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THE SPACE SHUTTLE PROGRAM FROM CHALLENGE TO ACHIEVEMENT SPACE EXPLORATION ROLLING ON TIRES

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ABSTRACT

The Space Shuttle Transportation System is the first space program to employ the pneumatic tire as a part of space exploration. For tires (Aircraft type), this program establishes new expectations as to what constitutes acceptable performance within a set of tough environmental and operational conditions. Tire design, stresses the usual low weight, high load, high speed, and excellent air retention features but at extremes well outside industry standards. Tires will continue to be an integral part of the Shuttle's landing phase in the immediate future since they afford a unique combination of directional control, braking traction, flotation and shock absorption not available by other systems.

INTRODUCTION

Unlike any preceding U.S. space venture, the decision to develop a reusable space exploration system; namely, the Shuttle system, carried with it needs and functions never before required by space travel. The particular need I'm referring to, is vehicle recovery by land rather than by sea; the particular function, and the focus of this talk, the use of landing gear tires. Recovery by land spelled out a set of requirements that could not be met more efficiently, within state-of-the-art technology, than by the use of a pneumatic tire system. These requirements include, in particular, braking traction, shock absorption, damping, directional control, and flotation characteristics.

The discussion to follow will include the tire design background, a description of key performance requirements which form the challenge, and the tire design which satisfied these punishing conditions. Both the nose landing gear tires and the main landing gear tires were developed and supplied by BFGoodrich. My comments will primarily focus on the main landing gear tire since it presented the greatest challenge and resulted in an unusual design.

TIRE DESIGN BACKGROUND

First some background information on the tire design's evolution.

Even before the Shuttle's first Orbital flight, BFGoodrich had developed three (3) successive generations of main landing gear tires, each in response to changing performance requirements and an ever growing vehicle weight. This total effort encompassed an eight (8) year time span starting in 1972. One basic objective of the tire development program was to avoid new exotic materials for which no track record existed. On this basis, nose and main gear tires were innovatively constructed from industry materials.

The first generation main landing gear tire, known as the baseline tire, was used exclusively on the Enterprise, the first Shuttle produced. At that time the vehicle's estimated maximum gross weight was at 88,906 Kgs. (196,000 lbs.); as it turns out, that would be the lightest weight vehicle compared to later models. The dynamic test requirement for qualification of the tire was based on only straight ahead landing rolls at the 88,906 Kg. (196,000 lbs.) vehicle weight. Within the spatial limits of the Orbiter wheel well and tire design optimization, a bias tire with a 28 PR designation was selected in a 1.13 M (44.5 in.) diameter, .41 M (16.0 in.) section width, fitted to a wheel with a .53 M (21.0 in.) diameter and a 15^{0} bead seat taper.

During the preorbital approach and landing tests, Rockwell Engineers had instrumented the landing gear to measure forces upon landing. From these readings, a new set of test requirements evolved, and subsequently, a new tire meeting them. The new test parameters reflected a more accurate set of vehicle reaction loads, coupled with a higher vehicle weight, now 108,864 Kgs. (240,000 lbs.) maximum. The new dynamic test requirements included an oscillating yaw condition to simulate the effect of crosswind. To match these conditions, the 2nd generation tire was designed and stepped up to a 34 ply rating, while remaining the same size. (Ply rating, by the way, is an index of relative tire strength.)

There were difficulties in meeting the requirements for the heavier vehicle and the design work for the 2nd generation tire was pushed to the first flight, tire delivery cutoff date. At that point, the 2nd generation tire was reliably capable of test loads equal to the maximum weight of the first flight vehicle; namely, 93,895 Kgs. (207,000 lbs.). This design, the 2nd generation tire, was certified as a first flight tire only and performed superbly during the April, 1981, flight of the Columbia.

Before the Columbia had been launched, a 3rd generation tire was well on its way to final certification. This tire, as proven in development tests, would pass the test requirements for a 188,864 Kg. (240,000 lbs.) vehicle as well as the severe crosswind yaw condition. This tire is also 34 ply rated but of a slightly different internal design. It is this main landing gear tire that will be the focus of my comments; it is this tire that is currently in use on the Challenger and Columbia.

