# DEVELOPMENTS IN NEW AIRCRAFT TIRE TREAD MATERIALS

Thomas J. Yager and John L. McCarty
NASA Langley Research Center

S. R. Riccitiello and M. A. Golub
NASA Ames Research Center

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## SUMMARY

Comparative laboratory and field tests were conducted on experimental and state-of-the-art aircraft tire tread materials in a program aimed at seeking new elastomeric materials which would provide improved aircraft tire tread wear, traction, and blowout resistance in the interests of operational safety and economy. The experimental stock was formulated of natural rubber and amorphous vinyl polybutadiene to provide high thermal-oxidative resistance, a characteristic pursued on the premise that thermal oxidation is involved both in the normal abrasion or wear of tire treads and probably in the chain of events leading to blowout failures. Results from the tests demonstrated that the experimental stock provided better heat buildup (hysteresis) and fatigue properties, at least equal wet and dry traction, and greater wear resistance than the state-of-the-art stock.

## INTRODUCTION

Apart from occasional traction problems on wet or icy runways, the major tire concerns of commercial and military aviation are those which lead to tire removal. The primary concern is tread wear or abrasion which results from braking and cornering maneuvers and from wheel spinup at touchdown. Cutting is another cause for tire removal and it is generally attributed to characteristics of the runway surface, such as sharp aggregate or uneven slab joints, and to the presence of foreign objects. Other causes include tearing and chunking where strips or chunks of rubber are separated from the tire during high-speed operations generally on a dry, rough runway. In the interests of operational efficiency, there is a clear need to prolong the lifetime of a tire tread to minimize replacement costs and to reduce the "downtime" of the aircraft. In the interests of aircraft safety, blowouts and related tire failures obviously need to be reduced to negligible levels.

Keeping a fleet of airplanes properly shod is a definite economic problem, particularly since the lifetime of a tire tread can extend from approximately 300 take-off and landing cycles all the way down to 10 to 15 cycles, depending upon the aircraft and the nature of its operation. Over half a million aircraft tires were manufactured in this country during 1975 to help maintain the operation of this nation's commercial and military aircraft. Fortunately, in contrast to automobile tires, the carcass of an aircraft tire



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undergoes relatively little deterioration during the lifetime of a given tread and these tires are customarily retreaded five or six times before being scrapped. The cost of retreading is approximately one-fourth the cost of a new tire. In view of such economic and inherent safety considerations, the Chemical Research Projects Office at Ames Research Center instituted a program to seek new elastomeric materials which would provide improved tire tread wear, traction, and blowout resistance. Additional impetus for the program was provided by the NASA Research Advisory Subcommittee on Aircraft Operating Problems, which recognized in a 1968 resolution the need for high-performance aircraft tires with improved wear and safety characteristics. The purpose of this paper is to briefly describe the results from initial developments at Ames on a new elastomer formulation for aircraft tires and to present preliminary results from traction and wear experiments conducted under the guidance of Langley Research Center on tires retreaded with this new formulation.

## TIRE TREAD RUBBER DEVELOPMENT

Among the many elements which make up an aircraft tire, the elastomer system constitutes the critical component since its molecular structure and chemical reactivity must offer the optimum balance of mechanochemical, thermal-oxidative stability and viscoelastic properties. State-of-the-art treads for jet transports typically comprise a 75/25 polyblend of cis-polyisoprene, either as natural rubber (NR) or "synthetic natural rubber" (SN), and cis-polybutadiene (CB). Although this is the basic blend, variations do exist between different tire manufacturers and for specific tire operational needs. (The tire tread for the Concorde, for example, is made from all natural rubber.) In addition to the elastomer system, other tread ingredients include a vulcanizing agent (sulfur or other curative), reinforcement pigments (e.g., carbon black), accelerators, stabilizers, processing aids, and cord material. Each of these ingredients, as well as assorted engineering parameters such as tread design and ply construction, must be optimized for a particular tire formulation and use.

