Final Report

BOEING B747- 400F, REGISTRATION B-18719

TYRE BURST DURING TRANSIT

19 OCTOBER 2018

AIB/AAI/CAS.169

Transport Safety Investigation Bureau
Ministry of Transport
Singapore

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The Transport Safety Investigation Bureau of Singapore

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SYNOPSIS

A Boeing 747-400 freighter landed at the Singapore Changi Airport at 0443LT on 19 October 2018 and was scheduled to depart two hours later. During the walk-around inspection, the tyre pressure of the No.11 tyre was found to be low.

While the tyre was being inflated by a technician with nitrogen, the tyre burst. A tyre pressure gauge that the technician had placed on the top of the tyre was propelled towards the fuselage and damaged the wing body fairing above the No.11 tyre. Another technician who was standing near the tyre felt a blast of cold air to the right side of his face. He was sent to the hospital for examination and there was no injury found.

The Transport Safety Investigation Bureau classified this occurrence as a serious incident.

AIRCRAFT DETAILS

Aircraft type	:	B747-400F
Operator	:	China Airlines
Aircraft registration	:	B-18719
Tyre Manufacturer	:	Bridgestone
Date and time of incident	:	19 October 2018, at about 0605LT
Location of occurrence	:	Singapore Changi Airport, Bay 507
Type of flight	:	Scheduled
Persons on board	:	2

1 FACTUAL INFORMATION

All times used in this report are Singapore Local Time (LT) unless otherwise stated. Singapore Local Time is eight hours ahead of Coordinated Universal Time (UTC).

1.1 Sequence of events

1.1.1 A B747-400 freighter flew from Taipei to Singapore and landed at Changi Airport at 0443LT on 19 October 2018 and taxied to bay No. 507. It was raining heavily at the time of the aircraft's arrival. The aircraft was scheduled to depart at 0640LT after a transit of about 2 hours.

1.1.2 At about 0500LT, one Licensed Aircraft Engineer (LAE) and one technician (hereinafter referred to as Technician A) of the aircraft maintenance service provider contracted by the airline operator performed a walk-around inspection of the aircraft. The LAE suspected that the pressure of the right body landing gear rear inboard tyre (No.11 tyre, see **Figure 1**) was low. After assessing by touch that the tyre was not hot, he tasked Technician A to measure the tyre pressure while he himself went to the cockpit and noted that the brake temperature was indicated as "0" on a scale of 0 to 9 on the wheel synoptic page of the aircraft's Engine Indicating and Crew Alerting System (EICAS)[1].

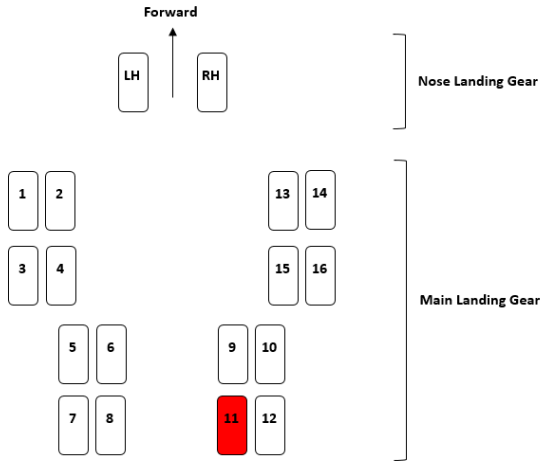


Figure 1: Wheel numbering system for B747-400F

1.1.3 Technician A used a manual tyre pressure gauge (see **Figure 2**) to measure

[1] "0" and "9" represented the Cold and Hot ends respectively. "0" corresponded to a brake temperature lying within the range from ambient temperature to 176°C.

the tyre pressure of the No. 11 tyre[2] and obtained a reading of 170 pounds per square inch (psi).

Figure 2: Manual tyre pressure gauge

1.1.4 Technician A informed the LAE of the tyre pressure reading and annotated it in the aircraft technical log accordingly. The LAE then returned to his office to refer to the B747-400 Aircraft Maintenance Manual (AMM) on the procedure for the servicing of the tyre, he referred to Chapter 12-15-06 of the AMM on "LANDING GEAR TIRES – SERVICING" (refer to section on tyre servicing in paragraph 1.4).

