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ORBITER WHEEL AND TIRE CERTIFICATION

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ABSTRACT

The Orbiter wheel and tire development has required a unique series of certification tests to demonstrate the ability of the hardware to meet severe performance requirements. Early tests of the main landing gear wheel using conventional slow-roll testing resulted in hardware failures. This resulted in a need to conduct high-velocity tests with crosswind effects for assurance that the hardware was safe for a limited number of flights. Currently, this approach and the conventional slow-roll and static tests are used to certify the wheel/tire assembly for operational use.

INTRODUCTION

The Space Shuttle Orbiter wheel and tire designs combined conventional aircraft materials into one of the most highly optimized assemblies yet developed. This is not obvious until the performance limits are compared to similarly sized equipment on commercial aircraft, which will reveal that the Orbiter's wheel/tire load capability is nearly twice as high.

To confirm that these wheels and tires were capable of meeting Space Shuttle requirements, an unusually stringent and highly realistic test and analysis program was developed to demonstrate the required capability as well as the performance margins available beyond the requirements. As more stringent requirements have arisen, the hardware has been proven acceptable in most cases without design changes.

GENERAL DESCRIPTION OF HARDWARE AND CERTIFICATION

The Orbiter main tire characteristics are as follows: 44.5-inch diameter, 16-inch width, 21-inch bead seat diameter, 34-ply rated, 200-pound weight, and 315-psi inflation pressure. The tire is of bias ply construction using conventional materials such as nylon, natural rubber, and steel bead wire (fig. 1). The tire's unique construction, developed by B. F. Goodrich, Akron, Ohio, has provided the desired very high load capability at a minimum weight. Consequently, reuses are limited when compared to military or commercial tires.

The main wheel is a split, forged aluminum alloy design with a steel hub pressed into the inboard half. The bearings have conventional tapered rollers but their uniquely high preload requirement provides a drastic increase in landing load capability at the sacrifice of reuse life.

The nose tire characteristics are 32-inch diameter, 8.8-inch width, 18-inch bead seat diameter, 20-ply rated, 50-pound weight, and 300-psi inflation pressure. The nose tire is also of bias ply construction and made of conventional materials.

The nose wheel is a split, forged aluminum alloy design but its bearings are located on a rotating or "live" axle rather than in the hub such as in the main wheel design. Both nose wheels are splined to the "live" nose axle providing a corotating feature which improves stability or reduces the tendency to shimmy.

Most of the vendor's qualification tests of the nose wheel and tire were similar to those of the main wheel and tire, the exception being that the main wheel and tire received additional off-limits tests because of a wider variety of performance requirements. In many cases, the main tire only was tested and its performance was extrapolated for nose tire use. Rather than repeat the many similar tests of the nose tire, the remaining material in this text will address the main tire only.

Nearly all wheel tests require the use of a flight-type tire to provide realistic wheel load paths and pressure seals. Tires are frequently tested on a high-strength (but heavy) laboratory wheel for safety and cost reasons. The most significant tests given the wheel/tire assembly are those that are most nearly representative of an abort landing load case. In such a test, the assembly is subjected to changing velocities, radial loads, and rollout yaw angles which duplicate those that can occur on an actual landing except that the tire rolls on a 10-foot diameter dynamometer "road wheel." This provides a cylindrical rolling surface, which is also smoother than a paved runway. The curved rolling surface is considered to provide an even more conservative or harsh test due to the increased stresses from the additional bending required as the tire tread conforms to the

