AEROSPACE INFORMATION REPORT

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Tire Prerotation at Landing

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE A-5C Aircraft Tires Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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1. SCOPE

This SAE Aerospace Information Report (AIR) applies to landing gear tires and airframe structure for all types and models of civil and military aircraft having tires as part of the landing gear.

1.1 Purpose

This report describes the advantages and disadvantages of prerotating tires prior to landing, and explains why this practice is not generally adopted. Two potential benefits of this practice are considered: 1) Tire wear and 2) Spin-up loads on the landing gear and aircraft structure.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org

SAE Journal, Volume 52, No. 10, "Prerotation of Landing Gear Wheels", by H.F. Schippel, 10/44.

SAE Paper No. 881360, “Spin-Up Studies of the Space Shuttle Orbiter Main Gear Tire”, Robert H. Daugherty and Sandy M. Stubbs, MASA Langley Research Center, 10/88.

ARP1070 Design and Testing of Antiskid Brake Control Systems for Total Aircraft Compatibility

2.2 Other Publications

AIAA 90-3272, “A Theoretical and Experimental Investigation into the Pre-rotation of Aircraft Tires”, I. Sobieski, 9/90.

NASA Technical Paper #2009, "Tire Tread Temperatures During Antiskid Braking and Cornering on a Dry Runway", Tanner, Dreher, Stubbs and Smith, 5/82.

NASA CCB III, 12-16-86, UCN: 11902, PCIN: S60035, CAT: CAT II, SCH: E, “MLG Wheel Spin-up”, by W. E. Lemen .

“Pre-rotation of Wheels Prior to Landing”, Royal Air Force Cosford, 1/99.

AFRL-VA-WP-TR-1999-3088, “The Extended Life Tire Program”, Shea, Taxman, and Macy, The Boeing Company, 12/99.

NACA TN 3250, “An Experimental Investigation of the Effects of Wheel Prerotation of Landing Gear Drag Loads”, 10/54.

US Patent Numbers: 2,464,872; 4,040,582; 2,408,963; 2,397,319; 4,205,812; 2,333,447; and 5,104,063

3. BACKGROUND

The idea of prerotating tires at landing has been proposed, and patented, many times in the past. The idea is often proposed during the development of new airplane models with the goal to reduce tire wear and/or to reduce design loads resulting from tire spin-up. This is understandable since it is clear that if tires could be made to spin prior to landing at or near the rolling rate corresponding to ground speed, tire wear could be reduced, and spin-up drag loads could be potentially eliminated or greatly reduced.

In 1988, studies of this practice for the Space Shuttle Orbiter demonstrated that tire wear could be reduced by about 50% if the tires were pre-spun to only 10% of synchronous speed. (The Space Shuttle is a special case from the standpoint of the high landing speed, the high torque required to begin spinning the tires, and the high vertical loads experienced at landing). These studies suggested that this practice may have benefits for commercial airplanes to reduce tire wear, dynamic landing loads, and runway contamination. After further study, NASA rejected tire prerotation for the Orbiter. The problem was addressed by changes to the tire tread material and design, and by changes to the runway surface at Kennedy Space Center.

In 1999, the Royal Air Force investigated the use of prerotation for the Tornado fighter, and concluded that prerotation by means of specially modified tires held promise of improved tire life and reduced landing loads, and recommended further testing. After their investigation was completed, tire prerotation was not adopted.

The only known application of tire prerotation is on several Cessna airplane models designed to operate on gravel runways. This practice minimizes debris spray.

The patents cover a range of devices to accomplish prerotation, from angled tread patterns, sidewall vanes, lugs, pockets, flaps etc., to electrical / hydraulic motors to exactly match the touch down speed. In practice however, these ideas have not been adopted. This report explains the reasons why tire prerotation is generally not practical.

4. SUMMARY OF ADVANTAGES AND DISADVANTAGES

Following is a summary of the advantages and disadvantages of rotating the tires prior to landing. These will be further discussed in the following Sections.

Advantages:

- Reduces tire wear
- Potential to reduce touchdown loads
- Reduces debris spray on gravel runways

Disadvantages:

- Does not reduce tire wear significantly for most airplanes
- Not a reliable means to reduce landing loads, (and may even increase loads)
- If employed, motors add weight, cost, complexity
- Reliability expected to be an issue
- Failure mode requirements minimize potential loads benefits
- Additional maintenance
- If employed, special tires require more testing and spares (left and right tires)
- Causes noise and vibration at landing approach
- Adversely affects on-ground indication systems using wheel spin-up signals upon landing

5. GENERAL CONSIDERATIONS

The two main benefits for tire prerotation are reduced tire wear and lower structural weight on the airframe resulting from reduced fatigue and ultimate design landing loads. These two topics are discussed specifically in Sections 6 and 7, respectively. This section discusses several other related issues which are common to both tire wear and loading considerations.

5.1 Electric or Hydraulic Motors

Studies have shown that electric or hydraulic motors have significant issues, making them generally not feasible for use in this application. The main issues are weight, cost, power limitations, system complexity and failure modes, maintenance, and reliability. The weight alone is generally higher than the weight savings from reduced spin-up loads.

5.2 Specialty Tire Considerations

It was concluded by the RAF study that prerotation by means of aerodynamic flow over specially equipped tires was the most promising approach. Vanes, or cups, would be added to the tire sidewall, thus optimizing the mechanical advantage, and placing the vanes well into the airstream. (Vanes mounted on the wheels do not have sufficient moment arm, have clearance issues, and aerodynamic flow is not as clean).