1.1.5 After consulting the AMM, the LAE decided to apply the Cold Tyre Pressure Check. He had assessed that the No. 11 tyre had cooled sufficiently in view of the heavy rain and of the fact that he had determined by touch that the tyre was not hot, as well as of the fact that he had noted from the aircraft's EICAS display that the brake temperature was indicated as "0", even though the elapsed time from aircraft landing was less than two hours[3].

1.1.6 The Cold Tyre Pressure Check required the LAE to compare the measured pressure (i.e. 170 psi) with the pressure to be found in the Tyre Pressure Limits Chart (see **Appendix 1**). He referred to this chart and thought that he should compare the measured pressure with the minimum nominal inflation pressure (MinNIP) for the tyre corresponding to the take-off weight (TOW) of the aircraft, i.e. 780,000 pounds (lb). The LAE determined that the MinNIP for the tyre was 185 (+5/-0) psi and that the difference (Δp) between the measured pressure and the MinNIP was 8.1% below the MinNIP.

1.1.7 The LAE referred to the chart again and noted that the maximum nominal

[2] The aircraft was not equipped with a tyre pressure indication system that could display tyre pressure readings in the cockpit.

[3] The AMM prescribed a Hot Tyre Pressure Check if the tyre had not been left to cool for two hours.

inflation pressure (MaxNIP) for the tyre was 213 psi. He calculated the average between the MinNIP (185 psi) and the MaxNIP (213 psi), and obtained a value of 200 psi (rounded off). The LAE then instructed Technician A to service No.11 tyre to 200 psi.

1.1.8 A while later, Technician A requested his Technician Supervisor for additional manpower to service the tyre as he was busy with refuelling the aircraft. The Technician Supervisor instructed another technician (hereinafter referred to as Technician B), who was working at a bay nearby, to assist Technician A.

1.1.9 At about 0600LT, Technician B arrived at the bay with a Nitrogen (N_2) servicing cart (see **Figure 3**). He used his manual tyre pressure gauge to measure the tyre pressure which indicated 170 psi, same reading as Technician A's earlier measurement. He then put his manual tyre pressure gauge on the top of the tyre and proceeded to service the tyre.

Figure 3: N_2 servicing cart

1.1.10 Technician B connected the hose from the N_2 servicing cart to the tyre's inflation valve and verified that the pressure reading on the low pressure gauge of the servicing cart indicated 170 psi as well.

1.1.11 Technician B began inflating the tyre by cycling the charging shut-off valve lever ON and OFF (see paragraph 1.4.1 for more information on the procedure for servicing a tyre) at the N_2 servicing cart. At one point in his cycling when the shut-off valve lever was at OFF position, Technician B noted that the tyre pressure had reached 180 psi.

1.1.12 Technician B then continued the inflation by turning the charging shut-off valve lever ON. Within seconds, the tyre burst. Technician A, who was near the No. 11 tyre, felt a blast of cold air to the right side of his face. Technician B, on

hearing the loud burst, turned around and saw Technician A lying on the ground with his hand on his face. Technician B attended to Technician A and observed that he was conscious but in a daze. Technician B then informed the Technician Supervisor and the LAE.

1.1.13 Technician A was sent to hospital for a check-up. No injury was found.

1.2 Damage to aircraft

1.2.1 The manual tyre pressure gauge that had been left on the top of the tyre was completely shattered (see **Figure 4**).

Figure 4: Shattered manual tyre pressure gauge

1.2.2 The aircraft sustained the following damage, likely to be a result of debris pieces from the manual tyre pressure gauge flying and hitting the areas concerned:

(a) There were cracks on the aircraft's wing body fairing above the tyre. Behind the fairing, there were cracks on a composite box structure and on a web support structure.

(b) The clamp that was holding one of the electrical conduits that ran adjacent to the right main landing gear's rear body truck tilt linkage was badly deformed, but there was no damage to the wire within the conduit.