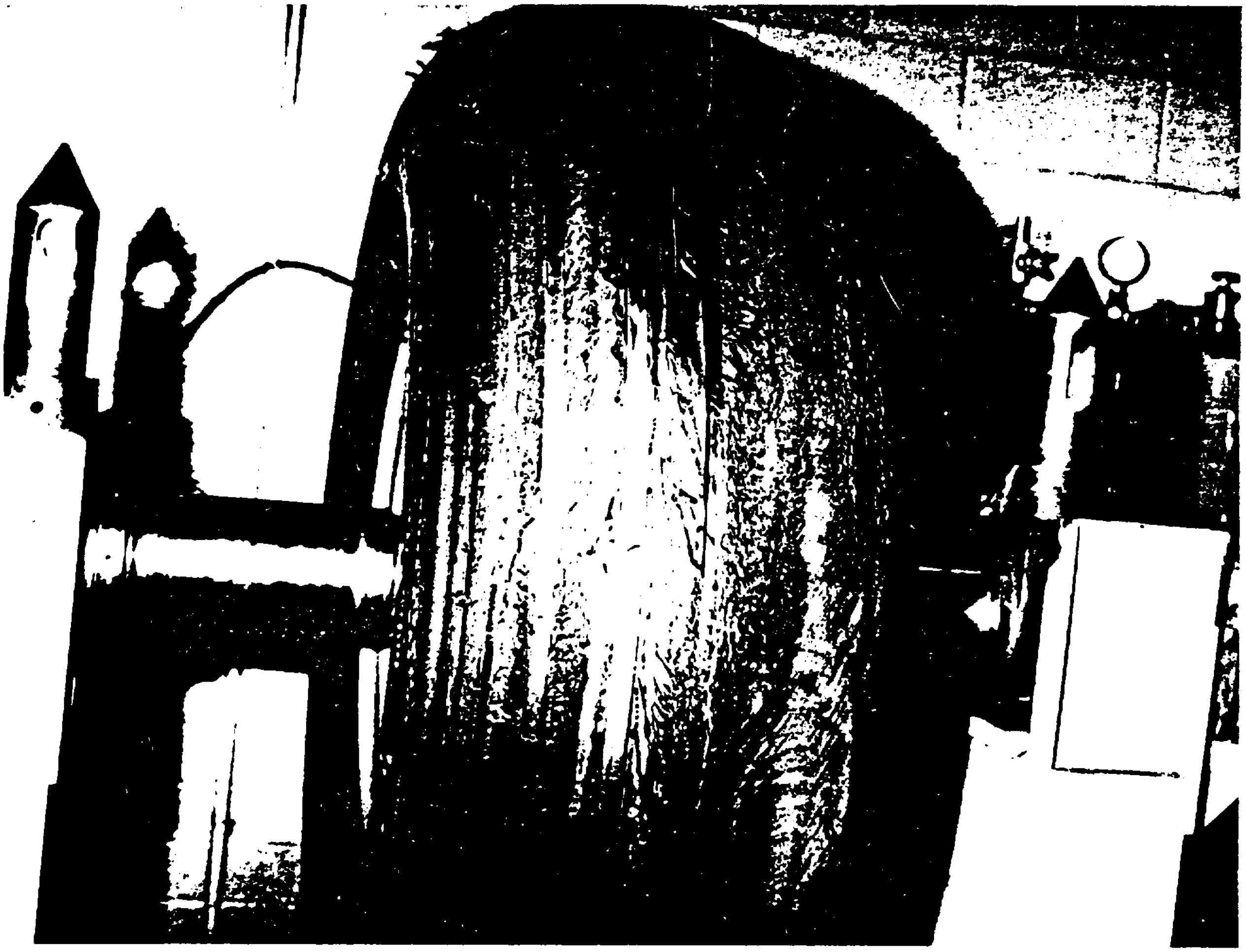

FIGURE 1.- MAIN WHEEL/TIRE ASSEMBLY AFTER CROSSWIND CERTIFICATION TESTS.

dynamometer surface. The tire inflation pressure must also be increased for a dynamometer test to maintain the same peak tire sidewall deflection at the center of the tire footprint when located against the dynamometer.

In addition to these dynamic landing load tests, the wheels and tires were also subjected to many other certification tests, such as burst pressure, slow-roll fatigue, leakage, thermal cycling, and static ultimate strength.

Other off-limits and engineering tests required are high velocity, extra heavy abort weight, lifetime fatigue, low pressure, thermal vacuum, sideload, and high crosswind.

It is interesting to note that commercial and military aircraft wheels are not subjected to dynamic landing load tests - only to slow-roll fatigue plus other static tests. The Orbiter could not be subjected to multiple high-speed taxi tests and numerous landings such as is practiced in conventional aircraft test programs. Therefore, the dynamic landing load tests plus the integrated system stability tests became necessary to demonstrate operational capability. In fact, the dynamic landing load tests have been used twice to certify the main wheel/tire assemblies for a limited number of orbital flights due to development problems uncovered in the wheel slow-roll fatigue life tests. Overall, wheel and tire certification requirements over the past several years have changed and increased into a more extensive program than the original concept.