The nose landing gear tire complementing the main tire carries a smaller portion of the vehicle load and as such is smaller in size: .80M (31.5 in.) diameter, .24M (9.30 in.) section width, on a rim .41M (16.0 in.) diameter. This tire is designated 32x8.8/20 PR. Suspended on a castered gear, many of the changing side load and vertical load conditions experienced by the main landing gear, while the Shuttle's weight was growing, did not affect the nose gear, therefore only one generation of nose gear tire was developed.

THE CHALLENGE - KEY TIRE PERFORMANCE NEEDS

The Shuttle's landing configuration required a unique combination of shock absorption, damping, and flotation capability under a variety of environmental and load conditions; something only the pneumatic tire could provide. These performance requirements breakdown into a set of test requirements familiar to the aviation world.

TEMPERATURE & AIR RETENTION

First let's examine the temperature and air retention requirements. The Shuttle tire must be capable of withstanding soak temperatures in space that cycle as low as -51°C (-60°F) and as high as +93°C (+200°F). These extremes are controlled by exposure of the Shuttle's surfaces in and out of the Sun.

In the landing phase, the tire is required to perform dynamically to soak temperatures ranging from -37°C (-35°F) to +55°C (+131°F). Initial flight data has shown the lower half of this temperature range to be more significant.

Throughout these soaks, air retention must be kept at a maximum. After temperature, time is the toughest parameter in retaining pressure. As it turns out, from the time the Shuttle is mated to the main fuel tank in preparation for launch to the point of touchdown, the tire inflation pressure cannot be serviced, only monitored. This time span can vary from a few weeks to several months.

WEIGHT

As with any project of this type, the lowest possible tire weight is foremost, tempered by the design's ability to do the job. Each MLG tire for the Shuttle weighs in at approximately (89 Kgs.) 196 lbs. Some control over this weight was predetermined when the tire size selection was made. It would take a 1.32 meter (52.0 in.) diameter tire, such as is found on a Lockheed Tristar L-1011, of the same PR in a commercial aircraft tire size to carry approximately the same load as the Shuttle's 1.13 meter (44.5 in.) diameter tire. The consequence of selecting such an undersized tire for weight and size is overloading.

LOAD

In tests, the actual tire dynamic loading for a single tire reaches more than twice its rated load, or about 58,968 Kgs. (130,000 lbs.), to give a peak operating deflection of 66%, as compared to a conventional commerical aircraft tire at a maximum operating deflection of 35%. This loading comparison is made outside the instantaneous spike loading any aircraft tire could experience upon landing.

SPEED - YAW

Landing touchdown speeds range from 394 Km/h to 422 Km/h (245 to 262 MPH). A B-727, or Lockheed Tristar by comparison, would land at speed from 225 Km/h to 257 Km/h (140 - 160 MPH); about 161 Km/h (100 MPH) slower than the Shuttle.

The yaw test parameter attempts to simulate the Shuttle's crabbed final approach condition under crosswinds, a condition not fully corrected at touchdown. The Shuttle tire must be capable of withstanding the lateral forces generated at 3.0 -5.4^{o} yaw under high loads and high speeds. This test requirement, single-handedly, has doubled the difficulty of meeting the Shuttle's performance requirements.

In order to ensure that a tire will operate to a given performance level under a variety of temperature, load, speed, and yaw conditions, two separate conditions are tested on an indoor roadwheel dynamometer. The two landing test conditions are based on two possible landing configurations; the first designated "Quick Pitchover", the second designated "Delayed Pitchover". The term "Pitchover" refers to the lowering of the Shuttle's nose after touchdown.

In the delayed case, the nose is held up for a period of time (approximately 10 seconds) and then lowered. In the quick case, the nose is lowered immediately after touchdown. Each landing profile produces a different reaction loading at the main gear.