1.2.3 The No.11 tyre had burst (see **Figure 5**). The wheel assembly of the No. 11 tyre was subsequently disassembled at a workshop and an inspection of the tyre interior revealed a continuous circumferential crack under the shoulders of the tyre (see **Figure 6**).

Figure 5: Burst tyre

Figure 6: Continuous crack line along the interior shoulders of the tyre

1.3 Personnel information

1.3.1 LAE

Gender	Male
No. of years as LAE	25 years

1.3.2 Technician A

Gender	Male
No. of years as Technician	17 years

1.3.3 Technician B

Gender	Male
No. of years as Technician	20 years

1.4 Tyre servicing for main landing gear tyres

1.4.1 Tyre service pressure

1.4.1.1 An aircraft operator would determine a tyre service pressure in accordance with the AMM. This tyre service pressure had to be between the minimum nominal

inflation pressure (MinNIP) and the maximum nominal inflation pressure (MaxNIP) as shown in the Tyre Pressure Limits Chart (see **Appendix 1)**. The MinNIP increases as the aircraft gross weight increases, whereas the MaxNIP is the same (213 psi) for all aircraft gross weight.

1.4.1.2 For an aircraft gross weight of 780,000 lb corresponding to the take-off weight (TOW) of the occurrence aircraft, the MinNIP was 185 (+5/-0) psi.

1.4.1.3 The aircraft operator involved in this occurrence set a tyre service pressure of 200 (+5/-0) psi. This value was within the range allowed by the AMM. The LAE was aware of the tyre service pressure set by the aircraft operator.

1.4.2 Cold Tyre Pressure Check Vs Hot Tyre Pressure Check

1.4.2.1 There were two tyre pressure check procedures described in the AMM: a Cold Tyre Pressure Check and a Hot Tyre Pressure Check.

(a) The Cold Tyre Pressure Check was to be used only if the tyre had been cooled for at least two hours after the aircraft had landed or if the tyre was not too hot to be checked for tyre pressure.[4]

(b) A Hot Tyre Pressure Check was to be applied if the tyre was too hot to check for tyre pressure and there was not enough time to allow the tyre to cool before the aircraft was dispatched.

1.4.2.2 According to the aircraft manufacturer, the Cold Tyre Pressure Check is the preferred method. The AMM states that the Hot Tyre Pressure Check is intended for occasional use only and is not intended to be used as a permanent alternative method to the more accurate Cold Tyre Pressure Check.

1.4.3 Cold Tyre Pressure Check procedure

1.4.3.1 The Cold Tyre Pressure Check procedure involved measuring the pressure of the tyre to be serviced and comparing this measured pressure with the

[4] The aircraft manufacturer recommended to wait till the tyres cool off to the approximate local ambient air temperature before conducting the Cold Tyre Pressure Check. To let the tyre reach the approximate local ambient air temperature, the aircraft manufacturer recommended a minimum wait of two hours after landing. However, the aircraft manufacturer also acknowledged that the actual amount of time needed for the tyre to cool to the ambient temperature depended on several variables and so the actual required time might vary from the recommended minimum two hours wait.

specified pressure[5] in the Tyre Pressure Limits Chart. The follow-up steps would depend on the difference (Δp) between the measured pressured and the specified pressure as follows:

(a) If Δp was less than 5% below the specified pressure, the tyre would only need to be inflated to the specified pressure (+5/-0 psi).

(b) If Δp was 5-10% below the specified pressure, the tyre would need to be inflated to the specified pressure (+5/-0 psi) and the tyre pressure checked again after 24 hours. If then the new Δp was less than 5% below the specified pressure, the tyre would need to be inflated to the specified pressure (+5/-0 psi). But if the new Δp was more than 5% below the specified pressure, the wheel and tyre assembly would need to be replaced and sent for an examination to determine the cause of the low tyre pressure. (This step was accompanied by a step that said "Replace tyres that required frequent refills to maintain nominal service pressure. These tyres could have tread loss or carcass rupture if you used them for too long.")