HARDWARE DEVELOPMENT HISTORY RESULTING IN CERTIFICATION CHANGES

The wheel/tire design, as initially developed, was used during the five Approach and Landing Test (ALT) flights. It was lighter and had less load capability than the wheels and tires used for orbital flights. Even though the ALT vehicle weight was 66 percent of the original Orbiter abort weight, the requirements became more severe when the abort weight was then increased from 227 000 to 240 000 pounds. Testing attempts to pass these increased conditions resulted in hardware failure. Not only was the tire failing tests but the wheel was experiencing bearing problems. With this bearing problem realization, it was obvious that more realistic dynamic landing load conditions must be conducted which would include crosswind effects. This prompted the decision to conduct such tests at the Wright Patterson Air Force Base (WPAFB) Facility where the testing would include crosswinds and the testing was automated for a faster and more convenient test setup.

Subsequent test failures at WPAFB, which included crosswinds, graphically revealed the inability of the tires and wheel bearings to survive flight requirements. In addition, the wheel was subject to cracking during the slow-roll fatigue tests resulting in redesign of both pieces of hardware several times before arriving at the combination in use today.

The main tire has been modified from a 28-ply-rated, 260-psi inflation pressure model to a 34-ply-rated, 315-psi version. The wheel design has had its inboard bearings moved off the wheel centerline to a more inboard location and housed in a steel hub to achieve more evenly distributed bearing loads. A dual O-ring seal system between the two wheel halves was used during the first orbital flight because of its improved leakage characteristics, but this design feature caused additional cracks during fatigue tests so the design reverted back to the single O-ring approach. Finally, the forging thickness was increased in several areas to provide protection against fatigue cracks. This latest wheel design will start certification slow-roll fatigue tests this year.

TEST FACILITIES

The wheel and tire manufacturers both use conventional dynamic and static test equipment suitable for commercial and military requirements. However, the maximum load capacities cannot meet the Shuttle requirements, and their ability to set up and repeat dynamic tests is relatively slow. Changing a dynamometer test condition is tedious, since it requires construction of a new load profile template.

In contrast, the WPAFB test facility is automated and test conditions are easily varied. After a wheel/tire assembly is mounted on a test axle, it is not touched by hand as it is translated from a cooling cage to the dynamometer where it is clamped to a yoke. Then it can be hydraulically stroked into the motor-driven road wheel to provide the loads and velocities required. If loads, velocities, or yaw angles must be varied, these can be typed into the computer in a matter of minutes and the command system is ready before the tire can cool down for a subsequent test. All landing load data are recorded on stripcharts as well as on tape.

The WPAFB dynamometer used in Orbiter dynamic landing load tests has greater and more diversified capabilities than any other similar facility in the free world. It not only can provide high radial loads, it can also achieve high velocities, crosswind, and camber effects. Specific dynamic capabilities include radial load: 0 to 150 000 pounds in 0.1 second; velocity: 0 to 300 knots; acceleration: 0 to 24 ft/sec^2; yaw angles: $\pm 20^\circ$; and camber angles: $\pm 20^\circ$.

The use of the WPAFB test facility has resulted in a better understanding of overall performance capability of the main wheels and tires than other types of aircraft that have flown. Since the effects of crosswind on wheels and tires during landing cannot presently be adequately analyzed, a realistic test is currently the safest approach.

Of the major achievements in the wheel and tire development programs, the most significant should include (1) development of the STS-2 34 ply-rated operational "K" model tire, (2) the main wheel bearing high preload concept, and (3) the use of the WPAFB test facility to test for crosswind effects.

DETAILED LISTING OF CERTIFICATION TESTS

TABLE 1.- B. F. GOODRICH MAIN WHEEL CERTIFICATION TESTS

Test	Wheel identification and test sequence								Test location
	A	B	C	D	E	F	G	H	
Acceptance	1	1	1	1	1	1	1	1	BFG
Combined static loads									
Inboard yield cond. I	2								BFG
Outboard yield cond. I	3								BFG
Inboard ultimate cond. I	4								BFG
Inboard yield cond. II		2							BFG
Outboard yield cond. II		3							BFG
Outboard ultimate cond. II		4							BFG
Burst pressure			2						BFG
Static pressure				2					BFG
Diffusion				3					BFG
Dynamic pressure				4					BFG
1000-mile roll test				5					WPAFB
Dynamic load profiles				6					WPAFB
STS-1 load profiles (INBD)					2				WPAFB
STS-1 load profiles (OUTBD)					3				WPAFB
Thermal relief plug					4				BFG
STS-2, STS-3, and STS-4 load profiles						2			WPAFB
Environmental tests							2		BFG
Structural torque							3		BFG
Dynamic brake test								2	BFG

