gear tire. The large assembly is the antiskid valve and hydraulic fuse assembly. For orientation, the back of the landing light is visible as (A). The (B) arrow points to the hydraulic supply tube, which is about 6 inches inboard of an imaginary line

drawn upward from the tire sidewall to a line that would extend between about where the (C-C) labels are shown. The short arrow (D) points to the filter cap which was found dented in the wreckage of N999LJ.

D.7.2 LEARJET MODELS 45 AND 60 LANDING GEAR FEATURES

Protection of systems components that 25.1309 would apply to in the landing gear well of the Learjet Model 60 were compared with the later design of the Learjet Model 45. With the exception of the Learjet Model 45, the main landing gear is similar throughout the series of Learjet airplane models, and is based on similarities to models that were certified prior to the changes in regulatory requirements. The Learjet Model 60 was certified on January 15, 1993, to the FAR Part 25 as amended by Amendments 25-1 through 25-73, except as stated in the Type Certificate Data Sheet. Foreign sales are certified in the country of ownership on a case by case basis. Learjet has recently presented certification data to Russia, Argentina, and China.

The Learjet Model 45 was jointly certified in 1997 to both FAR and JAR Part 25. The prime certification was to FAR part 25, as amended by Amendments 25-1 through 25-77. The JAR requirements that were defined as significant differences were also addressed in each compliance report. The JAR differences applicable to wheel well protection and defined in 45-D1346 and include JAR 25.729(f), 25.735(b), 25.863, and 25.1309(b)(c)(d) and (g).

Regulations Applicable to the Learjet Model 60:

Sec. 25.729 - Retracting mechanism.

> *(f) Protection of equipment in wheel wells. Equipment that is essential to safe operation of the airplane and that is located in wheel wells must be protected from the damaging effects of--*
> *(1) A bursting tire, unless it is shown that a tire cannot burst from overheat; and*
> *(2) A loose tire tread, unless it is shown that a loose tire tread cannot cause damage.*
>
> *Amdt. 25-72, Eff. 8/20/90*

Sec. 25.1309 - Equipment systems and installations.

> *(a) The equipment, systems, and installations whose functioning is required by this subchapter, must be designed and installed to ensure that they perform their intended functions under any foreseeable operating condition.*

(b) The equipment, systems, and installations must be designed to prevent hazards to the airplane if they malfunction or fail.
(e) In showing compliance with paragraphs (a) and (b) of this section with regard to the electrical system and equipment design and installation, critical environmental conditions must be considered. For electrical generation, distribution, and utilization equipment required by or used in complying with this chapter, except equipment covered by Technical Standard Orders containing environmental test procedures, the ability to provide continuous, safe service under foreseeable environmental conditions may be shown by environmental tests, design analysis, or reference to previous comparable service experience on other aircraft.

(ORIG)

Regulations Applicable to the Model 45:

Sec. 25.729 - Retracting mechanism.

(f) Protection of equipment in wheel wells. Equipment that is essential to safe operation of the airplane and that is located in wheel wells must be protected from the damaging effects of--
(1) A bursting tire, unless it is shown that a tire cannot burst from overheat; and
(2) A loose tire tread, unless it is shown that a loose tire tread cannot cause damage.

Amdt. 25-75, Eff. 1/6/92

Sec. 25.1309 - Equipment, systems, and installations.

(a) The equipment, systems, and installations whose functioning is required by this subchapter, must be designed to ensure that they perform their intended functions under any foreseeable operating condition.
(b) The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that--
(1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and
[*(2) The occurrence of any other failure condition which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.*
(c) Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional

hazards.
*(d) Compliance with the requirements of paragraph (b) of this section must be shown by analysis, and where necessary, by appropriate ground, flight, or simulator tests. The analysis must consider--**]***
(1) Possible modes of failure, including malfunctions and damage from external sources.
(2) The probability of multiple failures and undetected failures.
(3) The resulting effects on the airplane and occupants, considering the stage of flight and operating conditions, and
(4) The crew warning cues, corrective action required, and the capability of detecting faults.
(g) In showing compliance with paragraphs (a) and (b) of this section with regard to the electrical system and equipment design and installation, critical environmental conditions must be considered. For electrical generation, distribution, and utilization equipment required by or used in complying with this chapter, except equipment covered by Technical Standard Orders containing environmental test procedures, the ability to provide continuous, safe service under foreseeable environmental conditions may be shown by environmental tests, design analysis, or reference to previous comparable service experience on other aircraft.

Amdt. 25-41, Eff. 9/1/77

The lead landing gear engineer for Learjet noted that the later amendment of the FAR and the JAR account for the differences in the wheel well protection for Learjet Model 45 (M45) and Learjet Model 60 (M60) airplanes.

The following comparative photos show features of the main landing gear wells for the two airplanes for comparison. (See Figures 36A-40D)

Wheel well strut comparison, as viewed from rear

Figure 36A. Learjet Model 45 aft features of the right main landing gear, as viewed from behind. The hydraulic hoses and anti-skid wiring are between the tire planes of rotation and exposure of the flexible lines is limited to where the oleo distance may change.

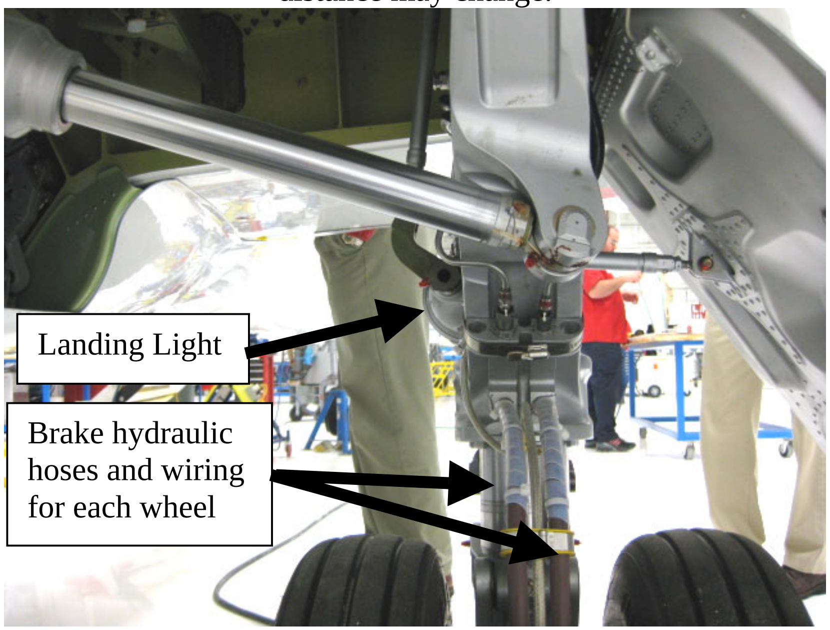


Figure 36B. Learjet Model 60 aft features of the right main landing gear, as viewed from behind. The hydraulic hoses and anti-skid wiring are in the plane of rotation for the outboard tire. Note hydraulic components between red arrows.