(c) If Δp was 10-20% below the necessary tyre pressure, the wheel and tyre assembly would need to be replaced and sent for an examination to determine the cause of the low tyre pressure.

(d) If Δp was more than 20% below the necessary tyre pressure, the wheel and tyre assembly would need to be replaced and sent for an examination to determine the cause of the low tyre pressure. In addition, the wheel and tyre assembly installed on the opposite side of the axle would also need to be replaced and the tyre sent for inspection for damage.

1.4.4 Hot Tyre Pressure Check procedure

1.4.4.1 The Hot Tyre Pressure Check procedure was intended for occasional use only. It was not intended to be used as a permanent alternative method to the more accurate Cold Tyre Pressure Check.

1.4.4.2 The procedure involved measuring the pressure of all the 16 main gear tyres. If all the pressures were above the minimum "Cold" specified pressure for the

[5] It was not very clear what the terms "specified pressure", "nominal service pressure" (see paragraph 1.4.3.1(b)), "necessary tyre pressure" (see paragraph 1.4.3.1(c) and (d)) that the AMM referred to. The investigation team believed the terms were all referring to the tyre service pressure that the aircraft operator could set (see paragraph 1.4.1). The LAE thought that the MinNIP (1.4.1.2) was the "specified pressure".

aircraft's gross weight conditions[6] but the pressure of the tyre to be serviced was substantially lower than those of the other 15 tyres, the average of these 15 other pressures was to be computed[7]. The follow-up steps would depend on the difference (Δp) between the pressure of the tyre to be serviced and the average pressure of the 15 other tyres as follows:

(a) If Δp was 5-10%[8] below the pressure of the average pressure of the other tyres, the tyre to be serviced would need to be inflated to the pressure value of the other tyre.

(b) If Δp was 10-20% below the average pressure of the other tyres, the wheel and tyre assembly would need to be replaced and sent for an examination to determine the cause of the low tyre pressure.

(c) If Δp was more than 20% below the average pressure of the other tyres, the wheel and tyre assembly would need to be replaced and sent for an examination to determine the cause of the low tyre pressure. In addition, the wheel and tyre assembly installed on the opposite side of the axle would also need to be replaced and the tyre sent for inspection for damage.

1.4.5 Procedure for servicing a tyre

1.4.5.1 The procedure for servicing a tyre is as follows:

- Connect the hose from the N_2 servicing cart to the tyre inflation valve and verify that the reading on the low pressure gauge (see **Figure 7**) of the N_2 servicing cart is the same as the reading obtained from the manual tyre pressure gauge.
- Open the N_2 cylinder shut-off valve to supply N_2 to the manifold and check that the reading on the manifold pressure gauge (high pressure gauge) is the same as that of the N_2 cylinders (of the order of 1,500 psi).
- Turn the charging shut-off valve lever ON to allow N_2 to flow from the manifold to the tyre.

[6] As mentioned before, the investigation team believed that the term "specified pressure" referred to the tyre service pressure, which in this case was 200 (+5/-0) psi for all aircraft gross weight conditions, i.e. between 200 and 205 psi. The minimum "Cold" specified pressure referred to the low end of this range, i.e. 200 psi.

[7] The AMM did not prescribe other possible scenarios, e.g. when the pressure of one or more of the remaining 15 tyres was substantially lower than those of the other 14 tyres. The aircraft manufacturer suggested that a Cold Tyre Pressure Check be conducted if such a case arose.

[8] The AMM did not prescribe anything for the case of Δp below 5%. The aircraft manufacturer deemed that no servicing was needed if the Δp was below 5%.

- Turn the regulator until the low pressure gauge shows the target pressure.
- Cycle the charging shut-off valve lever OFF and ON slowly and repeatedly. At each OFF position, read the tyre pressure from the low pressure gauge. When the low pressure gauge indicates the target pressure, disconnect the hose.
- Verify using the manual tyre pressure gauge that the tyre pressure has reached the target pressure.