TABLE 2.- JSC/ROCKWELL DYNAMIC WHEEL/TIRE TESTS
(APPLIED AFTER WHEEL COMPLETES 1000-MILE CERTIFICATION TESTS)

Landing weight, lb	Touchdown velocity, knots	Crosswind velocity, knots	Landing technique	No. of tests
207 000	212	0	Delay pitchover	2
207 000	212	10	Quick pitchover	3
240 000	225	20	Quick pitchover	1

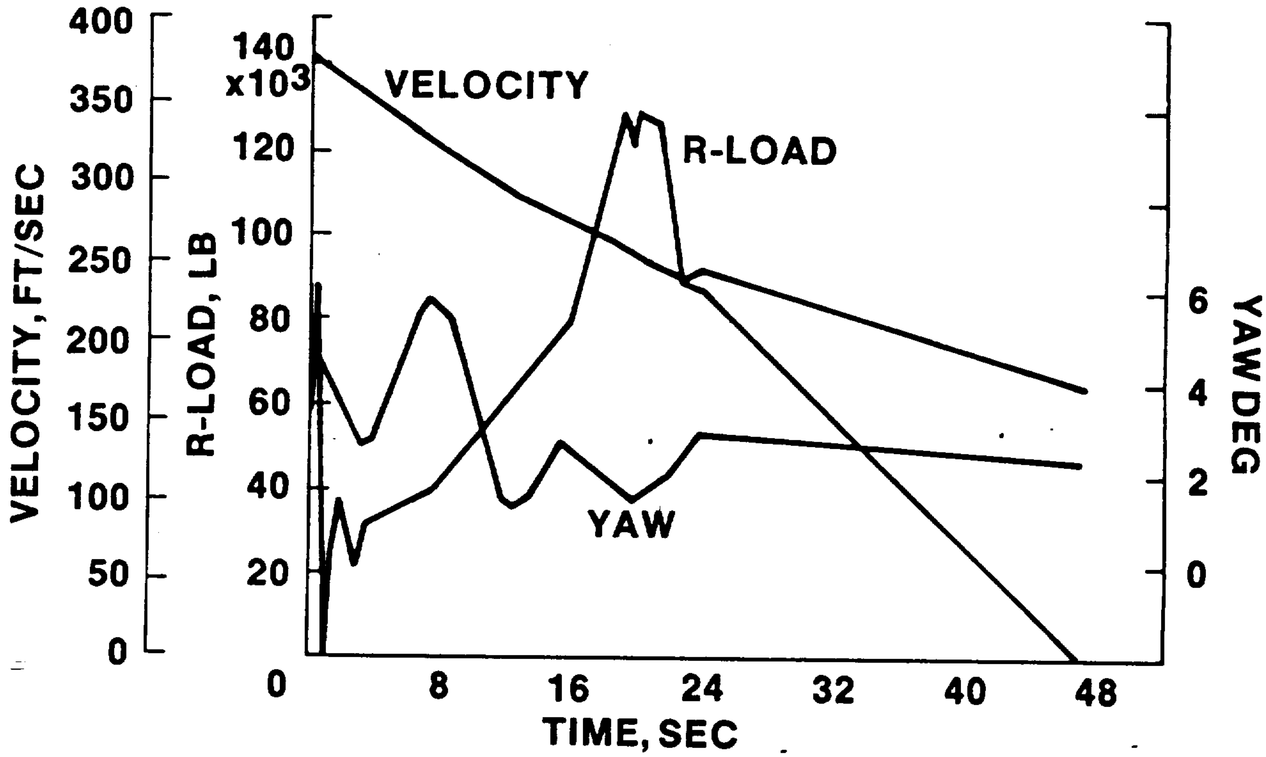

FIGURE 2.- TYPICAL LOAD/TIME PROFILE: 240 000-POUND VEHICLE WEIGHT, DELAYED PITCHOVER, 20-KNOT CROSSWIND.