Squat switch comparison, as viewed from front

Figure 37A. Learjet Model 45 right main landing gear. The arrows point to the dual squat switches located within the forward scissors assembly.

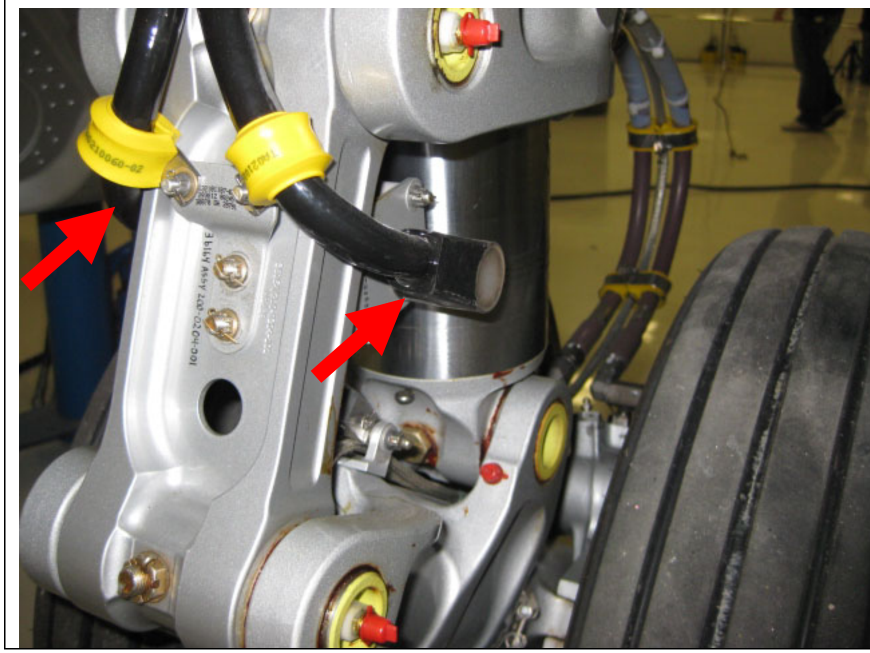


Figure 37B. Learjet Model 60 with an arrow indicating the single exposed squat switch on right main landing gear. (The photo includes a wooden stick that was installed to simulate air mode during tests.)

Outboard right wheel well comparison

Figure 38A. Learjet Model 45. Top of right wheel well, above rotational line of inboard tire, viewed upward. All visible hydraulic components are fused. Arrow points to protective white plate.

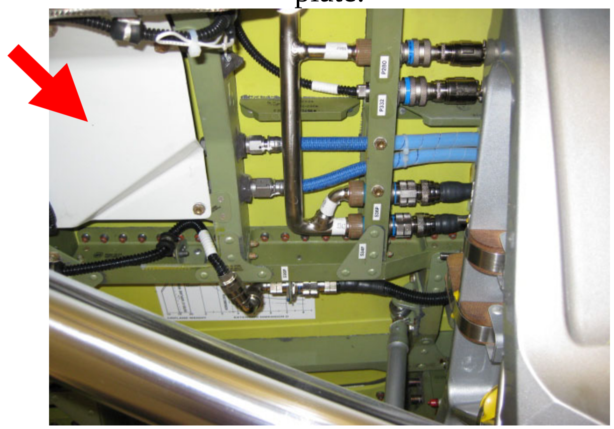


Figure 38B. Learjet Model 60. Hydraulic components mounted on wing spar that is above, and inboard of, the rotational plane of the right inboard tire. The upper-left arrow points to an unfused hydraulic return tube. The lower-right arrow points to an unfused hydraulic supply tube.

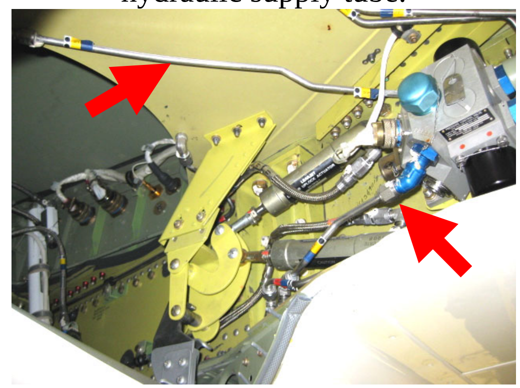
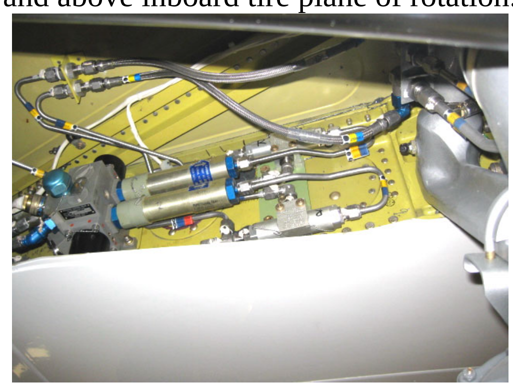


Figure 38C. Learjet Model 45 at top of right main landing gear strut, forward of the photo above (Figure 38A) and above the inboard tire plane of rotation.

Figure 38D. Learjet Model 60 at top of right main landing gear strut, slightly oriented outboard of the photo above (Figure 38B) and above inboard tire plane of rotation.



Outboard tire – comparing upward views in plane of rotation

Figure 39A. Learjet Model 45. Left main landing gear, above outboard tire. No hydraulic hoses or wiring are directly above the plane of rotation.