However, trials undertaken show that slipstream prerotation is unreliable to achieve full touchdown rotation speeds due to a number of factors:

- The size and type of tire vanes or cups limits the amount of applied torque to the wheel assembly
- Wheel bearing friction resists rotation
- Turbulence
- The fact that air speed is not the same as ground speed due to altitude and temperature effects
- Aerodynamic interference with the aircraft (e.g. the wind speed at the top of the tire, nearer the wing, may be faster than at the bottom, such that the tires can actually spin backwards).
- Difficulties in achieving equal tire speeds on gears with more than two wheels in a truck beam arrangement since the aft pair of tires is sheltered by the forward tires.

AIAA Report 90-3272, which investigated the effectiveness of tire cups on the Space Shuttle tire, concluded that only 5 to 10% of touchdown speed could reasonably be expected from the airstream. A Boeing 727 flight test in the 1970s was only able to achieve about 40 knots equivalent ground speed (~25%). As a result, some spin-up will still occur, so wear and drag load reduction is minimal. In some cases, slower tire speeds at touchdown can actually cause higher spin-up loads (see Section 7).

Additional maintenance will be incurred by using uniquely modified tires. There will need to be both left and right-handed spares, which is an increased cost to the operator, as well as increased production and testing cost to the tire manufacturer. It also means ground operation personnel will require additional training to ensure the tires are mounted properly. If the tires are mounted in reverse, the tires would actually spin backwards, causing even more tire wear and higher spin-up loads.

Also, the vanes are subject to foreign object damage (or failure by other means), making the prerotation less effective over time, and could even cause more frequent tire replacement, defeating the original purpose. A related issue was discovered during the Boeing 727 flight testing. At high takeoff speeds, the tire vanes began to break loose, and some were ingested in the engines, causing engine damage. The test was cancelled after this, and the idea was dropped.

Wheel well clearance may be impacted, as it is often very limited. These types of tires would also produce more vibration due to tire imbalance prior to touchdown as the vanes incur wear or damage.

Finally, the added weight for tire vanes is approximately the same as would be required for additional tread to achieve the same tire life, but without the complications noted above.

5.3 Effects on Brake Performance

It has been suggested that spin-up drag load offsets the work brakes are required to perform during stopping. If tires are pre-spun, brakes will have to compensate, resulting in slightly more brake wear and stopping distance. In general, this is not a significant factor since the energy required to spin the tires is less than 1% of the brake energy required to stop the airplane. A more important factor is the impact on the brake control system (see Section 5.4).

5.4 Interaction with On-Ground Indication Systems

Depending on the type of device or system used to prerotate tires, there may be complications arising from interaction with other systems. Examples are the antiskid system, the auto-speedbrake system, and other systems requiring rapid on-ground sensing. These systems often use wheel speed to trigger on-ground indication. Tire prerotation would require that such systems be modified to use other means to indicate ground contact. This would result in a significant impact to the system design, and would probably prevent prerotation from being feasible for retrofit applications. Wheel speed indication is very rapid, which is important for brake performance. Apart from truck pitch rotation on airplanes so equipped, wheel speed is the most rapid indication of ground contact. All other known measurements, such as weight-on-wheels or strut compression, are slower, and would result in a degradation in brake performance. This is a more important factor than tire wear, and would probably be a sufficient reason to reject prerotation even without considering the other disadvantages.

It is noted that one advantage of only partially spinning the tires to about 10% of landing speed is that this is below typical wheel spin-up indication speeds processed by the antiskid system, thereby minimizing the impact to these systems.

5.5 Noise and Vibrations

If the tires are pre-spun, tire imbalance prior to touchdown will cause noticeable vibration and additional noise. Noise is a very important factor at airports, and any increase in noise resulting from pre-spun tires must be accounted for in the overall decision to incorporate prerotation in the design. Passenger noise and ride comfort is also a potential issue due to the vibration transmitted to the cabin. These considerations may result in more stringent tire balancing requirements, (although this adds additional maintenance burden, and is not always effective).

It has been suggested that, without prerotation, tires tend to land with the heavy side down, so spin-up wear may act to balance the tires. Tire prerotation would eliminate this natural self-correcting balancing tendency. This is probably not a significant factor since wheel bearing friction and airstream forces make it difficult to predict the location of the heavy side of the tire at landing.

The specific system used for prerotation may affect shimmy stability. The inboard and outboard tires may touchdown at different speeds, causing a transient yaw moment to be applied to the gear. The shimmy analysis and testing must take this into account.

5.6 Certification and Testing

If a tire prerotation system is employed, additional certification compliance and testing will be required. This includes tire manufacturer qualification testing (if modified tires are used), as well as additional airplane flight testing. The impact to TSO testing would need to be defined. Failure modes must be investigated to ensure the aircraft level functional hazard requirements are respected. And the effects of system failure modes on structural requirements must be added to the certification basis.

5.7 Other considerations

Another factor to consider is airplane handling and control. If the tires are pre-spun at different speeds, which is likely if the airstream is used to rotate the tires, then the airplane could have a tendency to veer to one side.

6. EFFECTS OF PREROTATION ON TIRE WEAR

It is acknowledged that tire spin-up is a very aggressive wear phenomena, but the very short time period over which it occurs, results in only a small percentage of the overall tire wear. It is estimated that between 5 to 10% of total tire wear result from spin-up in normal operation. Normal braking continues all through the stopping cycle with the antiskid system controlling the brake pressure to just below the point where the tire starts to skid. The runway surface abrades the tire tread during this phase. Also, tire scrubbing during taxiing and turning contribute significantly to tire wear.