TABLE 3.- B. F. GOODRICH MAIN TIRE CERTIFICATION TESTS

Test	Tire identification and test sequence				Test location
	A	B	C	D	
Acceptance	1	1	1	1	BFG
Deflection	2				BFG
Burst	3	2			BFG
Dynamic load profiles[a]					
Delayed nose pitchover			2		WPAFB
Quick nose pitchover				2	WPAFB

[a]Dynamic load profile tests include 6 landings and 6 taxi tests per tire of which: 1 landing is a tire chilled to -35° F, 1 landing is a tire preheated to +135° F, 5 landings represent a 207 000-pound landing weight, 1 landing represents a 240 000-pound landing weight and crosswinds, and range from 0 to 20 knots.

TABLE 4.- JSC/ROCKWELL OFF-LIMITS TESTS

	Landing weight, lb	Touchdown velocity, knots	Crosswind velocity, knots	Pressure, psi	No. of tests	Tire ID
High velocity	212 000	245	0 to 10	315	5	A
	212 000	255	0	315	2	B
	240 000	255	0 to 10	315	2	B
Heavy weight	245 000	240	15 to 0	315	4	C
	251 000	240	15 to 0	315	4	D
Low pressure	240 000	225	10	256	1	E
	212 000	215	10	256	2	E
Tire life	212 000	215	0 to 10	315	24	F
	212 000	215	10	315	9	G
	240 000	225	20	315	3	G
	212 000	215	10	315	6	H
	240 000	225	20	315	1-1/2	H
High crosswinds[a]						

[a]To be conducted.

TABLE 5.- ENGINEERING TESTS

Thermal vacuum

1. 7 days in vacuum at 1×10^{-5} and at +15° F.
2. Subsequently subjected to 4 dynamic landing load profiles representative of a 207 000-lb landing weight, in 0- to 20-knot crosswinds and using quick nose pitchover technique.

Cornering force

- Yaw angles: ±4°
- Velocity: 100 to 200 knots
- Radial load: 80 000 to 100 000 lb
- Tire pressure: 315 psi

Flat tire during rollout tests - nose tire only

Abrupt load increased at 12, 20, and 30 seconds into roll

Tire pressure leakage studies

- Temperature: ambient to -65° F
- Time: 7 to 197 days

TABLE 6.- INTEGRATED SYSTEMS TESTS

Bendix main gear dynamic stability tests

275 dynamometer runs including mass impact on tire
Velocity range: 4 to 217 knots
"Nose up" and "nose down" tests: -4° to $+19^{\circ}$
Tire pressures: 205 to 280 psi
Tire unbalance: 100 to 300 in-oz.
Strut vertical loads: 23 000 to 120 000 lb
Strut compression: 2 to 14 in.

Bendix nose gear dynamic stability tests

272 dynamometer runs including mass impact on tire
Velocity range: 29 to 204 knots
Tire pressures: 237 to 325 psi
"Nose up" and "nose down" tests: -4° to $+4^{\circ}$
Strut vertical load: 9000 to 60 000 lb
Strut compression: 3 to 20 in.
Nose wheel steering: on and off
Tire unbalance: 25 to 75 in-oz.

Bendix main gear braking/antiskid stability tests

18 braking tests include the following ranges
Energy: 3.2 to 34.7×10^6 ft-lb (36.5×10^6 ft-lb is reuse limit)
Velocity: 50 to 147 knots
Tires: one and two wet, one flat, all dry
Brake pressure: 0 to 1500 psi (maximum)
Antiskid: on and off
Strut vertical load: 40 000 to 114 000 lb

Langley Research Center nose gear dynamic stability tests on flat track test facility

65 runs including mass impact on tire
Velocity: 40 to 104 knots
Vertical load: 15 000 and 30 000 lb
Tire pressure: 0, 150, and 300 psi
Sink speed: 0.5 to 3 ft/sec
Runway conditions: dry, damp, wet, and sand covered
Nose wheel steering: on and off

SUMMARY

The Orbiter wheel and tire designs have been successfully subjected to an extensive and rigorous certification program to demonstrate all flight capability requirements. The approach of using a Government test agency (WPAFB) in conjunction with the manufacturer's test capability has proven to be cost and schedule effective. The unique dynamic landing loads testing imposed on Orbiter hardware has resulted in interest by other government agencies of the potential for application of similar testing on conventional aircraft.

The certification program appears to have demonstrated the full range of the hardware capability and has provided confidence that it is safe for flight under the conditions expected.