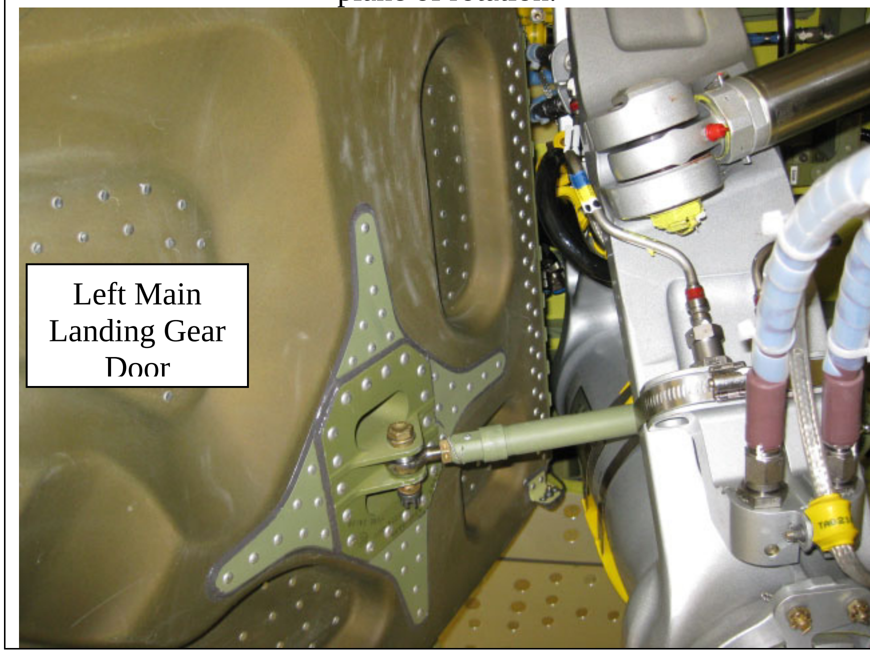
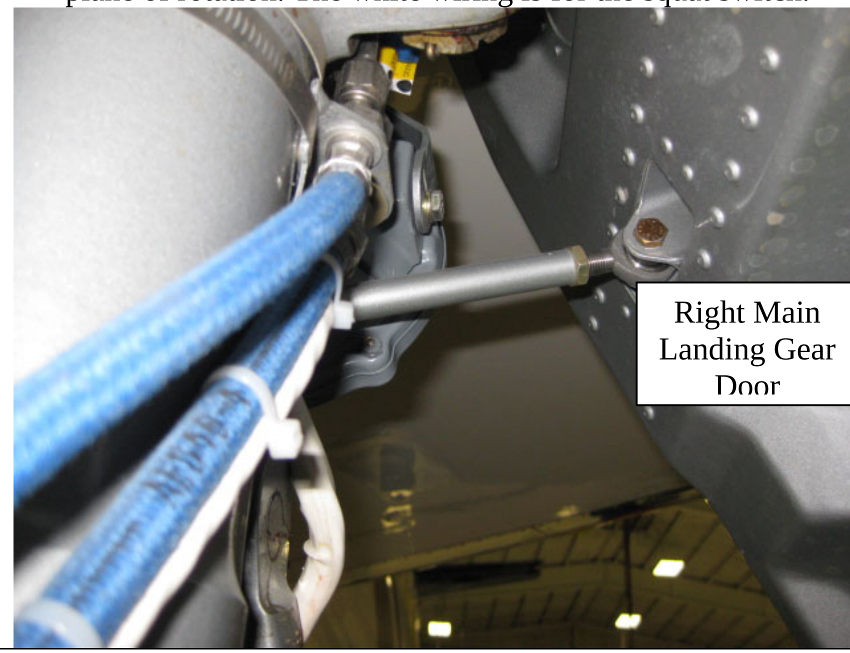


Figure 39B. Learjet Model 60. Right main landing gear, above outboard tire, showing wiring and hydraulic hoses above the tire plane of rotation. The white wiring is for the squat switch.



Inboard corners of wheel wells

Figure40A. Learjet Model 45: View shows the inboard aft corner of left the main landing gear well. The white protective plate covers hydraulic and electrical components.

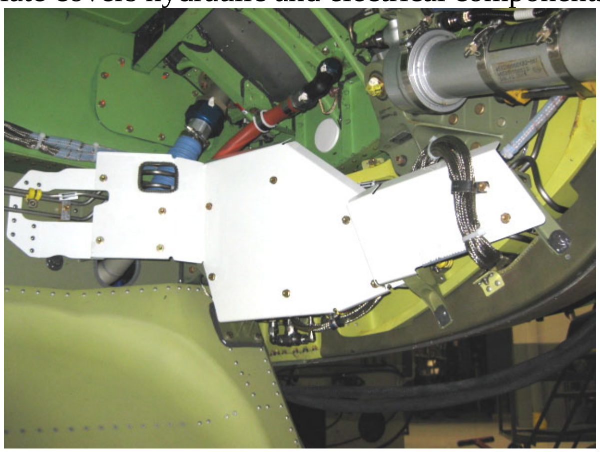


Figure40B. Learjet Model 60: View shows the inboard aft corner of right main landing gear well.

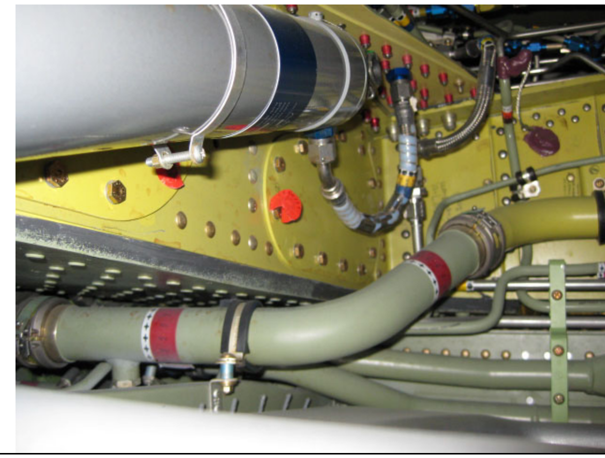


Figure40C. Learjet Model 45: The forward inboard corner of left wheel well, showing the white protective plate