It was decided early in the program to focus attention on the development of elastomers which would provide a higher thermal-oxidative resistance than state-of-the-art elastomers. This approach was pursued on the premise that thermal oxidation is involved in the normal abrasion or wear of tire treads and probably in the chain of events leading to blowout tire failures. It was also recognized that optimization of the tire formulation could best be accomplished by the tire industry once the enhanced thermal-oxidative stability of a new tread composition had been demonstrated.

The thermal-oxidation studies which ensued led to the view that a new elastomer, amorphous vinyl polybutadiene (VB), having its double bonds (which are required for vulcanization) outside the main polymer chain, would be more oxidatively stable at a given temperature than state-of-the-art elastomers which have their double bonds inside the main chain. An experimental tire tread stock, consisting of a 75/25 blend of NR/VB, was formulated and tested against state-of-the-art stock (75/25 NR/CB) for comparative heat buildup (hysteresis), fatigue, traction, and wear characteristics.

## RESULTS AND DISCUSSION

### Laboratory Tests

The initial tests on the two tread stocks were performed in the laboratory on small specimens using testing machines and procedures which have been standardized for such tests.

Heat buildup and blowout.- The results from heat buildup and blowout flexure tests are presented in figure 1. The figure shows that the temperature rise $\Delta T$ after 30 min of flexing in the two heat buildup tests is less in the experimental stock than it is in the standard or state-of-the-art stock. The difference is appreciable in the case where working of the samples commences at an elevated temperature. This comparison suggests that the experimental stock has the better thermal stability, particularly at higher temperature levels where this stability is needed. Similar temperature buildup trends are noted in the heat blowout tests in which the samples are worked at a higher energy level (sample loaded to 1110 N as opposed to 778 N in the buildup tests and a compression stroke of 6.4 mm as opposed to 5.7 mm). During the blowout test which commenced at 38° C, the standard stock failed after 36 min with a temperature rise of 81.7° C, whereas the experimental stock sample, which had not failed when the test was concluded after an hour, had a $\Delta T$ of only 62.2° C, which was measured after the sample had been subjected to a working time lasting 24 min longer. For the heat blowout test which commenced at 100° C, the temperature rise was essentially the same in both samples, even though the temperature of the experimental stock at failure was recorded after a working time approximately 50 percent longer than that of the standard stock sample. The longer blowout times associated with the experimental stock suggest that it is a stronger material than the state-of-the-art stock.

Cut growth.- Figure 2 presents the results from flexure tests on pierced samples of the experimental and standard stock to determine cut growth characteristics. The figure shows that at room temperature the experimental stock has a higher initial rate of cut growth than the standard stock; however the data suggest that the experimental stock has a lower overall cut growth after a prolonged period. More importantly, this observation of a better cut growth property of the experimental stock is reinforced by measurements taken after 1 hour at elevated temperatures where the potential for chunking is significant.

### Field Tests

On the basis of the successful performance demonstrated by the experimental rubber stock during laboratory tests, a number of size 49 · 17, type VII, aircraft tires were retreaded with the new NR/VB formulation. Following qualification for aircraft use on a dynamometer at Wright-Patterson Air Force Base, Ohio, the tires were shipped to Langley Research Center for traction and wear tests under actual and simulated flight conditions. For comparison purposes, additional tires were retreaded in the same mold but with the standard state-of-the-art NR/CB rubber formulation and also shipped to Langley.

Traction.- One tire of each rubber formulation was installed on the large test carriage at the Langley aircraft landing loads and traction facility, pictured in figure 3, to ascertain whether the new tread rubber stock had any traction deficiencies. Tires equipped with both the standard and the experimental stock were exposed to braking cycles, which extended from free rolling to locked wheel skids, on similar dry, damp, and flooded concrete runway surfaces at test speeds up to approximately 100 knots. The insert in figure 3 is a photograph of the fixture which supported the tire and was instrumented to measure the forces and moments exerted on the tire during the course of a braking test. Some typical results from these tests are given in figure 4 where the maximum braking friction coefficients developed by the two tires on a dry and on a flooded surface are presented as a function of carriage ground speed. The figure shows that the level of developed friction did not deteriorate when the tire equipped with standard tread stock was replaced by one with the experimental stock. Indeed, the experimental stock provided maximum friction coefficients on both the dry and the wetted surface which were as high or higher than those measured with the standard stock.