To create for you an appreciation of some of the dynamic test conditions (deflection, yawing, impact velocity), I have a brief film clip of a Shuttle main landing gear tire, testing under the conditions of a delayed pitchover landing. This film was taken at Wright-Patterson AFB, complements of NASA. There are four test cycles in this clip each identified by maximum gross vehicle weight, crosswind velocity, and touchdown velocity. All four tests are conducted on the same tire.

THE TIRE DESIGN

To meet all of these requirements, the tire design had to be geared for high reliability under long term static conditions and short term punishing dynamic conditions. The key features of the design can be described in five categories.

MOLD SHAPE

The Shuttle main landing gear tire is molded to a shape which is described in the industry as semicantilevered. The term simply defines the shape of the mid and lower sidewall by specifying the relationship of the wheel flange spacing to the average inflated section width. For a semi-cantilevered tire, this ratio is in a range from 60% to 70%. This mold shape has been found to be favorable to high deflection capability since the tire can be molded closer to the inflated/deflected shape.

LINER

The Shuttle MLG tire has a heavy innerliner to maximize air retention. The key design variables to achieving a minimum pressure decay rate over an extended period of time are material gauge and compound. Balancing weight against air retention capacity, and compound against operating temperature, a 100 ga. liner compound was adopted for the Shuttle main with an effective air retention rate 1.6 times better than conventional military aircraft tire materials.

Still state-of-the-art technology could not provide a virtually non-diffusing liner material. To compensate for this, a leak rate history is established for the tire/wheel assembly. Over-inflation is then based on the total anticipated pad checkout and flight time, and the assembly leak rate. The average long term static decay rate for main landing gear assemblies has been 1.38 Kilopascals/day (.20 PSI/day) on a base of 2172 Kilopascals (315 PSIG), for less than one-tenth of one percent per day. In a system that has no reinflate or service capability, the normal daily loss of 2-3% in the aviation industry would be totally unacceptable.

TREAD

At 2.54mm (.10 in.) skid depth, only a very thin skin of tread compound covers the outer carcass ply. High load and speed requirements limit the tire to a maximum of 6 landings. This results in a shallow skid design and a design that lacks groove definition across the tread (groove to rib ratio of 1:2.5). A very cool running compound is used in the tread, still, the phenomenon of surface blistering and reversion occur while testing on the dynamometer under extreme load and speed as demonstrated in the film.

CARCASS

The weight savings realized from the shallow tread allowed added strength to be designed back into the carcass design. The carcass design features a contoured cross section, very beefy in the lower sidewall and relatively thin in the upper sidewall. The exaggerated contouring controls the high flex point during radial loading but more importantly during lateral loading. The internal content of the tire was driven by the performance need (mindful of weight) and the ultimate manufacturing boundaries. A standard nylon carcass was selected but with a larger, stronger cord (12% stronger than conventionally used) to minimize the total number of plies. The insulating compound surrounding the cord, is non-uniformly distributed based on the needs of the critical stress points in the shoulder and lower sidewall. By minimizing insulation, the primary bias tire heat generator is reduced. But a tradeoff occurs, in that less rubber insulating material is available to distribute shear forces. The net result is a specialized bias tire matrix that performs in a satisfactory temperature range with good short term durability.

BEAD

The Shuttle tire bead base is of a more conventional design, however, it is large, to complement the contouring of the lower sidewall.

If you study the tire's total content in terms of three basic components--beadwire, fabric, and compound--and compare these to a conventional heavy duty commerical airline tire, the Shuttle tire contains 11% less insulating material but 6% more fabric.

CONCLUSION

The Shuttle tire program has been a story of innovative design within the boundaries of known materials. It has been an extensive and successful effort to balance material capability with performance requirements which fall well outside industry standards.

This tire design technology has been reapplied to other aircraft products but only to a very limited extent. More realistically, this technology has led to further investigation of materials and structures in an effort to minimize the less desirable tradeoffs of short operating intervals and short operating life; two tire characteristics not marketable in the aviation industry. Even with its life limitations, the pneumatic tire still provides that unique combination of directional control, shock absorption, flotation, and traction unlike any other system.