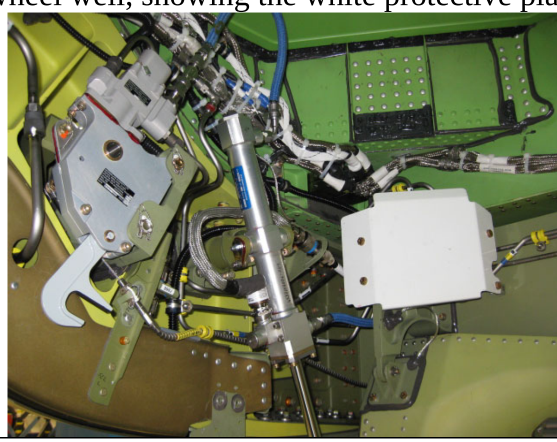
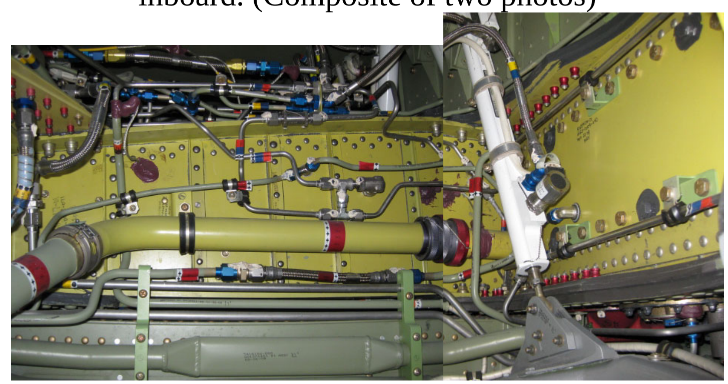


Figure40D. Learjet Model 60: View shows exposed hydraulic components on the front and inboard walls of right wheel bay inboard. (Composite of two photos)



D.8 OTHER AIRPLANE ACCIDENTS

According to the Boeing 2001 and 2008 summaries of all commercial transport airplane accidents for 1992-2008 data, takeoff provided an estimated world-wide risk exposure of 1.5% for a 1.5 hour flight. Takeoff, prior to initial climb, accounted for 12% (38 airplanes) of the fatal accidents. The on-board fatalities were 6% (381 people) in the 1992-2001 data and 16% (763 people) in the 1999-2008 data. These data were not restricted to tire-related accidents.

Prior to issuance of TSO-C62c, the Defense Technical Information Center published a report (Author: David W. Ostrowski , accession #ADA056032) in February 1977 pertaining to jet transport airplane rejected takeoffs (RTO's) at heavy weights and high speeds. The RTO accidents/incidents involving tires, wheels, and brakes prompted an assessment of RTO test procedures and the system by which RTO accountability was achieved for day-to-day operations. It was concluded that 3 to 4% of air carrier accidents, fatalities, and aircraft losses could be attributed to tire/wheel/brake related RTO's. Tire failures and the lack of accountability for the increased accelerate-stop distance required on wet/slippery runways were significant factors. Recommendations were made for reducing the incidence of tire failures and accounting for the increased accelerate-stop distance necessitated by wet/slippery runways.

Excluding runway low-friction and visibility factors (rain, ice, etc.), the NTSB database and internet were searched for tire failures on takeoff. The search specified accidents/incidents of turbojet/turbofan aircraft involving tires, from 1982 to present, reading the brief narrative to select those citing multiple tire loss. The 37 accidents and incidents included the following 10 business jets:

4 Learjets. Models: 25B, 35, 35A, 36

> Note: This group did not include Preliminary reports, which the subsequent lists do include. The certification of these older airplane models did not require demonstrating rejected takeoffs with worn brakes, which was required for the Model 60.

2 Beech /Hawker Siddely. Models: BH-125-600A, HS-125-700A
1 Dassault. Model: Falcon DA-20
1 Raytheon. Model: Hawker 800XP
1 Israeli Aircraft Industries. Model: 1124
1 Rockwell. Model NA-265-80 Sabreliner

Only one of the business jets listed involved injuries (to 2 persons) and all involved had either long taxis, rejected takeoffs, hot day conditions, suspected low tire pressure, or a combination. A review of the Airplane Flight Manuals (AFM) for the Model 55 Learjets involved in Wyoming and Illinois accidents revealed that specific waiting time intervals were not required after a rejected takeoff, unless the weight of the aircraft exceeded the landing maximum brake energy weight. The waiting time was found in the AFMs for the

Learjet Model 60 and the Hawker 800XP cited above (attempting takeoff after already rejecting two takeoffs and not waiting), but not for most of the airplanes listed above.

As in the takeoff accident at Columbia, involving N999LJ, and in landing accidents involving tire failures, departing the runway safety area was involved in accidents that accounted for nearly all fatalities and injuries. As with the non-injury list above, the majority of the fatality and injury records also involved long taxis, rejected takeoffs, hot day conditions, or a combination. (See Figure 41)

Figure 41. A sample of accidents achieving flight or departing the runway safety area that involved injuries and fatalities:

Date:	Place:	Model	Registration	Report Identifier	Narrative Summary:
2/20/2004	Fort Lauderdale, Florida	Learjet 25B	N24RZ	ANC04 FA026	Without brakes, the airplane touched down about midway on the 6001-foot long, dry runway, entered the overrun area, struck a chain link fence, crossed a road, and struck a building. 1 Injury
8/30/2002	Lexington, KY	Learjet	N45CP	NYC02 FA177	Reversers did not deploy and airplane went off end of runway. Airplane was certified to land without reversers. 1 fatal and 4 serious injuries
7/25/2000	Gonesse (Paris), France	Concorde	F-BTSC		Tire failure after striking debris on runway, leading to fuel leakage, fire, and loss of control. In six prior incidents, tire failures led to penetrations of structure and/or fuel tanks. French investigators found one tire failure per 1,500 flight cycles for Concorde, versus one per 100,000 cycles in the A340. 109 fatal.
9/26/1999	Gainesville, FL	Learjet	N244SC	MIA99F A267	During landing rollout, the brakes became ineffective. The aircraft continued to roll off the end of the runway, down an embankment, across a 4 lane road, and came to rest in a drainage ditch. The outboard right main tire had failed during landing roll. 2 of 5 occupants seriously injured
8/07/1997	Honolulu, HI	Lockheed L-1011	N740D A	LAX97 FA276	Tires failed after maintenance and the aircraft taxied out for the final time. The aircraft had taxied 11.3 miles within a 3-hour period. 1 Serious injury and 58 minor injuries
7/11/1991	Jedda, Saudi Arabia	DC-8-61	C-GMXQ		Long taxi at gross weight led to tire failure on takeoff , fire in landing gear well, and loss of control. Potential tire under-inflation discussed in accident report. 261 fatal
3/31/1986	Las Mesas, Mexico	Boeing 727	XA-MEM		A tire blowout occurred 14 minutes after the flight left Mexico City, rupturing fuel, hydraulic, electrical lines, and air conditioning ducts that passed near the wheel. 167 fatal