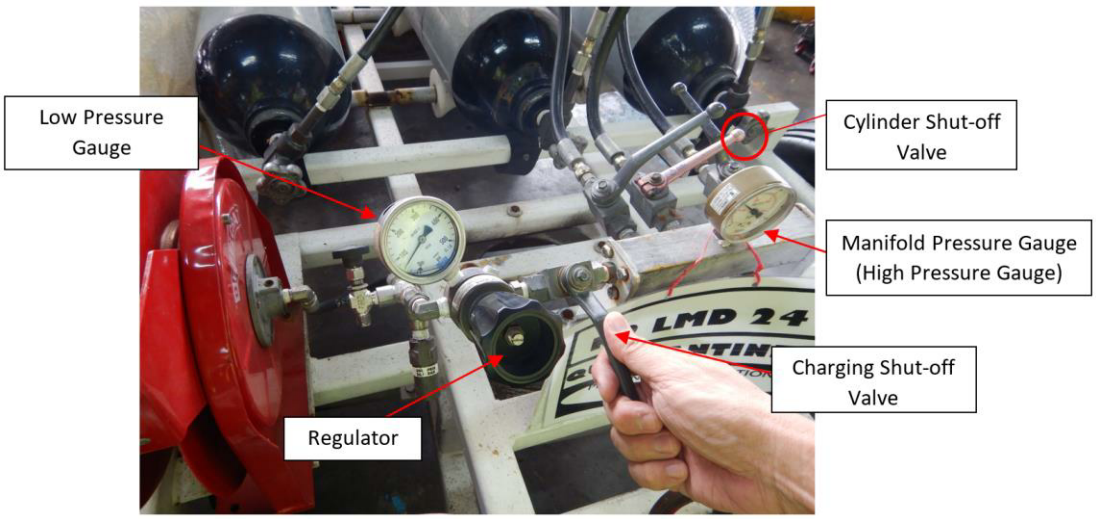


Figure 7: Gauges on the N_2 servicing cart

1.5 Tests and research

1.5.1 N_2 servicing cart

1.5.1.1 The functioning of the regulator of the N_2 servicing cart as well as the calibration of the low and high pressure gauges were checked after the occurrence and no abnormality was found.

1.5.2 Examination of burst tyre

1.5.2.1 The burst tyre was sent to the tyre manufacturer for examination. The examination concluded that there was a ply cord breakage on the inner surface at the shoulder of the tyre and that the ply cord breakage was consistent with the tyre having been operated under significantly low pressure.

1.5.3 Aircraft Daily Check Task Card

1.5.3.1 The aircraft operator's records of the Daily Check Task Card for the aircraft's tyre pressure checks from 22 Aug – 18 Oct 2018 showed that the measured pressure for all the tyres during this period were all within +5/-0 psi of 200 psi. The pressure of the tyres was last measured and checked on 18 October 2018, one day before the tyre burst incident. The pressures of all the other tyres were checked after the incident and they were found to be within limits.

2 ANALYSIS

The investigation looked into the following:

a. Assessment of the tyre temperature
b. Calculation of Δp for Cold Tyre Pressure Check
c. Inflating pressure of the tyre
d. Cause of tyre burst
e. Terms used in AMM

2.1 Assessment of the tyre temperature

2.1.1 At the time of the occurrence, the tyre had not been cooled for two hours. However, the LAE decided on a Cold Tyre Pressure Check. He had assessed that the No. 11 tyre had cooled sufficiently in view of the heavy rain and of the fact that he had determined by touch that the tyre was not hot, as well as of the fact that he had noted from the aircraft's EICAS display that the brake temperature was indicated as "0".

2.1.2 It has to be noted that the wheel synoptic page of the EICAS showed only the temperature of the brake unit and not the temperature of the tyre. The "0" indication on this page could still mean a temperature as high as 176^{o}C.

2.1.3 According to aircraft manufacturer, the cooling time for the tyre could vary depending on the weather conditions, ambient temperature, etc. The tyre was considered to be sufficiently cooled if its temperature was about the same as the ambient temperature. The aircraft manufacturer considered touching as an acceptable means to assess the temperature of the tyre.

2.1.4 The investigation team is of the view that the method of assessment by touch could be subjective and could vary from person to person. It would be desirable for the aircraft manufacturer to clarify on the method to be use for determining the temperature of the tyre in order for the appropriate pressure check to be chosen.