Wear.- The extent of the tread wear associated with each tire during the traction tests was obtained by noting the gauged difference in the average tread groove depth around the tire circumference prior to and following the test program. Unfortunately, it was difficult to use this information to form the basis for comparing the wear resistance of the two tread materials because the tires were not exposed to identical test conditions of ambient temperature, speed, and the number and length of each brake cycle. However, it was interesting to note that both tires experienced essentially the same average loss in tread thickness but the tire with the experimental tread material was exposed to approximately 50 percent more brake cycles than the tire with the standard tread material. Thus, on the basis of this information the experimental stock appeared to have better wear properties than the standard stock.

To acquire meaningful tire wear data resulting from actual aircraft take-off and landing operations, NASA enlisted the services of the FAA Aeronautical Center in Oklahoma City to fly sets of tires equipped with the experimental and standard tread stocks on a Boeing 727 airplane. For these tests, tires with the experimental stock were installed on the inboard wheel of one gear and the outboard wheel of the other; at the same time, tires with standard stock were mounted on the remaining wheels for comparison purposes. The upper photograph in figure 5 was taken during the course of this program and shows the airplane immediately following main gear touchdown, the smoke from that event being quite visible. The other two photographs in this figure are closeup views of a gear with newly installed tires and with a tire worn to the removal stage. Through the highly cooperative efforts of the FAA, tread depth measurements were periodically taken across the tread and around the circumference of all four tires in a test set to define the pattern and the extent of tread wear. Four test sets involving eight tires retreaded from the NR/VB stock and a like number retreaded from the standard state-of-the-art NR/CB stock from two sources were flown in this test program. The information contained in figures 6 and 7 typify the results.

Tread profiles at selected stages of the tread lifetime are given in figure 6. The profiles shown were obtained from tread depth measurements taken on a tire equipped with standard tread stock and mounted on the left inboard wheel.

The wear pattern is not unique; tires retreaded with both the experimental and standard stocks at other wheel locations on the gear showed similar wear propagation. The figure identifies the original tire profile and worn profiles after a designated number of landing operations, including that after 261 landings when the tire was removed because marker cords were visible. The history of this and the other treads in the aircraft test program differed from that of treads on commercial aircraft tires because the test airplane landings were predominantly touch-and-go operations conducted during pilot training exercises. However a query of aircraft tire retreaders revealed that Boeing 727 tires worn during commercial service had similar final profiles which showed very little wear near the outer edges of the tread. In view of this wear pattern, the two tire tread compounds were compared on the basis of tread depth measurements taken only along the two inner grooves. Results of measurements from two sets of test tires, which typify all the data, are presented in figure 7 where the wear in terms of percent tread worn is plotted as a function of the number of landing operations. The percentage tread wear was derived by averaging tread depth measurements along the circumference of the two inner grooves of both experimental tread stock tires and both standard tread stock tires in each set. Note that this percentage never reached 100 percent since each tire was removed from the airplane when a wear marker was exposed, and as a result some tread remained about the circumference, as shown in figure 5. Figure 7 shows that the wear performance exhibited by the experimental stock is equivalent to or better than the standard stock. The wear performance of this experimental tread stock is most encouraging because it means that a material has been developed which possesses good hysteresis, fatigue, and friction characteristics without a sacrifice in lifetime. Indeed, the formulation of the stock tested here was an initial attempt and, as such, was not considered the optimum blend of ingredients which are added to the elastomer system to provide the best wear characteristics. It is likely that a blend could be perfected which would considerably improve tread longevity.

It is also of interest to note in figure 7 that the number of landing operations in the tread life of the tires exposed to predominantly touch-and-go operations is comparable to the number of full-stop landing operations generally available with tires in commercial service. Since touch-and-go operations involve no wheel braking and very little cornering, this agreement would suggest that perhaps the major source of tire wear occurs during wheel spinup. The fact that the wear is predominantly in the central area of the tread - the area which at touchdown first contacts the runway surface - would appear to support this possibility.