The combined accident and incident records were also found to include airplane system damage, tire fragment ingestion causing engine damage and/or loss of power, punctures to the fuselage, damaged wing flaps, and/or punctures to the wing and fuel tanks.

The NTSB database is limited to reportable incidents and accidents, and the above search criteria further restricted the results. Additional accidents and incidents involving Learjet and other airplanes were found outside of the NTSB database search. (See Figure 42)

Figure 42. A list of multiple tires involved in takeoff accidents of business jets, focusing on Learjet events.

DATE	**Report Identifier**	**Place**	**Make**	**Model**	**Registration**	**Brief Narrative**
08/19/09		El Paso, Texas	Learjet	25D	XB-MYG	Left tires were destroyed, beginning at about 4500 ft into takeoff roll, followed by right tires. Pilots stopped with thrust reversers in runway safety area, about 10,300 feet from beginning takeoff on 9025 ft Runway 26L.
07/28/09		Las Vegas, NV	Learjet	55	N554CL	Both right tires failed on takeoff in about 110 F heat. The airplane had a 9,500 foot taxi to the runway and potential foreign material on the runway is being investigated. (Preliminary information)
03/30/09		Aurora, IL	Learjet	55	N40DK	Left main tires overheated following high energy stopping for maintenance purposes. According to tower manager, the aircraft performed three high speed taxi's and was in the process of a 4th attempt when the tower notified the crew of a fire on the left main gear. The airplane came to a stop at the middle of the 6,501 foot runway. (Preliminary information)
03/17/09	WPR09LA151	Casper, WY	Learjet	55	C-GCIL	Following a taxi to the end of the 10,165 foot long runway and an aborted takeoff to the departure end, the crew taxied back for a second takeoff. The right tires both failed at about 120 knots and the second takeoff was aborted. The Learjet came to a stop on the northeastern side of the airport with a small fire at the left main landing gear that was quickly extinguished by emergency responders. The operator reported that 4 days before, the airplane underwent a weekly inspection when the number one main landing gear tire (outboard left tire) was found to be 5 PSI low and the other three tires were at 185 PSI. (Preliminary information)
10/01/08		Punta Cana, Dominican Replublic	Learjet	55	N55UJ	All 4 main tires failed, beginning at about 100 knots. Last tire pressure check unknown. (Preliminary information)
08/20/08		Talahassee, FL	Learjet	25	N4447P	Minor damage. While on takeoff roll from Runway 9 at Tallahassee Regional Airport, the right main landing gear outboard tire failed. Debris

						from such tire struck the right main landing gear door, causing the door to partially break away from its hinge assembly. The partially attached right main gear door then contacted the right main landing gear inboard tire, causing damage to the tire that resulted in tire failure. The flight crew aborted the takeoff and successfully brought the aircraft to a full stop on the runway without further incident.
11/11/07		Kansas City, Mo	Learjet	60	N733SW	On takeoff attempt aircraft blew a tire, rejected the takeoff and turned into the grass.
10/29/07	SEA08LA014	Santa Ana, CA	Hawker	800 XP	N800CC	Inspection of the landing gear found that the left main landing gear tires overheated and blew during the third takeoff attempt. The airplane came to a stop beyond the runway in the safety area. The hydraulic line on the left main landing gear was severed when the tire blew and hydraulic fluid leaked out onto the hot brake surface and ignited. The Raytheon Aircraft Airplane Flight Manual states a required waiting period from completion of taxi-in following a rejected takeoff from a speed of 90 knots indicated airspeed or less, to before start of taxi-out for takeoff. After a single rejected takeoff, a waiting period of 25 minutes is required. After two or more successive rejected takeoffs, a waiting period of 45 minutes is required.
07/10/07		Boise, ID	Learjet	35	N387HA	Aircraft aborted takeoff after blowing tires and losing directional control. Damaged wheels, brakes & underside of wing & landing gear doors.
03/26/07	NYC07LA087	Hampton-Newport News/Williamsburg Airport, VA (PHF)	Learjet	36A	N527PA	During takeoff from runway 20 at Newport News (PHF), as the airplane approached 120 knots, the crew heard a "loud pop." The airplane began to pull to the left, and the pilot flying aborted the takeoff. The drag chute appeared to be inoperative, and the pilots were unable to stop the airplane on the runway. The airplane continued off the right side, impacted a runway light, and came to rest in the grass. Both of the left main landing gear tires had blown, and the left main landing gear was separated from the airplane. Additionally, substantial damage was noted to the left wing spar. Due to severe fragmentation of the tires, the origin of the tire failure could not be identified. Both tires were installed on the airplane approximately 3 weeks prior to the accident, and had accumulated 19 hours and 10 cycles since their installation.
11/24/04	Portugal 39/INCID/2004	Lisbon, Portugal	Learjet	35A	C-FRFO	At a speed of approximately 125 kts, the Captain decided to abort the takeoff due to the blowout of two main gear tires. The aircraft skidded along the runway on the right wheel rims, and at the end of the airstrip, at low speed, the aircraft veered to the left and had a runway excursion. There were no injuries and no aircraft fire. There were 330 feet between the initial tire fragment and the marking