2.2 Calculation of Δp for Cold Tyre Pressure Check

2.2.1 The aircraft operator had set a tyre service pressure of 200 psi irrespective of the aircraft's gross weight. The LAE was aware that the aircraft operator had set a service tyre pressure of 200 psi.

2.2.2 In determining the procedure for carrying out the Cold Tyre Pressure Check,

the LAE referred to AMM 12-15-06 and had likely misinterpreted[9] in using the MinNIP pressure of 185 psi in calculating the Δp against the measured 170 psi tyre pressure of No. 11 tyre. The LAE obtained a Δp of 8.1% which allowed the tyre to be re-inflated with the condition that the tyre pressure be checked again after 24 hours (see paragraph 1.4.3.1(b)).

2.2.3 However, according to the AMM, if the operator used a tyre service pressure of 200 psi, this should be the reference pressure for calculating the Δp, in which case the Δp would be 15%, and, accordingly, the wheel and tyre assembly would need to be replaced (see paragraph 1.4.3.1(c))

2.3 Inflation pressure of the tyre

2.3.1 The LAE had used the average of the MinNIP (of 185 psi) and the MaxNIP (of 213 psi) and arrived at 200 psi for servicing the tyre. However, the AMM did not have a tyre inflation procedure that was based on such concept of averaging. Fortuitously, the average value (199 psi) coincided practically with the tyre service pressure of 200 psi used by the aircraft operator. The investigation team was unable to obtain from the LAE an explanation as to why he needed to use the average of the MinNIP and the MaxNIP to determine the tyre service pressure.

2.4 Cause of tyre burst

2.4.1 The examination of the burst tyre by the tyre manufacturer suggested that there was a pre-existing ply cord deterioration condition on the tyre and that this condition was consistent with the tyre having been operated under significantly low pressure prior to the incident. Indeed, had the tyre been appropriately serviced, it seemed very unlikely that the tyre pressure could have dropped to 170 psi. The ply cord deterioration was likely accompanied by a slow deflation of the tyre which was somehow not noticed during daily checks of tyre pressure or transit walk-around inspections. The integrity of the tyre was compromised progressively by the ply cord deterioration and it was during this incident that the tyre wall could no longer withstand the internal inflation pressure and thus give way to a tyre burst.

2.5 Terms used in AMM

2.5.1 In the course of the investigation, the investigation team noted that the terms

[9] The AMM used different terms to refer to the pressure used for the calculation of Δp, which could have contributed to the LAE's misinterpretation (see paragraph 2.5.1).

“tyre service pressure”, “specified pressure”, “nominal service pressure” and “necessary tyre pressure” as used in the AMM were all referring to the same pressure. The use of the different terms can be confusing. It would be desirable if the aircraft manufacturer could use one same term for all of them.

3 CONCLUSION

From the information gathered, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 Notwithstanding that the tyre had not been cooled for two hours, the LAE decided on a Cold Tyre Pressure Check as he had assessed that the No. 11 tyre had cooled sufficiently in view of the heavy rain and of the fact that he had determined by touch that the tyre was not hot, as well as of the fact that he had noted from the aircraft's EICAS display that the brake temperature was indicated as "0".

3.2 In lieu of waiting for tyres to cool for two hours, the aircraft manufacturer considers it acceptable to assess whether the tyre has cooled to ambient temperature by "touch". However, this method has an element of subjectivity.

3.3 The LAE had misinterpreted the AMM in using the MinNIP pressure of 185 psi, instead of the operator's service pressure of 200 psi, in calculating the Δp against the measured 170 psi tyre pressure of No. 11 tyre. Using 185 psi as the reference pressure, the LAE determined the Δp to be 8.1%. He allowed the tyre to be re-inflated with the condition that the tyre pressure be checked again after 24 hours whereas if he had calculated the Δp with reference to 200 psi, the wheel and tyre assembly would have to be replaced.