The authors are aware that the tread wear evaluation obtained from the FAA Boeing 727 aircraft operations was based on a comparatively small data sample. Arrangements are being made to retread 50 additional tires with this experimental stock for use by a commercial airline during normal operations on a variety of runway surfaces.

## CONCLUDING REMARKS

Comparative laboratory and field tests were conducted on an experimental tire tread stock formulated of a 75/25 blend of natural rubber/amorphous vinyl polybutadiene and on a state-of-the-art tire tread stock with 75/25 natural rubber/cis-polybutadiene. These tests constituted the initial effort in an overall research program aimed at seeking new elastomeric materials which would provide improved aircraft tire tread wear, traction, and blowout resistance in the interests of operational safety and economy. The experimental stock was selected to provide high thermal-oxidative resistance, a characteristic pursued on the premise that thermal oxidation is involved both in the normal abrasion or wear of tire treads and in the chain of events leading to blowout tire failures. Results from the tests demonstrated that the experimental stock provided better heat buildup (hysteresis) and fatigue properties, at least equal wet and dry traction, and greater wear resistance than the state-of-the-art stock. No attempts were made in this initial phase of the overall tread development program to optimize the experimental formulation since the intent here was only to demonstrate the concept of an improved tread stock based on amorphous vinyl polybutadiene. Such an optimization, which could result in much longer tread lifetimes, would best be accomplished by the tire industry. Meanwhile, efforts continue at Ames and Langley Research Centers to develop and evaluate new tire tread compounds aimed at improving the economy and safety of aircraft ground operations.

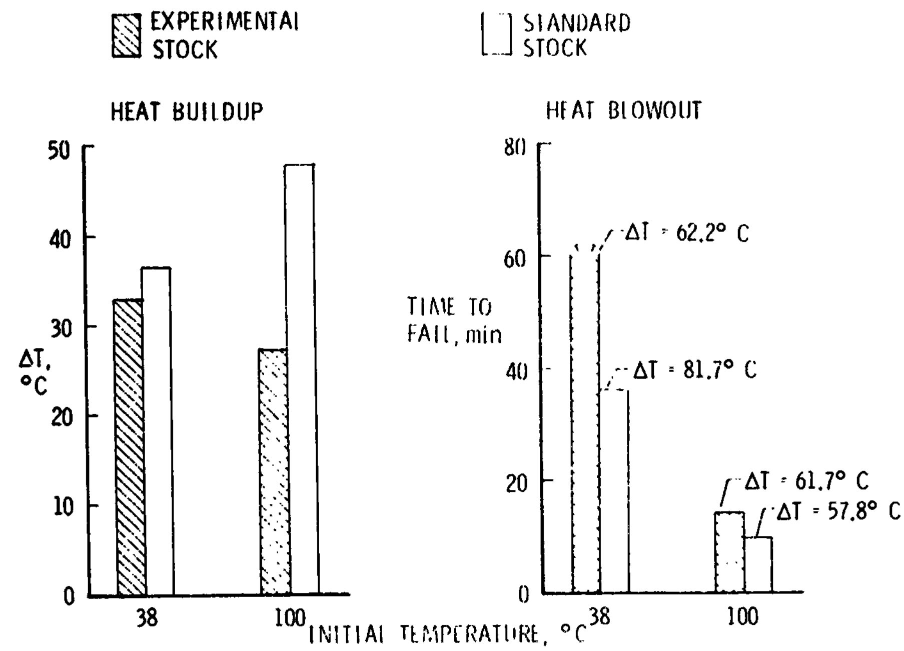



Figure 1.- Heat buildup and blowout test results.