						of the second rim on the runway. The distance between the rim marks and where the airplane came to a stop was 4,800 feet. The tire remains had evidence of heating in the forms of blued rubber, reverted rubber, charred nylon. Also found were liner wrinkles on sidewall and shoulder regions.
09/04/04	DEN 04LA 138	Colorado Spring, CO	Learjet	25B	N47MR	During the takeoff roll, the airplane began to vibrate on the right side and then the right tire blew. The left tire blew shortly thereafter. The airplane came to rest at the departure end of the runway. A post-accident investigation revealed substantial damage. An examination of the airplane systems revealed no anomalies.
03/03/01	Iceland AAIB M-00501 /AIG-02	Keflavik Airport, Iceland	Learjet	35A	N18LH	As the aircraft had traveled approximately 2800 feet of the runway and reached the speed of approximately 125 kts, it started to vibrate and then it swerved to the right, as one of the right hand main gear tires blew. The aircraft was below V1 (Take-off decision speed) and the Captain aborted the take-off, brought the thrust levers to idle, began braking and extended the spoilers. Shortly after the other right hand main gear tire blew and the aircraft skidded along the runway on the wheel rims, causing a large spray of fire sparks. The aircraft decelerated down the runway and stayed close to the centerline. There were indications that this scenario started as the tire tread separated and then the tire blew. Large parts of the tread were found on the runway and the rubber marks on the runway indicated that the inboard tire blew some seconds later as the brakes were applied.
01/14/01	ATL01FA021	Troy, AL	Learjet	60	N1DC	(Landing accident. Included as a reference, due to commonality of Model and damage to squat switches) The airplane collided with the deer shortly after touchdown and continued down the runway with the tires smoking, and veered off the right side of the runway near the end, crossed a taxiway, and impacted into a ditch and burst into flames. With an estimated empty weight of 15,800 pounds and estimated fuel of 1,100 pounds, it was calculated that the airplane traveled 1500 feet after touchdown in 4.2 seconds before striking the deer, the performance group at Learjet using the weather reported at Troy, Alabama (variable winds and temperature at 14 degrees Celsius) the airplane landed with a ground speed of 210 knots.
08/17/99	LAX 99FA 272	LAS VEGAS, NV	Beech	BH 125-600 A	N454DP	The pilot landed with the landing gear in the retracted position, when both the main and auxiliary hydraulic systems failed to extend the gear. The airplane caught fire as it skidded down the runway. The left inboard main tire had blown on takeoff and a
08/28/98	FTW 98FA	EL PAS	Dassault	FALCO	N126R	The airplane was dispatched as a cargo flight to pick up a load of 118 boxes of automotive

	376	O, TX		N DA-20		seatbelts. After refueling and loading the cargo on board, the flight crew taxied to runway 22 for a no-flap takeoff, which called for a V1 speed of 141 knots. Th
June 1998	NASA ASRS	Dulles International Airport	Learjet	60		National Aeronautics and Space Administration (NASA) Aviation safety Reporting System (ASRS) submittal regarding failure of both right main landing gear tires during takeoff roll. The squat switch was damaged, leading to uncommanded stowage of the engine thrust reversers and airplane departing the runway.
02/01/98	MIA98WA067	Al Manamah, Bahrain	Learjet	36A	N27MJ	At 120 knots on takeoff roll the airplane experienced a blowout on both left main landing gear tires and swerved to the left. The Captain applied right rudder and brake and aligned the airplane with the runway. Both right main landing gear tires blew out. He deployed the drag chute, the airplane went off the right side of the runway, and separated the right main landing gear.
05/0196	FTW96TA195	ALBUQUERQUE, NM	Rockwell	NA-265-80	N773W	The captain was taking off on runway 21 with the wind from 330 degrees at 6 knots. After the airplane had attained about 120 knots and had traversed about half the 10,000 foot runway, the captain aborted the takeoff, when he heard a loud noise and felt a
05/23/95	FTW95LA216	ROGERS, AR	Learjet	35A	N450MC	The right outboard tire failed while the airplane was accelerating within 15 knots of V1 speed during takeoff from a 6,011 foot runway. The pilot heard a loud noise preceded by a vibration. The crew aborted the takeoff, resulting in multiple tires failing.
09/08/94	LAX94LA356	RENO, NV	HAWKER SIDDELEY	HS-125-700A	N311NW	The captain said that the aircraft was near V1/Vr in the takeoff ground roll when he heard a loud bang followed by a vibration in the airframe. A second loud bang was then heard as the captain aborted the takeoff.
07/13/94	NYC94FA123	Atlantic City, NJ	Learjet	35	N69PS	The pilot (PIC) said that during takeoff, the airplane 'pulled' left before reaching v1 (takeoff decision speed) & he had difficulty maintaining directional control. He initiated an abort, but could not stop on the remaining runway. The plane crossed a concrete slab that previously supported an approach light & the main gear collapsed. The plane stopped 446' from the departure end of the runway. The outer left tire had blown during the takeoff roll, followed by the left inner tire & both right main tires. The PIC was unable to obtain reverse thrust. The thrust reversers should have been (but were not) armed before takeoff; this was not included on the checklist that was provided to the flightcrew. Also, the pic did not deploy the drag chute. Company maintenance personnel indicated the tires had been under-inflated when they were built up & installed, several days before the accident & that the tires had not been checked or reinflated after buildup. Goodyear reported the

						tires could have been up to 50% under-inflated. An exam of the tires disclosed evidence of under-inflation, & subsequent overheating.
04/06/94		Wichita, KS	Learjet	55 modified to 60	N60XL	Following taxi testing of up to 120 knots, three takeoffs were performed. The pilots later reported feeling vibration during the third takeoff roll and subsequently smelling hot rubber. During landing, the airplane settled to one side and the pilots reportedly felt no braking deceleration. Went off end of runway, collapsing the landing gear and creating a fuel leak.
. Mid-1980s		Orlando, FL	Learjet	55		All four tires failed during a takeoff for flight test. The takeoff was rejected. (See FAA Manager report in Airworthiness Group Chairman’s Factual Addendum, Engines And Thrust Reversers, dated August 3, 2009.
01/19/83	NYC83LA053	New Cumberland, PA	IAI	1124		During the takeoff roll at about 117 kts, the acft began to vibrate, pull to the left and decelerate. The takeoff was aborted. The acft continued off the left side of the rwy and came to stop against a small embankment. An exam of the rwy reveal tire markings that led to where the acft came to rest. Markings made by the left gear were consistent with those of a tire failure. The left main gear and wheel, underside of the fuselage and left tip tank were damaged. An inspection of the left brake and wheel assembly was made, but no evidence was found to indicate a malfunction or failure prior to the tire failure. The tire, goodyear pn 249k83-2, sn 22041595, had accrued 98 cycles prior to the accident.