3.4 The bursting of the tyre was probably a result of the progressive weakening of the tyre wall because of a ply cord deterioration condition. The integrity of the tyre was compromised progressively and it was during this incident that the tyre wall could no longer withstand the internal inflation pressure and thus give way to a tyre burst.

3.5 The AMM used various terms such as "tyre service pressure", "specified pressure", "nominal service pressure" and "necessary tyre pressure" which were all referring to the same pressure.

4 SAFETY ACTIONS

Arising from discussions with the investigation team, the organisation had taken the following safety action.

4.1 The maintenance service provider issued a Quality and Safety Briefing Sheet that was disseminated during toolbox briefing. The briefing reminded all maintenance staff to use the measured pressure to compare with the operating pressure set by the operator when they are calculating percentage loss of the tyre pressure.

4.2 The aircraft manufacturer issued a Temporary Revision for the B747-400 AMM on 17 May 2019 such that the terms “tyre service pressure”, “specified pressure” and “necessary tyre pressure”, where they meant the same pressure, were amended to “nominal service pressure”. Following the Temporary Revision, the AMM has been revised on 15 July 2019.

5 SAFETY RECOMMENDATION

A safety recommendation is for the purpose of preventive action and shall in no case create a presumption of blame or liability.

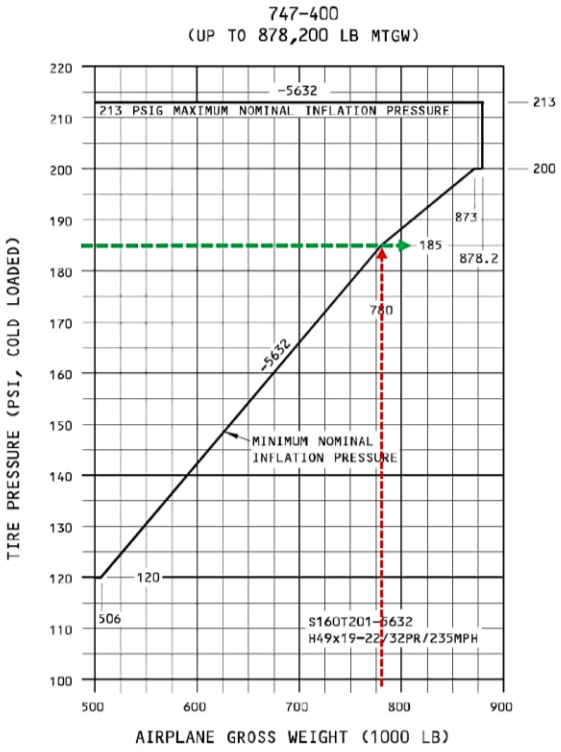
5.1 It is recommended that the aircraft manufacturer review the method of assessing the temperature of the tyre to ensure that the appropriate pressure check is used during tyre servicing. [TSIB Recommendation RA-2019-002]

Appendix 1

Tyre Pressure Limits Chart

BOEING

747-400
AIRCRAFT MAINTENANCE MANUAL



MAIN GEAR

NOTE:
1. FIND A TIRE PRESSURE IN THE APPLICABLE RANGE FOR THE TIRE AND AIRPLANE WEIGHT.
2. THE TOLERANCE FOR THE INFLATION PRESSURE IS +5/-0 PSI.
3. THE INFLATION PRESSURES THAT ARE SHOWN ARE FOR COLD, LOADED (THE WEIGHT OF THE AIRPLANE IS ON THE TIRES) TIRES. REDUCE THE PRESSURE 4% FOR UNLOADED TIRES.
4. THE OPERATIONAL WEIGHT OF THE AIRCRAFT MUST BE LESS THAN OR EQUAL TO THE MAXIMUM DESIGN TAXI WEIGHT (REFER TO THE AIRPLANE WEIGHT - CENTER OF GRAVITY LIMITS IN THE WEIGHTS AND BALANCE MANUAL FOR THE MAXIMUM DESIGN TAXI WEIGHT).
5. SEE AIRPLANE WEIGHT - CG CURVE FOR STRUCTURAL LIMITS.

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Tire Pressure Limits
Figure 302/12-15-06-990-803-003