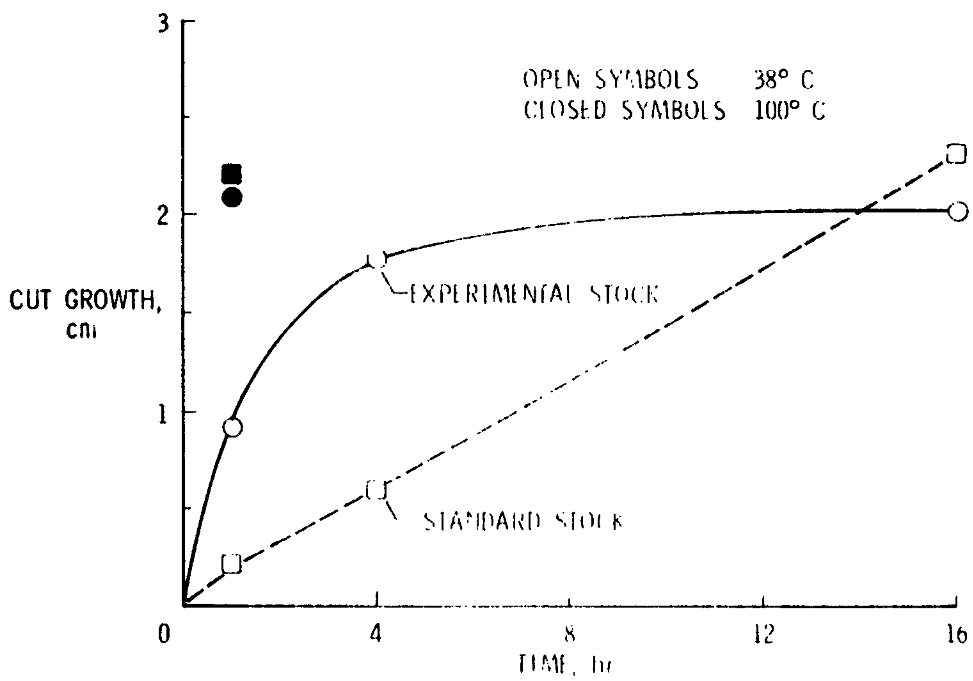



Figure 2.- Cut growth test results.

Figure 3.- Langley aircraft landing loads and traction facility.

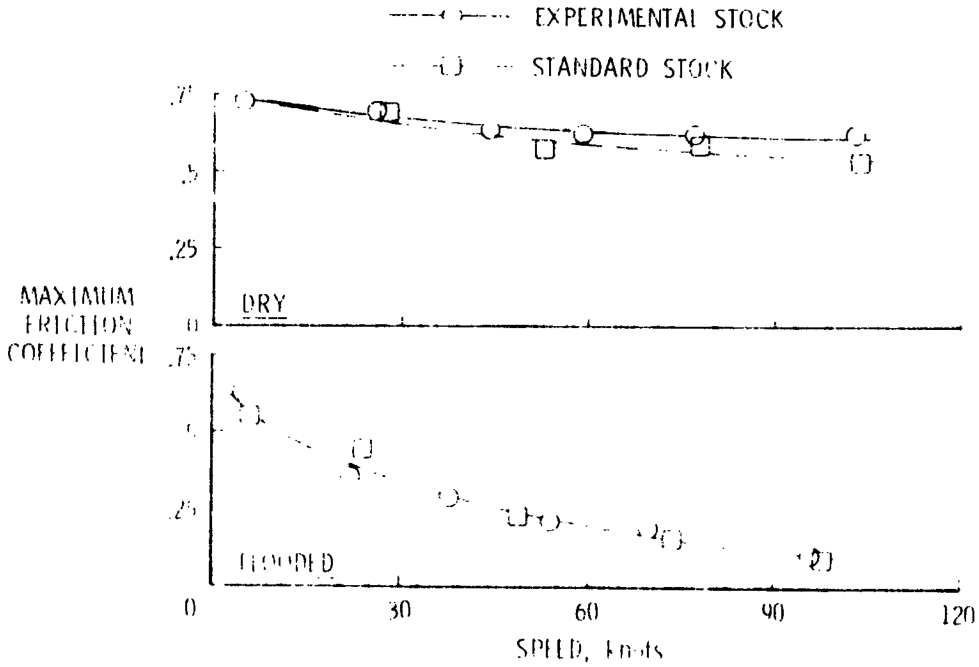
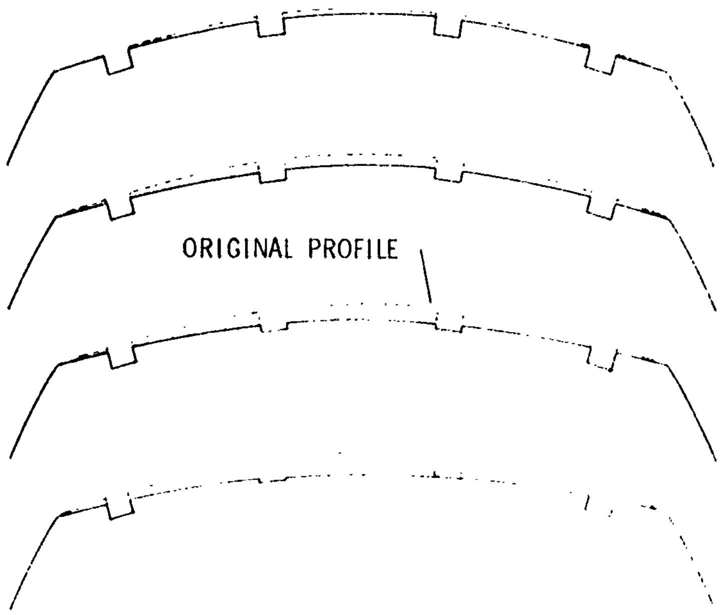