The following spreadsheet shows Learjet Model 55 and Learjet Model 60 damage from tire failures that had been reported to Learjet, as of October 6, 2008. (See Figure 42)

WIDE BODY TIRE FAILURE DAMAGE

Aircraft: (Model and a letter in lieu of serial numbers)
Damage that had been reported to Learjet as of October 6, 2008

Aircraft: (Model and a letter in lieu of serial numbers)	TOTA	%	**55A**	**60A**	**60B**	**60C**	**60D**	**60E**	**55B**	**55C**	**55D**	**55E**	**60F**	**60G**	**60H**	**60I**	**60J**	**60K**	**60L**	**60M**	**60P**	**55F**	**60Q**	**60R**	**60S**	**60T**	**60U**
Source: (FE denotes inquiries through Field Engineering. CI denotes Customer Inquiry																											
			FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	CI	CI	CI	CI	CI	CI	CI
															+CI		+CI										
Flap	18	72%	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1		1				1		
Spolier	3	12%	1					1								1											
Landing Light	2	8%	1									1															
Lower Wing Skin	7	28%	1	1				1				1				1		1			1						
Upper Wing Skin	1	4%	1																								
Fuselage Belly	1	4%	1																								
Wing Fairing	1	4%	1																								
Tail Cone	1	4%	1																								
Aft Baggage Door	1	4%														1											
Engine	2	8%	1												1												
Thrust Reverser	2	8%	1													1											
Nacelle	1	4%		1																							
MLG Gear Door	9	36%	1	1				1				1				1	1			1	1				1		
MLG Cylinder	8	32%	1	1			1					1			1	1								1	1		
MLG Piston	1	4%		1																							
MLG Torque Link	1	4%		1																							
MLG Axle	1	4%		1																							
Wheel Speed Wire	3	12%										1			1			1									
Brake Hose	4	16%										1			1	1	1										
Squat Switch	1	4%																			1						
Brake System	1	4%	1																								

Figure 43. Learjet reported accidents and incidents.

In addressing rejected takeoffs, the July 2005 issue of Business & Commercial Aviation magazine provided the following comments:

> NTSB's special investigative report titled "Runway Overruns Following High-Speed Rejected Takeoffs" (February 1990): "Few safety margins are included in the calculations of accelerate-stop distances. Therefore, any substandard performance by the pilots, brakes or other airplane equipment related to the airplane acceleration or stopping performance will result in the airplane overrunning the end of the runway."
>
> In fact, … more than half of the 74 airliner RTO accidents examined in a special study involved RTOs begun at speeds greater than V1. How does the recent business jet data compare? Roughly one-third of the RTO accidents in the last 12 years in business jets were aborted at a speed above V1.
>
> A Boeing review showed that of the RTO accidents initiated "very near V1," 80 percent of the wheel brakes failed. While the brakes were within acceptable wear limits, they were worn to such a degree that they did not have the capacity for dissipating a high-energy RTO.

D.10 NHTSA RULES AND CHANGES

The high-pressure Learjet tire design is based in intermittent service and tires on highway vehicles are generally based in continuous service. Other differences also exist, such as increased opportunity for cars and trucks to encounter road hazards. A review of the tire designs, regulations, and guidance did find some common aspects between the types of tires. Due to the NHTSA change in regulations taking place after the last change to TSO-C62 and the quantity of information developed from tires used on cars and trucks, this section relates some NHTSA-related material as a reference. This section does not provide a direct comparison of aircraft and surface vehicle tires.

Prior to issuance of Federal Motor Vehicle Safety Standard (FMVSS) 139, FMVSS 109 contained the requirements for passenger car tires and FMVSS 119 contained additional requirements for light duty light truck tires. The FMVSS 109 standard was adopted from the Society of Automotive Engineers (SAE) recommended practice J918c, *Passenger Car Tire Performance Requirements and Test Procedures*, which was first issued by the SAE in June 1965. The current FMVSS No. 109 included four performance requirements for tires:

- a strength test, which evaluates the strength of the reinforcing materials in the tire;
- a resistance-to-bead unseating test, which evaluates how well the tire bead is seated on the rim (regulating the tire-rim interface guards against sudden loss of tire air pressure when a tire is subjected to lateral forces such as during severe turning maneuvers);

- an endurance test, which evaluates resistance to heat buildup when the tire is run at or near its rated load nonstop for a total of 34 hours, and
- a high-speed test, which evaluates resistance to heat buildup when the tire is run at 88 percent of its maximum load at speeds of 75 mph, 80 mph, and 85 mph for 30 minutes at each speed.

Following a series of vehicle roll-over accidents involving tire failures, the United States Congress in the Transportation Recall Enhancement, Accountability, and Documentation Act of 2000 (TREAD Act) mandated that the NHTSA develop a new tire standard to replace FMVSS 109 and FMVSS 119. Endurance and high speed tests had already been established that were not required and NHTSA found that "one-third (32.8 percent) of all tires would need improvements to pass [the proposed improved] two [Endurance and High Speed] tests."

The NHTSA issued FMVSS 139 that was effective on January 6, 2006, which became effective June 1, 2007. The new FMVSS added such dynamic performance and other requirements.[31] Many of these requirements do not exist in the current FAA certification requirements for aircraft landing gear and tires. Requirements in the group of FMVSS standards that do not exist in 14 CFR Part 25.733 or TSO-C62c include requirements for side-loading, impact (road-hazard) tests, low inflation pressure performance tests. The NHTSA also began an investigation into how tire characteristics degrade with age. In the discussion portion of issuing FMVSS 139, NHTSA stated the following for the scope of the problem that existed:

> … data for 1995 through 1998 indicate that there are an estimated 23,464 tow-away crashes per year coded by the … investigators (relying on the police report of the crash) as having been caused by blowouts or flat tires. Based on that estimate, about one-half of one percent of all crashes are caused by these tire problems. The rate of blowout-caused crashes for light trucks (0.99 percent) is more than three times the rate of those crashes for passenger cars (0.31 percent). Blowouts cause a much higher proportion of rollover crashes (4.81) than non-rollover crashes (0.28), and more than three times the rate in light trucks (6.88 percent) than in passenger cars (1.87 percent).
>
> …data for 1999 through 2001 show that 1.10 percent of all light vehicles in fatal crashes were coded by investigators as having had tire problems. Light trucks had slightly higher rates of tire problems (1.34 percent) than passenger cars (0.92 percent). The annual average number of vehicles with tire problems in [data] was 528 (255 passenger cars and 273 light trucks).
>
> A further examination of the [data] indicates that heat is a factor in tire problems. An examination of two surrogates for heat, the region of the U.S. in which the crash occurred, and the season in which the crash occurred, indicates that the highest rates of tire problems occurred in light trucks in southern states in the

31 The FMVSS Final rule was 49 CFR Part 571, Docket No. NHTSA-03-15400, and is available at http://www.nhtsa.dot.gov/cars/rules/rulings/UpgradeTire/Final/Index.html

> summertime, followed by light trucks in northern states in the summertime, and then by passenger cars in southern states in the summertime. The lowest rates occurred in winter and fall. Based on these data, tires on light trucks appear to be more affected by higher ambient temperatures than tires on passenger cars.
>
> FMVSS No. 120, *Tire Selection and rims for motor vehicles other than passenger cars*, 49 CFR 571.120, …requires that these vehicles shall be equipped with tires and rims that are adequate to support the vehicle's certified gross weight.
>
> FMVSS No. 120 also contains a requirement related to the use of passenger car tires on vehicles other than passenger cars. The requirement states that when a tire that is subject to FMVSS No. 109 is installed on a multipurpose passenger vehicle, truck, bus, or trailer, the tire's load rating must be reduced by a factor of 1.10 by dividing by 1.10 before determining whether the tires on an axle are adequate for the GAWR [Gross Axle Weight Rating].

D.11 TIRE PRESSURE MONITORING SYSTEMS (TPMS)[32]

The NHTSA investigation also resulted in issuance of FMVSS 138 for tire pressure monitoring systems (TPMS) in motor vehicles, and mandating adoption of such systems. The FMVSS 138 requires a TPMS telltale warning lamp to activate within 20 min. of when the pressure in 1-4 tires reaching 25% or more below the manufacturer’s recommended cold inflation pressure, or reaching the minimum level of pressure specified, whichever is higher.

The NHTSA Tire Pressure Monitoring and Maintenance Systems Performance Report of January 2007 focused on testing and documenting the overall performance of a sample of commercial tire inflation and monitoring products to present the accuracy, responsiveness, resolution, and reliability of the various systems. The report contained a summary of the types of systems available.

For aircraft, an October 1978, Douglas Aircraft Companyreport for the military examined tire pressure indicating systems.[33] With the types of systems available at that time (no microprocessors), the systems were found to be marginally cost-effective, due to reductions in tire consumption and airframe damage.

The N999LJ investigation found TPMS systems were found available from multiple sources, Crane Aerospace and Messier-Buggatti. Both cite not only the potential safety aspects of the systems, but also that operators have found the systems to be cost-effective.

According to Crane, the SmartStem® low-cost system may be retrofit and:

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32 An alternative term is Tire Pressure Indicating Systems, or TPIS.
33 "Feasibility and Cost Effectiveness of Airborne Tire Pressure Indicating Systems" by Suiter,R. L

> On December 20, 2006, Boeing released SIL 777-SL-32-051 announcing a change to [Crane] Aerospace & Electronics' TBMS on all future B777 deliveries. The Crane SmartStem® is a wireless pressure and temperature sensor built into the tire's inflation stem that makes the daily tire pressure check quick, easy, accurate, and automatically documented. This technology has been selected for the latest Onboard Tire and Brake Monitoring System (TBMS) for current production Boeing aircraft. This technology is passive, obtaining its operating power from an external reader or interrogator. When the Reader is close to the coil attached to the ASIC [interrogation device], the circuit uses the Reader's signal to power measurement and communication of identification or sensor information. The advantage to this system is that there are no batteries, power sources, or wires.

According to Messier-Bugatti, the company:

has supplied braking control systems, including both brake temperature monitoring and tire pressure monitoring. Each system takes local readings and sends data to the flight deck for display. Abnormal readings trigger visual or aural warnings, allowing pilots to make the appropriate decision, whether specific procedures or earlier than scheduled maintenance. As of the end of 2007, the TPMS (tire pressure monitoring system) was in use on nearly 2,000 Airbus and Boeing commercial airliners, deployed by about 100 airlines. Airlines have saved costs through decreased tire expenses.

The Messier-Bugatti TPMS second generation (2G), developed for the A380, is a wireless model, with data transmitted via RF (radio frequency) from the wheel to the landing gear before being sent to the cockpit. Dassault's latest bizjet, the 7X, is equipped with this system. The TPMS 2G features a very simple design. It eliminates a number of mechanical parts, considerably reducing volume and weight, and all ball bearings, significantly improving reliability and maintainability. The antenna design also means a high degree of installation flexibility, most notably to fit small wheels. Messier-Bugatti's TPMS 2G is fully compatible with all types of aircraft, even smaller models such as single-aisle jetliners, regional and business aircraft and military airplanes. The TPMS-2G transmits digital data at high frequency (around 125 kHz), for a very low electromagnetic signature. It uses little energy, and has high measurement frequency (every 500 milliseconds). In the event of two abnormal measurements in a row, an alarm is triggered in just one second! It also has a built-in test (BIT) system, to identify and locate any LRU failure. But perhaps the major advantage of the TPMS 2G is its cost – 40% lower than the previous generation!

Learjet and Global Executive are investigating tire pressure monitoring systems (TPMS). Learjet reported that the wheel well is so confined that external tire valve stem systems may potentially strike something in the landing gear well when the landing gear is retracted.