Figure 4.- Tire traction test results.

Figure 5.- Aircraft tire tread wear evaluation.




| LANDING OPERATIONS | | |
|---|---|---|
| TOUCH AND GO | FULL STOP | TOTAL |
| 30 | 8 | 38 |
| 74 | 16 | 90 |
| 166 | 28 | 194 |
| 224 | 37 | 261 |

Figure 6.- Typical propagation of tire tread wear of the main gear tire on FAA Boeing 727 airplane.

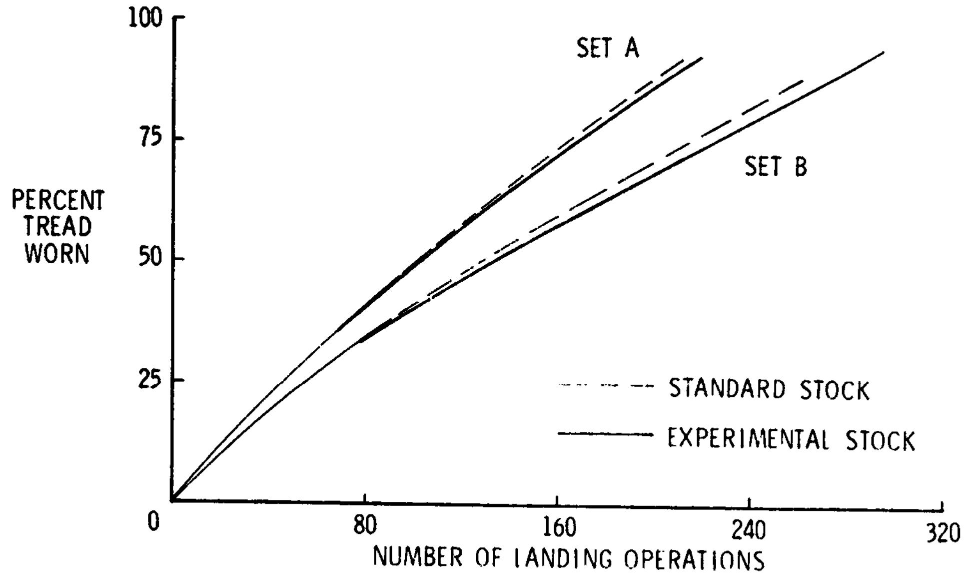



Figure 7.- Tire tread wear results from FAA Boeing 727 tests. Average wear at two inner grooves.